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MINERALOGICAL NOTES

SERIES 2

BY

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ILLUSTRATIONS.

MINERALOGICAL NOTES, SERIES 2.

By WALDEMAR T. SCHALLER.

INTRODUCTION.

The several papers here assembled represent in part the results of mineralogical research work carried out by the author in the chemical laboratory of the United States Geological Survey from January 1, 1910, to the end of the fiscal year 1910–11 (June 30, 1911). Earlier reports of a similar nature have been published as "Mineralogical notes" (1903–1904), a part of Bulletin 262, and "Mineralogical notes, series 1" (1905–1909), in Bulletin 490. In addition to these papers a report on the crystallography of ferberite from Colorado was prepared (with Mr. F. L. Hess) for publication in the "Proceedings of the United States National Museum," and a report on the gem-tourmaline field of southern California has been nearly finished.

Several of the papers contained herein were originally written in conjunction with some of the geologists of the Survey. In these papers full credit has been given for their contributions, several of which have been somewhat rearranged.

A STUDY OF THE RUTILE GROUP.

INTRODUCTION.

The rutile group, as discussed in this paper, comprises the minerals rutile, cassiterite, mossite, tapiolite, nigrine, iserite, ainalite, ilmenorutile, and strüverite, [1] all of which occur well crystallized. Recent analyses of ilmenorutile and strüverite in papers by Brögger [2] and by Prior and Zambonini [3] make it possible to study the entire group fairly conclusively.

The separation of titanium, columbium, and tantalum, when they are found together in a mineral, is not alone a most difficult operation, but one in which accurate results are not yet attainable. Interpretation of the analyses of such a group of minerals is therefore difficult because the accuracy of the analytical figures is considerably in doubt. Notwithstanding this primary difficulty, the explanation herein offered of the composition of the rutile group [4] serves to interpret the natural occurrences of these minerals and seems free from serious objection.

CHARACTERISTICS OF THE RUTILE GROUP.

The rutile group is well defined and striking. It comprises a number of minerals generally considered as well-established species, though all but two of them are of rare occurrence. A very striking fact is that these minerals are very similar crystallographically; for not only do they all crystallize in the tetragonal system with nearly the same value for the *c* axis ($c=0.6$), but they possess a further peculiarity that at once shows their close geometrical kinship in that they form twin crystals (twinning plane {101}), distorted in a direction parallel to the intersection of the two unit pyramids (111) and ($1\bar{1}1$). This peculiar distortion and twinning gave rise to the supposed species, skogbölite and ixiolite, which are, in fact, only twinned tapoilite crystals. If, now, it can be shown that there is a similar close chemical relationship between these minerals, sufficient evidence and material will be provided for a satisfactory study of this group.

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[1] Several other minerals doubtless belong to this group. Among these are zircon, thorite, and platnerite, but they are not included in the present discussion because the elements zirconium, thorium, and lead do not enter, so far as known, into the composition of the minerals here discussed.

[2] Brögger, W. C., Die Mineralien der südnorwegischen Granit-Pegmatitgänge.—I, Niobate, Tantalate, Titanate und Titanoniobate: Videnskabs-Selskabets Skrifter, Math.-Naturw. Kl., 1906, no. 6.

[3] Prior, G. T. and Zambonini, F., On strüverite and its relation to ilmenorutile: Mineralog. Mag., vol. 15, 1908, p. 78.

[4] All the analyses quoted in this paper have been taken from the literature. The only experimental work done consists of some qualitative tests.

Isomorphous relationships are strongly indicated by these minerals, and have already been suggested by several authors, notably Brögger and Prior.[1] The paper of Brögger is exceptionally rich in suggestions, and many hypotheses here advanced are proposed by him, though some are merely indicated by him as possibilities, their correctness not being demonstrable. The relations of rutile to tapiolite, mossite, and the compound $FeTiO_3$ are frequently brought out in his work. Particularly to the point is his suggestion at the end of the discussion of the relations of ilmenorutile that the occurrence of the compound $FeTiO_3$ in ilmenorutile makes it probable that the pure compound $FeTiO_3$ is possible in the tetragonal modification. Brögger's paper should be carefully read for a full discussion of the relations of these similar compounds.

In short, I would explain this entire group as consisting either of members of an isomorphous family or of mixtures of two or more of such members in varying proportions. The existence of several distinct primary compounds is recognized and three of them occur in nature in a pure state. All the other members of the rutile group can be satisfactorily explained as isomorphous mixtures of two or more of these primary compounds.

PRIMARY COMPOUNDS.

CHIEF PRIMARY COMPOUNDS.

The six most important primary compounds may best be treated by themselves as a group, reserving the minor compounds for subsequent discussion. These chief primary compounds are the following:

Occurrence of chief primary compounds.

Composition.	Formula.	Maximum percentage of occurrence in natural minerals.	Mineral.
Ferrous columbate	$Fe (CbO_3)_2$	39.2	
Ferrous tantalate	$Fe (TaO_3)_2$	Nearly 100	Tapiolite.
Ferrous titanate	$Fe (TiO_3)$	64.0	
Titanyl titanate	$(TiO) (TiO_3)$	Nearly 100	Rutile.[a]
Stannyl stannate	$(SnO) (SnO_3)$	Nearly 100	Cassiterite.[a]
Ferrous stannate	$Fe (SnO_3)$	36.1	

[a] The formulas of rutile and cassiterite are given in the form used by Brögger.

In the following description of the chief primary minerals or compounds just named, only such data as have a bearing on the

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[1] Op. cit. Rammelsberg (Handb. Mineralchemie, 2e Auflage, II, Specieller Theil, 1875, p. 357) states that the tin oxide present in the analyses of tantalite (probably tapiolite), is to be considered as $FeSnO_3$ in isomorphous admixture. A similar suggestion is offered for the titanium present, which is to be regarded as $FeTiO_3$.

possible isomorphous relations of the compounds are included. Unless otherwise stated the data are taken from Dana.[1]

Ferrous columbate.—The mineral known as mossite was described by Brögger,[2] who, on the basis of an analysis which showed columbium and tantalum to be present in molecularly equal quantities, felt justified in putting forth a new name. Pure or even approximately pure (tetragonal) iron columbate had not been found in nature, but Brögger referred the name "mossite" to such tetragonal compounds where the columbate is present in the ratio of 1:1 or 1+:1 of the tantalate. The value of the c axis for the isomorphous tapiolite is given by Brögger as 0.65215. Brögger's "mossite," a mixture of columbate and tantalate, has $c=0.64379$. The value of the c axis for the pure ferrous columbate should therefore be about 0.6354. Similarly, the density of the purest tapiolite analyzed, the "skogbölite,"[3] is 7.85. The density of Brögger's "mossite" is given as 6.45. From these data the density of the pure ferrous columbate, $Fe(CbO_3)_2$, is found to be about 5.05, a figure lower than the lowest authentic density (5.26) I could find recorded for columbite, which is for the dimorphous orthorhombic form of iron columbate. Similarly, the density (7.85) for tapolite, $Fe(TaO_3)_2$, is lower than the highest recorded value for tantalite. However, these figures are of uncertain value. "Mossite" often forms the peculiar distorted twinned crystals, elongated parallel to the intersection edge of $(111):(1\bar{1}1)$.

Ferrous tantalate or tapiolite.—The name tapiolite is here used to refer to the pure iron tantalate, $Fe(TaO_3)_2$. Like "mossite," this mineral often forms distorted twin crystals. The values of the c axis and the density, which have been given in the preceding paragraph, are 0.65215 and 7.85, respectively.

Ferrous titanate.—The tetragonal ferrous titanate $Fe(TiO_3)$[4] is present in large amount in iserite.[5] It is the admixed component of ferriferous rutile, or nigrine, and occurs in ilmenorutile and strüverite. Its physical properties are not known, but the c axis of iserite is close to 0.64 and the density of ferrous titanate has been calculated to be about 5. ± .25. (See p. 12.) Janovsky[6] describes iserite as occurring in tetragonal crystals, similar to rutile, twinned on {101}.

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[1] Dana, E. S., System of mineralogy, 6 ed., 1892.

[2] Brögger, W. C., Über den Mossit und über das Krystallsystem des Tantalit (Skogbölit) aus Finnland: Videnskabsselskabets Skrifter.—I, Math. naturw. Kl., 1897, No. 7, p. 19.

[3] Dana, E. S., System of mineralogy, p. 734, analysis No. 7.

[4] This is the same compound which, in its trigonal or rhombohedral polymorphous form, exists as the mineral ilmenite.

[5] Described by Janovsky and in Dana's "System of mineralogy," p. 239. Not to be confounded with iserine (Dana, op. cit., p. 219), which is referred to ilmenite.

[6] Janovsky, J. V., Über Niobit und ein neues Titanat von Isergebirge: Sitzungsb. Akad. Wiss. Wien, vol. 80, Math. naturw. Kl. (1), 1880, p. 39.

It is of a brown color, but pellucid and honey-yellow in thin lamellæ. Dana[1] states with regard to Janovsky's iserite—

> Groth (Z. Kryst., V, 400) justly remarks that the mineral is not far from the ferruginous rutile called "nigrine," and that a more exact determination as to form, homogeneity, etc., is needed to prove its independent character. If it is an independent species, the name is an unfortunate one, as tending to confusion with the distinct iserin, also called iserite.

Titanyl titanate or rutile.—The fourth mineral of this group is too well known to require extended description. It is tetragonal, $c=0.6442$, forms distorted twins like tapiolite, and has a density of 4.2. The interpretation of the composition of rutile as given by Brögger and Prior is as titanyl metatitanate $(TiO)(TiO_3)$.

Stannyl stannate or cassiterite.—Cassiterite, or stannyl metastannate, is also well known. It is tetragonal, $c=0.6723$, forms distorted twins, and has a density of 6.9.

Ferrous stannate.—Ferrous stannate, $Fe(SnO_3)$, not known in a pure state, is assumed to enter into the composition of some Mexican cassiterites to a considerable extent. It is probably present, though generally in small amounts, in nearly all cassiterites. Its properties are, of course, unknown.

Summary.—To better show the relationships of these chief primary compounds, their essential data, as given in the previous paragraphs, are brought together in the table below:

Properties of chief primary compounds.

Composition.	Formula.	Density.	Crystallography.
Ferrous columbate.......	$Fe(CbO_3)_2$......	5.05?	Tetragonal, distorted twin, $c=0.6354$.
Ferrous tantalate........	$Fe(TaO_3)_2$......	7.85?	Tetragonal, distorted twin, $c=0.6522$.
Ferrous titanate..........	$Fe(TiO_3)_2$......	5. ±.25	Tetragonal, twinned, $c=0.64$.[a]
Titanyl titanate	$(TiO)(TiO_3)$..	4.2	Tetragonal, distorted twin, $c=0.6442$.
Stannyl stannate	$(SnO)(SnO_3)$...	6.9	Tetragonal, distorted twin, $c=0.6723$.
Ferrous stannate..........	$Fe(SnO_3)$.......	....	

[a] Like rutile.

MINOR PRIMARY COMPOUNDS.

In addition to these chief primary compounds it is necessary to assume the existence of several minor primary compounds in order to explain the composition of all the members of the rutile group. These have not as yet been found in nature either as pure compounds or as present to any great extent in isomorphous mixtures. Consequently their properties are entirely unknown, but their close chemi-

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[1] System of mineralogy, 5th ed., Appendix 3, 1884, p. 105.

cal relationship can be seen by comparison of their formulas with those of type compounds such as $Fe(TaO_3)_2$ or $(SnO)(SnO_3)$. In the following list these minor primary compounds are given the highest percentages of their occurrence in any of the minerals herein described, as calculated by the methods used in this paper.

Occurrence of minor primary compounds.

Formula.	Composition.	Maximum percentage of occurrence in natural minerals.
$Zn(AsO_3)_2$	Zinc arsenate	11.6
$Zn(SnO_3)$	Zinc stannate	8.6
$Fe(AsO_3)_2$	Ferrous arsenate	2.8
$Mn(TaO_3)_2$	Manganous tantalate	(See p. 20.)
$(SnO)(TaO_3)$	Stannyl tantalate; presence doubtful	(See p. 20.)
$(TiO)(VO_3)_2$	Titanyl vanadate; presence suggested	(See p. 26.)

ISOMORPHOUS RELATION OF PRIMARY COMPOUNDS.

In this paper I have regarded minerals as isomorphous if they possess very similar geometric form and close analogy in chemical composition, and if they form mixed crystals resembling in form those of the end members.

The first of the above three requirements is very well satisfied by this group of chief primary compounds in so far as data concerning them are available, as is shown by the summary of the properties of the compounds in the table just given. The close agreement of the values of the tetragonal *c* axes and the further evidence of the common occurrence of distorted twins is very suggestive of the close geometrical relation between the compounds.

The second requirement, close analogy in chemical composition, is not so readily disposed of, chiefly because of the incompleteness of the existing knowledge of the chemistry of such compounds as are under discussion. No difficulty has been met, but it must be admitted that some of the propositions advanced are only theoretical conceptions, though nothing has been so far brought against them and their validity is generally acknowledged.

The acids which are considered as isomorphous are as follows:

Columbic acid, $H_2(CbO_3)_2$, forming columbates.
Tantalic acid, $H_2(TaO_3)_2$, forming tantalates.
Metatitanic acid, $H_2(TiO_3)$, forming metatitanates.
Metastannic acid, $H_2(SnO_3)$, forming metastannates.
Metarsenic acid, $H_2(AsO_3)_2$, forming metarsenates.[1]

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[1] The relative instability of the metarsenates is probably overcome in the Mexican cassiterites (see p. 36) by the "mass action" of the predominant metastannates, $R_2(SnO_3)$.

The isomorphous relation of columbic and tantalic acids is too well known to require any further comment. The same relation has been proved for several compounds of titanium and tin, as, for example, for salts of the type $R'_2M''''F_6$, where M'''' represents Ti or Sn. Ouvrard[1] showed the isomorphous relation of the salts $Ti_2Na(PO_4)_3$ and $Sn_2Na(PO_4)_3$. The relation of tin to columbium and tantalum still remains to be proved, but the isomorphous relation of stannates to columbates and tantalates has been assumed in explaining the composition of a number of minerals. The relation of metarsenic acid to the other acids mentioned above is purely theoretical. The bases which combine with the acids to form the compounds whose admixture produces the minerals of the rutile group are Fe'', Zn'', Mn'', $(TiO)''$, and $(SnO)''$. The relationship of the titanyl group $(TiO)''$ to the stannyl group $(SnO)''$ is similar to that of the acids and hardly needs further comment. It is only necessary to see whether Fe'' and $(TiO)''$ can be considered isomorphous, but I have not been able to find any satisfactory evidence on this question. Such a relation seems very probable and has been assumed by numerous writers, but it remains to be proved.

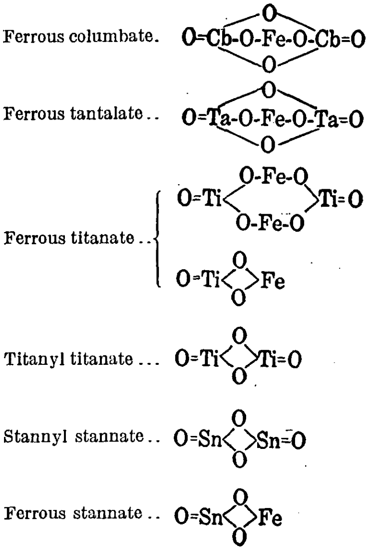

FIGURE 1.—Structural formulas for chief primary compounds of the rutile group.

That the isomorphous relationships of the bases and acids, as here given, are real and do occur in nature can only be shown by a consideration of the evidence as found in the natural occurrences of these minerals. A series of chemical salts in which these isomorphous relations can be traced may have been prepared and described, but I was not able to find any such descriptions in the literature. The evidence for a chemical analogy in these compounds can not, therefore, be considered definitely proved if the natural occurrences, which are, of course, the very ones for which the relationships are to be proved, are omitted. The evidence is largely theoretical, but at least no negative evidence has so far been brought to bear.

The formulas of the chief primary compounds may be expressed structurally in a form which at once suggests their very close chemical similarity.[2] These are shown in figure 1, the type structure

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[1] Compt. Rend., vol. 111, 1890, p. 178.

[2] It must be remembered that no claim is made that these structural formulas actually represent the composition of the minerals. They do, however, show that analogies exist in the structure of these compounds, and for this reason they serve a very useful purpose.

being taken from Brögger's paper. In the first formula proposed for ferrous titanate the formula is doubled, as in this form the close relationship to ferrous columbate and ferrous tantalate is better shown.

The third requirement of the isomorphous relation, namely, ability to form mixed crystals, can not be demonstrated on artificial preparations, as knowledge of these compounds, produced artificially, is very small. The natural occurrences, however, afford plenty of evidence of such isomorphous mixing.

Original occurrences of all the primary minerals and of their various mixtures have been found in quartz-feldspar rocks of the pegmatite type. Tapiolite, "mossite," and cassiterite are typically found in pegmatite. Rutile is only rarely found in pegmatite; Brögger[1] states that he has never observed rutile in granitic pegmatites of south Norway. However, Watson and Taber, in describing the rutile deposits of Virginia,[2] speak of its occurrence in a "coarse-granined feldspar-quartz-hornblende rock" whose textural relations "over many parts of the rock mass [are] similar to those of a coarse pegmatitic granite." Further, "no evidence has been developed from either the field or the laboratory study for regarding the rutile as of secondary or subsequent origin." Rutile is also mentioned as an original constituent of the large pegmatite dike at Baringer Hill, Llano County, Tex.[3] The minerals here considered as forming an isomorphous group have therefore the further common bond that they have been found in a similar rock, namely, a quartz-feldspar or granitic pegmatite. Of the minerals here considered as simply isomorphous mixtures of the primary compounds, ilmenorutile, strüverite, and probably ainalite are all found in granitic pegmatites.

ISOMORPHOUS MIXTURES OF ESSENTIALLY TWO[4] OF THE PRIMARY COMPOUNDS.

FERROUS COLUMBATE AND FERROUS TANTALATE.

The isomorphous relations of ferrous columbate and ferrous tantalate have already been stated (p. 11). It was, in fact, an isomorphous mixture of these two compounds in approximately the proportion 1:1 which Brögger described as "mossite."

The analysis given by Brögger of "mossite" from Moss, Norway, is given below.

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[1] Die Mineralien der südnorwegischen Granit-Pegmatit-gänge. I. Niobate, Tantalate, Titanate, and Titaniobate: Videnskabs-Selskabets Skrifter.—Math. naturw. Kl., 1906, no. 6.

[2] Watson, T. L., and Taber, Stephen, The Virginia rutile deposits: Bull. U. S. Geol. Survey No. 430, 1910, pp. 200–213.

[3] Hess, F. L., Minerals of the rare-earth metals at Baringer Hill, Llano County, Tex.: Bull. U. S. Geol. Survey No. 340, 1908, p. 292.

[4] A third compound is occasionally present in minute quantity.

Analysis and ratios of "mossite" from Norway.

	Per cent.	Ratio.
Cb_2O_5	82.92 {31	0.116
Ta_2O_5	52	.118
SnO_2	.18	.001
FeO	16.62	.231
	99.72	

The ratios show that this mineral consists of—

0.5 part, or 0.2 per cent, of stannyl stannate (SnO) (SnO_3)—cassiterite.
116 parts, or 39.2 per cent, of ferrous columbate, $Fe(CbO_3)_2$.
118 parts, or 60.6 per cent, of ferrous tantalate, $Fe(TaO_3)_2$—tapiolite.

Brögger's "mossite" is therefore a columbium-bearing tapiolite rather than a distinct species, and it would have been better if the name had not been proposed. It is hoped, as Hess and Wells[1] state, that the "custom of proposing names for unknown extrapolated members of a mineral series will not become general," and therefore the name "mossite" should be dropped, as it is believed that the material from Moss, Norway, is not entitled to specific distinction from tapiolite, being in fact only a columbic tapiolite.

Two analyses by Rammelsberg (Nos. 11 and 12 on p. 734 of Dana's System of Mineralogy) of tapiolite, or the so-called ixiolite, from Skogböle, Finland, gave the following results:

Analyses of ixiolite from Skogböle.

	1	2
Ta_2O_5	63.58	69.97
Cb_2O_5	19.24	[a]12.26
SnO_2	1.70	2.94
FeO	9.19	14.83
MnO	5.97	
Ign	.23	....
Total	99.91	100.00

[a] Including 1 per cent TiO_2, according to Dana.

Considering the 14.83 per cent FeO+MnO in the second analysis as FeO (justifiable because of the closeness of the molecular weights of FeO and MnO) and not considering the presence of titanium, the folowing ratios are obtained from the above analyses:

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[1] Hess, F. L., and Wells, R. C., An occurrence of strüverite: Am. Jour. Sci., 4th ser., vol. 31, 1911, p. 432.

Ratios of analyses of ixiolite from Skogböle.

	1	2
Ta_2O_5	0.144 } .216	0.158 } .204
Cb_2O_5	.072	.046
SnO_2	.011	.019
FeO	.128 } .212	.206
MnO	.084	....

From these ratios the composition of the samples of ixiolite is found to be as shown below.

No. 1 consists of—

72 parts, or 24.3 per cent, of ferrous columbate, $Fe(CbO_3)_2$.
144 parts, or 74.0 per cent, of ferrous tantalate, $Fe(TaO_3)_2$—tapiolite.
5.5 parts, or 1.7 per cent, of stannyl stannate $(SnO)(SnO_3)$—cassiterite.

No. 2 consists of—

46 parts, or 15.6 per cent, of ferrous columbate, $Fe(CbO_3)_2$.
158 parts, or 81.5 per cent, of ferrous tantalate, $Fe(TaO_3)_2$—tapiolite.
9.5 parts, or 2.9 per cent, of stannyl stannate $(SnO)(SnO_3)$—cassiterite.

An analysis of tapiolite from Sukula, Finland, by Rammelsberg, after the tetragonal character of the mineral had been established, is as follows:

Analysis and ratios of tapiolite from Sukula, Finland.

	Per cent.	Ratio.
Ta_2O_5	73.91	0.167 } .209
Cb_2O_5	11.22	.042
SnO_2	.48	.003
FeO	14.47	.201 } .212
MnO	.81	.011
	100.89	

The ratios show that the composition of this "tapiolite" is as follows:

1.5 parts, or 0.4 per cent, of stannyl stannate $(SnO)(SnO_3)$—cassiterite.
42 parts, or 14.1 per cent, of ferrous columbate $Fe(CbO_3)_2$.
167 parts, or 85.5 per cent, of ferrous tantalate $Fe(TaO_3)_2$—tapiolite.

Two analyses of tapiolite from Custer City, S. Dak., are given by Headden.[1] They are very similar and are made on like material, so that the discussion of one of them will suffice. The results, with the ratios calculated therefrom, are here given. The density of this material is 7.22.

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[1] Headden, W. P., Mineralogical notes, No. III: Proc. Colorado Sci. Soc., vol. 8, 1906, p. 167

Analysis and ratios of tapiolite from South Dakota.

	Per cent.	Ratio.
Ta_2O_5	78.61	0.178 } .194
Cb_2O_5	4.29	.016
FeO	16.85	.234
SnO_2	.07	
Cassiterite	.31	
WO_3	.11	
TiO_2	Trace.	
	100.24	

The above ratios indicate that this tapiolite is composed of:

16 parts, or 5.6 per cent, of ferrous columbate, $Fe(CbO_3)_2$.
178 parts, or 94.4 per cent, of ferrous tantalate, $Fe(TaO_3)_2$—tapiolite.

The excess of FeO remaining must be ascribed to impure material or to some error in the analysis.

The tapiolite from Topsham, Maine, described by Warren,[1] would seem to contain a small amount of ferrous columbate, judging from the value of the density 7.67–7.68, that for tapiolite being 7.85.

The summary of the isomorphous mixtures of ferrous columbate and ferrous tantalate given below shows readily the variation in the proportions in which the two compounds have been found in nature.

Isomorphous mixtures of ferrous columbate and ferrous tantalate.

Described by—	Locality.	Ferrous columbate.	Ferrous tantalate.
		Per cent.	*Per cent.*
Brögger	Moss, Norway	39.2	60.6
Rammelsberg	Skogböle, Finland (1)	24.3	74.0
Do	Skogböle, Finland (2)	15.6	81.5
Do	Sukula, Finland	14.1	85.5
Headden	Custer City, South Dakota	5.6	94.4

As the maximum percentage of ferrous columbate so far found in nature reaches only 39.2 per cent, the objection to considering "mossite" a well-established species is seen to be valid.

FERROUS TANTALATE AND STANNYL STANNATE (TAPIOLITE AND CASSITERITE).

An analysis of tapiolite (skogbölite) from Skogböle by A. Nordenskiöld gave the following results:

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[1] Warren, C. H., Mineralogical notes: 4. Crystallized tapiolite from Topsham, Maine: Am. Jour. Sci., 4th ser., vol. 6, 1898, p. 121.

Analysis and ratios of tapiolite from Skogböle.

	Per cent.	Ratio
Ta_2O_5	84.44	0.191
Cb_2O_5	....	....
SnO_2	1.26	.008
FeO	13.41	.186 } .199
MnO	.96	.013
CuO	.14	....
CaO	.15	....
	100.36	

From the ratios, the composition is found to be as follows:

4 parts, or 1.2 per cent, of stannyl stannate (SnO) (SnO_3)—cassiterite.
191 parts, or 98.8 per cent, of ferrous tantalate, $Fe(TaO_3)_2$—tapiolite.

It is interesting to note that Rammelsberg[1] gives three analyses of "tantalite" from Kimito, Finland, that contain respectively 6.81, 9.67, and 9.14 per cent of SnO_2. Though it is not possible to decide whether the material analyzed was tantalite or tapiolite, I believe it is more probably the latter. If this belief is correct, the samples present an additional instance of the isomorphism of tapiolite and cassiterite.

An analysis of supposed ixiolite from Wodgina in western Australia gave Simpson[2] the results shown in the table below. The mineral occurs in "indistinct crystalline aggregates," and though its identification as a tetragonal mineral is therefore not determined, Simpson regards it as related to the ixiolite from Finland. Its density is 7.36.

Analysis and ratios of ixiolite (?) from Australia.

	Per cent.	Ratio.
Ta_2O_5	70.49	0.159 } .188
Cb_2O_5	7.63	.029
SnO_2	8.92	.059
MnO	10.87	.153 } .172
FeO	1.34	.019
CaO	.42	....
MgO	.37	....
Ign	.18	....
	100.22	

From the above ratios the ixiolite (?) can be deduced to be of the composition shown below, the small amount of iron present being taken with the manganese. As can be seen from the ratios the

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[1] Rammelsberg, C. F., Handb. Mineralchemie, 1860, p. 391.

[2] Simpson, E. S., Further occurrences of tantalum and niobium in western Australia: Proc. Australian Assoc. Adv. Sci., 1909, vol. 12, 1910, p. 310.

$(MnO + FeO)$ is insufficient to take up all the $(Ta_2O_5 + Cb_2O_5)$, so that, assuming accuracy of the analysis, it becomes necessary to assume the presence of the group $(SnO)\ (TaO_3)_2$. On this basis the ratios indicate:

29 parts, or 9.9 per cent, of $Mn(CbO_3)_2$.
143 parts, or 74.0 per cent, of $Mn(TaO_3)_2$.
16 parts, or 9.6 per cent, of $(SnO)\ (TaO_3)_2$.
21.5 parts, or 6.5 per cent, of $(SnO)\ (SnO_3)$.

Assuming, however, that the $(Mno + FeO)$ exactly balances the $(Ta_2O_5 + Cb_2O_5)$, as would happen with only a slight change in the analytical figures, the composition of the sample can be expressed more simply as:

29 parts, or 9.8 per cent, of $Mn(CbO_3)_2$.
159 parts, or 81.3 per cent, of $Mn(TaO_3)_2$.
29.5 parts, or 8.9 per cent, of $(SnO)\ (SnO_3)$.

Either interpretation agrees with the analysis and both are in consonance with the character of the compounds propounded as forming, either singly or in isomorphous mixture, the several members of the rutile group. It is uncertain whether the mineral here described belongs to this group or to the orthorhombic columbite-tantalite group. If it is a member of this group, the discussion of it should also be placed under the heading "Isomorphous mixtures of more than two of the primary compounds." On account of the uncertainty as to whether it really belongs anywhere in the group no special emphasis is laid on the predominance of MnO replacing FeO. Should it be definitely determined that the mineral is tetragonal, like rutile, and not orthorhombic, the list of chief primary compounds would have to be increased by the addition of manganous tantalate, $Mn(TaO_3)_2$ and that of the minor primary compounds by the addition of manganous columbate, $Mn(CbO_3)_2$.

A cassiterite with nearly 9 per cent Ta_2O_5 was described from Finland and named ainalite by A. E. Nordenskiöld. Its analysis is given below in the first column and repeated in the second column, with the iron oxide given as FeO. The ratios are given in the third column.

Analysis and ratios of ainalite from Finland.

	Per cent.	Per cent.	Ratio.
SnO_2	88.95	88.95	0.589
Ta_2O_5	8.78	8.78	.020
Fe_2O_3	2.04		
FeO		1.84	.026
CuO	.78	.78	
	100.55	100.35	

The ratios indicate the following composition:

291.5 parts, or 88.3 per cent, of stannyl stannate $(SnO)(SnO_3)$—cassiterite.
20 parts, or 10.4 per cent, of ferrous tantalate, $Fe(TaO_3)_2$—tapiolite.
6 parts, or 1.3 per cent, of ferrous stannate, $Fe(SnO_3)_2$.

Several other cassiterites are given as containing from 2 to 5 per cent tantalic acid, but their analyses are too imperfect to warrant further discussion.

A cassiterite from Mecklenburg, N. C., gave Headden[1] the results shown in the table below. The density is 6.77.

Analysis and ratios of cassiterite from Mecklenburg, N. C.

	Per cent.	Ratio.
SnO_2	95. 18	0. 630
FeO	1. 11	. 015
Ta_2O_5	3. 82	. 009
	100. 11	

From the above values the composition of the cassiterite is deduced to be as follows:

9 parts, or 4.6 per cent, of ferrous tantalate, $Fe(TaO_3)_2$—tapiolite.
6 parts, or 1.3 per cent, of ferrous stannate, $Fe(SnO_3)$.
312 parts, or 94.1 per cent, of stannyl stannate $(SnO)(SnO_3)$—cassiterite.

A cassiterite from the Etta mine, South Dakota, likewise analyzed by Headden gave the following percentages and ratios. Its density is 6.62. In Headden's analysis the iron is reported as 1.80 per cent Fe_2O_3, and this has been changed to the corresponding percentage of FeO.

Analysis and ratios of cassiterite from South Dakota.

	Per cent.	Ratio.
SnO_2	94. 36	0. 625
FeO	1. 62	. 023
Ta_2O_5	2. 42	. 005
SiO_2	1. 00	....
	99. 58	

From the above values the composition of this cassiterite is expressed as:

5 parts, or 2.5 per cent, of ferrous tantalate, $Fe(TaO_3)_2$—tapiolite.
18 parts, or 4.1 per cent, of ferrous stannate, $Fe(SnO_3)$.
303.5 parts, or 93.3 per cent, of stannyl stannate $(SnO)(SnO_3)$—cassiterite.

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[1] Headden, W. P., Mineralogical notes, No. III: Proc. Colorado Sci. Soc., vol. 8, 1906, p. 167.

Both these cassiterites approach ainalite, which contains a little more Ta_2O_5 than either of the American cassiterites.

A cassiterite from the Greenbushes, Australia, contains, according to Simpson,[1] 1.76 per cent Ta_2O_5 and 0.61 per cent iron oxide, etc.

The following summary of the isomorphous mixtures of tapiolite and cassiterite seems to indicate that their miscibility with each other is very slight. Further examination of natural specimens will probably show, however, that their miscibility is complete.

Isomorphous mixtures of tapiolite and cassiterite.

Analyst.	Locality.	Ferrous tantalate (tapiolite).	Stannyl stannate (cassiterite).
		Per cent.	*Per cent.*
Nordenskiöld	Skogböle, Norway	98.8	1.2
Rammelsberg	Kimito, Finland	93 to 90	6.81 to 9.67
Simpson [a]	Wodgina, West Australia	[b] 91.1	8.9
Nordenskiöld	Finland	10.4	88.3
Headden	Mecklenburg, N. C	4.6	94.1
Headden	Etta mine, S. Dak	2.6	[c] 93.3

[a] See p. 19 for description of this mineral.

[b] Includes 81.3 per cent manganous tantalate ($MnTaO_3$) and 9.8 per cent manganous columbate ($MnCbO_3$).

[c] There is also present in the mineral 4.1 per cent ferrous stannate.

STANNYL STANNATE AND TITANYL TITANATE (CASSITERITE AND RUTILE).

A peculiar occurrence of elongated twins, reacting for both titanium and tin, was described by M. von Miklucho-Maclay.[2] If this occurrence is confirmed, the mineral may represent an admixture of rutile and cassiterite, a possibility entirely in accord with the facts.

TITANYL TITANATE (RUTILE) AND FERROUS TITANATE.

Three analyses of rutile from Graves Mountains, Ga., described as large black-brown prisms, pure and homogeneous, are given [3] in columns 1, 2, and 3 of the following table.

The average of these three analyses is shown in column 4, and by changing the values for Fe_2O_3 into the corresponding figures for ferrous oxide,[4] the results in column 5 are obtained, from which the ratios (under 6) are calculated.

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[1] Op. cit., p. 310.

[2] Rutil und Zinnstein im Greifensteiner Granit (Ehrenfriedersdorf): Neues Jahrb., vol. 2, 1885, p. 88.

[3] Pfeil, Karl, Ueber die Aufschliessung der Silikate und anderer schwer zersetzbarer Mineralien mit Borsaure-anhydrid: Centralbl. Min., Geol. u. Pal., 1902, p. 143.

[4] The assumption that the iron is really present as FeO and not as Fe_2O_3 depends, of course, on the supposed purity of the material.

Analyses and ratios of rutile from Georgia.

	Analyses.			Average.	Average.	Ratio.
	1	2	3	4	5	6
TiO_2	97. 64	97. 22	97. 52	97. 46	97. 46	1. 218
Fe_2O_3	2. 61	2. 62	2. 64	2. 62	....	....
FeO	....	....	....	....	2. 36	. 033
	100. 25	99. 84	100. 16	100. 08	99. 82	

From these values the composition is found to be:

33 parts, or 5.0 per cent, of ferrous titanate, $FeTiO_3$.
593 parts, or 95.0 per cent, of titanyl titanate (TiO) (TiO_3)—rutile.

An analysis of a jet-black rutile from St. Peter's Dome, Colo., gave[1] the results shown in the following table. The crystal form is that of rutile with dominant {111}; twinning not mentioned. Measurements "give results with the reflection goniometer agreeing closely with the calculated angles for this species [rutile]". Considering the SiO_2 and H_2O as extraneous, the TiO_2 and FeO give the ratios shown below:

Analysis and ratios of rutile from St. Peter's Dome, Colo.

	Per cent.	Ratio.
TiO_2	94. 93	1. 187
FeO	3. 77	. 052
SiO_2	1. 37	....
H_2O	. 71	....
	100. 78	

The composition of this rutile is, therefore:

52 parts, or 8.0 per cent, of ferrous titanate, $FeTiO_3$.
567.5 parts, or 92.0 per cent, of titanyl titanate (TiO) (TiO_3)—rutile.

The density of the sample is 4.288, which is somewhat higher than that of rutile (4.2).

An iron-black rutile in distorted pyramids {111}, but not twinned, from West Cheyenne Canyon, El Paso County, Colo., gave the analysis shown below.[2] Recalculating the iron reported as Fe_2O_3 to FeO, the analysis is as given in the second column; the ratios obtained from these figures are given in the third column.

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[1] Smith, W. B., Mineralogical notes No. III: Proc. Colorado Sci. Soc., vol. 2, 1887, p. 175.

[2] Genth, F. A., and Penfield, S. L., Contributions to mineralogy, No. 54, with crystallographic notes: Am. Jour. Sci., 3d ser., vol. 44, 1892.

Analysis and ratios of rutile from El Paso County, Colo.

	Per cent.	Per cent.	Ratio.
TiO_2	91.96	91.96	1.149
SnO_2	1.40	1.40	.009
Fe_2O_3	6.68	....	....
FeO	....	6.01	.083
	100.04	99.37	

From the values of the ratios, the composition of this sample is as follows:

4.5 parts, or 1.3 per cent, of stannyl stannate (SnO) (SnO_3)—cassiterite.
83 parts, or 12.8 per cent, of ferrous titanate, Fe (TiO_3).
533 parts, or 85.9 per cent, of titanyl titanate (TiO) (TiO_3)—rutile.

The density of the sample is given as 4.249, which seems to be a little low.

A nigrine from Bernau, Bavaria, is described by Rammelsberg[1] who gives the following analysis (first column), which is repeated in the second column with the ferric iron oxide changed to the corresponding amount of ferrous oxide. The density of this material is 4.41.

Analysis and ratios of nigrine from Bavaria.

	Per cent.	Per cent.	Ratio.
TiO_2	89.49	89.49	1.118
Fe_2O_3	11.03	....	
FeO	....	9.93	$\left.\begin{matrix}.110\\.011\end{matrix}\right\}.121$
MgO	.45	.45	
	100.97	99.87	

The ratios indicate the following composition:

121 parts, or 18.8 per cent, of ferrous titanate, Fe (TiO_3).
498.5 parts, or 81.2 per cent, of titanyl titanate (TiO) (TiO_3)—rutile.

Rammelsberg[2] mentions two other analyses of nigrine. The first (from Ohlapian, Siebenburgen, Transylvania) has, according to Klaproth, the composition shown below in the first column. With the iron and manganese oxides changed to the bivalent condition, the analysis is repeated in the second column. The density is given as 4.445 (Klaproth) and as 4.4–4.5 (Breithaupt). The mean value is 4.45.

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[1] Rammelsberg, C. F., Handb. Mineralchemie, Zweite Aufl., I. Theil, 1875, p. 169.
[2] Rammelsberg, C. F., Handb. Mineralchemie, 1860, p. 1009.

Analysis and ratios of nigrine from Transylvania.

	Per cent.	Per cent.	Ratio.
TiO_2	84	84.0	1.05
Fe_2O_3	14		
FeO		12.6	.17
Mn_2O_3	2		
MnO		1.8	.03
	100	98.4	

The ratios may be interpreted as follows:

20 parts, or 31 per cent, of ferrous titanate, Fe (TiO_3).
42.5 parts, or 69 per cent, of titanyl titanate (TiO) (TiO_3)—rutile.

The second analysis given is by Müller, who analyzed nigrine from Bariern with the results shown below:

Analysis and ratios of nigrine from Bariern.

	Per cent.	Ratio.
TiO_2	86.2	1.08
FeO	14.2	.20
	100.4	

This would correspond to a mixture in the following proportions:

20 parts, or 30 per cent, of ferrous titanate, Fe (TiO_3).
44 parts, or 70 per cent, of titanyl titanate (TiO) (TiO_3)—rutile.

The composition of the two samples is very close but the density given for the last sample is high, namely 4.56. It is not improbable that some columbium and tantalum were present in each sample, which would account for the rather high densities.

The analyses of iserite from Iser, Bohemia, given by Janovsky, are repeated in the first and second columns below, the average being given in the third column and the ratios in the fourth.

Analysis and ratios of iserite from Bohemia.

	Per cent.	Per cent.	Per cent.	Ratio.
TiO_2	70.03	68.99	69.51	0.869
FeO	28.77	28.57	28.67	
MnO	Not det.	1.41	1.41	.426
MgO	Not det.	.32	.32	
Cb_2O_5	Not det.	.44	.44	.002
Ta_2O_5				
		99.73	100.35	

In calculating the ratios from the average analysis, the (MnO + MgO) are included with the FeO, and the mixture of $(Cb_2O_5 + Ta_2O_5)$ is arbitrarily considered as pure Cb_2O_5.

The composition of iserite is from these analyses calculated to be as follows:

2 parts, or 0.6 per cent, of ferrous columbate, $Fe (CbO_3)_2$.
424 parts, or 64.0 per cent, of ferrous titanate, $Fe (TiO_3)$.
222.5 parts, or 35.4 per cent, of titanyl titanate, $(TiO) (TiO_3)$—rutile.

Considering the formula of rutile in the form here given, the mineral under consideration contains an excess of ferrous titanate. The density of iserite is given as 4.52. Knowing the density of ferrous columbate[1] (at least approximately) and also that of rutile, the density of pure ferrous titanate may be calculated. Taking the density of rutile as 4.2 and that of the ferrous columbate present in this iserite as 6.5 (Brögger gives 6.45 for his "mossite" with Cb : Ta = 1 : 1), there is obtained for the density of ferrous titanate the value 4.7. This is, however, lower than the values obtained from nigrine, as is shown in the table below.

The isomorphous mixtures of titanyl titanate (rutile) and ferrous titanate are shown in the following table:

Mixtures of titanyl titanate (rutile) and ferrous titanate.

Locality.	Ferrous titanate.	Titanyl titanate (rutile).	Density.	Calculated density of ferrous titanate.
	Per cent.	*Per cent.*		
Georgia	5.0	95.0	....	....
St. Peters Dome, Colo	8.0	92.0	4.288	5.3
El Paso County, Colo	12.8	85.9	4.249	5.1
Bavaria	18.8	81.2	4.41	5.3
Transylvania	31.0	69.0	4.45	5.0
Barien	30.0	70.0	4.56	5.4
Iser, Bohemia	64.0	35.4	4.52	4.74

All the calculations of the density of ferrous titanate, except the last, give values of 5 or over. The last, the value obtained from iserite, supposedly of correct determination, gives a figure much lower than any of the others. The density of ferrous titanate, therefore, can not be given any more definitely than 5 ±.25.

TITANYL TITANATE (RUTILE) AND TITANYL VANADATE (?).

The possible occurrence of titanyl vanadate as an additional member of the minor primary compounds is indicated by a rutile from Roanoke County, Va. This rutile is said to carry 5 percent

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[1] The small amount present would not have an effect greater than that due to experimental error.

V_2O_5 and a qualitative test, made at the suggestion of Mr. F. L. Hess, showed a decided reaction for vanadium. The presence of this vanadium can be most readily explained by the assumption of the presence of the molecule $(TiO)(VO_3)_2$ in isomorphous mixture with $(TiO)(TiO_3)$.

STANNYL STANNATE (CASSITERITE) AND FERROUS STANNATE.

The only analyses of iron-rich cassiterites that I could find are those made by Genth[1] on Mexican tinstones. Through the courtesy of Mr. F. L. Hess, of the Geological Survey, I was enabled to examine cassiterites similar to those described by Genth. On examining crushed fragments under the microscope the material appeared to be homogeneous, and no admixed ferric oxide could be seen. I therefore believe that iron is a fundamental ingredient of at least some of these ferriferous cassiterites and, assuming that it is present in the ferrous condition, instead of in the ferric, as reported by Genth, I have recalculated his iron determinations and given them here in the corresponding ferrous state. Not all Genth's analyses are reproduced, for many are very similar and one of such suffices. The numbers of the analyses are those given by him.

Analyses of ferriferous cassiterites from Mexico.

	I_b	II	V_a	V_b
SnO_2	92.84	93.98	86.99	86.81
FeO	3.71	5.06	10.40	11.46
As_2O_5	Trace.	....	Trace.	....
CuO	Trace.	....	.11	....
SiO_2	2.70	.23	.57	.52
Ign	.34	.24	.20	.34
	[a] 99.59	[a] 99.51	[a] 98.27	[a] 99.13

[a] If the iron is actually present as FeO the number giving the "ignition" value should be increased by the amount of oxygen required to oxidize the ferrous iron. This would raise the total values to 99.96, 100.02, 99.31, 100.28, respectively.

The ratios deduced from the above analyses, neglecting CuO, SiO_2, and ignition, are as follows:

Ratios of ferriferous cassiterites from Mexico.

	I_b	II	V_a	V_b
SnO_2	0.615	0.622	0.576	0.575
FeO	.051	.070	.144	.159

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[1] Genth, F. A., Proc. Am. Philos. Soc., vol. 24, 1887, p. 26.

These ratios give the following composition of the four samples:

I_b consists of $\left\{\begin{array}{l}\text{51 parts, or 11.8 per cent, of ferrous stannate, } Fe(SnO_3).\\ \text{282 parts, or 88.2 per cent, of stannyl stannate } (SnO)(SnO_3)\text{—cassiterite.}\end{array}\right.$

II consists of $\left\{\begin{array}{l}\text{70 parts, or 15.8 per cent, of ferrous stannate, } Fe(SnO_3).\\ \text{276 parts, or 84.2 per cent, of stannyl stannate } (SnO)(SnO_3)\text{—cassiterite.}\end{array}\right.$

V_a consists of $\left\{\begin{array}{l}\text{144 parts, or 32.3 per cent, of ferrous stannate, } Fe(SnO_3).\\ \text{216 parts, or 67.7 per cent, of stannyl stannate } (SnO)(SnO_3)\text{—cassiterite.}\end{array}\right.$

V_b consists of $\left\{\begin{array}{l}\text{159 parts, or 36.1 per cent, of ferrous stannate, } Fe(SnO_3).\\ \text{208 parts, or 63.9 per cent, of stannyl stannate } (SnO)(SnO_3)\text{—cassiterite.}\end{array}\right.$

The last two samples, isomorphous mixtures of ferrous stannate, $Fe(SnO_3)$, and stannyl stannate $(SnO)(SnO_3)$, include an amount of the first-named salt equal to about one-third of their total composition.

Two more analyses of these ferriferous cassiterites, shown below, have as their most noteworthy feature the presence of small amounts of As_2O_5. In certain other varieties the amount of As_2O_5 is even greater than in the two analyses quoted below. With the analyses are given the ratios deduced from them.

Analyses and ratios of cassiterite from Mexico.

	VI		IV	
	Per cent.	Ratio.	Per cent.	Ratio.
SnO_2	92.26	0.611	92.09	0.610
FeO	4.12	.057	4.90	.068
As_2O_5	1.25	.006	2.11	.009
ZnO	.57	.007		
CuO	Trace.			
SiO_2	.44		.66	
Ignition	.26		.07	
	98.90		99.83	

In considering the composition of these two cassiterites, it becomes necessary to admit two compounds hitherto not found in the list of primary compounds. The new compounds are zinc arsenate $ZnO.As_2O_5$, and ferrous arsenate, $FeO.As_2O_5$, or, as written in conformity with the other salts of these minerals, $Zn''(AsO_3)_2$ and $Fe''(AsO_3)_2$. These compounds I could not find described in the literature, but from a consideration of other series of polymorphic forms of the general rutile group formula, $R''(RO_3)''$, the validity of the assumption that $Zn''(AsO_3)_2$ and $Fe''(AsO_3)_2$ are isomorphously related to $Fe''(TiO_3)_2$ and its related compounds is strongly indicated by the composition of such minerals as lewisite and derbylite.

The two cassiterites whose analyses were just given are shown by the ratios to be made up of the substances and in the proportions shown below.

VI consists of
6 parts, or 1.9 per cent, of zinc arsenate, $Zn (AsO_3)_2$.
57 parts, or 12.9 per cent, of ferrous stannate, $Fe (SnO_3)$.
277 parts, or 85.2 per cent, of stannyl stannate, $(SnO) (SnO_3)$—cassiterite.

IV consists of
9 parts, or 2.8 per cent, of ferrous arsenate, $Fe (AsO_3)_2$.
59 parts, or 13.5 per cent, of ferrous stannate, $Fe (SnO_3)_2$.
271 parts, or 83.7 per cent, of stannyl stannate, $(SnO) (SnO_3)$—cassiterite.

The isomorphous mixtures of stannyl stannate (cassiterite) and ferrous stannate, as developed in the preceding pages, are summarized in the following table:

Mixtures of ferrous stannate and stannyl stannate (cassiterite).

Analyst.	Locality.	Ferrous stannate.	Stannyl stannate (cassiterite).
		Per cent.	*Per cent.*
Nordenskiöld [a]	Finland	1.3	[b] 88.3
Headden [a]	North Carolina	1.3	[c] 94.1
Headden [a]	Etta Mine, South Dakota	4.1	[d] 93.3
Genth	Mexico	11.8	88.2
Do	do	12.9	[e] 85.2
Do	do	13.5	[f] 83.7
Do	do	15.8	84.2
Do	do	32.3	67.7
Do	do	36.1	63.9

[a] Described on p. 21.

[b] This mineral also includes 10.4 per cent of tapiolite.

[c] This mineral also includes 4.6 per cent of tapiolite.

[d] This mineral also includes 2.6 per cent of tapiolite.

[e] This mineral also includes 1.9 per cent of zinc arsenate.

[f] This mineral also includes 2.8 per cent of ferrous arsenate.

ISOMORPHOUS MIXTURES OF MORE THAN TWO OF THE PRIMARY COMPOUNDS.

The mixtures of more than two of the primary compounds include strüverite, ilmenorutile, and some of the Mexican cassiterites analyzed by Genth.

STRÜVERITE.

Strüverite was described by Prior and Zambonini in 1908 and, as they state at the end of their paper, the name strüverite is proposed "for those members of the series which are rich in tantalic acid." These minerals are regarded "as essentially solid solutions of the tapiolite or mossite molecule $Fe[(Ta, Nb)O_3]_2$ with the rutile molecule

$TiO.TiO_3$." Such a conception, however, entirely ignores the slight but constant excess of FeO in the analyses. The tetragonal crystals of strüverite resemble those of rutile in habit and in their angular values. Prior and Zambonini state: "Of frequent occurrence are crystals elongated along the edge $s:s' = [(111):(1\bar{1}1)]$; most of these appear to be twins on a face of the form {101}, like the well-known twins of ilmenorutile, tapiolite, and mossite, and also of rutile from certain localities." The value deduced for the *c* axis is 0.6456. (Compare the values given on p. 12.)

The following are the analytical figures given by Prior and Zambonini for strüverite from Italy:

Analyses and ratios of strüverite from Italy.

	Analysis.		Average.	Ratio.	
	Per cent.	*Per cent.*	*Per cent.*		
TiO_2	41. 09	41. 32	41. 20	0. 515	
Cb_2O_5	46. 94	46. 98	23. 48	. 088	. 141
Ta_2O_5			23. 48	. 053	
FeO	11. 15	11. 62	11. 38	. 158	. 171
MnO	Trace.	....	Trace.	....	
CaO	. 51	....	. 51	. 009	
MgO	. 17	....	. 17	. 004	
			100. 22		

Inspection of the ratios shows that there is an excess of FeO over the amount required to combine with the Cb_2O_5 and Ta_2O_5. If, however, we assume the presence of sufficient ferrous titanate to take up all the remaining FeO, the interpretation of the above average analysis becomes simple and accurate. The ratios show, in fact, that the material analyzed is an isomorphous mixture of the four minerals in the proportions shown below.

88 parts, or 29.9 per cent, of ferrous columbate, Fe $(CbO_3)_2$.
53 parts, or 27.4 per cent, of ferrous tantalate, Fe $(TaO_3)_2$—tapiolite.
17 parts, or 2.6 per cent, of ferrous titanate, Fe (TiO_3).
249 parts, or 40.1 per cent, of titanyl titanate, (TiO) (TiO_3)—rutile.

For an isomorphous mixture of the proportions shown above, the calculated composition is given below in comparison with the strüverite analysis. The agreement of the calculated values with those in the analysis is very close, so that the explanation offered is consistent. The direct comparisons with the analytical figures clearly bring out the correctness of the view here proposed.

Two determinations of the density of strüverite give 5.54 and 5.59, from which a mean value of 5.57 may be taken.

Calculated percentages of strüverite from Italy compared with analysis.

	Calculated.	Analysis.
TiO_2	41.41	41.20
Cb_2O_5	23.62	23.48
Ta_2O_5	23.54	23.48
FeO	11.43	11.38
MnO	....	Trace.
CaO	....	.51
MgO	....	.17
	100.00	100.22

An occurrence of strüverite from the Etta mine, South Dakota, has been described by Hess and Wells.[1] According to their analysis, the South Dakota mineral, unlike the Italian strüverite, fits the definition of strüverite given by Prior and Zambonini.

The analysis of strüverite from South Dakota and the ratios calculated therefrom are given below. The close relation in crystalline form of this mineral to rutile is described in the paper referred to.

Analysis and ratios of strüverite from South Dakota.

	Per cent.	Ratio.	
TiO_2	49.0	0.613	.622
SnO_2	1.3	.009	
FeO	7.3	.101	.101
Ta_2O_5	35.7	.081	.106
Cb_2O_5	6.7	.025	
	100.0	....	

The ratios approximate the formula $FeO.(Ta,Cb)_2O_5.6H_2O$, but there is no warrant for assuming the existence of such a compound. The composition may be interpreted according to the following tabulation, which shows the mineral to be an isomorphous mixture of the primary compounds of the rutile group, tapiolite and rutile largely predominating.

25 parts, or 8.4 per cent, ferrous columbate, $Fe(CbO_3)_2$.
81 parts, or 41.4 per cent, ferrous tantalate, $Fe(TaO_3)_2$—tapiolite.
306.5 parts, or 48.8 per cent, titanyl titanate (TiO) (TiO_3)—rutile.
4.5 parts, or 1.4 per cent, stannyl stannate (SnO) (SnO_3)—cassiterite.

This strüverite is the only mineral of this entire group containing Cb, Ta, Fe, and Ti in quantity in which no ferrous titanate is present.

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[1] Hess, F. L., and Wells, R. C., An occurrence of strüverite: Am. Jour. Sci., 4th ser., vol. 31, 1911, p. 432.

That the percentages of the primary compounds closely represent the true composition of the mineral can be shown in another way, namely, by calculating back the percentage values of the different oxides and comparing them with the analytical figures. The values obtained should, of course, agree exactly or nearly so[1] with the analytical figures from which the percentages of the primary compounds were obtained. The calculated composition is compared with the analytical figures in the table below:

Calculated percentages of strüverite from South Dakota compared with analysis.

	Calculated.	Analysis.
TiO_2	49. 0	49. 0
SnO_2	1. 3	1. 3
FeO	7. 3	7. 3
Ta_2O_5	35. 8	35. 7
Cb_2O_5	6. 6	6. 7
	100. 0	100. 0

A black rutile or nigrine from South Dakota with a brilliant and metallic luster was described by Headden and Pirsson.[2] The streak was grayish black, the hardness 6, and the density 5.294. The measurements of the crystals agreed well with the angles of rutile, but the value given for the density is entirely too high for a rutile of the composition given by Headden and Pirsson. As their material was similar to that analyzed and described by Hess and Wells, their analytical figures are doubtless entirely wrong for the TiO_2.

Their analyses gave the values shown under 1 and 2, but no ratios are deduced because the value given for TiO_2 is considered erroneous.

Analyses of supposed rutile from South Dakota.

	1	2
TiO_2	90. 78	90. 80
SnO_2	1. 32	1. 38
FeO	8. 10	7. 92
MnO	Trace.	Trace.
	100. 20	100. 10

That the mineral described by Headden and Pirsson is similar to that analyzed by Wells is shown by comparison of the two analyses,

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[1] Slight differences will be found because of impurities in the mineral which are given in the analysis but are not figured in the ratios, and because the calculations are not carried to a sufficient number of decimals.

[2] Headden, W. P., and Pirsson, L. V., On black rutile from the Black Hills: Am. Jour. Sci., 3d ser., vol. 14, 1891, p. 249.

in which the constituents other than $TiO_2+Cb_2O_5+Ta_2O_5$ agree closely. The densities of the two minerals also correspond well.

Comparison of analyses of South Dakota mineral.

	Average of analyses 1 and 2.	Wells's analysis.	
TiO_2	90.79	49.0	91.4
Cb_2O_5		6.7	
Ta_2O_5		35.7	
SnO_2	1.35	1.3	
FeO	8.01	7.3	
MnO	Trace.	....	
	100.15	100.0	

Average density of mineral analyzed by Headden and Pirsson, 5.294.
Density of mineral analyzed by Wells, 5.25.

ILMENORUTILE.

Ilmenorutile is found in tetragonal crystals similar to rutile in angles and frequently twinned after (101), being often elongated parallel to the edge (111) : $(1\bar{1}1)$.

Ilmenorutile from the Ilmen Mountains was analyzed by Prior. His results and ratios are given below.[1] The density of his material is 5.14.

Analysis and ratios of ilmenorutile from the Ilmen Mountains.

	Per cent.	Ratio.	
TiO_2	53.04	0.663	
Cb_2O_5	21.73	.081	.114
Ta_2O_5	14.70	.033	
FeO	10.56	.147	
CaO	Trace.	....	
	100.03	....	

The ferrous iron is again in excess of that required for the columbate and tantalate, and the interpretation of the analysis shows four of the primary mineral species to be present in quantity. The composition is indicated to be as follows:

33 parts, or 5.0 per cent, of ferrous titanate, $FeTiO_3$.
81 parts, or 27.5 per cent, of ferrous columbate, $Fe(CbO_3)_2$.
33 parts, or 17.0 per cent, of ferrous tantalate, $Fe(TaO_3)_2$—tapiolite.
315 parts, or 50.5 per cent, of titanyl titanate, $(TiO)(TiO_3)$—rutile.

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[1] An earlier analysis given by G. T. Prior (Mineralog. Mag., vol. 15, 1908, p. 86) is excluded here because in it the $Cb_2O_5+Ta_2O_5$ were not separated.

The calculated values for the composition, as given in the table above, are shown with the analysis repeated in the table below.

Calculated percentages of ilmenorutile from the Ilmen Mountains compared with analysis.

	Calculated.	Analysis.
TiO_2	53.13	53.04
Cb_2O_5	21.66	21.73
Ta_2O_5	14.61	14.70
FeO	10.60	10.56
CaO	....	Trace.
	100.00	100.03

An analysis of ilmenorutile from Evje Kirschspiel, in Saetersdal, as described by Brögger[1] and corrected by Prior[2] gave the following results:

Analysis and ratios of ilmenorutile from Saetersdal.

	Per cent.	Ratios.
TiO_2	54.50	0.681
SiO_2	.23	......
Cb_2O_5	33.02	.124 } .125
Ta_2O_5	.43	.001 }
FeO	11.58	.161
MgO	.04	......
CaO	.22	......
	100.02	

Here, again, the ferrous iron is in excess and it becomes necessary, as suggested by Brögger, to consider the admixture of the molecule $FeTiO_3$. The composition of the mineral can then be expressed as follows:

36 parts, or 5.5 per cent, of ferrous titanate, $Fe(TiO_3)$.
124 parts, or 42.1 per cent, of ferrous columbate, $Fe(CbO_3)_2$.
1 part, or 0.5 per cent, of ferrous tantalate, $Fe(TaO_3)_2$—tapiolite.
322.5 parts, or 51.9 per cent, of titanyl titanate, $(TiO)(TiO_3)$—rutile.

A comparison of the calculated composition, as given above, with the analysis, is shown in the following table, in which is also given the nearly identical analysis of ilmenorutile from Ansel, near Tvedestrand, given by Brögger and corrected by Prior:

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[1] Videnskabs-Selskabets Skrifter.—Math. naturw. Kl., 1906, no. 6.

[2] Prior, G. T., op. cit., p. 86.

Calculated percentages compared with analyses of ilmenorutile.

	Calculated.	Ilmenorutile from Evje.	Ilmenorutile from Ansel.
TiO_2	54.69	54.50	54.50
Cb_2O_5	33.23	33.02	33.49
Ta_2O_5	.44	.43	....
FeO	11.64	11.58	11.68
SiO_2	....	.23	.05
MnO	....	....	Trace.
MgO	....	.04	Trace.
CaO	....	.22	.28
	100.00	100.02	100.00

Ilmenorutile from Iveland, Norway, was also analyzed by Prior. Tantalum could not be detected, so no admixture of tapiolite is present. The low summation is ascribed to a probable slight loss of columbium.

Analysis and ratios of ilmenorutile from Iveland.

	Per cent.	Ratio.
TiO_2	54.57	0.682
Cb_2O_5	32.15	.120
FeO	12.29	.170
CaO	.11	....
MgO	Trace.	....
	99.12	

It can at once be seen that the ferrous iron is greatly in excess of the columbic oxide, so that a relatively large amount of ferrous titanate must be present. The ratios lead to the following interpretation:

120 parts, or 41.1 per cent, of ferrous columbate, $Fe(CbO_3)_2$.
50 parts, or 7.7 per cent, of ferrous titanate, $Fe(TiO_3)$.
316 parts, or 51.2 per cent, of titanyl titanate, $(TiO)(TiO_3)$—rutile.

A comparison with the analysis of the values calculated from this composition is given below:

Calculated percentages compared with analysis of ilmenorutile from Iveland.

	Calculated.	Analysis.
TiO_2	55.20	54.57
Cb_2O_5	32.41	32.15
FeO	12.39	12.29
CaO	....	.11
MgO	....	Trace.
	100.00	99.12

ARSENICAL CASSITERITE.

Three analyses of the Mexican cassiterites[1] show them to be practically free from iron, but to contain considerable As_2O_5 and ZnO. In fact, the ZnO is always in molecular excess to the amount of As_2O_5 required to form $Zn(AsO_3)_2$, so that the small amounts of ZnO(+FeO) left over are combined with sufficient tin to form the compound $Zn(SnO_3)$, whose acceptance in the list of primary compounds is as well grounded as is that of $Fe(SnO_3)$.

Analyses of cassiterite from Mexico.

	VIII	IX	X
SnO_2	92.50	89.90	93.13
FeO	.20	.09	.18
ZnO	1.89	2.43	2.71
CuO	.16	.20	.09
As_2O_5	4.56	5.80	3.18
SiO_2	.24	.55	.43
Ign	.26	.40	.32
	99.81	99.37	100.04

Ratios of analyses of cassiterite from Mexico.

	VIII		IX		X	
SnO_2	0.613		0.595		0.617	
FeO	.003		.001		.003	
ZnO	.023	.028	.030	.034	.033	.037
CuO	.002		.003		.001	
As_2O_5	.020		.025		.014	

If the FeO and CuO are treated as ZnO, these ratios indicate the following composition for the above three samples:

VIII consists of
- 20 parts, or 6.2 per cent, of zinc arsenate, $Zn(AsO_3)_2$.
- 8 parts, or 3.0 per cent, of zinc stannate, $Zn(SnO_3)$.
- 302.5 parts, or 90.8 per cent, of stannyl stannate, $(SnO)(SnO_3)$—cassiterite.

IX consists of
- 25 parts, or 7.8 per cent, of zinc arsenate, $Zn(AsO_3)_2$.
- 9 parts, or 3.1 per cent, of zinc stannate, $Zn(SnO_3)$.
- 293 parts, or 89.1 per cent, of stannyl stannate, $(SnO)(SnO_3)$—cassiterite.

X consists of
- 14 parts, or 4.2 per cent, of zinc arsenate, $Zn(AsO_3)_2$.
- 23 parts, or 8.6 per cent, of zinc stannate, $Zn(SnO_3)_2$.
- 297 parts, or 87.2 per cent, of stannyl stannate, $(SnO)(SnO_3)$—cassiterite.

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[1] Analyzed by Genth, op. cit.

One analysis shows proportionately a large amount of As_2O_5, but the molecular amount of $ZnO+FeO$ still exceeds the amount required to form (Zn, Fe) $(AsO_3)_2$. This analysis and the ratios derived from it are shown below:

Analysis of cassiterite from Mexico.[a]

	Per cent.	Ratio.
SnO_2	84.30	0.558
FeO	1.39	.019
ZnO	2.96	.037
CuO	Trace.	....
As_2O_5	10.34	.045
SiO_2	.30	....
Ign	.57	....
	99.86	

[a] Genth's analysis VII b.

The composition of this sample is expressed by the following tabulation:

37 parts, or 11.6 per cent, of zinc arsenate, $Zn(AsO_3)_2$.
8 parts, or 2.4 per cent, of ferrous arsenate, $Fe(AsO_3)_2$.
11 parts, or 2.5 per cent, of ferrous stannate, $Fe(SnO_3)$.
273.5 parts, or 83.5 per cent, of stannyl stannate, $(SnO)(SnO_3)$—cassiterite.

CONCLUSION.

It has been shown that chemically all the minerals here described may be considered as isomorphous members of a series consisting of several distinct compounds or as mixtures of two or more of those compounds. All the mixtures have the same or nearly the same crystallographic values (tetragonal, $c=0.64$ approximately), and nearly all possess the peculiar distorted twinning. That no morphotropic series is at hand is shown by the constancy of the crystallographic axis c, and I believe that formulas such as $FeO.(Ta,Cb)_2O_5.4TiO_2$ for strüverite and $FeO.(Cb,Ta)_2O_5.5TiO_2$ for ilmenorutile, as suggested by Prior and Zambonini, are incorrect, and that the writers who have proposed them fail to consider the obvious isomorphous relations of the much simpler (in composition) primary compounds. Prior and Zambonini state, however, that "closer agreement between the amounts found and calculated are obtained when we assume an admixture of the molecule $FeTiO_3$ (as suggested by Brögger) or of $FeTi_2O_5$, molecules such as may be present in the ferriferous rutiles. On this assumption, the formula of ilmenorutile from the Ilmen Mountains would be $3.5[FeO.(Cb\frac{5}{7}, Ta\frac{2}{7})_2O_5.5TiO_2]+FeTi_2O_5$, and of that from Iveland $2.4[FeO.Cb_2O_5.5TiO_2]+FeTi_2O_5$." These formulas, however, contain compounds the existence of neither of which ($FeO.Cb_2O_5.5TiO_2$, $FeTi_2O_5$) has been demonstrated. The evidence of the mutual isomorphous mixing in varying proportions of the primary constituents is so strong that I believe the simpler explanation here offered to be nearer the true one. I would therefore propose that of the different minerals and mineral mixtures comprising the rutile group, as I define it, the only names[1] that should be kept up as distinct mineral species are the three following:

Tapiolite, $Fe(TaO_3)_2$ or $FeO.Ta_2O_5$.
Rutile, $(TiO)(TiO_3)$ or TiO_2.
Cassiterite, $(SnO)(SnO_3)$ or SnO_2.

In addition, the name ilmenorutile will serve, as a subspecies, to indicate those mixtures in which Fe, Ta, Cb, and Ti are present in quantity. Brögger's "mossite" is then only a columbium tapiolite. When the pure or nearly pure (tetragonal) iron columbate is found in nature, then a new name will be appropriate and necessary. Similarly, the compounds $FeTiO_3$ and $FeSnO_3$, when found in nature in a pure or nearly pure condition will be entitled to distinct new mineral names.

Nigrine and iserite are only iron rutile, ainalite is a tantalum cassiterite, and strüverite[2] the same as ilmenorutile. If it seems desirable, the various ilmenorutiles can be called columbium ilmenorutile, tantalum ilmenorutile, titanium ilmenorutile, iron ilmenorutile, and tin ilmenorutile, depending on which of these elements predominates in the composition of specimens.

The several cassiterites from Mexico analyzed by Genth can be called, to distinguish them from pure cassiterite, iron cassiterite, arsenic or arsenical cassiterite, zinc cassiterite, etc. Such a system of nomenclature at once defines a variety—for example, tantalum cassiterite means cassiterite containing tantalum. To give a new name for every variety of a known mineral would lead to such a multiplicity of names that any systematic scheme of nomenclature would be hopeless. The system here proposed is elastic enough to permit nearly all new finds to be referred to it.

A name should not be put forward—or if proposed should not be accepted—for a known mineral in which a small amount of some other element is present, particularly where the presence of that element is due to isomorphous replacement. If a rutile contains several per cent of iron in combination, it should not be given a distinct name (like nigrine), but should be called what it really is, an iron rutile, or a ferriferous rutile. If a calcite contains a little

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[1] As additional members of this group, which rank as well-defined species, are to be added zircon, thorite, polianite, plattnerite and perhaps others. See footnote on p. 9.

[2] Certainly the Italian strüverite has no claim for specific identity distinct from ilmenorutile.

cobalt, it should not be called cobaltocalcite, but simply a cobalt calcite. Indiscriminate use of distinct names for mere varieties or for certain isomorphous mixtures opens up the possibility of an infinite number of names which would in time so complicate the science of mineralogy as to make it unfit for practical service.

The mineral names used in this discussion which it is believed have no claim for recognition as distinct mineral species and the descriptive terms proposed to replace them are as follows:

Mossite	columbium tapiolite.
Nigrine and iserite	iron rutile.
Ainalite	tantalum cassiterite.
Strüverite [1]	ilmenorutile.

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[1] I here mean the strüverite from Italy. The mineral from South Dakota would be called tantalum ilmenorutile.

BARBIERITE, MONOCLINIC SODA FELDSPAR.

The existence of a monoclinic dimorphous form of albite isomorphous with orthoclase, was long ago suggested, but the presence of soda in orthoclase analyses has generally been otherwise explained, most commonly by granting the presence of albite or an orthoclase. In a recent paper by Barbier and Prost[1] analyses are given of feldspars in which the cleavage angle varies but a few minutes from 90° and in which soda is present in molecularly greater amount than the potash. The maximum soda content is reached in a feldspar from Kragerö, Norway, in which only 1.15 per cent K_2O was found.

Prof. Barbier was kind enough to send me some slides of the feldspar from Kragerö which, according to his analysis, consists essentially of the soda compound. One of the slides, a basal section giving parallel extinction and appearing to be uniform, was uncovered and the feldspar washed free from Canada balsam. The mineral was then immersed in an oil with a refractive index of 1.530, and it was seen that the index of the mineral was considerably lower than that of the oil. If the orientation of the mineral is the same as that of orthoclase a basal section would yield values for α and for γ. As these were both found to be decidedly lower than 1.530, the section can not be albite.[2] Unfortunately the very small section was accidentally lost before its soda content could be verified microchemically.

Microscopic examination by Prof. Barbier showed that with one exception albite was not present in his specimens, and consequently the existence of a monoclinic soda feldspar isomorphous with orthoclase must be admitted. I propose to call this particular monoclinic soda feldspar barbierite, in honor of Prof. Barbier, who is a member of the faculty of the University of Lyon, France. He has recently published, in addition to the paper above cited, an article on the feldspar group in which he gives a definite chemical difference between orthoclase and microcline.[3] Further analyses of soda-rich orthoclases are given by him in a later paper.[4] The feldspar from Kragerö is nearly pure barbierite.

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[1] Barbier, Ph., and Prost, A., Sur l'existence d'un feldspath sodique monoclinique, isomorphe de l'orthose: Bull. Soc. chim., 1908, III, p. 894.

[2] For albite, α=1.529, γ=1.539.

[3] Barbier, Ph., Recherches sur la composition chimique des feldspaths potassiques: Bull. Soc. franç. minéral., vol. 31, 1908, p. 152.

[4] Barbier, Ph. and Gonnard, F., Analyses de quelques feldspaths français: Bull. Soc. franç. mineral., vol. 33, 1910, p. 81.

Angel[1] recently described a soda-bearing monoclinic sanidine, which contains 4.92 per cent Na_2O and 6.75 per cent K_2O. The cleavage angle (001) : (010) is 90° 01′ and the extinction on (001) is parallel. The feldspar is monoclinic and consists approximately of equal parts of the isomorphous orthoclase and barbierite. In his paper Angel gives several references to earlier publications on feldspars which undoubtedly contain barbierite in isomorphous admixture.

This opportunity may be taken to call attention to an error in the first paper of Prof. Barbier referred to. The locality of one of the specimens is given as Francheville le Bas (Rhone). The correct locality is Orlienas (Rhone). Prof. Barbier asked me to call attention to this error in locality.

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[1] Angel, Franz, Ueber einen Natronsanidin von Mitrowitza: Neues Jahrb. für Min., Beil.-Band, vol. 30, 1910, p. 254.

CRYSTALLIZED TURQUOISE FROM VIRGINIA.

INTRODUCTION.

A sample of a bright blue mineral, from near Lynch station, Campbell County, Va., was brought to the Geological Survey for identification by Mr. J. H. Watkins. As a few preliminary tests failed to identify the mineral with any known species, a complete study of it was undertaken. The results obtained show that the supposed new mineral is identical with turquoise. The chief interest, however, lies in the fact that this turquoise is well crystallized, so that it was possible to measure several of the minute crystals and determine thereby the crystallography of the mineral. I am deeply indebted to Mr. Watkins for his kindness in furnishing the material (now deposited in the United States National Museum, catalogue No. 86990), and in allowing this description to be published. A photograph of the specimen is shown in Plate I, *A*.

The matrix of the specimen consists of irregular fragments of glassy quartz of various sizes, cemented together by thin layers of turquoise crystals. On one side of the specimen the turquoise forms a drusy, botryoidal layer, cavernous in texture and including many small irregular fragments of the glassy quartz. The turquoise, with its many included quartz fragments, polishes well and makes a very handsome ornamental stone. The spheres which form the botryoidal surface bristle with minute crystals and average about 2 or 3 millimeters in diameter. The individual crystals rarely are as much as a third of a millimeter long, being usually smaller and much thinner.

GENERAL DESCRIPTION.

The turquoise is blue in color and has a vitreous luster. Cleavage is present, possibly in two directions. The mineral is brittle and has a hardness of about 5, though the minute size and brittleness of the crystals make it difficult to determine the hardness with accuracy. The density, determined with a pycrometer on the powdered sample analyzed, is 2.816, which, when corrected for the 12.57 per cent insoluble material (mostly quartz) present,[1] gives for the pure turquoise the value 2.84.

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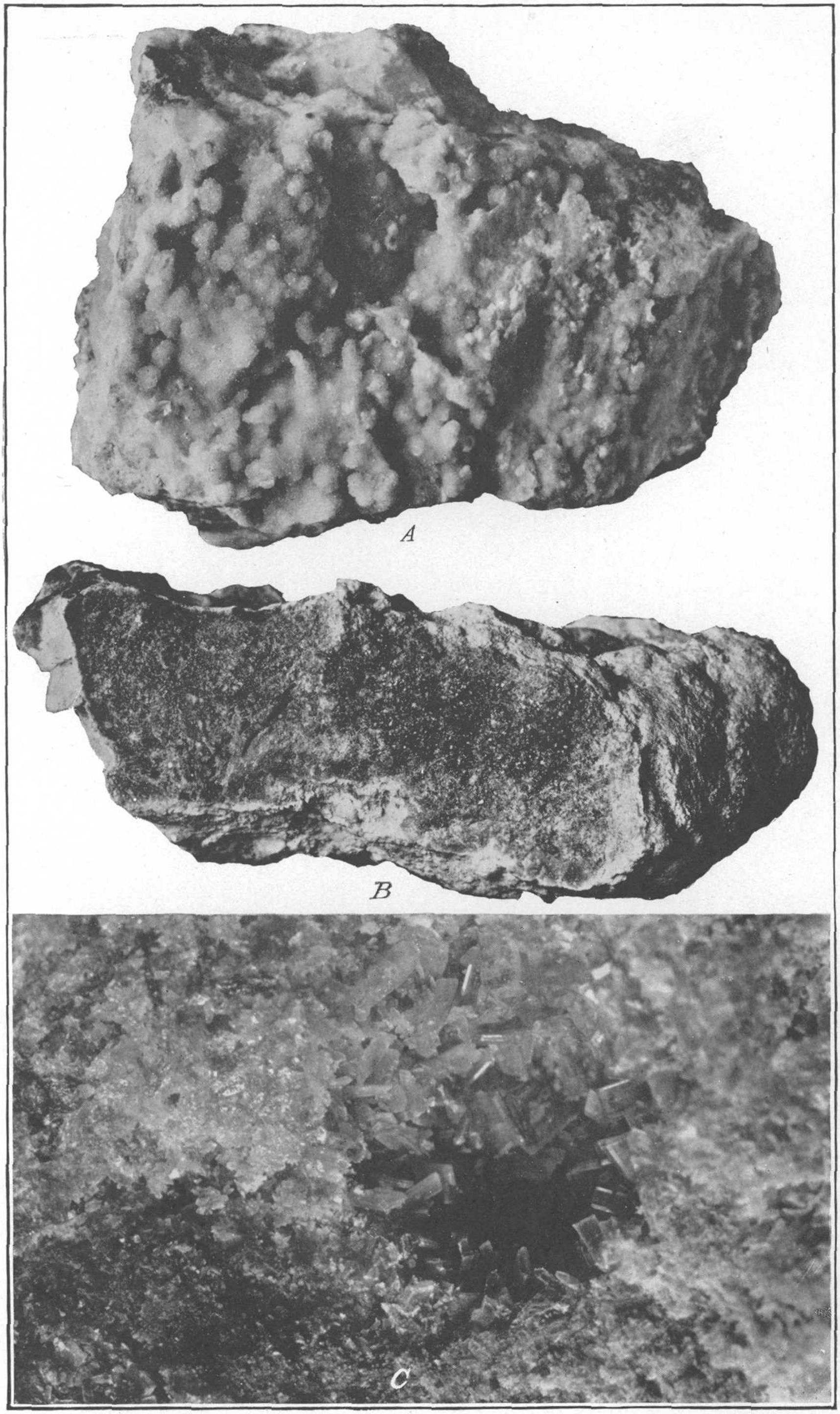
[1] See analysis, p. 45.



A. CRYSTALLIZED TURQUOISE FROM VIRGINIA, NATURAL SIZE.

B. VARISCITE NODULE FROM UTAH, NATURAL SIZE. ON THE LEFT, AN AGGREGATE OF CRYSTALS; ON THE RIGHT, THE ORDINARY COMPACT PHASE.

C. VARISCITE CRYSTALS IN A CAVITY OF AGGREGATE OF CRYSTALS, FROM UTAH. ENLARGED 6 DIAMETERS.

Examined under the microscope, the crystals are clear and transparent and the material is very pure. Pleochroism is distinct, from colorless to pale bluish. Extinction is inclined on all sections, and, as verified by the measurements, the crystals are triclinic. None of the sections showed a good interference figure, though such as were seen indicated biaxiality. One cleavage plate, possibly parallel to *M* $(1\bar{1}0)$, showed extinction of 12° against the vertical direction and 12° against the other edge $(1\bar{1}0 \wedge 0\bar{1}1$?). A different cleavage section of a rhombic shape showed extinction values of 5° and 34° respectively, but the orientation of this piece could not be determined. The double refraction of the mineral is high, about 0.04. The refractive indices are about: $\alpha=1.61$, $\gamma=1.65$. Lacroix[1] gives the value 1.63 for the mean index.

CRYSTALLOGRAPHY.

The crystals are very minute and so closely grown together that it was almost impossible to obtain any suitable for measurement. One complete crystal was found that gave fairly good reflections, and the measurements made from it were verified by those obtained on a second less perfect crystal. A third incomplete one also yielded a few measurements. The dimensions of the first two crystals were as follows:

Crystal No. 1, 0.27 mm. high (*c* axis), 0.32 mm. wide (*b* axis).

Crystal No. 2, 0.32 mm. high (*c* axis), 0.40 mm. wide (*b* axis), 0.12 mm. thick (*a* axis).

The crystals are triclinic and in angles very near to those of chalcosiderite. The angular values of turquoise and chalcosiderite are so close that the crystallographic elements of chalcosiderite have been adopted for those of turquoise, as the crystals of the latter mineral are poorly adapted for accurate measurements. In fact, were it not for a knowledge of the crystallography of chalcosiderite (isomorphous with turquoise, as is shown in this paper in the discussion of chemical composition), it is doubtful if the orientation of the turquoise crystals could have been interpreted.

The values for turquoise are, then, as follows: $a : b : c = 0.7910 : 1 : 0.6051$; $\alpha=92° 58'$, $\beta=93° 30'$, $\gamma=107° 41'$.

Forms: *b* $\{010\}$, *a* $\{100\}$, *m* $\{110\}$, *M* $\{1\bar{1}0\}$, *k* $\{0\bar{1}1\}$.

The comparison of the measured angles with the calculated ones[2] are shown below.

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[1] Lacroix, A., Minéralogie de la France, vol. 4, 1910, p. 529.

[2] These calculated values are, with one exception, taken from the values calculated for chalcosiderite by Maskelyne, Jour. Chem. Soc., vol. 28, 1875, p. 586.

Comparison of measures and calculated angles, turquoise.

Angle.	Measured.			Calculated.
	Crystal No. 1.	Crystal No. 2.	Crystal No. 3.	
	° ′	° ′	° ′	° ′
$1\bar{1}0 \wedge 100$	45 12	....	....	44 50
$100 \wedge 110$	31 14	31 28	31 25	31 10
$110 \wedge \bar{1}10$	104 14	....	104 03	104 00
$110 \wedge 010$ [a]	37 28	38 39	....	40 54
$0\bar{1}1 \wedge \bar{1}10$	107 42	105 15	....	105 36
$0\bar{1}1 \wedge 100$	....	95 33	....	95 45
$0\bar{1}1 \wedge 110$	....	110 00	....	109 36
$0\bar{1}1 \wedge 010$ [a]	....	117 26	....	119 19

[a] The faces of {010} gave very poor reflections.

The habit of the crystals is shown in figure 2.

The forms *a* {100} and *M* {$1\bar{1}0$} are large and striated vertically, *a* generally more striated than *M*. The prism *m* {110} is small sized and striated parallel to the edge (110): ($0\bar{1}1$). Between *m* and *k* {011} lies an undetermined small face very much striated. The clinopinacoid *b* {010} is very small and uneven and gives a very poor reflection. The dome *k* {$0\bar{1}1$} is the only terminal face definitely determined and is strongly striated on crystal No. 1, though perfectly smooth and yielding an excellent reflection on crystal No. 2. It may be that the face *k* on crystal No. 2 is a cleavage face, as an easy cleavage parallel to this dome was noted by Maskelyne on chalcosiderite.

The pointed appearance of the minute crystals is due to the sharpness of the upper right-hand corner where the intersection of *a*{100} and *k*{$0\bar{1}1$} yields an acute point.

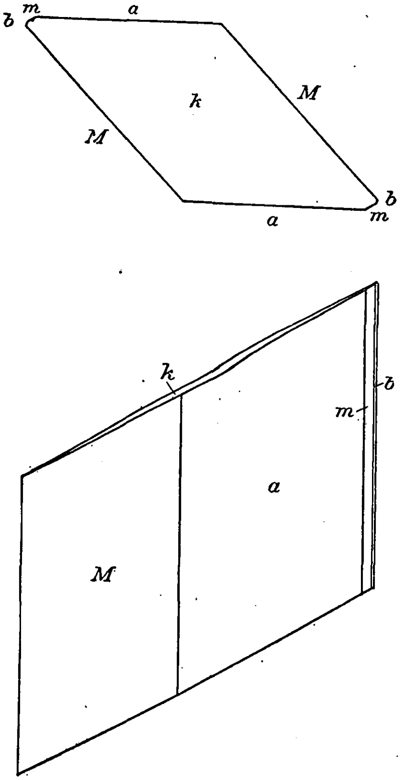

FIGURE 2.—Turquoise crystal. *b*{010}, *a*{100}, *m*{110}, *M*{$1\bar{1}0$}, *k*{$0\bar{1}1$}.

CHEMICAL COMPOSITION.

Abundant material was available for the analysis, which was made on carefully selected pieces free from all impurities except the quartz. It was found that the mineral is insoluble in boiling hydrochloric acid, but that after gentle ignition (when it has turned brown) it is readily soluble in acids. The mineral does not lose any water below 200° and retains its blue color at that temperature. Between 200° and 650°, all the water is given off[1] and the mineral becomes greenish in color. On higher heating the greenish color changes to a brown. The mineral is infusible before the blowpipe, but becomes brown.

The average analysis is shown in the table below in the first column; in the second column is given the same analysis with the insoluble matter (quartz) deducted.

Analysis and ratios of turquoise.

	Analysis.	Analysis (insoluble matter deducted).	Ratio.	
P_2O_5	29.84	34.13	0.240	2.07 or 2
Al_2O_3	31.91	36.50	.357	3.09 or 3
Fe_2O_3	.18	.21	.001	....
CuO	7.87	9.00	.113	.97 or 1
H_2O	17.59	20.12	1.118	9.64 or 9
Insoluble matter	12.57	....	....	....
	99.96	99.96		

The formula derived from the ratios of the analysis is $CuO.3Al_2O_3.2P_2O_5.9H_2O$. According to Penfield's suggestion[2] as to the relation of the hydroxyl groups, this formula can be interpreted as $CuOH.6[Al(OH)_2].H_5.(PO_4)_4$. I believe that this formula expresses the definite composition of turquoise and a comparison with other analyses shows that this formula is doubtless the correct one.

Among the best analyses of turquoise is that made by Penfield[2] on material from Lincoln County, Nev. This turquoise was "of exceptionally fine quality * * * very fine-grained, of a beautiful robin's-egg blue color, and broke with a smooth fracture * * * when examined under the microscope, the turquoise seemed to be perfectly uniform, showing no evidence of being made up of two substances * * * it acted somewhat on polarized light." Its density is given as 2.791.

In the following table are given the analysis of the turquoise from Virginia and Penfield's analyses of turquoise from Lincoln County, Nev. In the third column is shown the composition calculated for the formula proposed.

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[1] Nearly all the water is expelled below 400°.

[2] Penfield, S. L., On the chemical composition of turquoise: Am. Jour. Sci., 4th ser., vol. 10, 1900, p. 346.

Analyses of turquoise.

	Virginia.	Nevada.	Calculated for $CuO.3Al_2O_3$.-$2P_2O_5.9H_2O$.
P_2O_5	34.13	34.18	34.12
Al_2O_3	36.50	35.03	36.84
Fe_2O_3	.21	1.44	
CuO	9.00	8.57	9.57
H_2O	20.12	19.38	19.47
Insoluble matter		.93	
	99.96	99.53	100.00

The agreement of the three analyses is very close, so that the formula $CuO.3Al_2O_3.2P_2O_5.9H_2O$ expresses definitely the composition of this mineral.

Of the other analyses of turquoise, in which the purity of material is not so definitely known as in the two analyses just cited, only those given by Penfield [1] are quoted in the following table:

Analyses of turquoise.

	Calculated.	Persia. (Church.)	Russia. (Nicolajew.)	California. (Moore.)	New Mexico. (Clarke.)		
P_2O_5	34.12	32.86	34.42	33.21	31.96	32.86	28.63
Al_2O_3	36.84	40.19	[35.79]	35.98	[c]39.53	36.88	37.88
Fe_2O_3		[a] 2.45	3.52	2.99		2.40	4.07
CuO	9.57	5.27	7.67	7.80	6.30	7.51	6.56
H_2O	19.47	19.34	18.60	19.98	19.80	19.60	18.49
Miscell		[b] 0.36			[d] 1.28	[e] 0.54	[f] 4.20
	100.00	100.47	100.00	99.96	98.87	99.79	99.83
Sp. gr		2.75	2.89	2.86		2.80	

[a] Given as FeO. The figures are in better agreement with values calculated from formula if the iron is considered in the ferrous condition.

[b] MnO.

[c] Includes some Fe^2O^3.

[d] Insoluble, 1.15; CaO, 0.13.

[e] Insoluble, 0.16; CaO, 0.38.

[f] Insoluble.

The high alumina values may be partly accounted for by the admixture of a little aluminous rock. By considering some of the iron present as ferrous oxide, FeO, isomorphously replacing the CuO, the analyses agree very well with the values calculated for the composition.

Penfield's idea that the composition of the mineral should be expressed as $[Al(OH)_2, Fe(OH)_2, CuOH, H]_3PO_4$ can be more defi-

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[1] Loc. cit.

nitely fixed now, for the analysis of crystals of turquoise shows that the $Al(OH)_2$, $CuOH$, and H are present in fixed amounts, namely, in the proportions 6: 1: 5. Penfield's analysis agrees very closely with these figures.[1]

Crystallographic measurements have shown the apparent isomorphism of turquoise and chalcosiderite. The formula given for chalcosiderite is $CuO.3Fe_2O_3.2P_2O_5.8H_2O$, which differs from that proposed for turquoise only in containing one molecule less of water. From Maskelyne's [2] description of the material used for the analysis of chalcosiderite it seems probable that the sample was contaminated by a little andrewsite, limonite, and dufrenite, all of which contain less water [3] than chalcosiderite, so that the value he obtained is probably a little low. The correct formula for chalcosiderite should probably be written with $9H_2O$ instead of $8H_2O$, in which event the isomorphous character of this mineral with turquoise will be clearly brought out.

Turquoise..........$CuO.3Al_2O_3.2P_2O_5.9H_2O$, triclinic.
Chalcosiderite......$CuO.3Fe_2O_3.2P_2O_5.9H_2O$, triclinic.

SUMMARY.

In closing, the three main points developed in this paper may be briefly restated:

1. Turquoise is triclinic with the crystal form determined.
2. Turquoise has the definite composition $CuO.3Al_2O_3.2P_2O_5.9H_2O$.
3. Turquoise and chalcosiderite are isomorphous.

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[1] Penfield deduced the ratios 7: 1: 6 from his analyses, but 6: 1: 5 is still closer.

[2] Maskelyne, N. S., On andrewsite and chalcosiderite: Jour. Chem. Soc., vol. 28, 1875, p. 586.

[3] Andrewsite has 8.8 per cent, limonite 14.5 per cent, and dufrenite 10.5 per cent water; chalcosiderite has 15 per cent.

CRYSTALLIZED VARISCITE FROM UTAH.

INTRODUCTION.

The material on which the following descriptions are based was collected near Lucin, Utah, by Mr. Douglas B. Sterrett, of the United States Geological Survey. A part of the material consists of well-developed crystals, a form of occurrence so unusual for variscite that the identity of that mineral was not discovered until after detailed study. The quantity of material was sufficient to determine all the chief properties of the mineral, one of the most striking of which was brought out by Mr. Sterrett in heating a fragment of it before the blowpipe, for at a low temperature its vivid green color was changed readily to a deep lavender. The chemical study of the mineral was extended in order to find out if possible the cause of this change. The various properties of the lavender-colored variscite were studied, as well as those of the green mineral, in order to discover their relations. I wish to express my thanks to Mr. Sterrett for permission to describe this very interesting mineral and for his generosity in furnishing the material needed.

OCCURRENCE AND GEM QUALITY.

The following notes on the occurrence of the variscite near Lucin, Utah, and of the kind and quality of the gem stones procured are by Sterrett:[1]

> The variscite deposits, 5 miles northwest of Lucin, Utah, * * * are in the northern part of an irregularly shaped hill, called Utahlite Hill. Utahlite Hill is about 1 mile long in a northwest-southeast direction and about one-half mile wide. It has an elevation of about 5,000 feet above sea level and rises over 300 feet above the mesas and gentle slopes at its base, and about 500 feet above the railroad at Lucin. Four claims have been located and these are, in order from northwest to southeast, Utah Gem, Greenback Lode, Utahlite, and Protection Lode. * * *
>
> [The variscite deposits are] in and around small rocky summits standing above the rest of the hill. These summits have cavities and small caverns [in them] * * * resembling those made by wave action. They were probably formed on one of the shore lines of the former Lake Bonneville. The work done at the time of examination consisted of an open cut 50 feet long and 2 to 5 feet deep with several prospect pits.

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[1] Gems and precious stones: Mineral resources U. S. for 1910, U. S. Geol. Survey, 1912, pp. 894–896.

The rock in which the variscite occurs and which forms the crest of the hill is cherty or chalcedonic quartz, which contains inclusions of nodules and streaks of limestone. The limestone inclusions range up to a foot thick and in places are several feet long. The character of most of the rock is that of a hard breccia cemented together by silica. This breccia forms rough, rocky ledges and knobs rising from a few feet to 25 feet above the hill slopes. * * * Three of these knobs contain large quantities of variscite.

The variscite occurs in balls, nodules, and irregular masses in the chert. Veins of variscite are not common, but some with a northeast strike and northwest dip were seen. The nodules and balls of variscite range in size from a fraction of an inch to several inches across, and some of the segregations of variscite inclosing matrix are a foot across. The variscite fills fractured and brecciated zones in the rock, some of which it replaces, and it incloses other parts. The replacements are generally rounded, concretionary masses, often with banded concentric structure. The fragments of some of the brecciated rock, especially white quartz, that have been inclosed by and cemented with variscite, have remained angular and sharp. Some of the concretionary forms appear to grade from green variscite cores into the inclosing yellow, brown, gray, and white phosphatic and cherty minerals. There is considerable chalky mineral filling cavities in the variscite-bearing rock and coating the nodules and masses of variscite. A quantity of variscite pebbles and cobbles have been found in the cut in the loose detritus below the main outcrop on the Utahlite claim. These probably owe a large part of their rounded form to the nodular shape of the variscite in the original rock, but have also probably been rounded by water action on a former lake shore. The pebbles are coated with a white chalky substance, and have to be broken into before the presence or quality of the variscite can be determined.

* * * Both the variscite and the matrix minerals possess various shades of color, several of which are sometimes present in a single specimen. The different colors combined with the various markings and patterns due to the structure of the mineral and brecciation of the matrix furnish a large range in the types of stones that can be cut from the variscite. The variscite ranges in color from a very pale green through different shades of green to bright grass green. The matrix varies from white to gray, to yellow, to brown, and nearly to black.

The gems that can be cut from the variscite from the Edison and Bird mines range from large pure stones with light to dark green color through those with small quantities of matrix, to those in which the matrix predominates. The dark and bright green variscite is obtained in pieces that will cut into pure stones measuring more than an inch across, and paler-colored mineral will yield even larger pure stones. Some of the bright-green variscite is partly translucent, and thin pieces and small pebbles display their color well in the partially transmitted light. This is especially true of the coarser-grained, finely crystalline variscite. Specimens of matrix are obtained that will yield slabs 6 inches across, some of which show quite remarkable patterns and colors. One block of matrix found at this mine measures 4 to 6 inches in diameter and weighs several pounds. The whole mass is composed of variscite mottled with brown and white matrix. The pattern is the typical turtle-back, and the markings are coarser in some parts of the specimen than in others. The markings are due to rounded patches or nodules of pale to bright-green variscite, some of which are surrounded by rims of white or gray, and all filled in with purplish brown matrix. The brown matrix occurs only as an internodular filling, and the seams are rarely over a millimeter thick. Occasional larger patches of matrix occur where several seams meet around the variscite nodules. The rounded masses of variscite vary from a fraction of a millimeter to a centimeter in diameter. Other smaller pieces of mottled variscite have been found along with specimens of brown, gray, and white matrix, with practically the same texture. Some pieces of mottled matrix contain little if any variscite, but would itself cut into stones with the turtle-back markings.

Among other types of variscite matrix is that with bright grass-green variscite mottled with patches and cloud-like masses of lighter green material, or vice versa. Such matrix may contain seams and spots of white, gray, or yellowish mineral through it. A white quartz breccia cemented and filled in with bright green variscite is also a pleasing stone when cut, but is more difficult to polish because of the difference in hardness of the two minerals. The quartz occurs in sharp angular fragments, which are in excess of the variscite in some specimens, but generally less prominent.

The variscite and variscite matrix from this locality would yield very beautiful gems for the so-called barbaric jewelry. It is susceptible to nearly every form of cutting used with opaque gems, but on account of its comparative softness is not adapted to rough wear. For necklaces, pendants, brooches, pins, belt stones, etc., it is well suited. The especially bright colors of some of the variscite from this locality are rarely found in that from other places, and the variety of markings shown by the matrix is probably equal to any other material found.

GENERAL DESCRIPTION.

The material available for study consists of nodular aggregates of variscite, irregular in shape and of various dimensions. The deep green aggregates of crystallized mineral consist of tabular crystals, a few of which reach a millimeter in length. Their breadth is about half their length, and their thickness varies from about one-fourth of a millimeter to very thin plates. The coarser aggregates of variscite consist of well-developed crystals (Pl. I, *B*, *C*, p. 42), which are often nearly complete. The finer-grained material does not show such distinct crystals, and the very fine-grained compact mineral has more the appearance of a cryptocrystalline mass. Several small cavities in the coarse material were lined with projecting crystals which furnished good material for crystallographic study. The crystals are transparent and pale green when viewed under the microscope. A view of such a cavity enlarged six times is shown in Plate I, *C*.

OPTICAL PROPERTIES.

ORIENTATION AND PLEOCHROISM.

The crystallographic orientation was so chosen that the large, flat face of the crystals became the brachypinacoid *b* {010} and the striations on this face were placed vertically. Variscite being orthorhombic, these facts are sufficient to definitely orient the crystals so that the optical relations can be readily comprehended. The basal pinacoid, *c* {001}, was not observed on these crystals, and the macropinacoid, *a* {100}, is a rare form, seldom larger than a narrow face between the unit prisms *m* and m'''.

The optical relations were ascertained by studying the flat crystals and by means of two thin sections of the granular aggregate, which were carefully prepared without being subjected to any heat. If a section of the granular variscite be made in the ordinary manner, the heat employed in the operation is sufficient to change the green color of the mineral to deep lavender, with consequent changes in the various physical properties.

The extinction is parallel in all sections, and the mineral behaves optically in strict concordance with the orthorhombic symmetry of the crystals. The axial plane is parallel to the flat face *b* {010}, and the acute bisectrix is normal to the base *c* {001}, the obtuse bisectrix then being normal to *a* {100}. The mineral is positive, so that the acute bisectrix, identical in direction with the crystallographic axis *c*, is the axis of minimum velocity of light. The optical relationship can therefore be expressed in the conventional form as follows:

$$\begin{aligned} a &= X = \mathfrak{a} \\ b &= Y = \mathfrak{b} \\ c &= Z = \mathfrak{c} \end{aligned}$$

The axial angle is large; 2E was measured as about 113°. Dispersion was not marked, and its kind could not be determined.

Viewed in transmitted light under the microscope, the crystals are colorless if very thin, or pale green if somewhat thicker. The coloring pigment is not uniformly distributed, but is generally arranged in irregular cloudlike areas. In a few slides the coloring seemed to be distributed in some relation to the shape of the crystals and was most intense near their edges.

The pleochroism is distinct, but slight. Its relation to the crystal directions is shown in the following scheme:

a (*X*) = colorless.
b (*Y*) = pale green.
c (*Z*) = pale green.

The weakness of the pleochroism is in striking contrast to that of the heated lavender-colored material in which, as is described on page 53, the pleochroism is strong.

REFRACTIVE INDICES.

The indices of refraction were measured by the method of oil immersion for γ and α. The values found are: $\gamma = 1.577$ and $\alpha = 1.547$. Therefore $\gamma - \alpha = 0.030$, which is very close to the average value (0.032) found by actual determination of the birefringence. This birefringence was measured accurately on the flat brachypinacoid, and the average value obtained is 0.032. The value was measured on 11 crystals, with the following results:

Birefringence ($\gamma-\alpha$) *measured on* b {*010*}.

Crystal No.	Thickness in millimeters.	Birefringence.
1	0.055	0.034
2	.044	.029
3	.042	.035
4	.070	.027
5	.051	.031
6	.051	.037
7	.066	.029
8	.055	.034
9	.042	.030
10	.053	.030
11	.047	.034
Average.	....	.032

As the value 0.032 is, of course, more accurate than the value 0.030 obtained by measuring the indices directly, the values of and α are each changed one unit so as to bring their difference in accord with the more accurately determined value of the birefringence, and are therefore taken as 1.578 and 1.546, respectively.

The value for β was found by measuring the difference of refraction ($\beta-\alpha$) in basal sections of the mineral. A thin section of the crystalline aggregates furnished basal and macropinacoid sections of the same thickness, so that the value ($\beta-\alpha$) could be determined by noting the interference colors (first order blue) on the basal sections and comparing them with the colors on sections showing the maximum birefringence. The value ($\beta-\alpha$) was thus found to be 0.010. Therefore $\beta=1.556$.

A section of a crystal that seemed to be nearly parallel to $a\{100\}$ showed a very large axial angle and a difference of refraction of about 0.020, which, for a section parallel to $a\{100\}$, should be 0.022.

A summary of the optical properties as determined follows:

Axial plane b (010). $Bx_a \perp c$ (001). Positive.
$\alpha=1.546$, $\beta=1.556$, $\gamma=1.578$.
$\gamma-\alpha=0.032$, $\gamma-\beta=0.022$, $\beta-\alpha=0.010$.
$n=\dfrac{\alpha+\beta+\gamma}{3}=1.560$.

STRUCTURE OF CRYSTALS.

An additional feature of considerable interest is the structure of the crystals. Although the material is well crystallized and the individual crystals sharply bounded by plane and brilliant surfaces, the interior of the crystals is, in most cases, crowded with a mass of small particles irregularly bounded and not in parallel position with the crystal itself. In some crystals these particles are absent; in others they are sparsely scattered. Still other crystals contain a vast number of these particles, generally closely aggregated. These aggregates are either irregular in shape and occupy the center of the crystal, or else they are so arranged as to correspond with the shape of the crystal itself. Such a regular grouping of these particles is shown in figure 3, which illustrates also the tabular habit of the variscite crystals. In figure 3 the brachypinacoid *b*{010} is drawn in front in order to show better the mode of distribution of the particles. These particles are in general irregular in shape, though occasionally a rectangular one can be noted in the mass. The particles still manifest themselves in the dehydrated lavender crystals and show no difference, except in their orientation and shape, from the rest of the crystal.

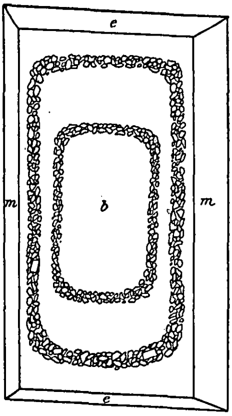

FIGURE 3.—Variscite crystal, showing regular grouping of small particles. *b* {010}, *m* {110}, *e* {012}. The brachypinacoid *b* {010} is drawn in ront.

PROPERTIES OF DEHYDRATED LAVENDER VARISCITE.

The very remarkable color change undergone by the mineral on dehydration at a relatively low temperature (below 160°) has a marked effect on its optical properties. The most striking change is in the pleochroism. The green crystals of variscite are only faintly pleochroic (colorless to pale green), whereas the lavender ones are strongly pleochroic with intense colors.

The optical orientation of these lavender-colored crystals could not be determined, though numerous attempts were made, both on loose crystals and on thin sections of the granular aggregate. The birefringence of the mineral has become so low that no definite results could be obtained when tests for axial angles were made. Both basal and brachypinacoidal sections seemed to show the emergence of a bisectrix with a very large axial angle, though, as stated, the results were inconclusive. It could, however, be easily seen that the optical orientation was changed. In the green crystals, viewed on the flat face *b*{010}, the vertical axis is a direction of minimum velocity, but on the lavender crystals this same direction is one of maximum velocity. Similarly, on basal sections the axis *b* is a direction of minimum velocity for the green crystals, whereas on the lavender ones the *b* axis is a direction of maximum velocity

The pleochroism of the lavender crystals is strong and very striking. All the colors are combinations of red and blue and are therefore rather hard to describe accurately. On crystals that are not too thin the colors are very intense and beautiful. The brachypinacoidal sections are strongly pleochroic, whereas basal sections hardly show any difference in shade in different directions. The colors observed may be described as follows:

a axis = lavender.
b axis = pinkish lavender.
c axis = violet.

The color effects given above are such as were noted on crystals that had been heated above 160° gradually. If the green crystals be suddenly heated to a high temperature, as, for instance, by putting them on a piece of platinum foil and suddenly heating them in the hot flame of a Bunsen burner, the results are different. The crystals are then considerably cracked, and on brachypinacoidal sections the optical orientation is like that of the green crystals—that is, the *c* axis of the crystal corresponds to a direction of minimum velocity. Moreover the pleochroism is interchanged so that—

a axis = violet.
c axis = lavender.

The changes in the indices of refraction and the birefringence undergone by the green variscite crystals on changing to the lavender phase are also very marked. The mean refractive index drops from 1.560 to about 1.448 and the birefringence from 0.032 to 0.003 or even less. The birefringence does not exceed 0.003 in any section and is much less in most. The approximate values of the indices are as follows:

$$\alpha = 1.447, \beta = 1.448, \gamma = 1.450;\ \gamma - \alpha = 0.003.$$

This decrease in the values of the refractive indices and the birefringence is accompanied by loss of water. It is a fact worth emphasizing that the loss of water, without destroying the optical possibilities of the mineral, decreases both these values.

When the lavender crystals are heated with water on the steam bath (not over 100°) for several days, they gradually lose their lavender color and become a dirty grayish-white. In this condition they are nonpleochroic. A sample treated in this way for about a week was then air-dried for several days, and the loss on ignition (water absorbed) determined. This amount was found to be 2.05 per cent. The ignited crystals again became deep lavender in color. It therefore seemed that it might be possible by appropriate treatment to change the dehydrated lavender crystals back to their original vivid green color. With this in mind, some of the lavender crystals were treated with hot water for several days until they became grayish-white in color, and then sealed in a glass bomb with a little water and heated for several hours at a higher temperature. The glass bomb was first heated for about four hours at 170°, the next day for the same time at 190°, and the third day for the same time at 225°. Unfortunately, it was not possible to heat the tube at these temperatures continuously, as should probably have been done. After three days' heating, as just described, the grayish-white crystals had become a very pale greenish-yellow, but when the crystals were removed from the tube and the loss on ignition determined after air-drying extending over several days, the result was disappointing. A loss of only 1.12 per cent was found, so that the crystals had absorbed less water in the glass bomb treatment than by simply treating with hot water.

The crystals from the glass bomb were very light brown or nearly colorless when viewed under the microscope. Pleochroism was distinct, though very slight. Parallel to the *c* axis, a direction of maximum velocity (unlike the green crystals), light brown; parallel to the *a* axis, a light brown with a decided greenish-yellow tint. The birefringence is about 0.006, the interference colors on the thicker crystals reaching into first order yellow. The areas of "Irregular aggregates" (shown in fig. 3) are more strongly colored and are indefinite in character. They somewhat resemble the kaolinization effects seen in rock slides.

RELATION TO ANALOGOUS MINERALS.

A brief comparison of the optical properties of variscite, as given, with those of the analogous minerals scorodite, strengite, and phosphosiderite, shows some close relationships as well as some marked differences.

The optical properties of variscite given by Lacroix[1] are not entirely in accord with those given in this paper, but this disagreement is due to the fact that Lacroix's material consisted of fibrous material and not of distinct crystals. He gives the axial plane as parallel to *b* {010}, with negative acute bisectrix normal to *a* {100}, whereas the acute positive bisectrix is normal to *c* {001}. The value of 2E is given as about 96° and the mean index as 1.579, which is a little higher than the value 1.560 found on the Utah crystals, but almost identical with the maximum index found on them, namely (γ), 1.578. The birefringence is stated to be a little higher than that of quartz, but the birefringence observed by Lacroix was probably not the maximum, which reached a value of 0.032 in the crystals from Utah.

Comparison of the chief optical properties of the different analogous minerals can be made most conveniently if they are shown in tabular form. The orientation of the variscite is so chosen that the axial phase is *b*(010), but it is possible, as shown in the following

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[1] Lacroix, A., Minéralogie de la France, vol. 4, 1910, p. 479.

pages of this paper, to orient the crystals so that the axial plane is *a* (100), analogous to that of scorodite and strengite.

Comparison of optical relations.

Mineral.	Axial plane.	Optical sign.	Bx_a.	2E.	Mean index.	Birefringence.
				°		
Variscite	*b*(010)	+	⊥(001)	113	1.560	0.03
Scorodite	*a*(100)	+	⊥(001)	130	....	.03
Strengite	*a*(100)	+	⊥(001)	60	1.825	.03
Phosphosiderite	*b*(010)	+	⊥(001)	126	1.73	....

In adopting the orientation for variscite as given in this paper, with the optic axial plane parallel to *b*(010), an interesting condition obtains for the isomorphous mixtures of variscite ($AlPO_4.2H_2O$) and strengite ($FePO_4.2H_2O$), for in the latter mineral the optic axial plane is parallel to *a*(100). Such an isomorphous mixture is represented by the mineral barrandite, of which two analyses are on record and in both of which the iron phosphate predominates, so that barrandite, instead of being a distinct mineral species, is in reality only an aluminous strengite.[1] In strengite the axial plane is *a*(100) and 2E equals 60°, whereas in variscite the axial plane is *b* (010) and 2E is nearly twice as large. The isomorphous admixture of a small amount of variscite in strengite would therefore tend to decrease the axial angle of strengite, and with a certain amount of variscite, the axial angle would become zero. A still greater amount of variscite in the mixture will give an increasing axial angle, but with the axial plane now parallel to *b*(010) as in pure variscite. Since the axial angle of strengite is much smaller than that of variscite, an isomorphous mixture with an axial angle of about zero should contain more strengite than variscite.[2] Both analyses of barrandite show an excess of the strengite molecule, the ratio in the first being 4:3 and in the second 5:2. In the analysis giving the last ratio, it is therefore highly significant to note that Lacroix in describing[3] barrandite states that the optic axes are very close, so that the value of 2E is very small. In the analysis of barrandite given by Lacroix the ratio of Fe_2O_3 to Al_2O_3 is about as 5:2. An approximate calculation of the value of the axial angle of such an isomorphous mixture shows that it should be very small, approximately 10°.

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[1] Compare p. 38.

[2] It is interesting to note that should an isomorphous mixture of variscite and strengite be found (without definite crystals) in such proportions that the axial angle is zero, the discoverer would be very likely to consider the find as a distinct new species, as it would be strictly uniaxial, whereas both variscite and strengite are biaxial.

[3] Lacroix, A., Minéralogie de la France, vol. 4, 1910, p. 486.

On the other hand, it must be stated that the density and mean refractive index of barrandite, as given by Lacroix, are not consistent with the values calculated from those of variscite and strengite, as the following table shows:

Comparison of values for barrandite.

	Density.	Mean refractive index.
Variscite	2.54	1.560
Strengite	2.87	1.825
Barrandite [a] found	2.59	1.575
Barrandite [a] calculated	2.78	1.749

[a] Barrandite consists of 5 parts strengite and 2 parts variscite.

The wide discrepancies in the found and calculated values of the density and refractive index, respectively, are not in accord with the idea of the isomorphous character of barrandite as developed for the optical properties.

CRYSTALLOGRAPHY.

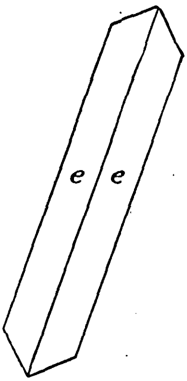
INTRODUCTION.

The flat crystals are orthorhombic in their symmetry and simple in their combination. The large face is taken as the brachypinacoid, and the chief forms noted, as shown in figure 4, are: *b*(010), *m*(110), and *e*(012). In addition to these forms the macropinacoid *a*(100) is sometimes present as a narrow face. Occasionally the crystals are much longer and the prism faces more developed in comparison with the brachypinacoid. The common habit of the crystals is shown in figure 4. A better idea of the shape of the crystals can be had from figure 3, on page 53, which shows a variscite crystal so drawn as to bring the brachypinacoid *b*(010) in front. The rectangular tabular shape of the crystals, due to the large development of the brachypinacoid, is well illustrated in the same figure.

Several other forms are present on these crystals, but they could not be determined. On crushing some of the coarsely crystallized aggregate and examining it under the microscope one occasionally sees an acutely-terminated crystal which has the corners replaced by small faces, probably those of the unit pyramid.

In orienting the crystals of variscite three positions are available, depending on the pinacoid to which the broad face is referred. This broad face is generally slightly striated vertically. In conformity with the analogous mineral scorodite, the striations are taken as parallel to the *c* axis. Striated crystals of scorodite have been described by several authors. Kokscharow[1] states that the form {010} is strongly striated vertically. Zimanyi[2] describes scorodite crystals on which the prism *d* {120} is vertically striated and Lacroix[3] mentions vertical striations on {120} and the two pinacoids {100} and {010}.

The crystals of variscite have been so oriented that the broad face is *b* {010}, as already described and illustrated in figure 3. Lacroix[4] mentions scorodite crystals slightly flattened parallel either to *a* {100} or to *b* {010}. He also states that a rare phase of strengite is formed by plates flattened parallel to *a* {100}.



The possibilities of the three available orientations will be discussed after the measurements of the variscite crystals are given.

CALCULATION OF ELEMENTS.

Variscite being orthorhombic, only two angular values are necessary for a determination of the crystallographic elements.

The fundamental values of variscite are:

$$b \wedge m = (010) : (110) = 48° \ 10'$$
$$b \wedge e = (010) : (012) = 61° \ 17'$$

From these values the axial ratio is found to be:

$$a : b : c = 0.8952 : 1 : 1.0957.$$

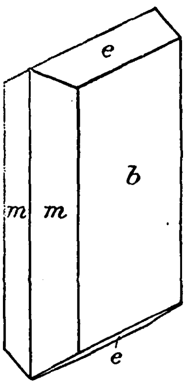


FIGURE 4.—Variscite crystal, *b*(010), *m*(110), *e*(012).

The measurements from which the fundamental values for variscite were obtained are as follows: In the measurements of the angle (010) : (110) it is possible to obtain eight values on each crystal, namely $(010 : 110)$, $(010 : \bar{1}10)$, $(0\bar{1}0 : 1\bar{1}0)$, $(0\bar{1}0 : \bar{1}\bar{1}0)$, $\frac{1}{2}(110 : \bar{1}10)$, $\frac{1}{2}(1\bar{1}0 : \bar{1}\bar{1}0)$, $90° - \frac{1}{2}(110 : 1\bar{1}0)$, $90° - \frac{1}{2}(\bar{1}10 : \bar{1}\bar{1}0)$. In the following table, of these possible eight values, only those are given where the reflections from the faces were fairly good and distinct. The numbers at the heads of the columns refer to individual crystals, and the averages of the various measurements are given below.

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[1] Kokscharow, N., Mineralogie Russlands, vol. 6, 1870, p. 309.

[2] Zimanyi, K., Beiträge zur Mineralogie der Komitate Gömör und Abanj-Torna: Föld. Közl., vol 35, 1905, p. 545.

[3] Lacroix, A., Minéralogie de la France, vol. 4, 1910, p. 472.

[4] Idem, p. 474.

Measurements of angle $b \wedge m = (010) : (110)$.

1	2	4	5	6	7
° ′	° ′	° ′	° ′	° ′	° ′
48 28	48 26	48 19	48 02	48 07	46 59
47 34	48 11	48 44	48 13	48 12	49 07
48 42	48 33	47 56	....	48 14	48 04
47 21	47 51	48 22	....	48 19	....
47 55	48 18	48 10	....	....	....
48 08	48 14	....	....	....	....
48 01	48 14	48 18	48 08	48 13	48 03

Average of 26 measurements=48° 10′.

For the faces of *e* {012} the number of possible measurements was not so large, because the crystals measured were broken off at the lower end.

Measurements of angle $b \wedge e = (010) : (012)$.

	° ′		° ′
Crystal No. 2...	61 21 61 15	Crystal No. 6...	61 31 61 10
Crystal No. 3...	61 22 61 08	Crystal No. 7...	61 26 61 10
Crystal No. 4...	61 28	Crystal No. 8...	61 14 61 01
Crystal No. 5...	61 19		

Average of 12 measurements=61° 17′.

The only crystallographic study hitherto made of variscite is the work of Chester[1] on the Arkansas mineral. He found some minute crystals with the forms *b* {010}, *a* {100}, *m* {110}, and *c* {001}. Of these, *b*, *m*, and *c* were well developed. The angle $m \wedge m'''$ ($110 : 1\bar{1}0$) is given as 65° 54′, but it has not been possible to correlate this angle with any simple form for the variscite-scorodite group.

The following table gives the coordinate angles for the forms of variscite. The table is adapted for measuring the crystals by the two-circle method, but, of course, it also gives the necessary interfacial angles.

Forms and coordinate angles for variscite.

[$a=0.8952$, $c=1.0957$, $p_0=1.2240$, $q_0=1.0957$.]

No.	Letter.	Symbol.		ϕ	ρ
		Gdt.	Miller.		
				° ′	° ′
1	*b*	0 ∞	010	0 00	90 00
2	*a*	∞ 0	100	90 00	90 00
3	*m*	∞	110	48 10	90 00
4	*e*	0½	012	0 00	28 43

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[1] Chester, A. H., Note on the crystallization of variscite: Am. Jour. Sci., 3d ser., vol. 15, 1878, p. 207.

The three possible orientations for the variscite crystals will now be given and their relation to the orientation of the analogous minerals scorodite, strengite, and phosphosiderite studied.

FIRST ORIENTATION.

The first orientation is the one chosen for the mineral, as it best shows the relation of variscite to the other minerals and at the same time yields the simplest indices for the crystal forms of variscite. In the comparisons two orientations are given for phosphosiderite, both of which are different from the accepted position of that mineral. The first one, given as phosphosiderite (1) in the following tables, is the one suggested by Bruhns and Busz;[1] and the second one, phosphosiderite (2) is obtained by interchanging the *a* and *c* axes in the generally adopted position and then doubling the new *a* axis.

The close relation between the angles of variscite and the other minerals of analogous composition is shown in the table below:

Comparison of angles (first orientation).

Angle.	Variscite.	Scorodite.	Strengite.	Phosphosiderite.	
				1	2
	° ′	° ′	° ′	° ′	° ′
$b \wedge m$=(010) : (110)	48 10	49 07	49 08	50 33	48 45
$b \wedge e$=(010) : (012)	61 17	64 30	63 50	64 52	61 57

A comparison of the axial ratio also shows clearly the similarity in values and the very close agreement of variscite with phosphosiderite (2). A greater difference is shown by comparison with the values of the other minerals.

Comparison of axial ratios (first orientation).

Mineral.	*a* axis.	*c* axis.
Scorodite	0.8658	0.9541
Strengite	.8652	.9827
Variscite	.8952	1.0957
Phosphosiderite (1)	.8229	.9381
Phosphosiderite (2)	.8772	1.0660

It is worthy of special notice that the agreement of values is much closer for variscite and phosphosiderite (2) than it is for either variscite and scorodite or strengite. This fact led to the suggestion

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[1] Zeitschr. Kryst. Min., vol. 17, 1890, p. 555. Also given in Dana's System of mineralogy, 6th ed., 1892. p. 823.

that perhaps the mineral here described was not variscite but a new mineral bearing the same relation to true variscite that phosphosiderite is supposed to bear to strengite. The analysis, however, shows that the crystallized variscite from Utah agrees well with the formula $Al_2O_3.P_2O_5.4H_2O$. A careful study of the relations of phosphosiderite to strengite, considered with the close crystallographic values of phosphosiderite and variscite, leads to the conclusion that phosphosiderite and strengite are identical, notwithstanding the apparent differences in their optical properties.

SECOND ORIENTATION.

In the second possible orientation the large face is made the macropinacoid *a* {100)} As the optical axial plane of variscite is parallel to this pinacoid, such an orientation would bring variscite into optical conformity with scorodite and strengite. It then becomes necessary, however, in order to retain the crystallographic analogy, to give to the prism *m* the symbol {340}. The dome *e* then becomes {102}, and the close angular agreement of the minerals in this position can be seen by the following table:

Comparison of angles (second orientation).

Angle.	Variscite.	Scorodite.	Strengite.	Phosphosiderite.	
				(1)	(2)
	° ′	° ′	° ′	° ′	° ′
$b \wedge m$=(100) : (340)	48 10	49 11	49 05	47 39	49 28
$b \wedge e$=(100) : (102)	61 17	61 02	60 24	60 19	58 43

On the basis of the above angular values, the following comparison of the axial ratios is made:

Comparison of axial ratios (second orientation).

Mineral.	*a* axis.	*c* axis.
Variscite	0.8379	0.9181
Scorodite	.8658	.9541
Strengite	.8652	.9827
Phosphosiderite (1)	.8229	.9381
Phosphosiderite (2)	.8772	1.0660

The agreement in values is much closer than for the first orientation, but the prism form loses its simple indices. It must be said, however, that this orientation has much to commend it and may, perhaps, be chosen in the future as the best one for the mineral, especially when the properties of strengite and barrandite are better defined than they are at present.

THIRD ORIENTATION.

A third orientation is made still possible by considering the large face as the basal pinacoid. Though the angular values derived from this orientation show a close agreement, such a habit is entirely at variance with all the other minerals of this group and the choice of orientation must be left to the first or second one.

By making the large face the basal pinacoid and taking *m* as {101} and *e* as {021}, the following comparison is obtained.

Comparison of angles (third orientation).

Angle.	Variscite.	Scorodite.	Strengite.	Phosphosiderite.	
				(1)	(2)
	° ′	° ′	° ′	° ′	° ′
$b\wedge m$=(001) : (101)............	48 10	47 47	48 38	48 45	50 33
$b\wedge e$=(001) : (021)............	61 17	62 20	63 02	61 57	64 52

From these values the following axial ratios are obtained:

Comparison of axial ratios (third orientation).

Mineral.	*a* axis.	*c* axis.
Variscite..	0.8170	0.9126
Scorodite..	.8658	.9541
Strengite..	.8652	.9827
Phosphosiderite (1)....................................	.8229	.9381
Phosphosiderite (2)....................................	.8772	1.0660

TWIN CRYSTAL.

A twin crystal was observed under the microscope among the crushed aggregate. The twinning plane is {102}, as the inclination of the twinned part of the complex to the untwinned part was measured as 31° and the angle (001) : (102) is calculated as 31° 28′. Similar twins were noted on phosphosiderite, again showing the striking crystallographic closeness of variscite with phosphosiderite, and emphasizing the probable identity of phosphosiderite with strengite.

RELATION TO ANALOGOUS MINERALS.

The angular values for the minerals of this group are so close in three different directions that great care must be exercised in choosing the correct position. This should always be verified optically, if possible, for on poor crystals it would be difficult to distinguish with certainty some of the angles. This similarity in angular values can be well shown by the following table:

Comparison of angles showing similarity.

Angle.	Variscite.	Scorodite.	Strengite.	Phosphosiderite.	
	° ′	° ′	° ′	° ′	° ′
(100):(340)	50 03	49 11	49 05	47 39	49 28
(010):(110)	48 10	49 07	49 08	50 33	48 45
(001):(101)	50 45	47 47	48 38	48 45	50 33
(010):(012)	61 17	64 30	63 50	64 52	61 57
(001):(021)	65 28	62 20	63 02	61 57	64 52
(100):(102)	58 32	61 02	60 24	60 19	58 43

It is possible that the mineral vilateite,[1] the violet crystals of Des Cloizeaux's hureaulite, may belong to this group. The crystals are described as monoclinic, but the angular differences from orthorhombic symmetry are slight, and Lacroix states that optically the mineral behaves somewhat like an orthorhombic substance. The similarity in axial ratios to scorodite and the other minerals of the group can be seen in the following table. For vilateite, half the *a* axis, as given by Lacroix, has been taken.

Comparison of axial ratios.

	a axis.	*c* axis.	β
			° ′
Vilateite	0.8479	0.8886	89 27
Variscite [a]	.8379	.9181	90 00
Scorodite	.8678	.9583	90 00
Strengite	.8652	.9827	90 00
Phosphosiderite (1)	.8229	.9381	90 00

[a] Second orientation.

CHEMICAL COMPOSITION.

GENERAL PROPERTIES.

The mineral is infusible before the blowpipe, but, as has been stated, changes its color in a striking way, the emerald green becoming a deep lavender and the crystals taking on a much more brilliant luster. Quantitative analyses show that all the water of the mineral is given off while the change of color is taking place, so that the lavender variscite is anhydrous. Chester [2] mentions a similar change in color for the variscite from Arkansas, but his investigations seem to have been generally overlooked. In describing the properties of the crystallized

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[1] Lacroix, A., Minéralogie de la France, vol. 4, 1910, p. 477.

[2] Chester, A. H., On the identity of the so-called peganite of Arkansas with the variscite of Breithaupt and callainite of Damour: Am. Jour. Sci., 3d ser., vol. 13, 1877, p. 295.

variscite Chester says: "The colors observed are deep emerald-green. * * * Before the blowpipe it becomes opaque, friable, and of a deep purple when hot, lighter purple when cold. In the glass tube yields much water and changes in color as above." The density of the green mineral was found to be 2.54.

The powdered mineral is insoluble in boiling hydrochloric acid, but readily dissolves in acids after dehydration and change in color. The striking color changes observed in the mineral led me to look especially for such rarer elements as had a strong chromatic effect. This search showed that chromium and vanadium were present in small amount and that a trace of iron occurred.

CHEMICAL ANALYSIS.

The results of the quantitative analysis and the ratios deduced therefrom are here given:

Analysis and ratios of crystallized variscite from Lucin, Utah.

	Analysis.	Ratio.	
H_2O	22.68	1.260	4.00
P_2O_5	44.73	.315	1.00
V_2O_3	.32	.002	1.02
Cr_2O_3	.18	.001	
Fe_2O_3	.06	....	
Al_2O_3	32.40	.318	
Ni, Co, Cu Mn, As Ca, Mg	None.	....	
	100.37		

The ratios agree very well with the formula $Al_2O_3.P_2O_5.4H_2O$, thus comparing with strengite ($Fe_2O_3.P_2O_5.4H_2O$) and not with phosphosiderite ($Fe_2O_3.P_2O_5.3\frac{1}{2}H_2O$), even though the crystals of variscite are much closer in angular values to those of phosphosiderite than to those of strengite.

The results obtained as to loss of water at different temperatures are as follows:

Loss of water on heating.

Temperature.	Color of powdered sample.	Loss of water.
°*C.*		*Per cent.*
....	Pale green	....
110 (first day)	do	5.09
115 (second day)	Light gray[a]	9.67
110 (third day)	Pale lavender	12.48
140	Lavender	19.81
160	Deep lavender	22.50

[a] The color here called light gray is very difficult to define. The mineral powder had lost its original green color but did not show any decided lavender shade. Perhaps the combination of some lavender and some green gave the resultant effect here called gray.

The vanadium and chromium were determined on a 4-gram portion of the mineral, the method used being that described by Hillebrand.[1] After the chromium had been determined colorimetrically, the correction necessary to apply to the vanadium determination was found by titrating a hot sulphuric acid solution of sodium chromate containing the same amount of Cr_2O_3 as was present in the sample of variscite analyzed. Qualitative tests with ferricyanide showed that there was no ferrous iron in the solution of the mineral which had been heated to 170°. It was, therefore, possible to determine the state of oxidation of the vanadium. For this purpose a gram of the mineral was heated to 160°, which process completely dehydrated it and changed its green color to an intense lavender. The powdered mineral was then dissolved in sulphuric acid and titrated with permanganate. The amount consumed was equivalent to 0.45 per cent V_2O_3, or, corrected for the chromium present, 0.41 per cent V_2O_3. This is higher than the value obtained on the 4-gram sample (0.32 per cent), but the lower result is regarded as the more accurate. It may be here stated that a cold solution of bichromate in sulphuric acid will consume a small but appreciable amount of permanganate, which has to be determined and allowed for in such instances as the present one. The ferric iron was determined colorimetrically, using potassium sulphocyanide.

An adequate explanation of the remarkable color change and of the accompanying changes in physical and optical properties has not been found.

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[1] Hillebrand, W. F., The analysis of silicate and carbonate rocks: Bull. U. S. Geol. Survey No. 422, 1910.

HINSDALITE FROM COLORADO.

INTRODUCTION.

In the description of the new mineral hinsdalite[1] it was stated that it was collected by Mr. E. S. Larsen in the summer of 1910 while he was engaged in the areal mapping of the geology of the San Cristobal quadrangle, Colorado. The mineral was found in considerable quantity at an elevation of about 9,950 feet on one of the dumps of the Golden Fleece mine, which is about 3 miles south of Lake City, Hinsdale County, Colo. The chemical analysis showed hinsdalite to be a hydrous sulphate and phosphate of lead and aluminum with a little strontium replacing the lead. It is therefore the lead analogue of svanbergite, or the aluminum analogue of corkite.

OCCURRENCE.

Mr. Larsen states that the country rock of the mineral occurrence belongs to the Picayune member of the Silverton volcanic series and consists of tuffs, lava flows, and intrusive bodies of rhyolite, latite, and andesite. The tunnel of the mine was not accessible, but from the material on the dump the new mineral appears to occur as an original component of a vein whose chief constituents, in the order of their abundance are quartz, hinsdalite, barite, pyrite, galenite, tetrahedrite, and rhodochrosite. The vein material contains bands of almost pure, coarsely granular hinsdalite, an inch or more across. These bands are bordered by a finely crystalline aggregate of quartz and hinsdalite in which are embedded well-formed crystals, many of them a centimeter across, of the new mineral. Beyond the fine aggregate is nearly pure granular quartz or quartz and barite. The galenite and tetrahedrite, and to some extent the pyrite, are concentrated in the quartz-hinsdalite aggregate.

DESCRIPTION OF MINERAL.

The following description of the mineral is by Mr. Larsen:[1]

> The granular hinsdalite is rather coarsely crystalline and the mineral shows a strong tendency to develop crystal faces. Some of the larger embedded crystals are rhombohedrons resembling cubes, with a perfect cleavage (basal) truncating one corner.

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[1] Larsen, E. S., and Schaller, W. T., Hinsdalite, a new mineral: Am. Jour. Sci., 4th ser., vol. 32, 1911, p. 251.

The crystal faces are always dull and rough, so that accurate measurements were impossible. Several crystals, however, could be measured with a contact goniometer and gave for the angle $r \wedge r'$ the values: 91.0°, 91.3°, 91.2°, 91.7°, average 91.3° or 91° 18′. The value of the *c* axis computed from this average angle is 1.2677. Measurements of the angle between the cleavage and the adjacent rhombohedron varied from 56° to 59° with an average of 57° 18′. The calculated value for the angle $c \wedge r$ is 55° 40′.

The faces commonly developed on the larger crystals are the unit rhombohedron $r\{10\bar{1}1\}$ and the base $c\ \{0001\}$. The smaller crystals are tabular parallel to the base and have both the positive and negative rhombohedrons. The basal sections are hexagonal, while the prismatic sections are lath-shaped with pointed ends. The optical properties show, however, that the mineral is only pseudorhombohedral.

The perfect basal cleavage gives wavy and striated surfaces and the striations are in some cases developed in three directions, forming hexagonal markings. The hardness of hinsdalite is about 4.5 and the density is 3.65. The streak is colorless. The luster is vitreous to greasy. The crystals are nearly colorless, with a greenish cast, but much of the mineral is dark gray from minute inclusions.

A microscopic study of thin sections revealed the fact that the larger crystals, at least, are strongly zoned. This zonal structure is easily seen in ordinary light or even in the hand specimens. Some of the zones are much more subject to alteration than others. Between crossed nicols the different zones show slightly different interference colors.

On account of the zonal growth it is not possible to obtain accurate and consistent optical data. Cleavage pieces of the mineral are not isotropic but are nearly normal to a positive, acute, bisectrix. The values of 2E vary from nearly 0° to 40°. Dispersion of the optic axes were not perceptible. In many cases the core of the larger crystals is nearly uniaxial and the most common value of 2E for the outer zones is 32°. The variation in the value of 2E is probably largely due to the zonal growths, though in some cases it is clearly due to overlapping of twin lamellæ. Basal sections of some of the crystals are divided into six radial segments and the plane of the optic axes for each segment is normal to the hexagonal prism edge and to the striations.

Accurate measurements of the angle between the segments was not feasible, though it approximates closely to 60°. Similar optical anomalies have been described for hamlinite [1] and for jarosite,[2] both members of the same series of minerals to which hinsdalite belongs.[3]

The indices of refraction for hinsdalite were determined by the oil-immersion method. The values of α and β are nearly the same and vary from 1.66 to 1.68, with an average value of 1.67; the value of Υ varies from 1.678 to 1.700. The birefringence was measured by comparing the interference color of sections parallel to the plane of the optic axes with that of the same section of quartz. For the greater part of the hinsdalite crystal, the value 0.019 was obtained. Some of the narrow zones gave a value as low as 0.016. Therefore the indices of refraction for hinsdalite may be taken as: $\alpha=1.670$, $\Upsilon=1.671$, $\gamma=1.689$.

CHEMICAL COMPOSITION.

The mineral is infusible, becomes blue when heated with cobalt nitrate, and gives a lead reaction when fused with sodium carbonate on charcoal. A little water is given off when it is heated in a closed tube. It is practically insoluble in acids.

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[1] Bowman, H. L., On hamlinite from the Binnenthal, Switzerland: Mineralog. Mag., vol. 14, 1907, p. 389.

[2] Slavik, Franz, Mineralogische Notizen: Zeitschr. Kryst. Min., vol. 39, 1904, p. 297.

[3] See the following paper in this volume.

After the qualitative analysis had shown what the essential components of the mineral were, a preliminary quantitative analysis was made, the results of which, though approximately correct, are not here given. With a knowledge of the composition and the experience gained in making the preliminary analyses, the chemical composition of hinsdalite was determined on carefully selected pure material. The results obtained, together with the ratios deduced therefrom, are shown below:

Analysis and ratios of hinsdalite.

	Per cent.	Ratio.	
PbO	31.75	0.142 } .172	1.93 or 2
SrO	3.11	.030 }	
CaO	Trace.		
Al_2O_3	26.47	.260	2.92 or 3
SO_3	14.13	.177	1.99 or 2
P_2O_5	14.50	.102	1.14 or 1
H_2O	10.25	.570	6.40 or 6
	100.21		

The ratios agree well with the formula $2PbO.3Al_2O_3.2SO_3.P_2O_5.6H_2O$, except that the P_2O_5 and H_2O are a little high. A comparison of the analysis with the calculated percentages is shown below. The sample analyzed consists of 82.56 per cent of $2PbO.3Al_2O_3.2SO_3.P_2O_5.6H_2O$ and 17.44 per cent of $2SrO.3Al_2O_3.2SO_3.P_2O_5.6H_2O$ (svanbergite).

Under 1 is given, in the table below, the analysis of the Colorado mineral; under 2 the calculated composition of $2PbO.3Al_2O_3.2SO_3.P_2O_5.6H_2O$; under 3 the composition calculated for a mixture of 82.56 per cent of the pure lead compound and 17.44 per cent of the pure strontium compound (svanbergite), and under 4, for comparison, the calculated composition of pure svanbergite.

Comparison of analysis with calculated composition.

	1	2	3	4
PbO	31.75	38.37	31.68	....
SrO	3.11	....	3.91	22.43
Al_2O_3	26.47	26.36	27.55	33.19
SO_3	14.13	13.77	14.39	17.32
P_2O_5	14.50	12.21	12.76	15.37
H_2O	10.25	9.29	9.71	11.69
	100.21	100.00	100.00	100.00

The Colorado mineral, or at least that sample of it which was analyzed, represents a strontium hinsdalite just as the only good analysis of svanbergite really represents a lead svanbergite.

The water of the mineral is all water of constitution—that is, it is driven off only at a high temperature. Practically no water was expelled up to 390°. The following table shows the results obtained:

Loss of water.

Temperature.	Total loss in weight.
°*C.*	*Per cent.*
110	0.02
170	.02
250	.08
390	.08
590	9.24

The crucible was heated in an air oven up to 250°, above which temperature an electric furnace was used. The results show that the water is lost between 400° and 600°, approximately.

In its relation to other members of the group, hinsdalite is best considered as the lead type of svanbergite. It may just as well be considered an aluminous corkite, the formula for corkite[1] being $2PbO.3Fe_2O_3.2SO_3.P_2O_5.6H_2O$. The systematic place of hinsdalite is thus well fixed. It adds another well-defined mineral to a group which already includes a considerable number of minerals.[2] The relations of these minerals are shown by the following tabulation:

Svanbergite....	$2SrO.\ 3Al_2O_3.\ 2SO_3.\ P_2O_5.\ 6H_2O$.	Rhomb. $c=1.2063$.
Hinsdalite......	$2PbO.\ 3Al_2O_3.\ 2SO_3.\ P_2O_5.\ 6H_2O$.	Rhomb. $c=1.2677$.
Corkite.........	$2PbO.\ 3Fe_2O_3.\ 2SO_3.\ P_2O_5.\ 6H_2O$.	Rhomb. $c=1.1842$.
Beudantite.....	$2PbO.\ 3Fe_2O3.\ 2SO_3.\ As_2O_5.\ 6H_2O$.	Rhomb. $c=1.1842$.

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[1] Cf. Lacroix, A., Minéralogie de la France, vol. 4, 1911, p. 596.

[2] See following paper in this volume.

THE ALUNITE-BEUDANTITE GROUP.

INTRODUCTION.

The analysis of the mineral hinsdalite, described in the preceding paper, led me to review carefully the various minerals forming the alunite-beudantite group. This review has brought out several points in regard to the relationships of some of these minerals about which it is very desirable to obtain more definite and accurate information. Some of the suggestions offered in this paper must remain unsettled until such new work can be performed. Prior[1] has compared the various minerals belonging to this group and has clearly shown their similarity in composition and in crystal form. Before this comparison is repeated here, a short discussion of the members or possible members of this group will be given.

PROBABLE IDENTITY OF HAMLINITE WITH GOYAZITE.

Goyazite was described by Damour[2] in 1884 as a hydrous phosphate of alumina and lime, the rather improbable formula $3CaO.5Al_2O_3.P_2O_5.9H_2O$ being given for it. Hussak[3] has recently tested the original specimens of Damour, and has found strontium to be present in greater amount than lime, so that goyazite is, in reality, a hydrous phosphate of alumina and strontia. Hartley, in analyzing plumbogummite,[4] has suggested that the accuracy of Damour's separation of P_2O_5 from Al_2O_3 is open to serious question because of the method used. If a similar inaccuracy is true for his analysis of goyazite, an interesting conclusion becomes at once evident—namely that the mineral described and analyzed by Penfield and named by him hamlinite is identical with goyazite. The probable identity of goyazite and hamlinite can be best shown by a comparison of their properties.

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[1] Prior, G. T., Note on a connection between the molecular volume and chemical composition of some crystallographically similar minerals: Mineralog. Mag., vol. 13, 1903, p. 217.

[2] Bull. Soc. min. franç., vol. 7, 1884, p. 204.

[3] Hussak, E., Über die sogenannten "Phosphat-Favas" der diamentführenden Sande Brasiliens: Min. pet. Mitt., vol. 25, 1906, p. 335.

[4] Hartley, E. G. J., On the constitution of the natural arsenates and phosphates: Mineralog. Mag., vol. 12, 1900, pp. 223, 225.

Comparison of goyazite and hamlinite.

Goyazite.	**Hamlinite.**
Yellowish, white.	Colorless, yellowish.
Semitransparent.	Transparent.
Uniaxial, positive.	Uniaxial, positive.
Tetragonal or hexagonal.	Hexagonal (rhombohedral).
Cleavage, basal.	Cleavage, basal.
$H=5$.	$H=4.5$.
$G=3.26$.	$G=3.228$, 3.159–3.283.
Per cent $Al_2O_3+P_2O_5=65.53$.	Per cent $Al_2O_3+P_2O_5=62.87$.
Fuses with difficulty.	Fuses about 4.

The hamlinite from Maine contains a little barium and fluorine, but their amount, in comparison to that of strontium and water (hydroxyl), respectively, is small. Moreover, the absence of barium and fluorine in goyazite has not been established.

UTAHITE AND RELATED MINERALS.

On the basis of our present knowledge, utahite, cyprusite, raimondite, pastreite, carphosiderite, and apatelite form a group of minerals which are very closely related. They are all hydrous sulphates of ferric iron with very similar quantitative composition, and all occur in hexagonal or rhombohedral scales. The only one of these minerals which has been found in measurable crystals is utahite, for which two values for the *c* axis have been given, namely, 1.1389 and 1.0576. If it is considered that the material analyzed was many times of doubtful purity and that perhaps the analytical methods used were not always of the best, the differences in their analytical figures become of minor importance, and it seems almost justifiable to regard them all as identical. They may be placed chemically in three divisions, according to their formulas, as follows:

I.	Utahite	$3Fe_2O_3.3SO_3.6H_2O$.
II.	Carphosiderite	$3Fe_2O_3.4SO_3.10H_2O$.
	Apatelite	$3(Fe,Al)_2O_3.3SO_3.9H_2O$.
III.	Raimondite	$2Fe_2O_3.3SO_3.7H_2O$.
	Pastreite	$2Fe_2O_3.3SO_3.7H_2O$.
	Cyprusite	$4(Fe,Al)_2O_3.5SO_3.7H_2O$.

These different formulas are all very closely related and when it is considered that, so far as the published descriptions go, the crystalline form of all these minerals is the same, it seems reasonable to regard them as identical. The above formulas are all close to

$$3Fe_2O_3.4SO_3.7H_2O,$$

though to none of the minerals has this formula been ascribed. This formula corresponds to that of a jarosite in which the K_2O is replaced by H_2O, as will be evident from the following comparison:

Jarosite	$K_2O.3Fe_2O_3.4SO_3.6H_2O$.
New formula	$H_2O.3Fe_2O_3.4SO_3.6H_2O$.

The formulas of carphosiderite and apatelite[1] may be expressed in similar form, for these minerals differ from the type only in containing a slightly greater amount of water:

$$\text{Carphosiderite} = H_2O.3Fe_2O_3.4SO_3.6H_2O + 3H_2O.$$

I would therefore propose that, unless careful work proves to the contrary, carphosiderite, apatelite, raimondite, pastreite, cyprusite, and utahite be regarded as the same mineral with the formula $H_2O.3Fe_2O_3.4SO_3.6H_2O$, and that to this mineral the name carphosiderite be applied by right of priority.

The compilation of analyses of these minerals, given in the accompanying table, shows their close chemical relationship and their general agreement with the formula $H_2O.3Fe_2O_3.4SO_3.6H_2O$.

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[1] Apatelite is only an aluminous carphosiderite.

Analyses of carphosiderite.

	Calculated.	Utahite.		Cyprusite.	Pastreite.		Raimondite.	Carphosiderite.		Apatelite.
		1	2 [a]		1	2		1	2	
H_2O	13.5	9.35	[12.41]	11.06	16.04	13.95	17.40	18.30	18.48	19.2
SO_3	34.7	28.45	26.83	35.34	30.47	30.55	36.08	31.82	30.18	29.7
Fe_2O_3	51.8	58.82	58.51	49.68	46.50	52.80	46.52	49.88	48.52	40.0
Al_2O_3				3.89						11.0
X		[b] 3.19	[c] 2.19		[d] 6.40	[e] 2.68			[f] 2.72	
	100.0	99.81	100.00	99.97	99.41	99.98	100.00	100.00	99.90	99.9
Density				1.7-1.8 !			3.19-3.22	2.49	2.73	3.2

[a] Arzruni and Thaddeeff, Zeitschr. Kryst. Min., vol. 31, p. 244.

[b] As_2O_5.

[c] Insoluble.

[d] SiO_2, 2.40; As_2O_5, 1.86; PbO, 1.25; (Al_2O_3, MnO, CaO), 0.89.

[e] As_2O_5, 2.05; (Al_2O_3, CaO, sand), 0.63.

[f] P_2O_5.

MISCELLANEOUS NOTES.

Though the members of the group are uniaxial rhombohedral, yet optical anomalies indicating biaxiality have been noted for a sulphate (jarosite), a phosphate (hamlinite), and a compound sulphate-phosphate (hinsdalite). Jarosite has been described as showing optical anomaly by Slavík,[1] who found that jarosite from Schlaggenwald showed, in basal section, a division into six parts, each part being biaxial, the trace of the axial plane normal to the prism edge. The negative, biaxial interference figure varied in size in different crystals, up to 32°. Some basal plates were pleochroic and decidedly doubly refracting.

Hamlinite [2] from Switzerland, at first thought to be a new species and called bowmanite,[3] shows optical anomalies. The larger crystals show a division into six sections, each showing a positive, biaxial figure, 2E varying from 0° to 50°. Hinsdalite likewise shows a pseudohexagonal character,[4] the crystals being built up of six sectors, each normal to an acute bisectrix, 2E varying from 0° to 40°. These optical anomalies are very suggestive of dimorphism in the series.

The isomorphous relation of sulphate and phosphate is still further confirmed by the presence of 2.72 per cent P_2O_5 in an analysis of carphosiderite from France and also by the presence of nearly 1 per cent P_2O_5 in a sample of alunite from Utah, tested by the writer.

The formulas of beudantite and corkite have been taken as suggested by Lacroix [5]; the arsenate has been called beudantite and the phosphate corkite. The composition of miriquidite, munkforssite, and munkrudite are too little known to include them definitely in this group, although their qualitative composition suggests that they belong to it.

Pharmacosiderite has been shown [6] to contain considerable potash, and Hartley's formula, $2FeAsO_4.Fe[O(HK)]_3.5H_2O$, can be written in such a form as to show its analogy to hamlinite, as $2(H,K)_2O.3Fe_2O_3.2As_2O_5.7H_2O+4H_2O$, in which formula the $4H_2O$ does not really belong to the mineral. Though pharmacosiderite is considered isometric, the form is very similar to the rhombohedral crystals of this group, and it would be highly desirable to test the mineral optically to see if it could be referred to a uniaxial mineral, as it commonly shows weak double refraction.

The composition of plumbogummite still needs careful study, for it is entirely possible that more than one species is included under

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[1] Slavík, Franz, Mineralogische Notizen: Zeitschr. Kryst. Min., vol. 39, 1904, p. 297.

[2] The name hamlinite is retained until its identity with or distinction from goyazite is definitely determined.

[3] Bowman, H. L., On hamlinite from Binnenthal, Switzerland: Mineralog. Mag., vol. 14, 1907, p. 389.

[4] See the preceding paper in this volume.

[5] Lacroix, A., Minéralogie de la France, vol. 4, 1910, p. 592.

[6] Hartley, E. G. J., On the constitution of the natural arsenates and phosphates: Mineralog. Mag., vol. 12, 1899, p. 152.

that name. The analyses of Hartley have established the presence in quantity of CO_2 in some varieties, while the analyses of Brazilian plumbogummite, given by Hussak, are free from any CO_2, although these latter contain more water than is usual. Perhaps the fine grinding of the samples has a very marked effect on the water content of these minerals, as Hartley has suggested for pharmacosiderite.

The mineral called harttite is an isomorphous mixture of about two parts of hamlinite and one part of a strontium alunite. More accurately the ratio is 1.97 parts to 1 instead of exactly 2 to 1. Its formula may therefore be written $2[2SrO.3Al_2O_3.2P_2O_5.7H_2O]+1[SrO.3Al_2O_3.4SO_3.6H_2O]$, which can be simplified to $5SrO.9Al_2O_3.4P_2O_5.4SO_3.20H_2O$. This is very close to the formula deduced by Hussak, which when quadrupled becomes $4SrO.8Al_2O_3.4P_2O_5.4SO_3.20H_2O$. In fact, the ratios deduced by Hussak from the analysis of harttite are in better agreement with the formula here proposed than with his own.

Ratios of harttite.

	Ratio of analysis.		Required by Hussak's formula.	Required by Schaller's formula (approximately).
SrO	1664	4.57	4.00	5.00
Al_2O_3	3355	9.22	8.00	9.00
P_2O_5	1528	4.20	4.00	4.00
SO_3	1475	4.05	4.00	4.00
H_2O	1733	19.60	20.00	20.00

CLASSIFICATION OF MINERALS OF THE GROUP.

The minerals forming the alunite-beudantite group may be divided into three smaller groups, the sulphates, the phosphates, and the sulphate-phosphates. Taking alunite as the type of the sulphates, hamlinite of the phosphates, and corkite as that of the sulphate-phosphates, we have:

Alunite...... $K_2O.3Al_2O_3.4SO_3.6H_2O$.
Hamlinite.... $2SrO.3Al_2O.2P_2O_5.7H_2O$.
Corkite...... $2PbO.3Fe_2O_3.2SO_3.P_2O_5.6H_2O$.

The analogous composition is not clearly seen in the three formulas just given, but it is possible, by rewriting them in a slightly different form, to show very clearly the analogy between them:

Alunite...... $K_2O.3Al_2O_3.6H_2O.2SO_3.2SO_3$.
Hamlinite.... $SrO.3Al_2O_3.6H_2O.2HPO_3.Sr(PO_3)_2$.
Corkite..... $PbO.3Fe_2O_3.6H_2O.2SO_3.Pb(PO_3)_2$.

By assuming the isomorphous replacement of SO_3 by HPO_3, the relationships become very clear. The formula can be, however, better written by regarding $=[SO_4]$ and $=[HPO_4]$ as the isomorphous groups which are replaceable. The formulas for these minerals then become:

Alunite.......	$[Al(OH)_2]6.K_2.[SO_4]_2.\ \ [SO_4]_2.$
Hamlinite ...	$[Al(OH)_2]6.Sr.\ [HPO_4]_2.[Sr(PO_4)_2].$
Corkite......	$[Fe(OH)_2]6.Pb.[SO_4]_2.\ \ [Pb(PO_4)_2].$

The general formula is written

$$[R'''(OH)_2]_6.R''.[M]_2.[M]_2,$$

in which

$R''' = Al, Fe'''.$
$R'' = K_2, Na_2, H_2, Pb, Sr, Ba.$
$M = SO_4, HPO_4, HAsO_4, Pb_{\frac{1}{2}}PO_4, Sr_{\frac{1}{2}}PO_4.$

The entire group then consists of the following minerals:

Sulphates.—Type formula $[R'''(OH)_2]_6.R'_2$ *or* $R''.[SO_4]_2.[SO_4]_2.$

Alunite............	$[Al(OH)_2]_6.K_2.[SO_4]_2.[SO_4]_2.$
Natroalunite......	$[Al(OH)_2]_6.Na_2.[SO_4]_2.[SO_4]_2.$
Jarosite............	$[Fe(OH)_2]_6.K_2.[SO_4]_2.[SO_4]_2.$
Natrojarosite......	$[Fe(OH)_2]_6.Na_2.[SO_4]_2.[SO_4]_2.$
Plumbojarosite....	$[Fe(OH)_2]_6.Pb.[SO_4]_2.[SO_4]_2.$
Carphosiderite.....	$[Fe(OH)_2]_6.H_2.[SO_4]_2.[SO_4]_2.$

Phosphates.—Type formula $[R'''(OH)_2]_6.R''.[R'PO_4]_2.[R''(PO_4)_2].$

Hamlinite........	$[Al(OH)_2]_6.Sr.[\ HPO_4]_2.[Sr(PO_4)_2].$
Plumbogummite ..	$[Al(OH)_2]_6.Pb.[\ HPO_4]_2.[Pb(PO_4)_2].$
Gorceixite........	$[Al(OH)_2]_6.Ba.[\ HPO_4]_2.[Ba(PO_4)_2].$
Florencite........	$[Al(OH)_2]_6.Ce_{\frac{2}{3}}.[Ce_{\frac{1}{3}}PO_4]_2.[Ce_{\frac{2}{3}}(PO_4)_2].$

Sulphate-phosphates.—Type formula $[R'''(OH)_2]_6.R''.[SO_4]_2.[R''(PO_4)_2].$

Beudantite.......	$[\ Fe(OH)_2]_6.Pb.[SO_4]_2.[Pb(AsO_4)_2].$
Corkite............	$[\ Fe(OH)_2]_6.Pb.[SO_4]_2.[Pb(PO_4)_2].$
Svanbergite.......	$[\ Al(OH)_2]_6.Sr.[SO_4]_2.[Sr(PO_4)_2].$
Hinsdalite........	$[\ Al(OH)_2]_6.Pb.[SO_4]_2.[Pb(PO_4)_2].$
Harttite..........	$[\ Al(OH)_2]_6.Sr.[SO_4]_2.[SO_4]_2.$ $2([Al(OH)_2]_6.Sr.[HPO_4]_2.[Sr(PO_4)_2]).$

SOME MINERALS FROM BEAVER COUNTY, UTAH.

INTRODUCTION.

While making an examination of some of the mines in Beaver County, Utah, in the summers of 1909 and 1910, Mr. B. S. Butler, of the United States Geological Survey, collected several minerals that on examination proved to be of unusual interest. One of these is a species not hitherto known, a second has never before been reported from this continent, and a third, although previously reported from but two localities, was found to be relatively abundant in this district.

BEAVERITE.

From the Horn Silver mine, near the town of Frisco, a mineral was obtained that proved on examination in the laboratories of the United States Geological Survey to be a new species. For this mineral, which is a hydrous sulphate of copper, lead, and ferric iron, the name beaverite was proposed,[1] after the name of the county from which it was first described.

OCCURRENCE AND ASSOCIATION.

As described by Butler, the mineralization in the Horn Silver mine occurs along a fault plane that has thrown Tertiary lavas down against Cambro-Ordovician limestone, the ore deposits being mainly a replacement of the volcanic rocks. The principal primary minerals of the deposit are galena, sphalerite, wurtzite, pyrite, chalcopyrite, a sulphantimonite of lead possibly jamesonite, pyrargyrite, argentite, quartz, barite, and sericite. The mine has been developed to a depth of 1,600 feet. For about 600 feet the primary minerals have been almost entirely altered by descending solutions, and this alteration has taken place in lesser degree to a much greater depth. The characteristic alteration in the deposit is to sulphates, with some secondary carbonates, chlorides, and sulphides. The following secondary minerals have been recognized: Anglesite, cerussite, plumbojarosite, jarosite, beaverite, linarite, bindheimite ?, smithsonite, calamine, goslarite, covellite, chalcocite, brochantite, malachite, azurite, chyrsocolla, chalcanthite, cerargyrite, sulphur, chalcedony, kaolinite, gypsum, alunite, and hydrous oxides of iron and manganese. The beaverite occurs with other secondary minerals in the upper part of

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[1] Butler, B. S., and Schaller, W. T., Some minerals from Beaver County, Utah: Am. Jour. Sci., 4th ser., vol. 32, 1911, p. 418.

the deposit. Only a small portion of the upper levels was accessible at the time of visit and the mineral was not seen in place, but the frequency with which it was met in the old dumps leads to the belief that it must have been rather common in some parts of the deposit.

PHYSICAL PROPERTIES.

The mineral is a canary-yellow material of earthy appearance, commonly mixed with other secondary lead and copper minerals, but of less common occurrence in small masses that appear to be composed of a single mineral. Such masses are easily crushed in the fingers. Under the high power of the microscope the material is seen to be crystallized in distinct hexagonal plates, too small for accurate measurement of the crystal angles or for determination of the optical character. The refractive index of the light ray vibrating perpendicular to the plates is higher than 1.74.

Almost every crystal contains a minute inclusion whose character has not been determined. The material analyzed appeared under the microscope to be very pure except for these inclusions, and it is possible that the silica that appears in the analyses is due to them.

CHEMICAL COMPOSITION.

The mineral is soluble in boiling hydrochloric acid, leaving the insoluble matter, chiefly silica, behind. On cooling, lead chloride separates out in considerable amounts. The lead reaction can also be readily obtained with sodium carbonate on charcoal. On adding ammonia in excess to the hydrochloric acid solution, the ferric iron is thrown down as a voluminous brown precipitate and the solution takes the deep blue color indicative of copper. By quantitative determination the presence of a small amount of alumina was established. The insoluble matter consists mostly of silica, only a slight residue remaining after treatment with hydrofluoric acid.

The average of the results of the chemical analyses is shown in the table below. The ratios obtained therefrom are also given.

Analysis and ratios of beaverite.

	Per cent.	Ratio.		
Insoluble	10.05			
CuO	9.70	0.121		0.92 or 1
PbO	29.44	.132		1.00 or 1
Fe_2O_3	17.28	.108	.144	1.07 or 1
Al_2O_3	3.64	.036		
SO_3	21.32	.266		2.01 or 2
H_2O	9.02	.501		3.80 or 4
	100.45			

The ratios agree well with the formula $CuO.PbO.Fe_2O_3.2SO_3.4H_2O$, in which the copper and lead are assumed to be present in equal molecular amounts and in which a little ferric iron is replaced by alumina. As the ratio of Fe_2O_3 to Al_2O_3 is as 3 : 1, the formula can be written more exactly as $4CuO.4PbO.3Fe_2O_3.Al_2O_3.8SO_3.16H_2O$. A comparison of the analysis reduced to 100 per cent after deducting the insoluble matter, with the values calculated for the formula last given, is shown below.

Comparison of analysis with calculated values.

	Analysis.	Calculated.
CuO	10.74	11.70
PbO	32.50	32.80
Fe_2O_3	19.13	17.61
Al_2O_3	4.03	3.75
SO_3	23.60	23.54
H_2O	10.00	10.60
	100.00	100.00

The water is all constitutional, as none was driven off below 250°. The actual results obtained are as follows:

Loss of weight of beaverite on heating.

Temperature.	Total loss.
°*C.*	*Per cent.*
110	0.04
170	.10
250	.14
390 [a]	3.72
590 [a]	10.45

[a] Heated in an electric furnace.

The loss at 590°, as given, is higher than the true value, as a little of the material was lost by adhering to the thermal couple, which accidentally dropped into the crucible.

No known mineral could be found with which beaverite seems to be related, so that for the present, at least, it must stand as an isolated member of the sulphate group.

WURTZITE.

OCCURRENCE.

The hexagonal zinc sulphide, wurtzite, is, according to Butler, present in considerable abundance in the primary ores of the Horn Silver mine. The principal primary minerals of this deposit have been noted above. The richer zinc ore, in the hand specimen, has the general appearance of light honey-yellow sphalerite, but under the microscope a portion is seen to be rather strongly birefringent, and some of this birefringent material has the outline of pyramidal crystals. Close examination of the mineral revealed pyramidal crystals that could be separated from the surrounding material.

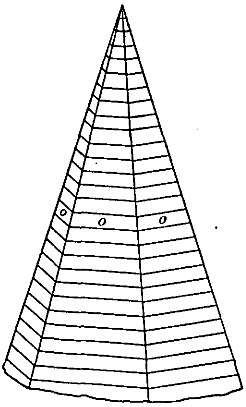

FIGURE 5.—Wurtzite, o $\{20\bar{2}1\}$.

CRYSTALLOGRAPHY.

Several of these crystals were removed from the matrix and measured. They showed a steep hexagonal pyramid which was strongly striated horizontally. Accurate measurements were not possible, as the striations caused the crystals to become rounded with consequent absence of plane faces. The crystals were measured on the two-circle goniometer and the ρ angle determined for the pyramid faces. This angle corresponds to that between the basal plane (absent on these crystals) and the pyramidal faces. The values obtained are shown below, the pyramid being the form *o* $\{20\bar{2}1\}$:

Measurements of o $\{20\bar{2}1\}$ *wurtzite.*

Crystal No.	1	2	3	4
Average measurement	61°	62°	60°	61°

Calculated value, 62° 06′.

The general habit of these crystals is shown in figure 5, in which the marked horizontal striæ are also shown.

The crystals of wurtzite dissolve readily in hydrochloric acid, giving off hydrogen sulphide. The solution contained abundant zinc, and no other metal was present in appreciable quantity.

Butler noted that the zinc sulphides in this mine have the property of tribo-luminescence, or of giving out light when scratched. This property is so marked that sulphides of zinc can be readily detected in the mine by drawing the point of the pick or mine candlestick across the ore. If zinc sulphides are present the point of the metal is followed by a line of sparks.

PLUMBOJAROSITE.

OCCURRENCE AND PHYSICAL PROPERTIES.

Plumbojarosite has previously been described from two localities, first from Cooks Peak, N. Mex.,[1] and second from American Fork, Utah.[2]

Mr. Butler found this rare mineral in no less than six mines and prospects in Beaver County (the Horn Silver, Hub, Moscow, Red Warrior, and Harrington-Hickory mines, and an unnamed prospect pit), and in some places a considerable quantity could be picked from the ore bins and dumps. It was reported that several tons of the mineral had been thrown on the dump of one mine and later, when found to contain metal values, had been shipped to the smelter.

The following description of its occurrence and physical properties is by Butler:

> The mineral is secondary, resulting from the alteration of ore composed mainly of sulphides of iron, lead, copper, and zinc. The secondary minerals for the most part are the oxides, sulphates, carbonates, and silicates of these metals, and with these are plumbojarosite, frequently jarosite, and other minerals in varying amounts. It is of interest to note that from the Horn Silver mine three members of the jarosite group were determined, namely, jarosite, plumbojarosite, and alunite.
>
> As seen in the hand specimen, the material is dark brown in color and distinctly micaceous in appearance, with a silky luster. Where the crystals are very fine the micaceous character is less pronounced, and the mineral, if not examined with some care, might be mistaken for limonite or some iron-stained material. Although the mineral is frequently in rather large pieces as it comes from the mine, it is readily crushed in the fingers and has an oily look and feel, similar to fine graphite. Under the microscope the crystals are seen to be thin hexagonal plates of a light golden-yellow color. The crystals vary greatly in size but rarely exceed 0.25 mm. in width. Measurement of the crystals has not been made, but they are undoubtedly hexagonal, and, so far as their properties have been determined, they correspond to the material examined by Wright from the American Fork locality. The crystals are uniaxial, optically negative with strong birefringence. It may be noted that the jarosite from the same mines is so similar to the plumbojarosite in physical properties that a distinction can be made only by chemical tests.

CHEMICAL COMPOSITION.

The analysis of the plumbojarosite is shown in the table below, where, for comparison, are also given the two analyses, by Hillebrand, of the mineral from New Mexico and American Fork, Utah. The values calculated from the formula $PbO.3Fe_2O_3.4SO_3.6H_2O$ are also given in the last column for comparison.

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[1] Hillebrand, W. F., and Penfield, S. L., Am. Jour. Sci., 4th ser., vol. 14, 1902, p. 213.

[2] Hillebrand, W. F., and Wright, F. E., Am. Jour. Sci., 4th ser., vol. 30, 1910, p. 191.

Analyses of plumbojarosite.

	Beaver County, Utah.	Cook's Peak, N. Mex.	American Fork, Utah.	Calculated.
Fe_2O_3	42.11	42.37	42.87	42.38
PbO	18.32	19.84	18.46	19.74
K_2O	.13	.17	.15	....
Na_2O		.21	.52	....
SO_3	27.59	27.06	27.67	28.33
H_2O	9.16	9.56	10.14	9.55
CuO	....	.27	.10	....
CaO	....	.05	.06	....
Insoluble	2.64	.51	.40	....
ZnO	.30	....	....	....
	100.25	100.15	100.37	100.00
Density	3.60	3.665	....	....

The three analyses agree closely with each other and with the calculated values.

CORKITE.

OCCURRENCE AND PHYSICAL PROPERTIES.

Mr. Butler states that—

> A light yellowish-green mineral that has the properties of corkite, a hydrous phosphate and sulphate of lead and iron, was collected from the Harrington-Hickory and the Wild Bull mines. So far as is known, these are the only localities on this continent from which the mineral has been reported.
>
> In both of the mines mentioned the original ores were a replacement of limestone near the intrusive rock, and considerable quantities of apatite and contact silicates were formed with the metallic sulphides, mainly pyrite, galena, sphalerite, and chalcopyrite. The corkite is a secondary mineral resulting from the alteration of these ores, the phosphate doubtless being derived from the apatite and the metallic content from the sulphides.
>
> In physical properties the mineral corresponds with that previously described. In the hand specimen it is a light-green, earthy-looking material, which when crushed in the fingers has a gritty feel like fine sand. Under the microscope it is seen to be well crystallized, the larger crystals being 0.15 millimeter in diameter. The crystals are golden yellow and have the general appearance of being a combination of the cube and octohedron. They are rather strongly birefringent, however, and are probably hexagonal rhombohedral. The index of refraction is higher than 1.74.

CHEMICAL COMPOSITION.

Corkite is readily soluble in boiling hydrochloric acid, from which solution lead chloride separates out in quantity on cooling. The solution contains, besides lead, abundant ferric iron and the sulphate and phosphate radicles. Qualitative tests failed to show the presence of any arsenic, and only a mere trace of copper is present. Heated in a closed tube, the mineral darkens and gives off water.

FERRITUNGSTITE FROM WASHINGTON.

A sample of tungstic ocher was collected by Mr. Howland Bancroft, of the United States Geological Survey, from the Germania tungsten mine of the Deer Trail mining district, in the northeastern part of the State of Washington. Mr. Frank L. Hess, also of the Survey, suggested that the tungstic ocher might prove of sufficient interest to warrant careful study. On microscopic examination, the earthy-looking ocher was found to be well crystallized and pure, and chemical tests showed that the ocher was a hydrous ferric tungstate, entirely different from ordinary tungstic ocher, or tungstite, which, as Walker[1] showed, has the formula $WO_3.H_2O$. For the privilege of describing this interesting new mineral I am deeply indebted to the two gentlemen above named.

Examination under the microscope shows that ferritungstite crystallizes in hexagonal plates, evenly developed but very minute. Those lying flat on the base are isotropic under crossed nicols but are too small to exhibit any interference figures. Such crystals as are partially tilted show decided double refraction on their edge. A small quantity of gangue, mostly quartz, is mixed with the mineral, but limonite stains are almost absent, though here and there traces can be seen. Probably less than one per cent of limonite is present in the purest ocher, such as was analyzed.

Ferritungstite results from the oxidation of wolframite and is associated with that mineral in massive quartz. The cleavage, hardness, and density of ferritungstite could not be determined. Its color is pale yellow to brownish yellow when pure. It gives off water in a closed tube and is decomposed by acids, yellow oxide of tungsten separating out.

Only a few tenths of a gram of pure material was available for analysis. Two samples were taken at different times from the same specimen. Qualitative tests showed the absence of MoO_3, SO_3, P_2O_5, and, in general, of substances other than those given in the analyses. The analyses of the two samples are given below.

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[1] Am. Jour. Sci., 4th ser., vol. 25, 1908, p. 305.

Analyses of ferritungstite.

	1	2
WO_3	37. 1	35. 8
Fe_2O_3	26. 6	27. 3
H_2O [a]	18. 6	20. 9
Insoluble	14. 7	[16. 0]
	97. 0	100. 0

[a] H_2O determined by loss on ignition.

The ratios deduced from these analyses are shown in the following table:

Ratios of analyses of ferritungstite.

	1	2
WO_3	0. 16 or 0. 94	0. 15 or 0. 88
Fe_2O_3	. 17 or 1. 00	. 17 or 1. 00
H_2O	1. 03 or 6. 06	1. 16 or 6. 82

These ratios are close enough to 1:1:6 to show that the formula for ferritungstite is $Fe_2O_3.WO_3.6H_2O$. Below are shown the two analyses with the insoluble matter deducted and recalculated to 100 per cent, compared with the theoretical values calculated from the formula $Fe_2O_3.WO_3.6H_2O$.

Comparison of analyses with calculated composition.

	Analysis 1.	Analysis 2.	Calculated.
WO_3	45. 1	42. 6	46. 4
Fe_2O_3	32. 3	32. 5	32. 0
H_2O	22. 6	24. 9	21. 6
	100. 0	100. 0	100. 0

The mineral is different from any yet described, and the new name proposed, ferritungstite, shows its chemical relation to ordinary tungstic ocher or tungstite.

NOTES ON MINERALS FROM GABBRO OF WAIMEA CANYON, HAWAII.

INTRODUCTION.

The following brief crystallographic descriptions are based on material furnished by Dr. Whitman Cross of the United States Geographical Survey, to whom I am indebted for his kind permission to publish these results. The crystals were found projecting into the cavities of a coarse gabbro (Dr. Cross's No. 15K) bowlder in the stream bed about one-fourth mile up the east branch of Waimea Canyon, which enters the main canyon about 5 miles above the mouth.

APATITE.

Apatite is present in long slender needles, colorless and transparent except where covered with an opaque grayish coating. The crystals, when terminated, show as prominent forms only $m\{10\bar{1}0\}$ and $x\{10\bar{1}1\}$. The six faces of the unit pyramid are usually triangular in shape and not all of uniform size. Besides the two dominant forms, *m* and *x*, there were noted five other forms, all very poorly developed. The prism $a\{11\bar{2}0\}$ is present as a long line face, and very minute striæ, corresponding to faces of $h\{21\bar{3}0\}$ and $k\{41\bar{5}0\}$, were also noted. The base $c\{0001\}$ and the pyramid $y\{20\bar{2}1\}$ were measured, the faces representing these forms being very minute short line faces. All the faces except some of those of *m* and *x* gave very poor and indistinct reflections.

The following measurements are the averages of the obtained values, on which the identification of the forms are based. The angles for the calculated values are taken from Goldschmidt's Winkeltabellen.

Measured and calculated angles of apatite.

Letter.	Form.	Measured.		Calculated.	
		ϕ	ρ	ϕ	ρ
		° ′	° ′	° ′	° ′
m.......	$10\bar{1}0$	0 00	90 00	0 00	90 00
a.......	$11\bar{2}0$	30 04	90 00	30 00	90 00
h.......	$21\bar{3}0$	18 13	90 00	19 06	90 00
k.......	$41\bar{5}0$	11 38	90 00	10 53	90 00
c.......	0001	....	1 00	....	0 00
x.......	$10\bar{1}1$	0 00	40 00	0 00	40 16
y.......	$20\bar{2}1$	0 00	60 00	0 00	59 27

ORTHOCLASE.

A single square prism of orthoclase was suitable for measurement. Both ends were broken off, so that the only forms identified are *c*{001}, *b*{010}, and *n*{021}. The measurements are as follows: $c \wedge b = 89° 50' - 90° 17'$ (90° 00′ calculated); $b \wedge n = 45° 08'$ (45° 03′ calculated).

TITANIFEROUS AUGITE.

The crystals of augite are small, being about 3 millimeters high (*c* axis), $2\frac{1}{2}$ millimeters wide (*b* axis), and slightly less than 1 millimeter thick (*a* axis). They are black and shining, but on the broken surface show the peculiar violet tinge possessed by titanium-rich augites.

Two crystals were found that could be measured. They both have the same habit, being stout tabular parallel to the orthopinacoid. The crystals are terminated by two large faces of the negative unit pyramid {$\bar{1}11$}.

The prism zone is fairly rich in faces, there being measured 11 faces belonging to six forms on the first crystal and 14 faces of five forms on the second crystal. Two of the prisms are new for augite.

The forms observed on these two crystals are as follows, the new forms being starred: *a*{100}, *b*{010}, *m*{110}, *Δ*{150}, **θ*{230}, **Υ*{530}, *g*{210}, *s*{$\bar{1}11$}. The following table gives a comparison of the angles measured and calculated.[1]

Measured and calculated angles of augite.

Letter.	Symbol.	Measured.		Calculated.	
		ϕ	ρ	ϕ	ρ
		° ′	° ′	° ′	° ′
a.......	100	90 00	90 00	90 00	90 00
b.......	010	0 02	90 00	0 00	90 00
m.......	110	43 37	90 00	43 33	90 00
Δ.......	150	11 12	90 00	10 46	90 00
θ......	230	32 09	90 00	32 22	90 00
Υ........	530	58 09	90 00	57 45	90 00
g.......	210	63 05	90 00	62 15	90 00
s........	$\bar{1}11$	25 34	33 36	25 07	33 04

Following is given a brief description of the different forms, arranged in the order of their size.

The orthopinacoid, *a*{100}, is by far the largest form on these crystals, and thereby determines their habit. The faces are striated vertically, though the reflections obtained were fairly good.

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[1] For the calculated angles the constants $a : b : c = 1.0934 : : 0.5894$, $\beta = 74° 09'$, are taken. These values, from Goldschmidt's Winkeltabellen, are almost identical with the values given for pyroxene in Dana's System of Minearalogy, 6th edition, 1892, p. 352.

All four faces of the negative pyramid *s*{$\bar{1}$11} are strongly etched, only incomplete narrow rims of the bright shining face being left, but these gave fairly good reflections. This pyramid is the only terminal face that could be found on either crystal.

The unit prism *m* is generally smaller than the pyramid *s*, though one face of *m* was nearly as large. The true value of the prism angle is probably a few minutes larger than the average value here given (43° 37′), as out of 10 measurements six lie between 43° 39′ and 43° 43′, but two low values slightly lower the general average.

The clinopinacoid, *b*{010}, is present as small faces, smaller than those of *a*{100}, *m*{110}, or *s*{$\bar{1}$11}, but generally larger than any of the other faces.

All the remaining forms are present as line faces in the prism zone. Of the known forms *Δ*{150} was noted but once as a small broad line face. Three faces of *g*{210} were measured on the second crystal, the faces being exceedingly fine striæ and the reflections very poor. In one no reflection could be seen. The three measured values are: 62° 00′, 63° 56′, 63° 19′; calculated, 62° 15′.

The new forms are two in number and are briefly described below:

**θ*{230}. Only one face of this form, a line face, was observed on the first crystal. It lay between *a* and *m* and was the only face in this quarter of the prism zone besides *a m b*. The reflection was faint but distinct. Two measurements of it gave the values 32° 05′ 32° 13′. The calculated value is 32° 22′.

**Γ*{530}. One face of *Γ* was noted on each crystal. The faces were all line faces and gave poor reflections, though the one from the first crystal (57° 47′) was very distinct and the difference between the measured and calculated angles is very slight. The measurements were 57° 47′ and 58° 30′; the average is 58° 09′, and the calculated value 57° 45′. A third face gave a measured angle of 59° 13′, and may possibly belong to this form.

Reflections were also measured from several other faces which agreed approximately for {320} and {520}, but they were too poor to warrant any further characterization.

The combination *a*{100}, *m*{110}, *b*{010}, and *s*{$\bar{1}$11}, with a tabular habit due to the predominance of *a*{100} seems to be characteristic of these brownish-violet titanium-rich basaltic augites.

CUPRODESCLOIZITE FROM CALIFORNIA.

Some samples of reported vanadium ore, sent to the United States Geological Survey by Messrs. A. L. Lombard and J. F. Main, of the Dirigo Mining & Milling Co., of Los Angeles, Cal., proved to be coated with a deposit of cuprodescloizite. The associated lead minerals are cerusite and vanadinite, and from these the cuprodescloizite seems to be derived. The locality is given as Camp Signal, in San Bernardino County, Cal.

A qualitative chemical test showed the presence in quantity of lead, copper, zinc, and vanadium, and of a little water. A direct quantitative determination of the vanadium gave 21 per cent V_2O_5.

The material, when examined under the microscope, was seen to be well crystallized in minute plates. Some of these were square or oblong; others were irregularly shaped. The rectangular plates gave parallel extinction, with the axial plane parallel to one of the sides, and with a very large axial angle. The plates are colorless or pale yellow. The thicker pieces are very slightly pleochroic in shades of yellow. The double refraction was not very high. A few tabular pieces showed an acute termination, the sides of which were inclined 52° to the trace of the axial plane. The sections, tabular parallel to $a\{100\}$, showed $c\{001\}$, $u\{011\}$, both large, and $b\{010\}$ small.

These various data are all in harmony with the properties of descloizite and cuprodescloizite, to which the mineral is therefore referred.

MINERALOGY OF THE FRENCH PHOSPHORITES.

INTRODUCTION.

In two recent publications,[1] Lacroix has described the mineralogy of the phosphorites of France and its colonies. These descriptions present so clearly the mineralogical composition of the phosphorites that I thought it would be of interest to students of the American phosphate deposits to present briefly the results reached by Lacroix. The data here given are, therefore, a free translation and compilation of his papers.

TYPES OF PHOSPHORITES.

The French phosphorites are of three types—

(1) Holocrystalline, fibrous; (2) amorphous (isotropic), homogeneous; (3) mixture of the amorphous and holocrystalline.

(1) The holocrystalline, fibrous type is composed of either dahllite or francolite. Dahllite is a hydrous carbonate and phosphate of lime, free from fluorine, and was first found in Norway, its occurrence there being described by Brögger and Bäckstrom[2] in 1888. Tschirwinsky's podolite, described[3] as a new mineral in 1907, is probably identical with dahllite.[4] Francolite was described in 1850 from Tavistock, Devonshire, England,[5] but has hitherto been considered a variety of apatite. Staffelite[6] is considered by Lacroix as identical with francolite, but the name is kept for the fibrous variety of francolite. Damour's hydroapatite[7] also is francoline. Francolite is similar to dahllite in composition, but contains a notable amount of fluorine.

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[1] Lacroix, A., Sur la constitution minéralogique des phosphorites françaises: Compt. Rend., vol. 150, 1910, p. 1213; Minéralogie de la France, vol. 4, second part, 1910, p. 555.

[2] Brögger, W. C., and Bäckstrom, H., Dahllite, a new mineral from Odegarden, Bamle, Norway: Abstracted in Zeitschr. Kryst. Min., vol. 17, 1890, p. 426; also in Dana's system of mineralogy, 6th ed., 1892, p. 866.

[3] Tschirwinsky, W., Podolite, a new mineral: Centralbl. Min. Geol. Pal., 1907, p. 279. For some earlier but incomplete descriptions in Russian publication, see abstract thereof in Zeitschr. Kryst. Min., vol. 46, 1909, p. 296.

[4] Lacroix, op. cit. See also the following paper in this volume.

[5] Henry, T. H., On francolite, a supposed new mineral: Philos. Mag., vol. 36, 1850, p. 134. The CO_2 present in the mineral was not detected by Henry. A better analysis of francolite from Cornwall was later given by Story-Maskelyne, N., and Flight, W., Mineralogical notes—3, Francolite, Cornwall: Jour. Chem. Soc. (London), vol. 24, 1871, p. 3.

[6] Stein, C. A., Ueber das Vorkommen von phosphorsauren Kalk in der Lahn- und Dill-gegend mit besonderer Berücksichtigung des Vorkommens bei Staffel, Amts Limburg: Jahrb. Ver. Naturk. Herzogthum Nassau, vols. 19–20, 1864–1866, p. 41. Abstracted in Jahrb. Min., 1866, p. 716.

[7] Sur l'hydro-apatite, espèce minérale: Annales des mines, vol. 10, 1856, p. 65.

(2) The amorphous, perfectly isotropic type is composed of the mineral collophanite, which is a hydrous carbonate and phosphate of lime, generally free from any appreciable amount of fluorine, but rarely containing a small amount (fluocollophanite).

(3) The third type is composed of the following minerals, in variable amounts:

(*a*) Dahllite; (*b*) francolite (var. staffelite); (*c*) an unknown mineral, similar to dahllite and francolite in chemical composition but differing optically from them; (*d*) collophanite.

This type of phosphorite, composed of an amorphous mineral and one or more crystalline minerals, is called quercyite. If the unknown mineral ((*c*) above) is absent, the subtype is called α–quercyite; if the unknown mineral is present, the subtype is called β–quercyite. Quercyite is often formed of alternating layers of α–quercyite and of β–quercyite.

DESCRIPTION OF MINERALS.

DAHLLITE.

Dahllite occurs as fibrous crusts, stalactites, or concretions with a radiating or confused fibrous structure, and also in a pure state as nodular masses and concretions, some resembling the fungus polypore having formed against the sides of pockets in the phosphorite. It is colorless, white, yellow, or greenish, and is transparent in thin pieces. The streak is white, and the luster vitreous, dull, silky, or slightly greasy in the very pure specimens. The fibrous concretions are very tenacious. The fracture yields a dull white surface, sometimes showing a regular fibrous structure, but more often the fibers are radiating or intermingled. From the similarity of the shape of the nodular masses of dahllite, quercyite, and collophanite, the dahllite may have formed by the dehydration of the quercyite or the collophanite.

Optically the mineral is hexagonal, uniaxial, and negative, the fibers being elongated parallel to the least index of refraction. It shows the helicoidal optical grouping. The birefringence is slightly greater than that of apatite. The mean refractive index $(n) = 1.625$ approximately; the hardness is 5, and the density ranges from 2.97 (on confused fibrous masses more or less porous) to 3.053. When heated in a closed tube, it decrepitates without fusion, giving off water. It is readily soluble in cold dilute acids, with evolution of CO_2. The formula is given as $2Ca_3(PO_4)_2.CaCO_3.\frac{1}{2}H_2O$, but is more probably $3Ca_3(PO_4)_2.CaCO_3.H_2O$. See discussion in the following papers in this volume. For analyses see the table at the end of this paper.

FRANCOLITE.

Francolite is found as minute hexagonal crystals showing the forms *c* {0001} and *m* $\{10\bar{1}0\}$. These are tabular, flattened parallel to *c* {0001}, and are generally grouped in rosettes or confused masses. More frequently it forms the fibrous variety staffelite, as mammillated fibrous crusts or as very pure spherolites which were formerly considered to be apatite. These spherolites occasionally show minute crystals, about 1 millimeter in length, with free ends. They are colorless, white, yellow, or greenish, with a vitreous luster which tarnishes or becomes dull on exposure to air, the specimens changing from translucent to opaque. The streak is white.

The hexagonal crystals show a division of the basal section into six sectors, each normal to an acute negative bisectrix, the trace of the large axial angle being, in each sector, parallel with the prism edge. By superposition of biaxial plates the crystals often appear uniaxial. The birefringence is, like that of dahllite, 0.004 to 0.005, and the mean refractive index $(n) = 1.625$ approximately. The hardness is 4 to 5, and the density 3.09 to 3.128. In its pyrognostic and chemical properties, it is similar to dahllite, except that it shows the presence of fluorine. The formula given for it is $(CaF)_2Ca_8(PO_4)_6 . CaCO_3 + H_2O$. Analyses are given at the end of this paper.

UNKNOWN MINERAL.

The unknown mineral, mentioned as forming the characteristic component of *β*-quercyite, has not been found in a pure state, so that its chemical composition is not accurately known, but from analyses of specimens of *β*-quercyite rich in this unknown mineral (analyses Nos. 11 and 12 of this paper), its composition is doubtless near that of dahllite and francolite. The distinguishing test, however, is its optical character, for it is positive while both dahllite and francolite are optically negative. The birefringence of this positive mineral is about double that of the negative ones.

COLLOPHANITE.

The amorphous mineral collophanite forms concretionary masses, resembling opal or gum, and has a conchoidal fracture. An earthy variety is called monite. Some of the nodules or masses are nearly transparent, and others are only translucent, but most of them are opaque. The nearly transparent kind looks like carnelian stone, the others more like enamel. It is colorless, white, yellow, brown, or reddish. It has a vitreous luster, a little resinous or earthy in the variety monite. It is isotropic. The index of refraction is not constant for different specimens. Two different samples gave for sodium light the values 1.569, 1.612. The hardness is 4.5, and the density of the common variety 2.69–2.82, though that of monite is as low as 2.1. One variety is very poor in or entirely free from fluorine; a second variety (fluocollophanite) contains fluorine ranging up to an amount, in proportion to the P_2O_5 content, equal to that present in apatite. Its pyrognostic and chemical properties are like those of the crystallized compounds. Collophanite is often impure from admixed substances. It may be distinguished from similar minerals, such as opal, by its ready solubility in acids with evolution of CO_2, and by its P_2O_5 reaction. The formula given for it is $x[Ca_3(PO_4)_2]$ or $x[(CaF)_2Ca_8(PO_4)_6]+yCaCO_3+zH_2O$. See following papers. Analyses are given at the end of this paper.

QUERCYITE.

The name quercyite is applied to mixtures of the amorphous collophanite and the crystalline dahllite, francolite, and the unknown mineral. The most common type of the French phosphorites is this variable mixture called quercyite. Only a small portion of the phosphorites are composed of either collophanite or one of the crystallized phosphates. The mixture in quercyite is so intimate that it is impossible to separate the constituents mechanically. If the crystalline mineral present is optically negative the mixture is called α-quercyite; if the unknown mineral (optically positive) is present, the mixture is called β-quercyite. Quercyite is often composed of alternating layers of α- and β-quercyite. Some of the layers may be nearly free of any crystalline material when they are composed of only collophanite. The density of α-quercyite is 2.83 to 2.87, and the mean refractive index about 1.608.

SUMMARY OF PROPERTIES.

This completes the list of minerals forming the French phosphorites. For convenience their chief diagnostic properties, including those of α-quercyite and of fluorapatite, are here tabulated:

Properties of phosphorite minerals.

	Dahllite.	Francolite.	Unknown mineral.	Collophanite.	α-Quercyite.	Fluorapatite.
Density	2.97–3.05	3.09–3.13	(?)	2.69–2.82	2.83–2.87	3.2
Mean refractive index	1.625	1.625	(?)	1.569–1.612	1.608	1.63
Birefringence	0.005 (approx.).	0.005 (approx.).	0.009 (approx.).	0.000	0.005	0.004
Optical character	Negative.	Negative.	Positive.	Isotropic.	....	Negative.
Distinguishing chemical component	CO_2,H_2O	F,CO_2,H_2O	(?)	CO_2,H_2O	F,CO_2,H_2O	F.

CHEMICAL COMPOSITION.

The chemical composition of the minerals and of their mixture—quercyite—can be seen by the analyses given below. They have been grouped together in this way in order to render the comparison more easy.

Dahllite analyses.....	1. Original analysis, Bamle, Norway.
	2. Mouillac, Quercy, France.
	3. Podolite, crystals, Podolie, Russia.
	4. Podolite, crystalline aggregate, Podolie, Russia.
Francolite analyses...	5. Cornwall, England.
	6. d'Encourtiech, Ariège, France.
	7. Staffelite, Staffel, Limburg.
Collophanite analyses.	8. Original analysis, Sombrero, Antilles.
	9. Pouzillac, Gard, Cévennes, France.
Quercyite analyses....	10. α-quercyite, Mouillac, Quercy, France.
	11. β-quercyite, Mouillac, Quercy, France.
	12. β-quercyite, Castillo de Belmez, Cordone, Spain.

Analyses of phosphorite minerals.

	Dahllite.				Francolite.			Collophanite.		Quercyite.		
	1	2	3	4	5	6	7	8	9	10	11	12
CaO	53.00	53.65	51.15	51.31	54.09	52.32	54.67	50.70	49.73	51.85	50.45	52.50
P_2O_5	38.44	38.40	39.04	36.44	38.14	40.00	39.05	39.10	37.40	37.60	36.60	37.75
F		Trace.	.00	.26	3.34	3.36	3.05		.88	1.50	.83	Trace.
CO_2	6.29	5.30	3.90	4.18	2.25	5.30	3.19	3.96	3.75	4.00	4.62	5.70
H_2O	1.37	2.10	(?)	(?)	1.59		1.40	5.02	7.05	4.80	6.00	3.20
$(Al,Fe)_2O_3$		.57	3.04	2.19	.91	.43	.06		.50		1.30	.85
MgO	[a] .79						.69	.80				
$(K,Na)_2O$	1.00			1.11					.30			
Organic				.56								
SiO_2 (insoluble)				4.87								
	100.89	100.02	97.13	100.92	101.01	101.41	101.42	99.58	99.61	99.75	99.80	100.00
Less O for F				.11	1.41	1.41	1.28		.37	.63	.35	
				100.81	99.60	100.00	100.14		99.24	99.12	99.45	

[a] FeO.

THE PROBABLE IDENTITY OF PODOLITE WITH DAHLLITE.

A comparison of the properties and chemical composition of podolite and dahllite shows them to be essentially identical. Dahllite was described in 1888 by Brögger and Bäckström,[1] and podolite by Tschirwinsky [2] in 1907, and the summary of the properties of the two minerals given below has been prepared from the printed descriptions.

Properties of dahllite and podolite.

Dahllite.	**Podolite.**
Occurs in crusts with fibrous structure, on apatite.	Occurs in crystalline masses or in prismatic crystals on phosphorite, also in spherulites of prismatic crystals.
Density is 3.053.	Density is 3.077.
Color is pale yellowish white.	Color is yellowish.
Uniaxial, negative.	Apparently hexagonal, crystals show optical anomalies, negative.
Double refraction and index of refraction slightly greater than that of apatite.	Double refraction somewhat greater than that of apatite.
	Mean index of refraction 1.635.
Soluble in cold dilute acid with evolution of CO_2.	Soluble in HCl with evolution of CO_2.
Composition..... $H_2Ca_{14}P_8C_2O_{39}$ or $2Ca_3P_2O_8.CaCO_3.\frac{1}{2}H_2O$	Composition..... $Ca_{10}P_6CO_{27}$ or $3Ca_3P_2O_8.CaCO_3$

To better compare the two formulas, they are given below with Ca given in constant amount.

Dahllite..	$H_{10}Ca_{70}P_{40}C_{10}O_{195}$
Podolite...	$Ca_{70}P_{42}C_7O_{189}$

The analyses of the two minerals are shown in the following table for comparison:

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[1] Brögger, W. C., and Bäckström, H., Dahllite, a new mineral from Odegarden, Bamle, Norway. Abstracted in Zeitschr. Kryst. Min., vol. 17, 1890, p. 426; also in Dana's System of mineralogy, 6th ed: 1892, p. 866.

[2] Tschirwinsky, W., Podolite, a new mineral: Centralbl. Min., Geol. u. Pal., 1907, p. 279; abstracted in Zeitschr. Kryst. Min., vol. 46, 1909, p. 296.

Analyses of dahllite and podolite.

	Dahllite.	Podolite.	
		Crystals.	Crystalline aggregate.
CaO	53.00	51.15	51.31
P_2O_5	38.44	39.04	36.44
CO_2	6.29	3.90	4.18
H_2O	1.37	Not det.	Not det.
Fe_2O_3	[a] .79	3.04	1.73
Al_2O_3			.46
K_2O	.11		.45
Na_2O	.89		.66
F		.00	.26
Organic			.56
SiO_2			4.87
Total	100.89	97.13	100.92

[a] FeO.

The above figures show the undoubted identity of the three substances analyzed. The CO_2 values for podolite are slightly lower than that given for dahllite, but the differences are slight. Water was not determined, but it must unquestionably have been present, for such a secondary mineral as podolite would be very likely to contain some, and a small amount, at least, must have been absorbed by the ground sample. The poor summations and the varying values in general lead one to suspect that further analyses of purer material, carefully made, would lead to slightly different results.

THE COMPOSITION OF THE PHOSPHORITE MINERALS.

INTRODUCTION.

The previous paper on the mineralogy of the French phosphorite deposits contains several analyses of these minerals, which, with those already published, furnish sufficient criteria for a determination of their formulas. I have therefore calculated the ratios from the different analyses and by averaging them up, have deduced formulas for the minerals in question. Below the actual ratios obtained, I have given them with CaO taken as 100.

DAHLLITE.

From analyses 1 to 4, given on page 95, the following ratios are obtained:

Ratios from dahllite analyses.

	1	2	3	4
CaO	0.945	0.956	0.912	0.915
P_2O_5	.271	.270	.275	.256
CO_2	.143	.120	.090	.095
H_2O	.076	.117	(?)	(?)
CaO	100	100	100	100
P_2O_5	29	28	30	28
CO_2	15	13	10	10
H_2O	8	12	(?)	(?)

The average values of these yield the formula.

$$100(CaO).\,29(P_2O_5).\,12(CO_2).\,(10H_2O),$$

which is sufficiently close to the simple one

$$10CaO.\,3P_2O_5.\,CO_2.\,H_2O.$$

to suggest strongly that this is the correct formula for dahllite.

FRANCOLITE.

From analyses 5 to 7, given on page 95, the ratios shown below are deduced:

Ratios from francolite analyses.

	5	6	7
CaO	0.964	0.933	0.974
P_2O_5	.269	.282	.275
F	.176	.177	.161
CO_2	.051	.084	.072
H_2O	.088	.088	.078
CaO	100	100	100
P_2O_5	28	30	28
F	18	19	17
CO_2	5	9	8
H_2O	9	9	8

The average of these values gives—

$$100(CaO).\ 29(P_2O_5).\ 18(F).\ 7(CO_2).\ 9(H_2O)[\text{minus } 9O],$$

which reduces to the simpler formula

$$10(CaO).\ 3(P_2O_5)\ 2(F).\ (CO_2).\ (H_2O)\ [\text{minus } 1O],$$

which may be written

$$9CaO.\ 3P_2O_5.\ CO_2.\ H_2O.\ CaF_2.$$

The average ratio of P_2O_5 to CaO is 3 to 10.44, being for analysis No. 5, 3 to 10.75; for analysis No. 6, 3 to 9.93; and for analysis No. 7, 3 to 10.63. This value lies almost exactly halfway between the 3:10 ratio required by my formula above and the 3:11 required by Lacroix's formula for francolite.

COLLOPHANITE.

From the values given in analyses 8 and 9, on page 95, the following ratios are deduced:

Ratios from collophanite analyses.

	8	9
CaO	0.904	0.886
P_2O_5	.275	.263
F	....	.046
CO_2	.090	.085
H_2O	.279	.392
CaO	100	100
P_2O_5	30	30
F	....	5
CO_2	10	10
H_2O	31	44

The average formula developed is

$$10CaO.\ 3P_2O_5.CO_2.\ 3+\ H_2O(+F?).$$

SUMMARY.

The three formulas developed are repeated here in order to show their relation to one another. To the list are added those of apatite, both the fluoapatite and the hypothetical hydroxyapatite.

Dahllite	$9CaO.3P_2O_5.CaO.\ CO_2.H_2O.$
Francolite	$9CaO.3P_2O_5.CaF_2.CO_2.H_2O.$
Collophanite	$9CaO.3P_2O_5.CaO.\ CO_2.H_2O+nH_2O.$
Fluoapatite	$9CaO.3P_2O_5.CaF_2.$
Hydroxyapatite	$9CaO.3P_2O_5.CaO.\ H_2O.$

The derivation of dahllite from the dehydration of collophanite becomes very simple, proceeding according to the reaction,

$$\underset{\text{(Collophanite)}}{9CaO.3P_2O_5.CaO.CO_2.H_2O.nH_2O} = \underset{\text{(Dahllite)}}{9CaO.3P_2O_5.CaO.CO_2.H_2O} + nH_2O.$$

By the introduction of fluorine, the reaction would yield francolite instead of dahllite:

$$\underset{\text{(Collophanite)}}{9CaO.3P_2O_5.CaO.CO_2.H_2O.nH_2O} + 2HF = \underset{\text{(Francolite)}}{9CaO.3P_2O_5.CaF_2.CO_2.H_2O} + nH_2O.$$

NATRAMBLYGONITE FROM COLORADO.

OCCURRENCE.

The mineral described in this paper was collected by me in 1908 in a large pegmatite mass 4 miles northwest of Canon City, Colo. The presence of lithium minerals—lepidolite and pink tourmaline—had been noted in this pegmatite by Sterrett [1] and it was through his kindness and that of Mr. J. D. Endicott, of Canon City, that I was enabled to visit the locality and collect a suite of specimens from the pegmatite. As described by Sterrett, the tourmaline and associated minerals occur on a low, oval hill composed of pegmatite inclosed in contorted biotite and hornblende gneiss. Pink tourmaline and lepidolite are abundant, though no cavities or pockets affording gem tourmaline were seen, the mineral being found only in the solid pegmatite.

ASSOCIATION.

The minerals associated with natramblygonite are few in number and do not possess any unusual properties. Tourmaline is abundant in black, pink, or green crystals, though no faces except those in the prism zone were seen on any of the crystals collected. A dark-green, nearly black core with a pink shell seems to be a common color association for this locality. Small masses of minute bluish crystals, and some larger green ones embedded in muscovite, were also noted. Most of the tourmaline is opaque and partly altered. The micas, muscovite and lepidolite, are also abundant. Lepidolite occurs in scaly pink masses, also as larger plates and in indefinite crystalline aggregates of pink or purplish colors. Albite generally is tabular in platy masses or in groupings of small crystals. The quartz and potash feldspars are massive and the original piece of natramblygonite, now deposited in the United States National Museum, is also massive. The mineral has recently been found in well-developed crystals.

DESCRIPTION OF MINERAL.

The specimen of the mineral measures about 5 by 7 by 3 centimeters and consists of a mass of cleavable natramblygonite surrounded by feldspar and lepidolite. Small veins and isolated masses of lepidolite are scattered through the new mineral. Small amounts of pink tourmaline and of albite were also detected embedded therein.

Three directions of cleavage can be detected, one more prominent than the other two. A section of the mineral cut parallel to the most prominent cleavage showed the other two cleavages intersecting at

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[1] Sterrett, D. B., The production of precious stones in 1908: Mineral Resources United States for 1908, U. S. Geol. Survey, 1909, p. 44.

about 70°. In its general appearance the mineral resembles massive amblygonite very much. The hardness is 5.5, and determinations of the specific gravity varied from 3.01 to 3.06, with an average value of about 3.04. The luster is vitreous, inclining slightly to greasy. The color is grayish white to white. In the hand specimen it is translucent to opaque.

Examined in thin section under the microscope, inclusions of quartz, feldspar, and mica can be seen, and also an irregular distribution of a kaolin-like dust. Two directions of polysynthetic twinning lamellæ intersecting at about 86° are prominent, and lie at an angle against the cleavage cracks. The best cleavage is nearly normal to a bisectrix, and the section parallel to this cleavage shows a biaxial interference figure with a large angle. The optical sign of the mineral is negative. Its mean refractive index lies near 1.60.

Heated in a blowpipe flame the mineral easily fuses, without decrepitation but with slight intumescence to an opaque white enamel, The flame is yellow with no indication of the red characteristic of lithium. In this particular natramblygonite differs markedly from amblygonite, and can thereby be distinguished from the common mineral. It would be well to test amblygonite from different localities by this flame test. Heated in a closed tube, water is given off and the mineral then quietly fuses without decrepitation to a blebby enamel firmly fused to the glass tube.

CHEMICAL COMPOSITION.

Analysis of a selected sample of natramblygonite gave the values shown below. The sample was finely crushed and all visible impurities and doubtful pieces picked out by hand under a magnifying glass. All of the final sample sank in a Thoulet solution of density 3.01+ and floated in solution of density 3.06. Beryllium was tested for but could not be detected. The mineral is difficultly soluble in H_2SO_4, in which solution no calcium could be found.

Analysis and ratios of natramblygonite.

	Per cent.	Ratio.	
P_2O_5	44.35	0.312	1.00
Al_2O_3	33.59	.329	1.06
Li_2O	3.21	.107	.93
Na_2O	11.23	.181	
K_2O	.14	.001	
H_2O+	4.78	.266	.85 } 1.32
F	5.63	.296	.47
	102.93		
Less O for F	2.37		
	100.56		

The ratios yield the formula $P_2O_5.Al_2O_3.(Na,Li)_2O.(H_2O,F_2)$ which may be written more simply $AlNa(OH)PO_4$, with the Na partly replaced by Li and the (OH) by F. The ratios for water and fluorine are a little high, probably due to the difficulty of the fluorine determination. It is worthy of note, however, that the ratios for water and fluorine are all high in Penfield's analyses of amblygonite.[1] The relations of natramblygonite to amblygonite are clear, the first being essentially the sodium mineral and the second the lithium one:

Natramblygonite,	$Na[Al(OH,F)]PO_4$.
Amblygonite,	$Li[Al(OH,F)]PO_4$.

Nothing was seen which would indicate that the new mineral here described was originally the lithium compound and was afterward changed to the sodium one. The alteration of amblygonite, described by Carnot and Lacroix,[2] yielded the mineral morinite, which contains lime and soda, without any lithia, and much more water and fluorine than was present in the amblygonite.

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[1] Penfield, S.L., On the chemical composition of amblygonite: Am. Jour. Sci., 3d ser., vol. 18, 1879, pp. 295.

[2] Carnot, A., and Lacroix, A., The chemical composition of morinite: Bull. Soc. franç. minéralog., vol. 31, 1908, p. 149.

THE PROPERTIES OF MOSESITE.

GENERAL DESCRIPTION.

The name mosesite was proposed by Canfield, Hillebrand, and Schaller, for a mercury mineral, described by them,[1] from Texas, in honor of Prof. Alfred J. Moses, of Columbia University, New York, who first definitely described the interesting mercury minerals at Terlingua, Brewster County, Tex.

In the general description of the mineral Mr. Canfield states that the small yellow crystals, associated with montroydite, were perched on calcite crystals, on which they appeared to lie with but little or no bond. The slightest touch would loosen them, leaving no scar upon the calcite, but merely a clean spot. A careful search revealed 26 crystals, 22 of which are simple octahedrons and the others spinel twins. No other forms were observed, and none of the mineral was massive. A second specimen showed hundreds of crystals scattered over a surface of calcite measuring 4 by 6 centimeters, which rests upon the pinkish rock characteristic of the Terlingua specimens. Canfield gives the following description of these crystals:

> Nearly all of the crystals are spinel twins. They are frequently grouped together in confused masses; one polysynthetic twin—a 5-ling—was seen. Simple octahedrons are rare. None was modified by other forms. No other mercury mineral is present in the specimen unless some delicate, elongated, light-yellow particles should prove to be kleinite.
>
> There are no indications that the crystals are affected by the light. If light affects the color, it must act very slowly. The color of those crystals which are so situated as to have some protection from the light is exactly like that of the most exposed. No difference in color could be noted between the surface and the interior of the crystals. Most of the crystals are translucent. The largest crystal found is brilliant and transparent and measures 0.5 millimeters along its edge. Generally the faces of the crystals are bright and uneven. They are very brittle, with signs of cleavage.[2] The fracture is uneven. The hardness slightly exceeds that of calcite. The mineral crumbles to a powder under the pressure required for this test. No piece could be obtained that was large enough to determine the density. The luster is adamantine. The color is a rich lemon to a canary yellow. The streak and powder are a very pale yellow.

CHEMICAL PROPERTIES.

Mr. Canfield gives the following description of the chemical properties of the mineral:

> When heated gradually to a low temperature in a closed tube, the assay turns to a dark reddish brown, almost black. As the heat increases the color changes rapidly

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[1] Canfield, F. A., Hillebrand, W. F., and Schaller, W. T., Mosesite, a new mercury mineral from Terlingua, Tex.: Am. Jour. Sci., 4th ser., vol. 30, 1910, pp. 202-208.

[2] The cleavage is imperfect octahedral.—Schaller.

to white, but without changing the form of the original crystals. Fumes of calomel are given off and condense in the tube. Many globules of mercury collect in the tube beyond the coating of calomel. Continued heating soon causes the assay to volatilize and disappear. If a fresh fragment of the mineral is heated rapidly in the closed tube it decrepitates violently, almost explosively, then it fuses and volatilizes.

In cold hydrochloric acid the mineral is changed slowly to a white substance, which retains the original form. If the acid is hot, the change is more rapid but the product is the same.

Dr. W. F. Hillebrand examined the material chemically and found that—

So far as the very scanty material permitted of ascertaining, the composition of mosesite approaches that of kleinite; that is, it is a mercury-ammonium compound containing chlorine and the sulphate group besides a little water. Determinations made on 0.04 gram of material gave 5 per cent Cl and 3.5 per cent SO_4. The former amount is considerably lower and the latter somewhat higher than in kleinite, but the values are no more than approximations. There is, however, one marked chemical difference, which will be considered later.

Spectroscopic tests that were kindly made by Dr. P. G. Nutting, at the Bureau of Standards, showed prominent mercury and nitrogen spectra and also the red line of hydrogen, the last being ascribed by him to water vapor. A singular feature of the behavior in vacuo was the immediate appearance, when the current was turned on and before the application of heat, of a mercury spectrum.

The mineral was at the time not between the electrodes, but far to the rear of one of them, at the sealed end of the Plucker tube. Under these conditions the color of the mineral fragments underwent a pronounced and permanent change from bright yellow to a yellowish gray. With a minute crystal of kleinite there was a mere indication of the mercury lines before heating, and no color change was observed. As soon as the temperature of mosesite was raised to visible incipient decomposition, the spectra of both nitrogen and mercury became brilliant. As mentioned by Mr. Canfield, mosesite does not seem to undergo the color changes in sunlight and darkness that appear to be characteristic of the deeper-colored crystals of kleinite.

When heated in a narrow tube closed at one end, the color changes and the sublimates were much like those afforded by kleinite, and there was the same liberation of an active gas that set free iodine from potassium iodide. Ammonium bromide liberated ammonia as from kleinite.

The behavior toward hydrochloric acid, noticed by Mr. Canfield, affords a certain chemical means of distinguishing mosesite from kleinite where only these two are concerned. When covered with concentrated hydrochloric acid mosesite is entirely decomposed in a few hours, with separation of a coherent white material that shows the behavior of calomel. The solution contains the sulphate and ammonium groups, besides much mercuric mercury. Kleinite, on the other hand, shows no perceptible change for a long time, but in the course of 48 hours a minute crystal of it was almost entirely decomposed. There remained only a whitish residue that looked as if it might be the claylike matter that is such a persistent contaminant of the mineral. It was free from calomel.

It will be remembered that the chemical evidence points to kleinite being a mixture or solution of mercury-ammonium chloride with a mercuric sulphate and perhaps chloride. There would seem to be an association of similar general character in mosesite, but with a mercurous sulphate or chloride replacing in part or wholly the corresponding mercuric salts of kleinite.

CRYSTALLOGRAPHY.

In studying the crystallography and optical properties of mosesite, I found that the crystals are apparently octahedra of the isometric system. Twinning on the spinel law has been observed several times; when this occurs, the crystals of mosesite are very commonly flattened parallel to a pair of octahedral faces. Mr. Canfield has mentioned a 5-ling, a spinal twin repeated five times.

The faces of the crystals are never smooth. Though bright and often highly polished, they are uneven, and only a few of the faces give a single reflection. Most of the faces when measured on the goniometer give a number of signals, no particular one of which is brighter than the others. This condition has rendered accurate determination of the form of the crystals impossible. An additional feature that has rendered accurate measurements difficult is the tendency for a number of crystals to grow together, some in nearly parallel position and others at widely different angles. A mass of signals, therefore, resulted from examining such groups of mosesite on the goniometer, and on the minute crystals that were available it was not possible to know what signals to measure and what ones to exclude. Where only two or three faces were measured in a zone, it was well-nigh impossible to be sure of having the zone accurately centered. The measurements, the occurrence of (probable) spineltwins, and the optical relations about to be described make it fairly certain that the crystals of mosesite are in reality octahedra. No form other than the octahedron was observed.

On part of a spinel twin, the faces of which gave a mass of very poor reflections, there were measured:

$o \wedge o'$	=68°	70° 32′ calculated.
	=68° (cleavage face)	70° 32′ calculated.
	=68° 28′	70° 32′ calculated.
$o \wedge \underline{o}$	=41° 13′	38° 56′ calculated.

A second crystal, also a spinel twin, gave:

$o \wedge o'$	=108° 54′	109° 28′ calculated.
	=107° 53′	109° 28′ calculated.
	= 71° 38′	70° 32′ calculated.
	= 70° 47′	70° 32′ calculated.
	= 68° 51′	70° 32′ calculated.
	= 72° 28′	70° 32′ calculated.
$o \wedge \underline{o}$	= 37° 06′	38° 56′ calculated.
	= 38° 56′	38° 56′ calculated.

A third crystal was adjusted as closely as possible in polar position for two-circle measurement and on revolving the crystal, the four octahedral faces were seen to lie in the positions required for the form {111}.

From the above data, meager and poor as they are, the isometric character of the crystals is deduced, especially as this is supported by the investigation of the optical properties.

OPTICAL PROPERTIES.

Under the microscope mosesite is pale yellow, nonpleochroic, and seems to possess a moderate double refraction. When a fragment is crushed many of the resultant pieces have a triangular or rhombic shape, due to the octahedial cleavage. When a fragment of fluorite was crushed and examined under the microscope similar effects were seen, though the cleavage was much better developed.

The crystallographic measurements have shown that the crystals are in all probability isometric octahedra and should, therefore, be isotropic when examined under the microscope with crossed nicols. Such an examination, however, shows the mineral not to be isotropic, but doubly refracting. On heating the mineral to 186°, the crystals lose their double refraction and become isotropic. Mosesite is therefore dimorphic, the isometric optical condition that agrees with the geometrical form being stable only above 186°, the mineral changing to the dimorphous doubly refracting condition at temperatures below 186°.

As examined at ordinary temperatures, the sections show great similarity to kleinite. Much of the material does not extinguish at all; other parts extinguish four times during a complete revolution of the stage, and the interference colors are brilliant. On crushing a fragment between two glass slides and examining the very small particles, they are seen to be nearly colorless, and, unlike the larger pieces, isotropic. It seems that the local heat developed by the crushing is sufficient to heat these small particles to at least 186° and cause their reversion to the isotropic state.

Seven different fragments were heated on glass slides in an air oven to the temperatures given and with the results shown in the following table:

Effect of heating mosesite.

No. of slide.	Temperature.	Effect.	Probable temperature of change.
	° C.		
1	150	No change; mineral still doubly refracting.	
	200	Brown and isotropic.	150-200°.
2	160	Brown and doubly refracting.	
	167	Doubly refracting.	
	180	Doubly refracting.	
	189	Isotropic.	180-189°.
3	169	Doubly refracting, but section too opaque for further study.	Above 169°.
	190		

Effect of heating mosesite—Continued.

No. of slide.	Temperature.	Effect.	Probable temperature of change.
	° C.		
4	169	Doubly refracting.	
	184	Doubly refracting.	
	186	Nearly isotropic.	
	190	Isotropic.	186–190°.
5	184	Doubly refracting.	
	186	Nearly isotropic.	
	188	Nearly isotropic.	
	190	Isotropic, except for a few minute doubly refracting spots.	184–186°.
6	186	Doubly refracting.	
	192	Still doubly refracting in places, but partly isotropic. This particular piece may have been thicker than the others, and therefore did not revert so readily.	186–192°+.
7	186	Isotropic on thin edges, but doubly refracting in thicker center.	
	192	Isotropic.	186–192°.

From these data the temperature of reversion to the isotropic isometric state probably lies between 180° and 190° and is taken as 186°. If the "molecular inertia" of mosesite is considerable, as is the case with kleinite,[1] then this temperature, 186°, is probably a little high. On cooling, the isotropic mineral does not immediately again become doubly refracting. Examination after 24 hours shows the mineral to be still isotropic. The change back seems to be, like that of kleinite, a very slow one, but doubtless it is gradually taking place. A section of kleinite described by Hillebrand and Schaller[2] as almost entirely reverted after 30 months is now, after 4 years, completely changed back to its original doubly refracting condition.

The optical similarities shown by these two minerals, coupled with their evident chemical relationship, suggested trying the effect of heating kleinite to the reversion temperature of mosesite (186°). When this was done, kleinite[3] became optically isotropic, like mosesite. The results of the experiments are shown in the table below:

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[1] Hillebrand, W. F., and Schaller, W. T., The mercury minerals from Terlingua, Tex.: Bull. U. S. Geol. Survey No. 405, 1909, p. 26.

[2] Idem, p. 25.

[3] Fragments were used that were not parallel to the base, as these would become isotropic at 130°, kleinite being uniaxial, hexagonal.

Effect of heating kleinite.

No. of slide.	Temperature.	Effect.
	°C.	
1	177	Doubly refracting; no change.
	187	Doubly refracting; no change.
	194	Doubly refracting; no change. Probably too thick.
2	177	Doubly refracting; no change.
	194	Isotropic.
3	177	Doubly refracting; no change.
	194	Partly isotropic, the remainder doubly refracting as before. The isotropic part, while still transparent, had become brown, the doubly refracting part remaining pale yellow.

It would be premature to speculate on the significance of this observation on the optical behavior of kleinite.

THAUMASITE FROM BEAVER COUNTY, UTAH.

INTRODUCTION.

The interesting mineral thaumasite was first described in 1878 by Baron von Nordenskiöld [1] from material collected at the copper mines of Åreskuta, Jemtland, Sweden. Since that time it has been noted from other localities in Sweden, and in 1896 it was described by S. L. Penfield and J. H. Pratt from Berger's quarry, West Paterson, N. J.

Dr. Edgar T. Wherry, of Lehigh University, has been kind enough to call my attention to a second New Jersey locality for thaumasite. Dr. Wherry writes:

> During the past few years, however, it has been found in considerable amount at another place in the same region, but sufficiently distant to be worth distinguishing—Francisco Bros.' quarry at Great Notch, 3 miles southwest of Paterson. It has been taken so as a matter of course that it should be found there, that nobody appears to have taken the trouble to call particular attention to it, and I can only find two published references, both in out-of-the-way places:
>
> Papke, Hermann, A visit to the mineral localities at Paterson and Great Notch, N. J.: Mineral Collector (N. Y.), October 15, 1908, p. 118.
>
> Levison, W. G., On the origin and sequences of the minerals of the Newark (Triassic) igneous rocks of New Jersey: Bull. New York Mineralog. Club No. 2, Dec., 1909, p. 23.

During the summer of 1909, Mr. B. S. Butler, while engaged in a geologic survey of the Frisco district, Beaver County, Utah, found a mineral of unusual appearance which on examination in the office proved to be thaumasite. The mineral was found in the old Hickory mine of the Majestic Copper Co., located in the Rocky Range, Rocky district, Beaver County, Utah, about 4 miles northwest of the town of Milford, which is on the San Pedro, Los Angeles & Salt Lake Railroad.

GEOLOGIC OCCURRENCE.

Mr. Butler describes the geologic occurrence as follows: [2]

> The Rocky Range is composed at the southern end, where the mine is located, of a series of interbedded dolomitic limestones and quartzites of probable Carboniferous

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[1] Compt. Rend., vol. 87, 1878, p. 313.

[2] Butler, B. S., and Schaller, W. T., Thaumasite from Beaver County, Utah: Am. Jour. Sci., 4th ser., vol. 31, 1911, pp. 131-134.

age which have been intruded by monzonite. The intrusion of the monzonite has produced typical contact alteration of the limestone, resulting in the formation of magnetite, garnet, and pyroxene, with some pyrite and chalcopyrite. At the Old Hickory mine the limestone for several feet from the contact has been largely replaced by magnetite with a small percentage of the contact silicates and sulphides of iron and copper. As the distance from the contact increases the amount of magnetite decreases and the contact silicates become correspondingly more abundant, and these in turn give place to the carbonates composing the limestone. The zone of magnetite carrying copper values as chalcopyrite and secondary alterations of this mineral (covellite, chalcocite, and copper carbonate) has furnished the ore that has been shipped from the mine. In the general vicinity of the mine, and especially to the north and northwest, there are veins from a fraction of an inch to upward of a foot in width, composed of a dense white material with conchoidal fracture that on analysis proved to be composed largely of magnesium carbonate with some calcium carbonate. These magnesite veins, however, were not observed in the Old Hickory mine.

The Old Hickory mine has been developed to a depth of about 300 feet and four levels have been opened. A vertical shaft extends to the lowest level, while the second level, about 100 feet deep at the shaft, is connected with the surface by a tunnel. The first level is about 80 feet below the surface and about 20 feet above the tunnel level. On the first level the magnetite body has been opened for a distance along the strike of about 125 feet. To the east of this, a distance of from 10 to 25 feet from the magnetite body, a parallel drift has been run in the altered limestone. One hundred feet south of the shaft a crosscut from this drift extends to the east about 25 feet, where it encounters quartzite. Throughout this eastern drift and crosscut are a great number of veins of white material varying from the thickness of paper to upwards of two inches. To the north of the crosscut many of the veins are open, the crystals projecting into the openings, while others are composed of a dense white substance. The material from these veins proved on examination to be a mixture of quartz and carbonate, the latter probably largely calcite. In the east crosscut, just east of the drift and extending across the drift to a crosscut on the opposite side, is a zone of veins having a general northeast-southwest direction, though the individual veins vary in direction and are connected by crossveins, making a network. These are composed of thaumasite completely filling the fissures.

The fissuring occurred later than the contact metamorphism of the limestone, and the filling of the fissures with thaumasite of course occurred at a still later period. The thaumasite was not found associated with the quartz and carbonates in the same veins, and the relative age of the minerals was not determined. At the Paterson occurrence the thaumasite is in trap, associated with heulandite, apophyllite, laumantite, pectolite, chabazite, scolecite, and natrolite, the thaumasite crystallizing later than the zeolites. No zeolites were found associated with the thaumasite at the Old Hickory mine, though these were especially looked for. It seems probable, however, that the mineral was found under physical conditions similar to those favorable to the formation of zeolites.

PHYSICAL CHARACTER.

In the hand specimen the thaumasite from Beaver County is a nearly pure white mineral with a silky luster due to its fibrous character. It is readily recognized in the field as an unusual mineral by its luster and low specific gravity (1.84). Under the microscope it is seen to be composed of minute slender prisms, none of which showed any terminal faces. Microscopically it is most readily distinguished by its low index of refraction and rather high double refraction; $\omega = 1.507$, $\varepsilon = 1.468$ as determined by Lévy and Lacroix. The indices of refraction for the Beaver County occurrence were approximately determined by Butler by immersion in solutions of known index as $\omega = 1.500+$, $\varepsilon = 1.464+$. The mineral extinguishes parallel to the elongation of the prisms and is probably hexagonal, as it has been found to be in the previously described occurrences. Crystals suitable for measurement and careful determination of the refractive indices were not found.

CHEMICAL COMPOSITION.

A determination of the density of the thaumasite by means of the Joly balance gave the value 1.84. A second determination, using the Thoulet solution and small fragments of the mineral, gave the value 1.85. These figures are slightly lower than those found by Penfield (1.88) on the New Jersey thaumasite.

The analyses of the Utah thaumasite, with the ratios deduced therefrom, are shown below:

Analyses and ratios of thaumasite, Utah.

	Per cent.	Ratio.		
SiO_2	10.14	0.169	1.06	1
SO_3	12.60	.156	.98	1
CO_2	6.98	.159	1.00	1
CaO	26.81	.479	3.00	3
H_2O	42.97	2.387	14.95	15
$(Al, Fe)_2O_3$	.20	.002		
MgO	.23	.006		
Alk.,P_2O_5	Trace.			
	99.93			

The ratios agree very closely with the established formula $3CaO.SiO_2.SO_3.CO_2.15H_2O$, and the mineral is very pure, only a trace of some foreign matter—probably a silicate—being present.

A comparison of the analyses of the mineral from Utah, from New Jersey, and from Sweden (the average of the three original analyses given by Lindström) strikingly shows the uniform composition of this rare mineral.

Comparison of analyses of thaumasite.

	Jemtland, Sweden.	New Jersey.	Utah.	Theoretical composition.
SiO_2	9.70	9.26	10.14	9.64
SO_3	13.02	13.44	12.60	12.86
CO_2	6.86	6.82	6.98	7.08
CaO	27.28	27.13	26.81	27.01
H_2O	42.20	42.77	42.97	43.41
$(Al,Fe)_2O_3$	.16		.20	
MgO			.23	
Na_2O	.11	.39	Trace.	
K_2O	.08	.18		
P_2O_5			Trace.	
Cl	.12			
	99.53	99.99	99.93	100.00

The new locality in Utah makes the third general locality in which this mineral has been found, or the fifth distinct mine, the three localities in Sweden being fairly close together.

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THE IDENTITY OF STELZNERITE WITH ANTLERITE.

Stelznerite was described as a basic copper sulphate by Arzruni and Thaddéeff[1] in 1899, their paper being edited by A. Dannenberg on account of the death of Arzruni. Prof. F. W. Clarke has recently called my attention to the chemical identity of stelznerite with a mineral analyzed by Dr. W. F. Hillebrand and named antlerite.[2] I have extended the investigation by examining optically some of the original type material in the U. S. National Museum, for which privilege I wish to acknowledge the kindness of the assistant curator, Dr. J. E. Pogue. All the facts ascertained point to the identity of stelznerite with antlerite.

Antlerite, under the microscope, was seen to consist of a homogeneous aggregate of very minute crystals of short prismatic habit and of pale greenish color. The crystals extinguished parallel but were too small for any determination of their optical orientation. The small crystals were not perceptibly pleochroic, but on the thicker ones a decided pleochroism was noticed, identical with that described for stelznerite.

Parallel to the elongation of the crystals, the color was blue green; normal thereto the color was yellow green. The double refraction is high. These data are all in accord with those given for stelznerite. The values of the density, 3.93 (antlerite) and 3.884 (stelznerite, not corrected for admixed gypsum) agree closely.

Chemically the two minerals are also seen to be identical, as was first noted by Prof. Clarke. The formula deduced for stelznerite is $3CuO.SO_3.2H_2O$, or $CuSO_4.2Cu(OH)_2$, while Hillebrand calculated the more complex one, $10CuO.3SO_3.7H_2O$, or $3CuSO_4 + 7Cu(OH)_2$, for antlerite. The analyses of antlerite are compared with those of stelznerite in the table below. Nos. 1 and 2 are Hillebrand's analysis of antlerite, with 8 and 6 per cent, respectively, of gangue deducted, and Nos. 3 and 4 are the analyses of stelznerite. The fifth column gives the calculated composition for the formula $3CuO.1SO_3.2H_2O$ and the sixth that for the more complicated formula $10CuO.3SO_3.7H_2O$.

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[1] Arzruni, A., and Thaddéeff, K., Neue Minerale aus Chile; Stelznerit, ein neues basisches Kupfersulfat: Zeitschr. Kryst. Min., vol. 31, 1899, p. 229.

[2] Hillebrand, W. F., Mineralogical notes; 6. A basic cupric sulphate: Bull. U. S. Geol. Survey No. 55, 1889, pp. 48-54. Also given in Dana's System of mineralogy, 6th ed., 1892, p. 928.

Analyses and calculated compositions of antlerite and stelznerite.

	Antlerite.		Stelznerite		$3CuO.SO_3.2H_2O$.	$10CuO.3SO_3,7H_2O$.
	1	2	3	4	(Calculated.)	(Calculated.)
CuO	68.19	67.64	67.08	64.01	67.22	68.45
SO_3	20.46	21.49	22.40	22.19	22.61	20.69
H_2O	11.11	10.76	10.22	10.37	10.17	10.86
ZnO	.29	.04				
CaO	.05	.04	.06	.57		
Fe_2O_3			.34	1.14		
Residue			.44	1.42		
Moisture				.33		
	100.10	99.97	100.54	100.03	100.00	100.00

Though the first analysis of antlerite agrees better with the more complex formula, the second analysis agrees as well with the simpler stelznerite formula. As no certain differences could be found in the optical properties and as the analyses agree so closely with one another, the two minerals stelznerite and antlerite must be considered identical.

The characterization given stelznerite is much more complete than that of antlerite, and the formula deduced, $CuSO_4.2Cu(OH)_2$, is also simpler and is doubtless the correct one for the species. The name antlerite has, however, priority by 10 years, and is the one to be adopted.

On careful investigation antlerite will doubtless be found to be much more abundant than is now thought, and much of what is now called brochantite may be found, on analysis, to be the closely related antlerite. The artificial brochantite, described by Dana,[1] is more likely antlerite.

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[1] Dana, E. S., System of Mineralogy, 1892, p. 926.

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