

*On Strüverite and its relation to Ilmenorutile.*

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THE mineral strüverite occurs<sup>1</sup> as a rare accessory constituent of the pegmatite which is found in large detrital masses in the neighbourhood of Craveggia (Val Vigizzo, northern Piedmont), namely on the Piano dei Lavonchi and in other localities on the eastern slope of the mountain across which runs the road from Vasca to the Alp Marco. In this pegmatite Professor G. Spezia<sup>2</sup> in 1882 noted the occurrence of beryl, and two years later Professor G. Strüver<sup>3</sup> that of columbite, a mineral which had not hitherto been found in the Alps. Still later, notices of other rare minerals from the pegmatite were published by Professor A. Piccini<sup>4</sup> and Professor A. Cossa<sup>5</sup>. One of the minerals noted by Piccini is probably strüverite, but owing to paucity of material, he was unable to characterize it exactly.

The new mineral occurs in small crystalline masses embedded in the quartz and felspar of the pegmatite. It is present in very small amount, and it was with great difficulty that sufficient material could be isolated for the physical and chemical investigation, the results of which are given in the present paper.

<sup>1</sup> A detailed description of the occurrence and of the physical characters of strüverite has been published by one of us : Ferruccio Zambonini, 'Strüverite, un nuovo minerale.' *Rend. R. Accad. Sci. Napoli*, 1907, ser. 3, vol. xiii, pp. 35-41. The details of the chemical examination are given for the first time in the present paper.

<sup>2</sup> G. Spezia, *Atti R. Accad. Sci. Torino*, 1882, vol. xvii, p. 769.

<sup>3</sup> G. Strüver, *Rend. R. Accad. Lincei*, Roma, 1884, ser. 4, vol. i, p. 8.

<sup>4</sup> A. Piccini, *Rend. R. Accad. Lincei*, Roma, 1886, ser. 4, vol. ii; sem. 2, p. 46.

<sup>5</sup> A. Cossa, *Gazz. chim. ital.*, 1887, vol. xvii, p. 31.

*Crystallographic and physical characters of strüverite. (F. Z.)*

In colour the mineral is iron-black: its powder is grey-black. The lustre is brilliant on a freshly fractured surface. The hardness is 6. The specific gravity was determined on two different samples as 5.54 (F.Z.) and 5.59 (G.T.P.). The mineral is opaque even in the thinnest flakes: it is infusible before the blowpipe.

Well-developed crystals are rare and generally very small. The largest crystal found measures 8 mm. in its longest direction: it is bipyramidal in habit (fig. 1), and shows the forms  $a$  {100},  $m$  {110}, and  $s$  {111}. Of the much smaller crystals, some are like the large one, while others are of prismatic habit (fig. 2). Crystals of this second type are sometimes tabular parallel to  $a$  {100} (fig. 3). Of frequent occurrence are crystals elongated along the edge  $s : s = [(\bar{1}11) : (1\bar{1}\bar{1})]$ ; most of these appear to be twins on a face of the form {101}, like the well-known twins of ilmenorutile, tapiolite, and mossaite, and also of rutile from certain localities.

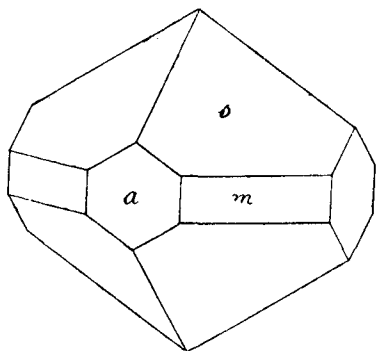


Fig. 1.

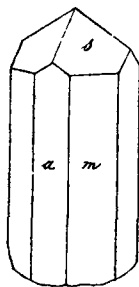


Fig. 2.

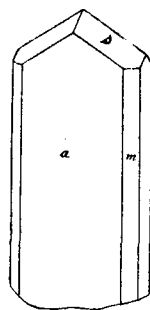


Fig. 3.

Crystals of strüverite.

The pyramid-angle  $(111) : (\bar{1}\bar{1}\bar{1})$  could be measured with great exactness: the values obtained on different crystals are:—

$$56^{\circ} 54', 56^{\circ} 55', 56^{\circ} 56', 56^{\circ} 57', 57^{\circ} 2'.$$

From the mean value,  $56^{\circ} 57'$ , was calculated the axial ratio—

$$a : c = 1 : 0.6456.$$

The following table gives the measured and the calculated angles:—

	Limits of measured angles.	Number of measurements.	Mean.	Calculated.
$ss' = (111):(1\bar{1}1)$	$56^{\circ} 54' - 57^{\circ} 2'$	5	$56^{\circ} 57'$	—
$as = (100):(111)$	$61 19 - 61 46$	7	$61 33$	$61^{\circ} 31\frac{1}{2}$
$ms = (110):(111)$	$47 31 - 47 41$	2	$47 36$	$47 36\frac{1}{4}$
$ss'' = (111):(\bar{1}\bar{1}1)$	—	1	$84 48$	$84 47\frac{1}{2}$
$aa' = (100):(010)$	$89 57 - 90 8$	2	$90 2\frac{1}{2}$	$90 0$
$am = (100):(110)$	$44 57 - 45 2$	6	$45 1$	$45 0$
$mm' = (110):(1\bar{1}0)$	$89 51 - 90 6$	3	$89 59$	$90 0$

The crystallographic constants of strüverite approximate very closely to those of rutile, tapiolite, mossaite, and ilmenorutile.

*Chemical composition of strüverite.* (G. T. P.)

A preliminary examination made by one of us (F. Z.) had shown the presence of niobic and tantallic acids, together with titanlic acid, oxide of iron, and traces of oxide of manganese: colorimetric determinations, moreover, had indicated that the titanlic acid was present to the amount of about 44 per cent.

For the two quantitative analyses only about a gram of material, apparently perfectly pure and homogeneous,<sup>1</sup> was available. The quantitative analysis of the mineral presented considerable difficulty; the following description of the methods employed is therefore given in some detail.

It is well known that the methods at present available for the separation of niobic, tantallic, and titanlic acids are very imperfect. C. H. Warren<sup>2</sup> has shown that the volumetric method by reduction with zinc is inaccurate, and that in the usually employed method of fusion with acid sulphate of potassium and leaching out with water, a certain amount of tantallic and niobic acids may pass into solution with the titanlic acid. In the course of the present investigation it has been found that the error due to the latter cause is much more considerable than has hitherto been conceived. In the presence of such large amounts of titanlic acid as occur in strüverite (40 per cent.), the greater part of the tantallic and niobic acids may in this way pass into solution. Further, if the melt with acid sulphate of potassium be treated, instead of with water, with a dilute (5 per cent.) solution of sulphuric acid

<sup>1</sup> On the homogeneity of the mineral see the previous paper by Zambonini, loc. cit., p. 44.

<sup>2</sup> C. H. Warren, Amer. Journ. Sci., 1906, vol. xxii, p. 520, or Chem. News, 1906, vol. xciv, p. 298.

(as is necessary when the titanitic acid is to be subsequently colorimetrically determined), practically the whole of the tantalic and niobic acids passes into solution with the titanitic acid.

In both analyses the mineral was fused with acid sulphate of potassium and the melt treated with water only slightly acidified with sulphuric acid. The insoluble residue of niobic and tantalic acids was collected and tested in the usual way with ammonium sulphide, &c., for tin and tungsten, and with hydrofluoric acid for silica. After the removal of the tantalic and niobic acids, the titanitic acid with iron, &c., in the filtrate was twice precipitated by ammonia. The complete solubility of this precipitate in hydrofluoric acid showed the absence of the yttria and ceria earths and thoria. In the first analysis, for the separation of the iron, the precipitate with ammonia was converted into sulphate and the solution was poured into a concentrated solution of ammonium carbonate containing ammonium sulphide. The separation was not quite perfect, for a little iron was later volumetrically determined in the precipitate containing the titanitic acid, and a little titanitic acid was also found in the sulphide of iron and colorimetrically determined.

In the second analysis the titanitic acid, &c., was separated from iron by precipitation with sodium thiosulphate. In this case also the separation was not quite complete and a little iron retained in the precipitate of titanitic acid was subsequently determined by precipitation with ammonia and ammonium sulphide in a solution containing tartaric acid. As it was feared that some niobic and tantalic acid had passed into solution with the titanitic acid after the fusion of the mineral with acid sulphate of potassium, the precipitate obtained with sodium thiosulphate was ignited and then re-fused with acid sulphate of potassium. On treating the melt with cold water, a further insoluble residue was obtained and was added to the niobic and tantalic acids separated after the first fusion of the mineral. The combined insoluble residues were brought into solution in hydrofluoric acid, and the tantalic and niobic acids were separated by Marignac's method. They were found to be present in approximately equal parts by weight. Finally they were converted into sulphates, and any titanitic acid which had been retained in the insoluble residues was determined colorimetrically.

The filtrate, containing the bulk of the titanitic acid and presumably free from niobic and tantalic acids, was made up to 500 c.c. with dilute (5 per cent.) sulphuric acid, and in portions of this solution the titanitic acid was colorimetrically determined. The results showed that titania was not the only oxide present in the solution. The other oxide,

amounting to about 28 per cent. of the mineral, was at first supposed to be zirconia, and this idea appeared to be confirmed by the fact that portions of the solution from which most of the sulphuric acid had been removed gave a good precipitate with hydrogen peroxide and an alkali phosphate.<sup>1</sup> Further investigation, however, showed that zirconium was absent, and that the supposed zirconia really consisted of niobic and tantalic acids which had passed into solution with the titanitic acid as indicated above (p. 80).

The absence of zirconium was proved by the failure to obtain the characteristic needles of the oxychloride<sup>2</sup> and by the fact that portions of the 500 c.c. solution, after removal of the excess of acid, were wholly precipitated by long-continued boiling. Moreover, it was found that slimy precipitates similar to those obtained in the case of strüverite also resulted by the addition of hydrogen peroxide and an alkali phosphate to sulphuric acid solutions of niobic and tantalic acids, and even to solutions of titanitic acid if they contained little free acid and were allowed to stand for some time. In the latter case similar precipitates were obtained by the use of an excess of acetate instead of a phosphate with the hydrogen peroxide. As these precipitates form, the deep colour at first produced by the hydrogen peroxide gradually fades, but is restored on the addition of excess of sulphuric acid. These precipitates with titanitic acid consist of the phosphate and acetate of the higher oxide of titanium, which, it was subsequently found, have been quite recently described by P. Faber.<sup>3</sup> The slimy precipitates obtained with solutions of niobium and titanium are very different in character from the gelatinous precipitate produced by the addition of hydrogen peroxide and an alkali phosphate to solutions of zirconia. In the case of zirconia it was incidentally found, in accordance with the experience of Hillebrand and others,<sup>4</sup> that no precipitate of the higher oxide could be obtained by the addition of pure, dilute hydrogen peroxide to acid and moderately dilute solutions of the sulphate. It was only by the use of the pure and

<sup>1</sup> The idea that zirconium was present as an essential constituent of the mineral was unfortunately communicated to Dr. Zambonini before the completion of the analyses, and was published by him in the paper to which reference has already been made (see footnote, p. 78). The chemical data there given therefore need correction.

<sup>2</sup> R. Ruer, *Zeits. anorg. Chem.*, 1905, vol. xlv, p. 456.

<sup>3</sup> P. Faber, 'Ueber das Wesen des sechswertigen Titans.' *Zeits. anal. Chem.*, 1907, vol. xlv, pp. 277-291.

<sup>4</sup> W. F. Hillebrand, 'The analysis of silicate and carbonate rocks.' *United States Geol. Survey*, 1907, Bull. no. 305, p. 119.

undiluted 'perhydrol' of Merck in large excess<sup>1</sup> to fairly concentrated solutions that a precipitate could be obtained. With commercial hydrogen peroxide, however, precipitates were obtained even in acid and dilute solutions, owing to the impurity of phosphate invariably present.

The investigation had so far proved the absence of zirconium, and suggested the presence of niobic and tantallic acids in the solution containing the bulk of the titanic acid. The presence of niobium was confirmed by fusing with potassium carbonate the precipitate obtained by means of hydrogen peroxide and a phosphate, and treating the water-extract with phosphoric acid and zinc dust, according to a method recently described by W. B. Giles.<sup>2</sup> A brown coloration showed the presence of niobic acid. Another portion of the 500 c.c. solution (see p. 81) was then tested for tantalum by precipitating with ammonia, dissolving the precipitate in hydrofluoric acid and treating the solution by the method of Marignac for the separation of tantalum and niobium. A good crop of fine needles of the double fluoride of tantalum and potassium was obtained. These needles and the filtrate from them were decomposed by sulphuric acid, and in each solution (freed from fluorine) the titanic acid was determined colorimetrically. The total weight of  $Ta_2O_5 + TiO_2$  obtained from the needles was 0.0483 gram, of which 0.0212 consisted of titanic acid; while the total weight of  $Nb_2O_5 + TiO_2$  from the filtrate amounted to 0.0801 gram, of which 0.0524 consisted of titanic acid. The tantallic and niobic acids were therefore present in about equal parts by weight.

The following experiments were then made in order to test the solubility of niobic and tantallic acids in presence of excess of titanic acid:—

- (1) A mixture of columbite (from Moss, Norway) and tantalite (from Greenbushes, Western Australia) was made in the following proportions:—

tantalite,	0.1591 gram.
columbite,	0.1653 „

This was fused with acid sulphate of potassium, and the melt was treated with a 5 per cent. solution of sulphuric acid. An insoluble residue of niobic and tantallic acid weighing 0.2553 gram, and thus equivalent to about 79 per cent. of the mixture, was obtained.

<sup>1</sup> When a few drops only of 'perhydrol' are added to a concentrated solution of zirconium sulphate, the precipitate first formed dissolves on shaking, and a permanent precipitate only results after the addition of a considerable excess of the hydrogen peroxide.

<sup>2</sup> W. B. Giles, Chem. News, 1907, vol. xciv, pp. 1 and 37.

- (2) A mixture of approximately the same weights of columbite and tantalite was taken, and to it was added an amount of rutile (from Passau, Bavaria) corresponding to about 40 per cent. (as in strüverite) of the total mixture, as follows:—

tantalite,	0.1733	gram.
columbite,	0.1487	„
rutile,	0.2034	„

On fusion with acid sulphate of potassium and treatment of the melt with a 5 per cent. solution of sulphuric acid as in (1), *practically the whole passed into solution.*

- (3) Another mixture was made of tantalite, columbite, and rutile in approximately the same proportions as in (2), thus:—

tantalite,	0.1626	gram.
columbite,	0.1506	„
rutile,	0.1905	„

In this case the melt from the fusion with acid sulphate of potassium was treated with cold water alone, without sulphuric acid. An insoluble residue weighing 0.2062 gram was obtained, and of this as much as 0.0563 gram was colorimetrically determined to consist of titanic acid. The residual 0.1499 gram of niobic and tantallic acids corresponded only to about 30 per cent. instead of the theoretical 50 per cent. of the mixture.

The results of the analyses of strüverite are as follows:—

	I.	II.	Mean.	Molecular ratios.
TiO <sub>2</sub>	... 41.09 ...	41.32 ...	41.20 <sup>1</sup> ...	0.515
Nb <sub>2</sub> O <sub>5</sub> } Ta <sub>2</sub> O <sub>5</sub> }	... 46.94 <sup>2</sup> ...	46.98 ...	{ 23.48 <sup>3</sup> ...	0.088 0.053
FeO	... 11.15 ...	11.62 ...	11.38 ...	0.158
MnO	... trace ...	— ...	trace	
CaO	... 0.51 ...	— ...	0.51	
MgO	... 0.17 ...	— ...	0.17	
			100.22	

Weight of material used in I, 0.4508; in II, 0.4843 gram. The simplest formula suggested by the numbers is FeO.(Ta,Nb)<sub>2</sub>O<sub>5</sub>.4TiO<sub>2</sub>, for which the theoretical composition is as follows:—

<sup>1</sup> A third determination of the titanic acid, made on 0.0747 gram of material, gave the number 40.72.

<sup>2</sup> Of this percentage of niobic and tantallic acids, 27.85 passed into solution with the titanic acid.

<sup>3</sup> The experiments described on pp. 81, 83 indicate that the tantallic and niobic acids are present in about equal parts by weight.

TiO <sub>2</sub>	...	...	44.03
Ta <sub>2</sub> O <sub>5</sub>	...	...	23.03
Nb <sub>2</sub> O <sub>5</sub>	...	...	23.03
FeO	...	...	9.91
			100.00

The molecular ratios, however, correspond more exactly to a formula  $3\text{Fe}(\text{Ta},\text{Nb})_2\text{O}_6 \cdot 10\text{TiO}_2$ , and the mineral is perhaps to be regarded (see later, p. 88) as a solid solution of the rutile molecule (TiO<sub>2</sub>) and the tapiolite or mossite molecule Fe(Ta,Nb)<sub>2</sub>O<sub>6</sub>. The specific gravity of such a mixture in proportions by weight of 2:3 (corresponding to the above analyses), if we take the specific gravity of rutile as 4.18 and that of mossite as 6.45, would be 5.54, which approximates closely to the specific gravity, 5.59, of the material analysed.

*Chemical composition of ilmenorutile.* (G. T. P.)

The mineral ilmenorutile, with which strüverite presents such a striking crystallographic similarity, was discovered by Koksharov in the Ilmen Mountains, Urals, in 1854, and has long been considered as a doubtful variety of rutile. Recently, however, it has been raised to the rank of a definite species by Brögger,<sup>1</sup> who has published the following analyses of Norwegian specimens, one of which agrees very closely with the analysis of the original mineral from the Ilmen Mountains, made by R. Hermann in 1866.

	Ilmen Mts. (Hermann.)	Evje, Norway. (Heidenreich.)	Tvedestrand, Norway. (Heidenreich.)
TiO <sub>2</sub>	... 66.90	... 73.78	... 67.68
SiO <sub>2</sub>	... 1.37	... 0.23	... 0.05
SnO <sub>2</sub>	... 0.89	—	—
Nb <sub>2</sub> O <sub>5</sub>	... 19.64	... 13.74	... 20.31
Ta <sub>2</sub> O <sub>5</sub>	... —	... 0.43	... —
FeO	... 10.18	... 11.58	... 11.68
MnO	... 0.77	... trace	... trace
MgO	... —	... 0.04	... trace
CaO	... —	... 0.22	... 0.28
	99.75	100.02	100.00
Sp. gr.	... 4.92	... 4.70-4.71	... 4.71

<sup>1</sup> W. C. Brögger, 'Die Mineralien der südnorwegischen Granit-Pegmatitgänge. I. Niobate, Tantalate, Titanate und Titanoniobate.' Videnskabs-Selskabets Skrifter, Math.-Naturv. Klasse, 1906, no. 6, p. 41.



According to these analyses, ilmenorutile presents no very close relationship with strüverite in quantitative chemical composition. The percentage of titanitic acid is considerably higher, while the niobic acid is present in much too small amount to unite (as in strüverite) with all the ferrous oxide to form the molecule  $\text{FeNb}_2\text{O}_6$ . It will be noticed, however, in the case of the two Norwegian specimens having the same specific gravities, that the analyses only differ in the relative amounts of the titanitic and niobic acids. The idea was therefore suggested that the separation of the two acids had been incomplete, and in view of the results of the preceding investigation it seemed probable that in all three analyses the titanitic acid had been determined gravimetrically, and that a large proportion of what was weighed as titanitic acid consisted really of niobic acid which had passed into solution after the fusion of the minerals with acid sulphate of potassium. To test this idea, colorimetric determinations were made on a specimen of ilmenorutile from the Ilmen Mountains in the Koksharov Collection in the British Museum, and also on a specimen of the mineral from Evje which was kindly supplied by Professor Brögger. The results were as follows:—

$\text{TiO}_2$	...	Ilmen Mts.	...	Evje.
		53.04		54.50

Taking these numbers for the titanitic acid and adding the differences from the old numbers to the niobic acid, we have the following corrected results:—

	Ilmen Mts.		Evje.		Tvedestrand.
$\text{TiO}_2$	... 53.04	...	54.50	...	54.50
$\text{SiO}_2$	... 1.37	...	0.23	...	0.05
$\text{SnO}_2$	... 0.89	...	—	...	—
$\text{Nb}_2\text{O}_5$	... 33.50	...	{ 33.02	...	33.49
$\text{Ta}_2\text{O}_5$			{ 0.43	...	—
$\text{FeO}$	... 10.18	...	11.58	...	11.68
$\text{MnO}$	... 0.77	...	—	...	trace
$\text{MgO}$	... —	...	0.04	...	trace
$\text{CaO}$	... —	...	0.22	...	0.28
	—		—	...	
	99.75		100.02	...	100.00

As further confirmation of these results, complete quantitative analyses were made of the specimen from the Ilmen Mountains; and of one from Iveland, Norway, for which I am also indebted to the kindness of Professor Brögger. The results are as follows:—

	Ilmen Mts.		Molecular ratios.		Iveland.		Molecular ratios.	
TiO <sub>2</sub> ...	53.04	...	0.663	...	54.57	...	0.682	
Nb <sub>2</sub> O <sub>5</sub> ...	21.73	...	0.081	...	32.15 <sup>1</sup>	...	0.120	
Ta <sub>2</sub> O <sub>5</sub> ...	14.70	...	0.033	...	—	...	—	
FeO ...	10.56	...	0.147	...	12.29	...	0.170	
CaO ...	trace	...	—	...	0.11	...		
MgO ...	—	...	—	...	trace	...		
	<hr/>				<hr/>			
	100.03				99.12			
Sp. gr. ...	5.14 <sup>2</sup>	...		...	4.64 <sup>3</sup>			

Weight of material used in the analysis of the mineral from the Ilmen Mountains, 0.5413 gram; in that of the mineral from Iveland, 1.1073 gram.

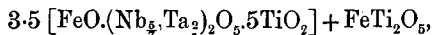
The analysis of the mineral from Iveland was conducted by methods similar to those used in the case of strüverite. Preliminary analyses of the Russian mineral were also made in the same way. In one of these the amount of tantalic and niobic acids in the insoluble residue left on treating with water the melt from the fusion with acid potassium sulphate was only about 14 per cent., and in another only about 12 per cent. In the final analysis of the Russian mineral, the result of which is given above, no attempt was made to separate the niobic and tantalic acids from the titanic acid. They were all precipitated together, and the tantalum (mixed with titanium) was separated from niobium (mixed with titanium) by Marignac's method, as described in the case of strüverite on p. 83. After the colorimetric determination of the titanium in the two sulphuric acid solutions, the total weight of niobic and titanic acid in the one, and of tantalic and titanic acid in the other, was determined by driving off most of the sulphuric acid, diluting, and precipitating by long-continued boiling.

<sup>1</sup> Of this percentage of niobic acid as much as 25.22 passed into solution with the titanic acid. The loss in the analysis is probably partly due to loss of niobic acid in washing the ammonia precipitate, and partly to loss on evaporation with hydrofluoric acid in testing for tantalic acid by Marignac's method: no needles of the tantalum salt were obtained.

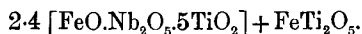
<sup>2</sup> Determined on 0.5310 gram of material. The specific gravity of a mixture (corresponding to the above analysis) of 55 parts of rutile (sp. gr. = 4.2), 19 parts of tantalite (sp. gr. = 7.3), and 23 parts of columbite (sp. gr. = 5.3) would be 5.10.

<sup>3</sup> Determined on 1.3497 gram of material. The specific gravity of a mixture (corresponding to the above analysis) of 55 parts of rutile (sp. gr. = 4.2) and 45 parts of columbite (sp. gr. = 5.3) would be 4.69.

The simplest formula suggested by the above analyses of ilmenorutile is  $\text{FeO.Nb}_2\text{O}_5.5\text{TiO}_2$ , the calculated percentages for which are given below under I. Closer agreement between the amounts found and calculated are obtained when we assume an admixture of the molecule  $\text{FeTiO}_3$  (as suggested by Brögger) or of  $\text{FeTi}_2\text{O}_5$ , molecules such as may be present in the ferriferous rutiles.<sup>1</sup> On this assumption, the formula of the ilmenorutile from the Ilmen Mountains would be



and of that from Iveland



The calculated percentages corresponding to these formulae are given under II and III respectively.

		I.		II.		III.
$\text{TiO}_2$	...	54.06	...	52.00	...	55.60
$\text{Nb}_2\text{O}_5$	...	36.21	...	22.33	...	32.15
$\text{Ta}_2\text{O}_5$	...	—	...	14.87	...	—
$\text{FeO}$	...	9.73	...	10.80	...	12.25
		100.00		100.00		100.00

#### *Relation of strüverite to ilmenorutile.*

The preceding analyses show the close chemical relationship of strüverite and ilmenorutile. The simplest formula deducible from the analyses is for strüverite  $\text{FeO}(\text{Ta},\text{Nb})_2\text{O}_5.4\text{TiO}_2$  and for ilmenorutile  $\text{FeO}(\text{Nb},\text{Ta})_2\text{O}_5.5\text{TiO}_2$ . The experiments described on p. 83 suggest that niobium, tantalum, and titanium readily form complex combinations<sup>2</sup> which render the analytical separation of these three elements so difficult. Strüverite and ilmenorutile might naturally therefore be regarded as salts of complex titan-niobic and titan-tantallic acids, represented by the above formulae, and related to each other as polycrase to euxenite or blomstrandine to priorite.<sup>3</sup> This view of the

<sup>1</sup> The experience of the solubility of niobic and tantallic acids in presence of excess of titanic acid, which was gained in the analyses of strüverite, naturally suggested the idea that possibly the iron in ferriferous rutiles might be combined with niobic and tantallic acids, and that these acids might have been previously overlooked. A colorimetric determination, however, of the titanic acid in a specimen of nigrine from Transylvania gave the number 96 per cent., and thus lent no support to this view.

<sup>2</sup> This view has already been expressed by W. Prandtl, *Zeits. Kryst. Min.*, 1905, vol. xl, p. 395.

<sup>3</sup> W. C. Brögger, 1906, loc. cit.

chemical composition of the minerals would be in accordance with the very close agreement in percentage composition of the Norwegian specimens from three distinct localities and of the mineral from the Ilmen Mountains, but it fails to explain satisfactorily the very close crystallographic similarity of the minerals with tapiolite, mossite, and rutile.

On the whole, therefore, until analyses by improved methods have been made of materials from other localities, it seems best for the present to regard all three minerals, from Italy, Russia, and Norway, as essentially solid solutions of the tapiolite or mossite molecule  $\text{Fe}[(\text{Ta}, \text{Nb})\text{O}_3]_2$  with the rutile molecule  $\text{TiO} \cdot \text{TiO}_3$ . In support of this view may be mentioned the fact that some of the small crystals of ilmenorutile from the Ilmen Mountains, when viewed in bright sunlight, show on certain faces minute patches of transparent red rutile in absolute crystallographic continuity with the prevailing black and opaque mineral.

According to this view of the chemical composition, we propose to reserve the name strüverite for those members of the series which are rich in tantalic acid, and to keep the name ilmenorutile for those, like the Norwegian specimens, in which niobic is the prevailing acid. Strüverite and ilmenorutile thus bear somewhat the same relation to each other as tapiolite (rich in tantalic acid) to mossite (rich in niobic acid). In accordance with its high percentage of tantalic acid, strüverite has a much higher specific gravity (5.59) than the Norwegian ilmenorutile (4.69). It has also a slightly higher axial ratio (1 : 0.6456) as compared with the axial ratio of the mineral from the Ilmen Mountains (1 : 0.6436), just as tapiolite has a higher axial ratio (1 : 0.6525) than mossite (1 : 0.6438).

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