ART. XXIV.—*On the Occurrence of Thaumasite at West Paterson, New Jersey*; by S. L. PENFIELD and J. H. PRATT.

IN 1878 Baron von Nordenskiöld* described a mineral from the copper mines of Åreskuta, Jemtland, Sweden, which, according to the analyses of Lindström,† had the composition CaSiO_3 , CaCO_3 , CaSO_4 , $14\text{H}_2\text{O}$ and to which the name thaumasite was given, from *θαυμάζειν*, to be surprised. The mineral was not found in distinct crystals but was crystalline and on a fracture showed a fine fibrous structure. Its homogeneous character and its right to be considered a distinct mineral species rested upon the following: The material seemed to be homogeneous when examined with the microscope, and the three analyses of Lindström, made upon material collected in the early part of this century by Polheimer, in 1859 by Nordenskiöld, and in 1878 by Engberg, agreed not only very closely with one another but also with the theory demanded by the formula.

That a mineral with such a remarkable composition was capable of existence was not accepted by all mineralogists, and Bertrand,‡ on examining thin sections of it with the microscope was led to believe that it was a mixture, composed of a uniaxial mineral with negative double refraction supposed to be calcite, of a biaxial mineral gypsum, and of a third mineral, the optical properties of which could not be made out, probably calcium silicate or wollastonite.

The idea of Bertrand's that thaumasite was a mixture was not accepted by Nordenskiöld, and the latter to sustain his position presented the following arguments,§ which were very convincing: First, if it were possibly a mixture it certainly would be very remarkable that three independent samples, collected at such widely separated periods, should agree so closely in percentage composition. Second, there is no known hydrated calcium silicate which, when mixed with calcite and gypsum, could yield a product containing over 42 per cent of water. Third, it would not be possible for a mixture of calcite, gypsum and wollastonite, with specific gravities of 2.72, 2.31 and 2.90 respectively, to yield a product with such a low specific gravity as thaumasite, 1.877.

Specimens were moreover sent to Lacroix for renewed

* Comptes Rendus. vol. lxxxvii, p. 313, 1878.

† Öfv. Ak. Stockholm, vol. xxxv, No. 9, p. 43, 1878.

‡ Bull. Soc. Min. de France, vol. iii, p. 159, 1880, and vol. iv, p. 8, 1881.

§ Geol. För. Förhandl., Stockholm, vol. v, p. 270, 1880.

optical examination, and in a letter to Nordenskiöld he states* that the material was found to be practically homogeneous, uniaxial and with negative double refraction, but whether hexagonal or tetragonal could not be determined. The uniaxial material which Bertrand had taken for calcite was in reality thaumasite, and Bertrand in a letter to Nordenskiöld† withdrew his objection. He gives also the approximate indices of refraction $\omega=1.503$, $\epsilon=1.467$, which differ from those of calcite.

In 1890 Widman‡ described specimens of thaumasite belonging to the mineral collection of the University of Upsala, which are reported to have been found at Kjölland, about thirteen miles from the original locality Åreskuta, and two analyses by Hedström quoted by him agree very closely with the ones made by Lindström. From Hedström's analyses the formula CaSiO_3 , CaCO_3 , CaSO_4 , $15\text{H}_2\text{O}$ was derived, and as pointed out by Widman this slight change in the formula agrees satisfactorily with the analytical results of Lindström, who really had found over fourteen and one-half molecules of water.

It is with pleasure that the authors are able to announce the discovery of this unusually interesting mineral at Burger's quarry, West Paterson, New Jersey, the material having been first brought to our notice by Mr. Geo. L. English, of New York, who sent a specimen of it to the mineralogical laboratory of the Sheffield Scientific School for identification. The mineral occurs as an aggregate of prismatic crystals, sometimes so loosely held together that the individuals can be separated by crushing between the fingers, while more often the masses are firm and have somewhat the appearance of white alabaster. Occasionally distinct prismatic crystals were observed, averaging 0.5^{mm} in diameter and 2 to 4^{mm} in length, but they were poorly formed and without distinct terminations. Some of the masses showing fine prismatic crystals have a decidedly silky luster. There is a distinct prismatic cleavage. Measurements were only possible in the prismatic zone and approximated to 60° , which determine the crystallization as hexagonal. On examining fragments imbedded in Canada balsam ones can readily be found which show a uniaxial interference figure with negative double refraction. Using a polished plate, the index of refraction for the ordinary ray was determined by means of total reflection in α -mono-bromnaphthalene and found to be 1.5125 for yellow Na. By means of a prism of $32^\circ 58'$ the following values were also obtained for yellow, $\omega=1.519$

* Geol. För. Förhandl., Stockholm, vol. ix, p. 35, 1887.

† Ibid., vol. ix, p. 131, 1887.

‡ Ibid., vol. xii, p. 20, 1890.

and $\epsilon=1.476$. It must be stated, however, that a prism cut from a crystalline aggregate cannot yield wholly satisfactory results, as the light does not traverse a single individual, and that for example which yielded the extraordinary value above was vibrating in crystals whose vertical axes were approximately and not perfectly parallel to the edge of the prism. Levy and Lacroix* give $\omega=1.507$ and $\epsilon=1.468$.

In order to be absolutely sure of the uniform character of the material for analysis, selected pieces of the mineral were crushed and sifted to a uniform grain and separated by means of methyl iodide CH_3I , which was diluted with ether. That every particle of the mineral in the separator floated at a specific gravity of 1.887 and sank at 1.875, a difference of only 0.012, is sufficient proof of the homogeneous character and great purity of the material. Lindström gives as the specific gravity of the Swedish mineral 1.877 and Widman gives 1.83.

The results of the analysis are as follows:

	I.	II.	III.	Average.	Ratio.	
SiO_2	9.23	9.33	9.23	9.26	.155	.97
CO_2	6.87	6.77		6.82	.155	.97
SO_3	13.56	13.32		13.44	.168	1.05
CaO		27.08	27.19	27.13	.484	3.04
H_2O	42.81	42.72		42.77	2.377	15.00
Na_2O	.39			.39		
K_2O	.18			.18		
				99.99		

The ratio of $\text{SiO}_2:\text{CO}_2:\text{SO}_3:\text{CaO}:\text{H}_2\text{O}$ is very nearly 1:1:1:3:15, demanded by the formula CaSiO_3 , CaCO_3 , CaSO_4 , $15\text{H}_2\text{O}$. The analytical results are, moreover, very close to those obtained upon the Swedish mineral by Lindström and Hedström. A slight amount of alkali sulphate is probably present as impurity, therefore the alkalies have been neglected in making the above calculation. That Na_2O and K_2O are not isomorphous with CaO is shown by the following experiment: 1.1765 gram of the powdered mineral were treated in a platinum dish for over two days with cold water, the insoluble mineral was then filtered off and the soluble portion analyzed, with the following results: SiO_2 , 0.39 per cent; SO_3 , 0.56; CaO , 0.56; $\text{Na}_2\text{O}+\text{K}_2\text{O}$, 0.25. These indicate that thaumasite is slightly soluble and that the alkalies have an independent existence, for a quantity of $\text{Na}_2\text{O}+\text{K}_2\text{O}$ equal to about one-half of that found in the original analysis was

* Les Minéraux des Roches, p. 286, 1888.

extracted, while relatively only a very small proportion of the calcium was dissolved, a result which would not have taken place if the alkalies had belonged with the thaumasite. A small quantity of alkali sulphate may, therefore, be regarded as impurity, and deducting from the analysis the alkalies and sufficient SO_3 (0.64 per cent) to convert them into sulphates, and recalculating to one hundred per cent, the following results are obtained, which agree satisfactorily with the values required by theory:

	By recalculation.	Theory.
SiO_2	9.38	9.64
CO_2	6.90	7.08
SO_3	12.95	12.86
CaO	27.47	27.01
H_2O	43.30	43.41
	<hr/> 100.00	<hr/> 100.00

Hoping to obtain data concerning the constitution of the mineral, experiments were made to determine the temperature at which the water was driven off. As determined by Lindström, the mineral slowly loses water at 100°C ., and in our experiment, after heating for over ninety hours, a loss of 29.35 per cent was obtained, but the weight had not become constant. At 150° the weight soon became constant and then at 200° , 250° and 300° respectively constant weights were obtained, and in each case the heating was continued until the loss of weight during several hours did not amount to more than a few tenths of a milligram. Between 300° and 360° no loss of weight was obtained, but the material still contained water which, as seen by a closed tube experiment, was expelled at much below a red heat.

The results obtained from .6663 grams of the air-dry mineral are as follows:

	Loss.	Proportional parts using $\frac{1}{18}$ of total H_2O as unity.
Two days in dessicator.....	Nothing	
Nine hours at 150°	37.41	13.13
Seven hours at 200°	1.82	0.64
Eight hours at 250°	1.41	0.50
Five hours at 300°	1.05	0.37
Below redness	1.08	0.38
Total	<hr/> 42.77	

It is evident from the above that 13 molecules are to be regarded as water of crystallization and two molecules, suffi-

cient to form four hydroxyls, as constitutional. The last two molecules are, moreover, expelled at four separate temperatures, indicating the existence of four hydroxyls which play different parts or have different positions in the molecular structure. It is evident also that the CaSiO_3 , CaCO_3 , and CaSO_4 , together with the water, are united in some way into a complex molecule, and probably as suggested by Groth* in some way analogous to the combination of silicate and sulphate in the hyne-nosean group of minerals or of silicate and carbonate in cancrinite. Regarding silica as the linking non-metallic element, the following constitution may be suggested as a probable one:

The above may also be expressed as $[(\text{CaOH})\text{CO}_2] [(\text{CaOH})\text{SO}_4] [\text{CaOH}] \text{HSiO}_3, 13 \text{ H}_2\text{O}$. The formula agrees in a very satisfactory manner with the results obtained in driving out the water, for it demands four independent and different hydroxyl molecules.

Formul may be written with four hydroxyls and with either carbon or sulphur as the linking element, but they do not seem to the authors so probable as the one given above.

The occurrence of thaumasite at Paterson is in the trap which has been quarried for road material. It is associated with heulandite, apophyllite, laumontite, pectolite, chabazite, scolecite and natrolite, all of which are found at the locality in beautiful crystals. Widman mentions the occurrence of apophyllite with the thaumasite at Kjlland. The thaumasite has crystallized later than the zeolites and occurs upon or surrounding them. A considerable quantity of it was found.

In closing the authors express their thanks to Messrs. Geo. L. English & Co. of New York for generously furnishing them with material for the investigation.

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Sheffield Scientific School, February, 1896.

* Tabellarische Uebersicht der Mineralien, p. 149, 1889.