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Mathematisk-fysiske Meddelelser. **IV**, 8.

RE-EXAMINATION OF SOME ZEOLITES

(OKENITE, PTILOLITE, ETC.)

BY

O. B. BØGGILD



KØBENHAVN

HOVEDKOMMISSIONÆR: ANDR. FRED. HØST & SØN, KGL. HOF-BOGHANDEL
BIANCO LUNOS BOGTRYKKERI

1922

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By a revision of the numerous specimens of the needle-shaped or radiated zeolites of the Mineralogical Museum of Copenhagen I found that those minerals were in many cases falsely determined, and by undertaking a thorough examination of them I found out some facts which, as I think, are rather interesting and ought to be generally known.

The okenite is in its common forms a rather uniform and well known mineral. It is very obvious, however, that most of its physical properties have been very imperfectly examined and that consequently, in many cases where its outer appearance is not so easily recognised and where it has not been chemically analysed it has been incorrectly determined.

The ptilolite has also hitherto been very imperfectly examined so that it has been quite impossible to determine that mineral without chemical analysis. The newly described mineral flokite from Teigarhorn, Iceland, has proved to be identical with the ptilolite, which has been found from many different localities and with a very varying outer appearance.

The three common minerals, scolecite, mesolite and natrolite, are so well described and generally known that there is in general nothing to be added in this respect. There is only one phenomenon which I have found occa-

sion to point out, viz. the regular intergrowth and commixture of those minerals, in some instances together with thomsonite; this phenomenon, which is of a very common occurrence and very characteristic, has almost never been described and consequently deserves a closer description.

I. Okenite.

Occurrence. The okenite has been found almost only in the North-Atlantic basalt formation where in some places it seems to be very common. In other parts of the world there are only two occurrences known with certainty, namely Poonah at Bombay and Rio Putagan in Chile. Other occurrences named in the literature are, in my opinion, very uncertain, as will be mentioned later on. It is very probable, however, that the mineral, when searched for, will prove to be rather common in other basaltic regions too.

With the exception of Rio Putagan, where the okenite is found as a thin coating upon lava, the mineral is only known as a filling out of cavities in basalt. As it is mostly very compact and solid it has in most cases been taken up as loose pieces on the shore, and it is characteristic that, among the numerous specimens in the Museum of Copenhagen, there does not exist any where the surrounding rock is left; small traces of basalt are, however, eventually found as intrusions in the okenite.

Concerning the association of minerals, together with which the okenite is found, very little is stated, and only CURRIE¹ gives some instances which shall be mentioned

¹ The Mineralogy of the Faerøes arranged topographically. Trans. Edinb. Geol. Soc. IX, 1905—6.

in the following. As CURRIE does not mention how he has determined the mineral which may, in some cases, be difficult to recognise with certainty without optical examination, we cannot be sure that his determinations are all right, but in most cases I think they will be so.

In this connection it must be mentioned, too, that CORNU¹ mentions okenite (?) together with calcite and natrolite as occurring in cavities in the basalt at Krebsberg in Bohemia. In another place² he mentions the okenite from two other Bohemian localities, Grosspriesen and Daubitz, and it is stated to occur as a characteristic "Begleitmineral" to the zeophyllite. As CORNU does not in any case state how he has determined the okenite, we cannot be quite sure that this mineral is really found in Bohemia (Compare p. 17).

In the following I shall give the associations known for the Färöes and Greenland: for the other localities, from which the mineral is described (Iceland, India and Chile) it is not possible to state anything in this respect for want of material.

In the Färöes the okenite seems to be a common mineral; concerning the occurrence on these islands CORNU and GÖRGEY³ give the very interesting information that the mineral is only found in the basalts above the coal formation and among them only in those of the porphyric type, but they do not mention any special locality. The mineral has been found in the following places:

1. Nolsö. From Tjörnunes CURRIE mentions that HEDDLE⁴ has described the mineral as forming a vein lined on

¹ Centr. f. Min. 1909. p. 157.

² Centr. f. Min. 1906. p. 80.

³ Zur Geologie der Färöer. Centralblatt für Min. 22, 1908, 675.

⁴ Trans. Geol. Soc. Glasgow, X, 1892, 249. In that place there is nothing about okenite.

each side by minute crystals of heulandite. CURRIE states that on HEDDLE's ticket it is said to have been analysed, but that he has not succeeded in tracing this analysis.

2. Strömö. From Kvivig CURRIE mentions a specimen in the British Museum, which is the same as has been analysed by CONNELL¹; but, as CURRIE states, here must be some uncertainty, as the locality has been added on the ticket by a subsequent hand. From Tjörnevig according to CURRIE the mineral has been mentioned by HEDDLE². From Fjöruglivrar CURRIE mentions the mineral as uncertain (possibly tobermorite). From Strömnäs CURRIE mentions okenite upon heulandite, forming the base of the dome-cavity of a geode. At Kvalvig the mineral has been found by HEDDLE²; CURRIE mentions that heulandite is found in minute crystals under the okenite and assumes that it is that occurrence which has been analysed by SCHMID³ without giving further reasons for that assumption.

3. Vaagö. From that island, without further locality, there exists a very interesting specimen in the Museum of Copenhagen. Outermost there is a distinct layer of almost 1 cm, which in the outer part consists of small masses of mesolite but in the larger inner part of finegrained quartz penetrated by mesolite needles. Upon that layer is placed the okenite which is mostly of the common appearance but in the inner part leaves a large cavity, into which protrude innumerable free crystals, which have afforded an excellent material for crystallographical examination.

¹ Ed. Phil. Journ., 17, 1834, 198.

² Trans. Geol. Soc. Glasgow, XII, p. 249; on that place there is nothing about zeolites, but in the same volume, p. 1., there is the paper of HEDDLE about the Mineralogy of the Faröe Islands, where he mentions the okenite from another locality on Strömö, Kvalvig.

³ Pogg. Ann. 126, 1865, p. 143.

5. Österö. From Kambur CURRIE mentions okenite filling small druses, which are lined very thinly with another zeolite, perhaps heulandite. From Eldevig the Museum of Copenhagen possesses two specimens, collected by CORNU, which afford very interesting mineral associations. In the one specimen there is the following succession (Fig 1): outermost a thin layer of green earth (1): thereupon a thin layer (ca. $\frac{1}{2}$ mm) of some grained zeolite, probably heulandite (2). Upon that comes a regular layer (2 mm) of chalcedony (3), and thereupon follows the okenite (4), while the whole interior part of the geode is filled with grained apophyllite (5). On the one side of the geode, the original underside, there are placed several regular horizontal layers of different minerals between the chalcedony and the okenite. These are in the bottom a fine grained, milky apophyllite (6); thereupon a chalcedony, almost 1 mm thick (7), whereupon follows a very thin intrtransparent layer of a not determinable substance (8). Then follows a new layer of grained apophyllite, quite transparent (9) and lastly a layer of ptilolite (10); this is however very impure and throughout mixed with okenite and perhaps with other minerals too.

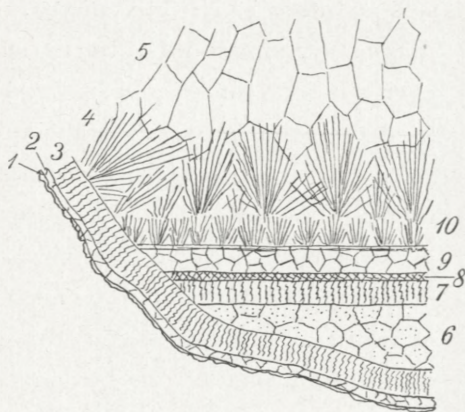


Fig. 1. Okenite from Eldevig.

The other specimen is not so complicated being mostly filled out with a very hard ptilolite penetrated by numerous small spherulites of chalcedony, while only a small space

in the interior is left for a rather disintegrated okenite or sometimes for grained apophyllite.

6. Bordö. From that island, without special locality, has originated the mineral »bordite«, analysed by ADAM¹, which is identical with okenite. Further, as stated by CURRIE, it is probable that the mineral analysed by CONNELL² has come from the same island. The Museum of Copenhagen possesses a specimen from Bordö, which has, in the outer part, a very thin layer of heulandite while the okenite itself is rather pure, only mixed, in some places, with small masses of apophyllite. In the inner part of the geode a cavity is left; the okenite is, however, not regularly crystallised there but possesses a curiously furrowed inner surface.

7. Viderö. From Tunna fjall CURRIE mentions okenite under (?) stilbite.

In Greenland the mineral is only known from the island of Disko, but it seems to exist there in very large quantities. Kutdlisat on the north-eastern side of that island is probably the original locality for the mineral, analysed by KOBELL³ and described by BREITHAAPT.⁴ On the south-eastern side of the island, close east of Godhavn, there are two localities, Blæsedal and Skarvefjeld, from which the Museum of Copenhagen possesses numerous specimens of a rather uniform appearance. The okenite is here alone in the geodes or associated with chabasite or apophyllite, and it may be formed before or after those minerals or, sometimes, contemporaneously with them. In the south-western part of the island there is the large fjord, Diskofjord, from where the museum possesses many spec-

¹ Dufrenoy, Min. 4, 1859, 697.

² Edinb. Phil. Journ. 17, 1834, 198.

³ Kastn. Archiv. 14, 1828, 333.

⁴ Pogg. Ann. 64, 1845, 170.

imens, mostly with the same associations as above and sometimes also with a thin coating of heulandite. As special localities in the same fjord, which are represented in the Museum of Copenhagen, may be mentioned Tarajungisok, where the okenite is seated upon crystals of desmine, Karusuit, where in one specimen it is surrounded by chabasite and in another case is associated with calcite, heulandite and apophyllite, and as the last locality Erkratok, where the first formed mineral is heulandite in small crystals, while in the interior part of the geode there is a cavity with small but well developed okenite crystals.

As the general result it will be seen, that the okenite can be associated with many different other zeolites together with chalcedony, quartz and calcite. It is, however, rather obvious, that two minerals are more common followers of the okenite than any others viz. the heulandite and the apophyllite, the first being in most cases the older and the second the younger. What is the cause of the common occurrence of these minerals with the okenite, cannot easily be seen; especially the heulandite is not chemically more related to the okenite than most of the other zeolites. The apophyllite has more affinity to the okenite, both minerals belonging to the class of zeolites without alumina, but it is on the other side difficult to understand, why the two minerals are in no case accompanied by other zeolites of the same class, especially the gyrolite, which mineral is rather common in the basalt of the same region.

Crystalline form. The crystals have been described by BREITHAUP¹ who has examined freely developed, needle-shaped crystals from the Museum in Vienna. He states that the crystals, which could be determined with great

¹ Pogg. Ann. 64, 1845, 170.

exactness on the goniometer, were rhombic, pseudohexagonal with the combination (001), (110), (010) and sometimes (120); the prismatic angle (110):(110) was found to be $57^{\circ} 41'$. With exception of this last value, which appears approximatively in my crystals, but not as a prismatic angle, I have found the crystals as different from those of BREITHAAPT as possible. It is difficult to imagine that the last named crystals really belong to okenite, but on the other side I cannot find out any mineral which has a form similar to that described by BREITHAAPT and which can, with any probability, occur together with okenite. Among the zeolites known there is none of that form and among the other minerals which occur under the same circumstances the same is the case. The aragonite has, to be sure, a similar prismatic angle, but most of the not composite-twinned crystals are not in possession of basis. In order to solve the problem I wrote to Professor F. BECHE Vienna and asked him to send me some of the crystals of okenite examined by BREITHAAPT, but he kindly informed me that Dr. A. MICHEL had searched for those crystals in the collection in Vienna without being able to find them. Dr. MICHEL suggests that: "Wahrscheinlich ist es später als etwas anderes erkannt worden, denn unter Okenit und verwandten Mineralien findet sich keine Stufe, die auf die Beschreibung Breithaupts passen würde".

The crystals which have been examined by me originate from two localities, mentioned in the foregoing chapter, viz. Vaagö (p. 6), and Erkrotok on Disko, Greenland (p. 9). That they really belong to the okenite can be demonstrated by their optical properties, which in all respects are in accordance with those of the commonly known fibrous aggregates of the mineral, upon which they are placed as con-

tinuations of the fibres. The crystals are in most cases seemingly well developed, pure and transparent, and the only hindrance to their exact determination is their small size. They have the form of flat, elongated tables, almost like a ruler; the length may be a few millimeters while the maximum breadth is 0.08—0.1 mm and in most cases much smaller, and the maximum thickness reaches a dimension of almost 0,008 mm. It is clear that the reflexions under these circumstances must be very poor: only the rather large faces of b (010) can give good signals while all the others only give very faint spots of light which cannot be exactly measured and which may, in consequence, deviate several degrees from each other. For the faces in the prism zone there is, in addition, the circumstance, that this zone is very highly striated, while the face c , though much smaller, gives much better values. That the system and the twin formations are correctly stated can, however, be considered as absolutely certain, as the results here are in full accordance with the optical properties. The measurements are made with the two-circled goniometer which is the only method of finding the reflexions of the very small faces.

The system is the triclinic with the axial angles:

$$\alpha = 122^{\circ}54', \quad \beta = 67^{\circ}46', \quad \gamma = 50^{\circ}10'.$$

$$(001):(010) = 115^{\circ}02', \quad (100):(001) = 87^{\circ}17',$$

$$(100):(010) = 56^{\circ}.$$

while the length of the axes could not be determined for want of other well developed faces. The crystals were placed on the goniometer with the zone $a:b$ as the equatorial one, and the values of φ are counted from the face of b . Then we get for the face a (100):

$$\varphi = 56^{\circ} (54-58^{\circ})$$

and for c (001):

$$\varphi = 141^\circ \text{ (136--146)}, \quad \rho = 33^\circ \text{ (31--34)}.$$

The angle of 56° between a and b has some resemblance to the prismatic angle of BREITHAUPT, but as the two faces are highly different in respect to size and lustre, it is impossible that they can be regarded as belonging to the same prism. It is only the crystals from Greenland which have the said angle of 56° , while those from the Färöes, instead of the face a , have another which is placed at a distance from b of ca. 76° ($68\text{--}82^\circ$): there must probably exist some prismatic face here, but its position is so indistinct that it is quite hopeless thereof to try to get the ratio between the axes a and b from it. Sometimes there has, on the Greenlandic crystals, been found a face which in one case has given the position:

$$\varphi = 118^\circ, \quad \rho = 54^\circ,$$

but it is impossible from that value alone, which is rather uncertain, to get any further axial element. The face lies outside the zone (001) : (100) and must, in consequence, be a pyramidal one.

The angle β which has been calculated to be $67^\circ 46'$, is easily observed by measurement of the crystals lying on the face b under the microscope, and in this manner I have in several cases measured this angle to $67\text{--}68^\circ$.

There are three kinds of crystals, which are schematically drawn on the figure 2, viz. I, a single crystal, II, a twin after b (010) and III, a twin after the axis c . It must be remembered, however, that most of the smaller faces cannot be seen directly but are determined only by their positions measured on the goniometer. Of these kinds the second is by far the most common. While the third class is easily

distinguished from the others by the more symmetrical outline of the crystals the two first can be distinguished only on the goniometer or when they are placed on the edge enclosed in a liquid.

As for the common twins (II) it must to be remarked, that while the faces a on the forepart and the faces c in most cases give rather distinct reflections, it is never possible to obtain such from the faces of a , which should form the reentrant angle on the backside; the crystals are here obviously bounded by very imperfect or rounded faces. The twins after the axis c (III) give in most cases better reflexions. The composition-face for these twinings is forming an angle of 39° with (010) , and this obliquity is easily seen when these crystals are enclosed in a liquid and turned round.

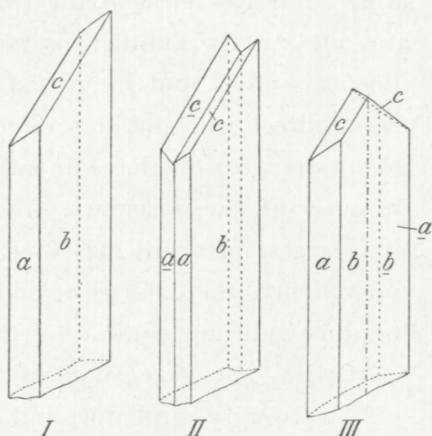


Fig. 2. Okenite. I. Single crystal;
II. Twin after (010) ;
III. Twin after the axis c .

Physical properties. Cleavage. It is commonly stated¹ that there is trace of a cleavage in the longitudinal direction. Now, it is certainly a very difficult matter to cleave out those very small crystals, but there can be no doubt that there must exist a very perfect cleavage after b (010) as the crystals possess, on that face, a marked pearly luster. When seen under the microscope that cleavage is, in most cases, very distinct, while it is impossible with certainty

¹ After LACROIX, Bull. Soc. Fr. Min., 8, 1885, 342.

to detect any cleavage in other directions. Best seen perhaps, is the cleavage, in the common fibrous masses of the mineral, which are very characteristic and easily to be recognised from other similar minerals (mesolite, ptilolite a. o.) by the occurrence of those brilliantly shining cleavage faces, in most cases of a peculiar curved form.

Concerning the common aggregates of the okenite there is not much to be added to the former descriptions of that mineral. It is characteristic that the fibres in most cases are not strictly parallel, as is mostly the case with other fibrous zeolites, but interlaced between each other in different directions, and this circumstance is the cause of the great strength of the mineral, which has been obvious to most of the observers, f. i. HEDDLE¹ who states that "the largest of these masses (3—8 inches in diameter) almost defied the efforts of half-a-dozen men and a 28-lb hammer". In opposition to the single individuals of the aggregates the free crystals are perfectly straightlined, and it is very probable that the first formed crystals of the compact masses are developed in the same manner but afterwards bent by the pressure of the later grown elements. For the crystals are quite flexible and elastic as mica. There are, however, found exceptions from the rule that the individuals of the compact okenite are irregularly arranged, and in such cases it may be very difficult, without closer examination, to distinguish that mineral from other zeolites.

The colour is not in most cases pure white, sometimes a little yellowish and sometimes bluish. Most specimens are almost quite intransparent, especially some more altered forms, but in other cases the mineral may be translucent

¹ Trans. Geol. Soc. Glasgow, XII, 1902, p. 10.

as alabaster, and it is then often bluish in reflected light and yellowish in transmitted light. The free crystals are mostly quite colourless and transparent.

The specific gravity is somewhat varying, which is perhaps mostly caused by the different degree of compactness. In the literature have been stated values from 2.28 to 2.36. For the compact forms I have found similar values viz. 2.323, and 2.325 for the purest varieties of the more translucent okenite. The crystals are a little heavier, varying between 2.326 and 3.332.

The optical properties of the okenite have been determined by LACROIX¹ who finds them in accordance with the rhombic symmetry: the extinction is parallel, positive in the longitudinal direction, the optic axial plane is parallel to, while the acute, negative bisectrix is normal to that direction. The axial angle is large. The mean refraction is determined at 1.556 and the double refraction at 0.0091.

By my examination I have come to results which are in most respects in opposition to those obtained by LACROIX and in full accordance with the triclinic symmetry. What is the cause of the differences between the results of LACROIX and those obtained by me I cannot say; in the following I shall state the optical properties, as I have found them: as the free crystals are in all respects in accordance with the common fibrous masses, of which I have examined a very large mass of specimens, there can be no doubt that all that I have examined is really okenite.

As for the extinction there is the curious circumstance which has, perhaps, led to the assumption that the crystals were rhombic, namely that it is parallel for rays normal to

¹ Bull. Soc. Min. de Fr., 8, 1885, 316; *ibidem*, 10, 1887, 152. M. Lévy et Lacroix, Les minéraux des roches, 1888, 346.

b (010), and as free crystals naturally always lie on that face, being by far the largest of all, it is somewhat difficult to look through them in other directions. When they, however, are placed in a liquid between glass hemispheres and turned round, we see in all other directions a marked obliquity. When for instance, they are placed on the edge, when the light then passes them in a direction lying in the face *b* (010) and normal to the vertical axis, there is an oblique extinction of 30—34° to the trace of (010), and when they are placed in a vertical position the obliquity is 25°. How these directions of extinction are orientated in relation to the obtuse or acute crystallographical axial angles, I have not succeeded in finding out, but the existence of so marked and constant obliquities in both directions shows that the crystals must be triclinic. As for the fibrous okenite the obliquity is in most cases not very distinct, as the fibres are mostly very irregularly interlaced, but in the rare cases, when the fibres are quite parallel, we cannot but remark the oblique extinction.

The optic axes are very difficult to find. By turning the crystals round in different directions in the glass hemispheres it is possible to find certain directions without interference colours, but in convergent light we see no distinct axis; it is certain that the axes are orientated very unsymmetrically in relation to the crystal faces, and it seems that the axial angle is very large.

The refraction is almost the same as for nelk oil, ($n = 1.541$), and the mineral can in all cases be easily determined by that property combined with the positive double refraction in the longitudinal direction. In most cases it is the longitudinally swinging ray which coincides with the refraction of the oil, while the transverse one has a

little smaller refraction. The values are, however, somewhat varying and I have for different specimens found the following:

$\gamma^1 = 1.541$	$\alpha^1 = 1.534$
1.533	1.525
1.544	1.535
1.541	1.530

The last pair of values are found for a pure crystal and must also be considered as the best possible. The real values for α , β and γ I have not been able to determine, as the axes of elasticity are orientated in a very unsymmetrical manner. For the double refraction in the common fibrous aggregates it has not been possible to obtain any good value as the fibres are orientated in a rather accidental manner while the single crystals are too small for an exact determination. The mean value is, however, not very different from that obtained by LACROIX, viz. ca. 0.01.

Before leaving the okenite I must point out two instances where the mineral has been described in the literature and where the values given for the refraction directly show that the mineral concerned must have been some other.

In his paper on the zeolites from the phonolite at Hegeberg in Bohemia MICHEL¹ among other zeolites describes the okenite as one of the best developed minerals from that locality. The values stated for the refraction and the specific gravity show that the mineral in question cannot be okenite, and in another paper² MICHEL has analysed it and found that it has the composition of scolecite, although the optical properties were not in accordance with

¹ Tscherm. Min. Mitt. 30, 1911, p. 482.

² Festschr. Corn. Doelter, 1920, p. 28.

that mineral. The substance has been referred to the mineral metascolecite described by RINNE¹.

In his first paper MICHEL has also determined the refraction of the okenite from the Färöes and found it to be 1.520, which value is, certainly, too small. He mentions the refraction found by LACROIX (1.556) but finds it too large for a zeolite. With this conclusion I cannot agree, as the non-aluminous zeolites, to which the okenite belongs, are stronger refracting than the others (for apophyllite $n = \text{ca. } 1.350$ and for gyrolite and zeophyllite $n = \text{ca. } 1.56$). Consequently we should for the okenite beforehand expect a refraction lying between these values.

In another place mention is made of the okenite by EAKLE and ROGERS² who describe it as an alteration product of wilkeite in the form of opaque masses with pearly luster and a fibrous structure. The index of refraction was determined at 1.565 ± 0.005 , the double refraction at $0.009-0.01$; the extinction is parallel and the elongation parallel to the slower ray. If the refraction is correctly determined it does not seem possible that the mineral can be okenite. The above named value is highly accordant with that for gyrolite ($\omega = 1.5645$, $\varepsilon = 1.5590$) and for zeophyllite, and in cross sections those minerals will show a fibrous structure with the slower ray parallel to the elongation; for those minerals the expression pearly luster is also much more significant than for the okenite where this property is only seen with difficulty because of the smallness of the faces. Only the double refraction is not so large for the gyrolite as for the mineral examined by EAKLE and ROGERS, but the difference between both does not, perhaps, exceed the exactitude with

¹ Sitzber. d. k. preus. Akad. d. Wiss. 46, 1890, p. 28.

² Amer. Journ. Sci. 37, 1914, p. 206.

which this property can be examined. The other properties stated are common to both minerals.

II. Ptilolite (Flokite).

The ptilolite was described by CROSS and EAKINS, first from the Green and Table Mountains, Jefferson Co., Colorado¹ and afterwards from the vicinity of Silver Cliff, Custer County, Colorado². Since then it has been described from the following localities: Crownprince Rudolf Island (Franz Josef Land), described by COLOMBA,³ St. Piero in Campo, Elba, described by G. D'ACHIARDI,⁴ Teigarhorn, Iceland, described by LINDSTRÖM⁵ and finally from Challis, Idaho, described by LOUIS K. KOCH⁶, and from Guadalcanar (one of the Salomon Islands), described by TSCHERMAK⁷. Two further occurrences, the Färöes and Seiser Alp, which are described and analysed by THUGUTT⁸ under the name of mordenite and which possibly belong to the ptilolite, will be mentioned later on under the said occurrences.

The mineral from Teigarhorn was, in 1917, described as a new species under the name of Flokite by Miss CALLISEN⁹. Indeed it was at that time scarcely possible to indentify with full certainty the mineral from Teigarhorn with the original ptilolite, as its physical properties were very imper-

¹ Amer. Journ. Sci., 32, 1886, p. 117.

² Amer. Journ. Sci., 44, 1892, p. 96.

³ Atti R. Accad. delle Science di Torino 37, 1902, p. 553. Zeits. Kryst. 40, 1905, p. 101.

⁴ Atti della Societa Toscana di Sci. nat. residente in Pisa, 22, 1906, p. 150. Zeits. Kryst. 44, 1908, p. 664.

⁵ Geol. Fören. Förh. Stockholm, 29, 1907, p. 106.

⁶ The American Mineralogist, 2, 1917, p. 143.

⁷ Sitzb. Akad. Wiss. Wien, 126, I, 1917, p. 547.

⁸ C. r. Soc. sci. Varsovie, 5, 1912, p. 76; N. Jb. Min. 1913, 2, p. 33.

⁹ Medd. Dansk geologisk Forening, 5, Nr. 9, 1917.

factly stated and the chemical compositions not fully congruent. By means of specimens of the original ptilolite which I obtained from the museum of Washington I have been able to ascertain, that both minerals are identic and that the name flokite must, consequently, fall away. For the sending of the specimens I must render my best thanks to the Curator of the Museum in Washington, Dr. W. FOSHAG.

On examining our zeolites in the Museum of Copenhagen I found the ptilolite from many different localities and of a rather different outer appearance, and as I think that the same will be the case when other collections are revided I suppose that the ptilolite must be considered as a common mineral. I think, then, that it will be proper to give a full description of the mineral, as many of its properties, especially the crystalline form, are hitherto rather imperfectly known.

Occurrence. All the occurrences of the ptilolite which I have been able to ascertain are listed below in topographical arrangement.

The Färöes. From Eldevik at Österö we have the two specimens which are described under the okenite (p. 7). The first specimen contains only a thin layer (c. 1 mm) of the ptilolite situated between apophyllite and okenite; the mineral seems not to be quite pure and is rather difficult to determine. In the other specimen there is first a very thin layer of chabasite upon which the ptilolite is seated in form of small radiating masses which are highly penetrated with chalcedony; in the innermost part of the geode there may be apophyllite or okenite.

From Österö THUGUTT, as above cited, describes a mordenite as colourless, finely fibrous and under the mi-

crosscope spherulitic; it is mixed fibrous silica from which it cannot be completely separated. According to that description it is most probable that the mineral in question is a ptilolite, the chemical composition being the same for the two minerals.

From the Färöes without known locality there are in the museum of Copenhagen specimens of two different kinds, which must have originated from quite different occurrences. The one of these is represented by a brecciated basalt whose large fragments are cemented together by a rather compact, snowwhite ptilolite the fibres of which are so small that they are only visible under the microscope, and are irregularly interlaced. While most of the substance is very pure it contains in other places groups of very small, rounded quartz grains.

The second of the mentioned occurrences is very peculiar, the ptilolite occurring in the form of regular stalactites. In a gray basaltic rock there are large cavities, the walls of which are coated with a very thin, green layer of some zeolite penetrated with glauconite. Upon that is seated the ptilolite in a layer of some few millimeters but from the wall it protrudes in the interior of the cavity in the form of stalactites which are in some cases rather regular and parallel, but in others more or less flattened and curved. In the interior of each stalactite we find the same green zeolitic mass as is found in the outer part of the cavity. The ptilolite itself is seemingly very pure; the first formed layers forming the outer parts of the coating of the walls and the inner parts of the stalactites are compact, while the later formed parts are rather loose. The single fibres are so thin that they can only be seen under the microscope.

Iceland. Besides the formerly known locality, Teigarhorn, I have succeeded in finding the mineral from

three other places. As the Museum in Copenhagen contained a very small material of fibrous zeolites from Iceland, I wrote to the lector B. SÆMUNDSSON in Reykjavik and asked him to send me what he possessed of those, and in a not very large collection the three new occurrences were found. It seems, consequently, that the mineral must be rather common in Iceland. The known occurrences are:

1. Teigarhorn. The mineral from here¹ is the most perfect and pure form of all ptilolite as it is mixed with no other mineral with the exception of small inclusions, which are found in some instances, and which can not be more exactly determined. The surrounding rock is a gray basalt; the outer part of the geode is filled by a compact mass of ptilolite from which the shining and well-developed crystals freely protrude. Only in few cases heulandite is found as a later formation and sometimes the spaces between the ptilolite are filled by small, spindle-shaped quartz crystals.
2. Laxfoss at Grimsá. Small geodes without surrounding rock: the ptilolite is of the common loose and hairy form but in the outer parts it is incrustated with chalcedony forming outermost a compact layer of ca. 1 millimeter, inside of which there are found scattered, regular small spheres.
3. Hunavatn. As from the former locality here are found small geodes (up to 2 centimeters in diameter) without rock: the ptilolite has the form of well-developed straightlined needles and their formation has been succeeded by heulandite which fills up the spaces between the ptilolite in the outer parts of the geodes.

¹ As Miss CALLISEN points out one of the specimens is labelled "Eskefjord?" but the whole appearance shows that it must have come from the same locality as the others, viz. Teigarhorn, the most famous place in the world for large and well-developed zeolites.

4. Thorskufjarðar Heiði. From here we have a single larger geode without rock; the ptilolite is quite pure with very fine needles of a loose and feltlike consistency.

East-Greenland. At the south side of Gaasefjord in Scoresby Sound there has been found a piece of basalt with numerous amygdaloids consisting of pure ptilolite of the common feltlike appearance.

West-Greenland. On the island of Disko there are three localities for ptilolite: 1. Nungerut, near the coal mine Ritenbenk, at the north-east coast of the island. From here we have a rather large (up to 8 centimeters) geode, which has outermost a layer of ca 5 millimeters of ptilolite of the common appearance, while the whole interior is filled up with desmine. 2. At Skandsen is found a large geode (up to two decimeters in diameter) of a fine appearance with a green outside and a pure snowwhite interior, as it is in most cases entirely filled up by a pure, loose, feltlike ptilolite whose single fibres are exceedingly thin. In some places in the outer parts of the geode there are crystals or grained masses of apophyllite, which mineral has crystallised before the ptilolite, as it is never penetrated by that mineral. 3. Kuanit at Godhavn. From here originates a large geode almost completely filled with ptilolite of the common feltlike form with very fine fibres. It is however not quite pure as it is, especially in the outer parts, mixed with chalcedony, mostly in the form of small, regular spheres, formed after the ptilolite.

Franz Joseph Land. At Teplitz-Bay at Crown-prince Rudolf Island is found, as described by COLOMBA¹, a specimen of calcite penetrated by needles of ptilolite; the

¹ l. c.

specimen originates from a cavity in basalt. The needles of the ptilolite are long, colourless and flexible with silky luster.

Italy. From this country the following three localities for the mineral are known:

1. Fassa in Tyrol. In an augite porphyry irregular cavities and fissures are quite filled with different minerals; sometimes there is a red heulandite without ptilolite, but in the cavities which interest us here there is outermost a layer of gray chalcedony without ptilolite, while the whole interior is filled with red chalcedony, or in some cases calcite, both penetrated with very fine fibres of ptilolite. The whole specimen is labelled crocalite, and it is very probable, that that name ought to be referred to the ptilolite and not, as is commonly the case, to natrolite. If we compare the different descriptions of the crocalite, especially those by HAUY¹: "Ce minéral est engagé sous la forme de globules dans une roche de trapp amygdaloïde, qui renferme en même temps des grains de pyroxène et de petites masses de stilbite rouge. Il est lui-même d'un beau rouge incarnat, et point électrique par la chaleur; sa cassure est mate et sa dureté peu considérable", by LEONHARD²: "Der sogenannte dichte Zeolith (Mesotype compacte, Krokolith), namentlich jeder aus Tyrol, ist einer, äusserlich oft nicht mehr erkennbares, Gemenge von Quarz oder Hornstein mit aufgelöstem Mesotyp oder Stilbit" and by GLOCKER³: "Der sogenannte Krokolith aus dem Fassathale wird für eine Gemenge von Quarz mit Mesotyp, nach anderen mit Stilbit gehalten," with that given above of the locality, we shall see that they are in most respects very similar, and it is, there-

¹ Cours de Min. de l'an XII; Lucas: Tabl. méthodique des Espèces Min. 1806, 334.

² Handbuch der Oryktognosie, 1821, p. 455.

³ Handbuch der Mineralogie, 1831, p. 788.

fore, most natural to refer the crocalite to the ptilolite, as long as no natrolite or other mineral is known, of the same appearance and occurring under similar circumstances, from that locality.

From the same locality perhaps originates a mineral, described by THUGUTT¹ under the name of mordenite; the locality is given as Seiser Alp. The mineral is needle-shaped of a pink colour and is accompanied by analcite, calcite and quartz. Those qualities fairly well recall the above stated, but more difficult to explain is the statement that there should be an obliquity of extinction of $7-8^{\circ}$ and a cleavage forming $3-4^{\circ}$ with the horizontal direction. Both qualities are not in very good accordance to those of either the ptilolite or the mordenite and are, perhaps, not exactly determined.

2. The valley of Zuccanti in the district of Vicenza. From here the Museum possesses two specimens consisting of a basaltic rock, the cavities of which are filled with a radiated ptilolite of a strong brick-red colour. Beside that mineral there are sometimes found, in the outer parts of the cavities, masses of calcite, which is obviously formed before the ptilolite while the inner parts of the geodes, the spaces between the needles, are filled up with a grained quartz. While the needles in one of the specimens are exceedingly fine, as is most commonly the case with the mineral, the other specimen is very remarkable by the fact that the crystals are of such large dimensions that it has possible to use them for crystallographical and physical examinations besides those from Teigarhorn and Elba.

3. Speranza at St. Piero in Campo, Elba. The mineral from there was first mentioned by GRATTAROLA² and after-

¹ l. c.

² Bolletino del R. Comitato Geologico d'Italia. 7, 1876, p. 323.

wards by SANSONI¹ under the name of "hydrocastorite", which mineral, as suggested by D'ACHIARDI², is perhaps only a mixture of stilbite and ptilolite. The last named author points out that those two minerals are intimately mixed at that locality, where moreover the following zeolites are stated to occur viz. heulandite, chabasite, "foresite" and dachiardite. The zeolites are situated on the walls of the cavities of a granite pegmatite, the most characteristic minerals of which are tourmaline, beryl, castor and pollux. As will be seen, the occurrence differs highly from all others known for the ptilolite.

A small specimen of the ptilolite from Elba, which the Museum in Copenhagen succeeded in obtaining, is very remarkable by the fact, that it contains larger crystals of the mineral than those formerly described from that locality. GRATTAROLA gives the dimensions 0.002—0.0425 mm, while D'ACHIARDI uses the expression "un minerale aciculare esilissimo" (very fine needle-shaped). The crystals which I have measured have a thickness of up to 0.3 mm and are very convenient for goniometrical measurements; while most of them are broken in the ends, I have succeeded in finding a few, which were in possession of pyramidal faces, as will be described later on.

Scotland. From Dumbarton the Museum of Copenhagen possesses a specimen of the mineral. The surrounding rock, of which only small remnants are left, seems to be of a trachytoid character; the walls of the cavities are externally coated with a thin layer of grained quartz and sometimes also with small crystals of heulandite. Upon that layer is placed the ptilolite, which has, as usual,

¹ Mem. Soc. Toscana Sc. Nat. 4, 1879, p. 311.

² l. c.

the form of radiated groups; the whole space between the needles of the ptilolite is filled out by grained quartz and sometimes by larger individuals of calcite. The ptilolite is of a strong brick-red colour; the single needles are very thin and insignificant.

United States.

1. Table and Green Mountains, Colorado. This locality, which is the original one for the mineral, consists of an andesitic rock, the pores of which are coated by chalcedony. In some instances this mineral or quartz fills the inner part of the cavity, but in other cavities there is upon the chalcedony deposited heulandite or ptilolite. In one specimen, which the U. S. National Museum kindly sent me for examination, I found in many of the cavities, either alone or together with the ptilolite, small crystals of baryte. The dimensions of that mineral are in some cases one to a few millimeters, while in others they are quite microscopical and lie in a large number scattered among the needles of the ptilolite. The ptilolite itself from that locality is very insignificant, the transverse dimensions of the needles being almost 0.001 millimeters; the needles are only to a very small degree parallelly arranged as they, more than is the case at the other localities, form loose, feltlike masses.

2. Silver Cliff, Custer Co., Colorado. This locality has, like the former, been described by CROSS and EAKINS; the rock is a devitrificated pitchstone belonging to a rhyolitic lava-flow: the small vesicles are coated and in some cases quite filled by quartz, while others contain baryte or ptilolite, which mineral has great similarity with that from the former locality.

3. Challis, Idaho. This locality consists, as described

by KOCH, of a basic rock with rather large (up to 1 dm in diameter) cavities, on the walls of which there is a 1 cm layer of chalcedony on which the ptilolite rests mixed with numerous microscopic spindle-shaped crystals of quartz. In a specimen from the locality, which I got from the U. S. National Museum, it was obvious, that the unusual thick outer layer must be divided in two: an outer, one of 1—2 mm, formed before the ptilolite, and an inner one penetrated by needles of that mineral. The two layers were separated from each other by a distinct line of demarcation while there is a gradual transition from the inner layer to the loose ptilolite. That mineral itself is arranged in small radiated groups, the single needles are very thin.

Salomon Islands, Guadalcanar. From here, as described by TSCHERMAK¹, we have small (3 cm in diameter) white spheres in some volcanic rock. The analysis by Cossmat shows that the material must have been rather pure.

As will be seen from the foregoing the occurrences of the ptilolite are in most respects very similar to those of other zeolites, the surrounding rock being mostly of basaltic character and only in a few cases more acid, andesitic or granitic. The associations are very variable for the different localities. Of 19 known occurrences there are 5, where the ptilolite is the only mineral, while in the other instance it is accompanied by other zeolites, by quartz (or chalcedony), calcite or baryte. Zeolites are in 6 instances found together with the ptilolite; they are of many different kinds and are in some cases formed before and in some after the ptilolite. Calcite is found from four of the localities mentioned; it is mostly formed after the ptilolite, only at Zuc-

¹ Sitzb. Akad. Wiss. Wien, 126, I, 1917, p. 547.

canti it seems to be of an earlier formation. Baryte is found at the two localities in Colorado, in both cases as a later formation. Most characteristic is the common association of the ptilolite with chalcedony or quartz, which circumstance is, perhaps, due to the high acidity of that zeolite, which contains much more silica than other zeolites with the exception of the mordenite. In 9 instances the ptilolite is connected with quartz, which mineral is sometimes formed before and sometimes after the ptilolite, while in some cases it is of both formations. It is in most cases impossible to determine if the mineral in question is quartz proper or chalcedony, as it mostly form a very fine-grained mass.

Crystalline form. The system is commonly assumed to be rhombic because of the parallel extinction; only Miss Callisen suggests the monoclinic symmetry for the mineral from Teigarhorn (the "flokite") as it has a distinct oblique extinction on (010) connected with a twin formation after (100). As all other essential properties are alike for the mineral from that locality and from others, it will be most natural to assume that there is some optical anomaly, so much more as those crystals show anomalies also in other directions. Besides the constant obliquity of 5° on (010) there is in some instances found an obliquity of $1-2^\circ$ on (100) and also very variable extinctions in transverse sections. As all the better crystals from other localities show absolute parallel extinctions in all three directions, we must assume that the mineral is in reality rhombic.

Distinct terminal faces have not been observed before; for the mineral from Green and Table Mountains CROSS and EAKINS state that the terminations of unbroken

prisms are square, and also COLOMBA mentions that the crystals from Franz Josef Land often possess a basis normal to the directions of the needles. As for the crystals from Elba, Grattarola states that the prisms are terminated by a face which is either at a right angle to the direction of the prism, or forms an angle of 70° with this direction; D'Achiardi has found two symmetrically arranged terminal faces. As for the crystals from Teigarhorn Miss CALLISEN has found no terminal faces but has made the first measurements of the prismatic angle for which she has found the value $(100):(110) = 41^\circ 18'$ ($40^\circ 35' - 42^\circ 12'$).

As material for crystallographical examination has been used the crystals from Teigarhorn, from Zuccanti and from Elba as their dimensions exceed all other pitilolites. Most crystals are somewhat ruler-shaped and flattened later (100) the dimension after the b-axis being in maximum ca. 0,3 mm and after the a-axis ca. 0,1 mm from all three localities. Some of the crystals from Teigarhorn are, however, rather equidimensional in both directions and others are flattened after (010).

On the crystals from Zuccanti I have not found any terminal faces, but on these from Elba and Teigarhorn I have succeeded in finding such. As I was in possession only of a very small material from Elba, I found but two crystals which were terminated by the pyramide (111) with all four faces on each crystal. Among the numerous crystals from Teigarhorn several were found in possession of the form n (101) without any trace of the pyramid.

The crystals are rhombic with the elements:

$$a : b : c = 0.8785 \ 1 : 0.3606.$$

The crystals from the two localities are developed as shown in the figures 3 and 4. As fundamental angle is

used the prismatic angle $(100):(110)$, which was measured by Miss CALLISEN to $41^{\circ} 18'$ and for which I have found very similar values on the crystals from Elba and Zuccanti. As the other fundamental angle I have used the value of ρ for the face o (101), which I have found to be $22^{\circ} 49'$ as a mean value of 9 measurements varying from $22^{\circ} 30'$ to $23^{\circ} 10'$. As the value of ρ for p (111) I have found $29^{\circ} 8'$ varying from $28^{\circ} 47'$ to $29^{\circ} 30'$; the calculated value is $29^{\circ} 15'$.

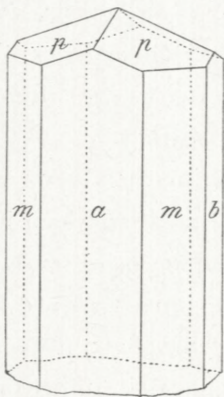


Fig. 3.
Ptilolite. Elba.

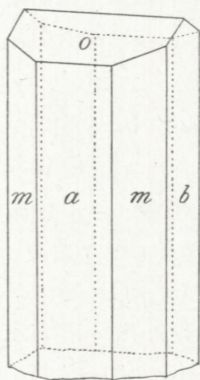


Fig. 4.
Ptilolite. Teigarhorn.

The faces in the vertical zone are always vertically striated, and give mostly numerous reflexions; on the contrary the faces of p and o are well developed and give single reflexions, which, however, are very weak because of the extreme smallness of those faces.

Physical properties. Cleavage. CROSS and EAKINS state that there are parallel to the basal plane traverse fissures as of cleavage. I have never succeeded in finding such and on broken prisms which I have placed on the goniometer I have seen no reflexion in the place of the basis, so I think that there can be no traceable cleavage in that di-

rection. The same result is obtained by Miss CALLISEN who states that there is conchoidal fracture normal to the prism zone; on the contrary she has found an excellent cleavage after (100) and (010). In my opinion there is, however a marked difference between those two directions. When we see the traverse sections of the needles, we always find numerous fissures after (100) but mostly only few after (010), and if we observe the needles themselves there seems to be a more marked pearly luster after the first named face; this observation is, however, rather uncertain because of the smallness of those faces. As a general result I would describe the cleavage after (100) as excellent and that after (010) as distinct.

The outer appearance of the mineral is very varying in the different cases. Sometimes the single crystals freely protrude and are well developed but in most cases they are connected to aggregates, which are mostly of a rather loose consistency but sometimes very compact; it seems, however, that the ptilolite in all those cases is impregnated with quartz. The aggregates sometimes consist of distinct radiated groups but sometimes the fibres are so interlaced that the mineral becomes perfectly felt-like. In a single instance, from the Färões, the ptilolite is arranged in stalactitic forms.

The colour of the aggregates is in most cases a very pure white, sometimes with a faint reddish, yellowish or brownish tinge. A very marked exception from all other ptilolites are the three occurrences, Fassa, Zuccanti and Dumbarton, from which places the mineral is of a strong brickred colour, very similar from all three occurrences. The colour seems to originate from very small inclusions, the nature of which it is impossible to determine.

The hardness is, as determined by Miss CALLISEN,

5. For the specific gravity KOCH has given the value 2.30 while Miss CALLISEN has found the value 2.102. As this seems to be a rather large discrepancy I have tried to determine the gravity and have found; for the pure crystals from Teigarhorn and from Elba, values varying from 2.10 to 2.12; only for the red crystals from Zuccanti have I found values up to 2.3 or even higher. From the other localities the crystals are so small that it will be impossible to get any exact result.

The optic properties are mostly in perfect accordance with the rhombic symmetry: only the crystals from Teigarhorn show some anomalies, as mentioned above. From the other localities the crystals have a parallel extinction in all directions and the sign of the needles is negative, which in connection with the weak refraction and double refraction is the most valuable property for determining the mineral. The plane of the optic axes is parallel to (100) and the acute bisectrix is normal to (001). The sign of the double refraction is negative. The axial angle is observed with great difficulty because of the smallness of the crystals; by placing one of the crystals, which is flattened after (010), between glass hemispheres and turning round, we can see the positions, in which there is no double refraction and where the sign by further turning changes from negative to positive, and thereby we get the obtuse axial angle of almost 120° in glass and $2V$ to 57° app.

The indices of refraction have been given by D'Achiardi: $\alpha < 1.480, 1.485 > \gamma' > 1.480$, by Koch: $\alpha = 1.475, \beta = 1.477, \gamma 1.478$ and by Miss Callisen: $\alpha = 1.4720, \gamma = 1.4736$. The double refraction is directly determined by Miss CALLISEN to be 0.002. The most obvious phenomenon in the numbers mentioned is the marked difference between the

mineral from Elba on the one side and the other occurrences on the other side. But it is very easily seen that there exists in reality such a difference, if we place the mineral in ricinus oil ($n = 1.480$); while the ptilolite from most occurrences is distinctly lower refracting than the oil, that from Elba and from one of the other localities (Thorskuðfjarðar Heiði on Iceland) has almost the same refraction as the oil or a little larger. It is probable that the difference in refraction is due to some difference in chemical composition and if we compare the best analysed occurrences, Elba and Teigarhorn, we shall see that the mineral from Elba contains almost 4 per cent of $SiO_2 + Al_2O_3$ less than that from Teigarhorn and correspondingly almost 3 per cent more of lime + alkalis, which is perhaps sufficient to explain the larger refraction of the mineral from the first named occurrence.

By heating the needles undergo curious alterations; COLOMBA has found that they become double refracting at a temperature of 120 to 125°, also the very thin ones, on which it is not possible to see any interference colour at ordinary temperature; by cooling they go back to the original condition. Miss CALLISEN has found that the crystals at 117—118° change their sign and get positive in the longitudinal direction but by cooling they become normal again. Both statements are correct; by heating the crystals first lose their double refraction, and thereafter get a double refraction which is much stronger than the ordinary, so that p. i. a crystal, which from the beginning shows a white of the first order, after heating goes up to red of second order. By further heating this colour remains very constant and by cooling the whole process goes back, but it takes rather a long time, one to two hours, before the original state is restored throughout the whole crystal.

The fusibility is somewhat differently stated by the different authors, from difficult to easy. I think that the cause of the divergent opinions is the fact that, if we take a single crystal, which is always very thin, we shall see that it is easily melted in the common Bunsen burner, but if we take a more compact piece it will be melted by the blow pipe only to a small degree. The fusibility is certainly more difficult than for all other zeolites with the exception of the mordenite and must be estimated at a value between 3 and 4. On the other hand all authors agree that the mineral is not dissociated by hydrochloric acid. It is quite certain that the properties which place the two minerals apart from other zeolites, are due to the exceptionally high percentage of silica, which lies between 67 and 70 in the two zeolites while in all others it never goes up over 60.

III. Intergrowths of different needle-shaped zeolites.

What makes the determination of the zeolites in question rather difficult and complicated is the fact that in many cases they have grown contemporaneously and form a mixture which is in some cases rather intimate. Only in some cases a more regular intergrowth is formed, but in most instances it is not possible to state any other regularity than the fact that the longitudinal direction of the two minerals is more or less strictly parallel, while the other directions seemingly are more accidentally orientated.

As far as I can see only two instances of intergrowth are hitherto described, and they are both of the more regular kind. The first instance is the combination of mesolite with natrolite, which has been described by CESÀRO¹

¹ Bull. de l'Acad. r. de Belge (Cl. des Sc., nr. 4, 1909, p. 486).

and by GÖRGEY¹, and the other is that of natrolite and thomsonite described by HIBSCH². Of those I have only found instances of the first combination, which seems to be rather common. On the other side of the more irregular intergrowth I have found the following combinations: mesolite-natrolite, mesolite-thomsonite, mesolite-scolecite, natrolite-scolecite, and natrolite-thomsonite of which the last seems to be rather common.

Mesolite-natrolite.

This combination, which has been described by Görgey from the locality Friedrichsthal at Bensen near Böh-mish-Leipa, consists in the lower parts of the crystals of natrolite, whereupon follows the mesolite while the natrolite again forms the upper part. The boundary lines between both minerals are sharp but somewhat irregular, in most cases forming an angle with the point turned upward. After CESÀRO the mesolite is the first formed mineral, the needle consisting half of that mineral and half of natrolite. As Cesaro, however, in his drawing has the point of the angle turned downward, it is possible that he has turned the first formed crystal incorrectly, as it is not very probable that the first formed crystal should have ended in in a reentrant angle.

In all the specimens which I have had occasion to examine, I have only found a combination of first formed natrolite and later formed mesolite, and the angle, which is formed by the boundary line, is turned with the point upward. In some instances there are however signs of a later formation of natrolite, which forms a very thin

¹ Tschermak's min. u. petr. Mitt., 28, 1909, p. 97.

² Tschermak's min. u. petr. Mitt., 34, 1917, p. 196.

outer coating upon the mesolite, distinctly visible, however, because of the double refraction of the natrolite. Most of the specimens originate from Nolsö, one of the Färöes, while others whose locality is not stated seem to have come from the same place. Only one specimen originates from Lyngmarksfjeld near Godhavn on the island of Disko, Greenland.

As some of the crystals were rather large and well developed, I have measured them on the goniometer to see how the two minerals were arranged. I found that in that respect was there some variation, as in some instances the prismatic faces of both were orientated exactly in the same zone, but that in others they would diverge up to half a degree. In the instances where the *c*-axes of both minerals were parallel the prisms were mostly arranged in such a manner that the bisectrices of the prismatic angles were parallel, whereby the differences in the positions of the corresponding prismatic faces were as small as possible. In other instances the arrangement was such that one pair of prismatic faces nearly coincided in both minerals.

In other cases the two minerals are more irregularly connected. A specimen from Nova Scotia consists of rather big and straight crystals of mesolite, between which there are found masses of very fine fibrous natrolite with rather irregular arrangement of the single fibres. Between those are intermingled small needles of scolecite.

In other cases again there seems to be a much more intimate mixture of the two minerals and it may be rather difficult to determine them with certainty especially the natrolite. The mixture is white and intransparent and has almost the same refraction as the mesolite, but instead of being single refracting, as is the case with the pure mesolite

when in thin crystals, it is distinctly double refracting with a positive sign in the direction of the needles. It is possible that the mesolite is mixed with a smaller quantity of natrolite, not so much, however, that the refraction is sensibly smaller than that for the mesolite. Such (positive) mesolite I have found from Suderö, one of the Färöes, from Iceland and from Turner Island in East Greenland.

Mesolite-thomsonite.

This combination I have found only in one specimen from Cape Brewster in East-Greenland, where it forms radiated masses, on the outside of which there are seen free crystals of both minerals among each other. In thin sections they are mostly intimately mixed in parallel positions, part of the thomsonite crystals being, however, orientated in traverse or accidental positions.

Mesolite-scolecite.

This combination is somewhat differently developed; in a specimen from Mount Henry, East Greenland, the mass is formed by rather big and straight crystals of scolecite, between which there is a very fine and silky mesolite, but in a specimen from Eskifjord, Iceland, and another from Iceland without further locality, the opposite is the case. Here the crystals of mesolite are rather straight and solid and the scolecite is developed as fine fibres between them. In the outer parts of the spherical masses the mesolite, however, passes into fine fibres, which in feather-like arrangement loses itself in the scolecite and afterwards disappears so that the free ends of the crystals are only formed of that mineral. On a specimen from Bordö, the Färöes, both minerals are rather fine, and fin-

ally we have a specimen from Turner Island, East Greenland, where the constituents are so fine, that in most cases they cannot be distinctly distinguished from each other under the microscope. As the mesolite makes up the larger part of the mixture, the refraction of this is very nearly the same as that of the pure mesolite, but the presence of the scolecite makes the sign of the double refraction negative in the direction of the needles. We have here, accordingly, a "negative" mesolite as a perfect analogy to the above named positive one.

Natrolite-scolecite.

Beforehand we should find it rather improbable that these two minerals could be formed at the same time, but in the above mentioned specimen from Nova Scotia we certainly have a fibrous natrolite with single fibres of scolecite; the mixture of both minerals fills out the spaces left between larger crystals of mesolite.

Natrolite-thomsonite.

While I have not had occasion to observe any regular intergrowth between these two minerals like that described by Hibschi I have in many instances found the two minerals grown together in such a manner that the *c*-axes of both were parallel or almost parallel without it being possible to find any other parallelism between them. The individuals of thomsonite are always elongated after the named axes and behave quite like a typical needle-shaped zeolite. The needles of both minerals are always rather thin so that it has been attended with some difficulty to determine them with certainty. Mostly the natrolite is the most regularly developed mineral occurring

in straight needles, between which the needles of thomsonite are placed in a somewhat more irregular manner. In some cases there is, however, no marked difference between the behaviour of both.

The combination of natrolite with thomsonite has been found in large amounts on Nolsö, one of the Färöes; from the spherical masses of them protrude crystals of both minerals, but while those of thomsonite are very imperfect, those of natrolite are mostly well developed and in their distal ends regularly intergrown with mesolite as mentioned above. Another instance of the combination natrolite-thomsonite is found at Præstfjeld, Suderö, the Färöes.

In Greenland the minerals are found at the localities Ekorgfat, Ujarartorsuak, Tuapagsuit and Kaersuarsuk on the north side of Nugsuak and at Ivnersuit at the south side of Disko. No special interest is connected with those localities.

From Antrim in Ireland the Museum possesses some specimens, labelled "Harringtonite" or "Antrimolite"; they both consist of the combination of natrolite with thomsonite and are found as small geodes in basalt. It is, however, not possible to conclude that the said two Irish minerals would have the same composition in other instances. This can only be proved by an optical examination of the original material. The original analyses are in very good accordance with the composition of the mesolite, while a mixture of natrolite and thomsonite would produce a somewhat different result.

IV. Scheme for the Determination of the Fibrous Zeolites.

If we wish to undertake an exact and not too slow determination of the six zeolites mentioned in this paper, viz.

the okenite, the ptilolite, the natrolite, the mesolite, the scolecite and the thomsonite, I think that it is best done by means of the optical properties, especially the refraction, and I have found it practical to use the fluids mentioned below for the last named determination. Naturally it is not excluded that other zeolites may exist as fibrous aggregates or as needle-shaped crystals, but of the minerals of that kind, which have been described, e. g., the metanatrolite and the erionite, I have had no material for comparison, and I think that all other fibrous zeolites than the first named six will prove to be very rare, and they will probably be detected by the fact that they are not in full accordance to the optical properties stated below. The optical signs (positive or negative) given in the scheme are only in relation to the direction of the needles, as the real (absolute) signs are in all cases very difficult to determine. As standard fluids I have used such as are rather constant and not very volatile. They are:

1. Nelk oil ($n = 1.5415$).
2. Chlorbenzene ($n = 1.524$).
3. Cedar oil ($n = 1.512$).
4. Ethylbenzoate ($n = 1.505$).
5. Ricinus oil ($n = 1.480$).

For the six minerals in question the essential optical properties are the following:

1. Okenite. Extinction in single crystals parallel, in aggregates oblique (up to 34°). Refraction nearly the same as for nelk oil. Double refraction rather strong (ca. 0.01), positive.

2. Thomsonite. Extinction parallel. Refraction (β) almost the same as that of chlorbenzene¹. Double refraction

¹ The indices of refraction of the thomsonite seem to be somewhat

strong (up to ca. 0.02, negative), or weak (up to ca. 0.005) positive, changing sign if the needle is turned round.

3. Scolecite. Extinction oblique (up to ca. 17°). Refraction for the almost vertically swinging ray (α) exactly as for cedar oil. Double refraction mean (ca. 0.007), negative.

4. Mesolite. In most cases no double refraction (when in thin needles), in some instances, when impure, weak positive or negative double refraction. Refraction very nearly the same as for ethylbenzoate.

5. Natrolite. Extinction parallel. Refraction for the horizontally swinging rays (α and β) nearly the same as for ricinus oil. Double refraction rather strong (ca. 0.01), positive.

6. Ptilolite. Extinction parallel. Refraction nearly the same as or somewhat lower than that of ricinus oil. Double refraction weak 0.002—0.003, negative.

variable, but in most cases the lower values (α and β) are not very far from that of chlorbenzene while that of γ is much higher. The values given by Descloizeaux ($\alpha = 1.497$, $\beta = 1.503$, $\gamma = 1.525$) are certainly much too low).



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