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[THIRD SERIES.]

ART. XXIX.—*On the Mineral Locality at Branchville, Connecticut: Fourth Paper.* Spodumene and the results of its Alteration*, † by GEORGE J. BRUSH and EDWARD S. DANA. (With Plate IV).

IN the present paper we give the results we have obtained in a study of the spodumene from Branchville, Conn., and of the various minerals derived from its alterations. It is, after the feldspars, mica and quartz, the most important of the original minerals of the locality, and occurs, though mostly in an altered condition, in very large quantities.

* For previous papers upon this subject see this Journal, III, xvi, 33, 114, 1878; xvii, 359, 1879; xviii, 45, 1879.

† An extended and valuable memoir upon "Spodumene and its alterations from the granite veins of Hampshire Co., Mass.," has been recently published by Mr. A. A. Julien in the Annals of the New York Academy of Sciences, Vol. i, No. x (see this Journal, xix, 237, March, 1880). It is proper that we should state here that most of the results of this paper, including every analysis, had been completed previous to the appearance of that of Mr. Julien, and when we had no further knowledge of its contents than is suggested by the preliminary notice of cymatolite published by him in this Journal for May, 1879 (xvii, 398). The fact, however, that Mr. Julien was engaged upon this investigation and had been at work upon it for several years was known to us, and we felt it only right that we should defer the publication of our article until his had appeared. It will be seen that our results, though arrived at independently and based upon material from a different source, in many cases confirm those of Mr. Julien, and this, as we believe, adds much to the interest of the whole subject. Our conclusions, however, differ essentially in some respects. We have found that cymatolite is not a true species, but only a mechanical mixture of albite and muscovite. This fact, taken with the presence of the analogous complex substance, β spodumene, makes it now possible to give a reasonably clear and thorough explanation of all the changes involved in this most interesting case of pseudomorphism.

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A. UNALTERED SPODUMENE.

The greater part of the unaltered spodumene occurs in confusedly crystalline masses, showing distinct cleavage, but seldom any approach to crystalline form. It is possible to obtain the mineral nearly pure, though somewhat intermingled with albite, in blocks weighing several hundred pounds. In this form the spodumene has a dull white color; it is in many cases somewhat discolored, and is only partially translucent; the cleavage surfaces are often coated with delicate dendrites of manganese oxide. The associated minerals, in addition to the albite and a little quartz and mica, are apatite, lithiophilite, columbite, garnet and uraninite, with various other uranium minerals formed from alteration.

In addition to this massive variety, the spodumene also occurs in an unaltered condition as nuclei of distinct pseudomorphous crystals. These crystals often occur of enormous size, imbedded for the most part in massive quartz, though sometimes extending into the albite. The nucleus of spodumene (see below and figures 1a, 5, 8, 14, Plate IV*) is in every case sharply separated from the altered mineral surrounding it, and its characters show that the crystals must originally have had rare beauty. One of the finest crystals that we have found thus far had, as imbedded in the quartz, a length of three feet, a width of eight inches and a thickness of two inches. The unaltered spodumene, of a fine amethystine color, made up about one-fourth of the whole, extending rather regularly through the middle of the crystal. Unfortunately, the spodumene was much rifted and fractured, so that its former transparency had, for the most part, disappeared. The exterior of the crystal consisted principally of β spodumene, with small quantities of cymatolite and albite. Another altered crystal was measured while imbedded in the quartz, of which a length of over *four feet* was exposed. It is not possible to extract these crystals entire, but many fragments have been obtained which have a width of over a foot across the prism and a thickness of two to four inches. In habit the crystals are much like those from Norwich, Massachusetts. They are generally broad or flat, through the development of the orthopinacoid, and comparatively thin; not unfrequently they are well terminated. Occasional stout crystals, having a square prismatic form, much like pyroxene, are also observed.

In the better specimens the spodumene is perfectly transparent, sometimes colorless, and again of a beautiful rose-pink or amethystine-purple color. It shows the prismatic cleavage with unusual perfection, and that of the clinopinacoid irregu-

* Figures 1 to 14 inclusive are to be found on the accompanying Plate, the other figures (15-20) are in the text.

larly. The angle of the prismatic cleavage—viz., $87^{\circ} 13'$ —was obtained with great exactness.

Chemical composition.—An analysis of the transparent pink spodumene was made by Mr. S. L. Penfield with the following results. Specific gravity = 3.193.

	I.	II.	Mean.		Ratio.
SiO ₂	64.32	64.18	64.25		1.071 4
Al ₂ O ₃	27.14	27.26	27.20	.262 }	.263 .98
Fe ₂ O ₃	0.18	0.22	0.20	.001 }	
Li ₂ O	7.64	7.59	7.62	.254 }	.260 .97
Na ₂ O	0.39	0.39	0.39	.006 }	
K ₂ O	tr	tr	tr		
Ignition	0.24	0.24	0.24		
	99.91	99.88	99.90		

The ratio of Li₂O : Al₂O₃ : SiO₂ = 1 : 1 : 4 ; this corresponds to the oxygen ratio* of 1 : 3 : 8. The formula is then, neglecting the very small amount of soda,



This result agrees exactly with that reached by Dœlter in his investigation of the composition of spodumene,† and with that of Julien.‡ It is to be noted, however, that the percentage of lithia here obtained is higher and that of soda lower than in any analyses previously published. For example, Dœlter found in the Norwich mineral 7.04 Li₂O, 1.10 Na₂O and 0.12 K₂O; in that from Brazil 7.09 Li₂O and 0.98 Na₂O. Julien obtained in the Goshen spodumene 6.89 Li₂O, 0.99 Na₂O, 1.45 K₂O; and in that from Chesterfield 6.99 Li₂O, 0.50 Na₂O, and 1.33 K₂O. Dœlter concludes for the Norwich mineral that the amount of lithia obtained is rather too small than too large, and attributes the soda present to incipient alteration. The correctness of this view seems to be proved by the analyses here published of the Branchville mineral, which certainly left nothing to be desired in regard to purity or freedom from alteration. The great tendency of spodumene to change by the assumption of potash or soda and loss of lithia will be made evident by what follows.

B. ALTERATION OF SPODUMENE.

As the result of the alteration of the spodumene, we have found two substances which at first sight seem to be homogeneous, and each of which has a definite chemical composition, and which, notwithstanding, are only intimate mechanical mixtures of two species; one of these, called by us β spodumene, is made up of albite and a new lithia mineral to which

* This ratio was obtained by Brush from analyses of the Massachusetts mineral in 1850. *Am. Jour. Sci.*, II, x, 370.

† Tschermak, *Min. u. Petr. Mitth.*, i, 517, 1878.

‡ *l. c.*, p. 325.

we have given the name *eucryptite*; and the other is cymatolite, an aggregate of albite and muscovite. We have also found the following independent minerals:—albite, microcline, muscovite, and killinite. The two complex substances and all of the last named minerals, except the mica, occur as distinct pseudomorphs, having the form of the spodumene. The mica, taken independently of its constant associate the albite, plays only a secondary part. In addition there are other pseudomorphs, of composite character, consisting, as Mr. Julien has well expressed it, "of vein granite."

We will first give the physical and chemical characters of the various minerals (including the two aggregates) taken separately, and then go on to describe more minutely the way in which they are associated together.

I. PRODUCTS OF THE ALTERATION.

1. β Spodumene.

The substance which we have, for convenience, called β spodumene, since we do not regard it as deserving an independent name, seems to mark the first step in the alteration of the spodumene.

Physical characters.—It is a compact, apparently homogeneous mineral, having a rather indistinct fibrous to columnar structure, this being always at right angles to the adjoining surface of the original mineral. Hardness 5.5 to 6; specific gravity 2.644–2.649. Color white to milk white, and again slightly greenish-white; translucent. Fusibility=2.25.

Chemical composition.—Analyses of three independent specimens have been made by Mr. S. L. Penfield. Number 1 was taken from a crystal, part of which consisted of the transparent pink spodumene, described above, and the outer portion was this mineral (similar to fig. 5). The line of demarcation was perfectly sharp, so that the purity of the material analyzed cannot be questioned. The results of the analysis are as follows:—

No. 1, G.—2649.	I.	II.	Mean.		Ratio.
SiO ₂	61.35	61.42	61.38		1.023 4
Al ₂ O ₃	26.26	25.74	26.00	.253 }	.255 .99
Fe ₂ O ₃	0.24	0.24	0.24	.002 }	
Li ₂ O	3.63	3.59	3.61	.120 }	.254 .99
Na ₂ O	8.32	8.25	8.29	.134 }	
K ₂ O	tr	tr	tr		
Ignition	0.46	0.46	0.46		
	<hr/>	<hr/>	<hr/>		
	100.26	99.70	99.98		

The second portion analyzed was from a fragment of a large and entirely altered crystal; its dimensions were 9 by 8 by 2½ inches. It consisted mostly of cymatolite, and the β spodu-

mine had all the appearance of passing insensibly into it; a single fragment, across the prism, could be obtained made up of both minerals, the fibrous structure of the one being continued in the other (similar to fig. 1b). The analysis yielded:—

No. 2, G.—864.	I.	II.	Mean.		Ratio.
SiO ₂	61.46	61.57	61.51		1.028 4
Al ₂ O ₃ not determined		26.56	26.56		.258 1
Li ₂ O	3.55	3.44	3.50	.117	} .249 0.97
Na ₂ O	8.15	8.13	8.14	.131	
K ₂ O	0.15	0.15	0.15	.001	
Ignition	0.29	0.29	0.29		
		100.14	100.15		

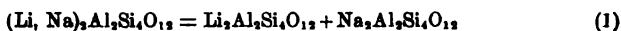
The third portion was part of a smaller and well developed crystal, having the external prismatic form complete. It consisted in the interior of spodumene, then the β spodumene making up the greater part of the whole, and finally a thin crust of cymatolite. The specimen analyzed was, as far as the eye could detect, perfectly pure and homogeneous. The color was greenish-white and it was decidedly translucent. The analysis afforded:—

No. 3, G.—869.	I.	II.	Mean.		Ratio.
SiO ₂	61.78	61.64	61.71		1.028 4
Al ₂ O ₃	26.57	26.69	26.63		.259 1
Li ₂ O		3.83	3.83	.128	} .260 1
Na ₂ O		8.16	8.16	.132	
K ₂ O		tr	tr		
Ignition		0.21	0.21		
		100.53	100.54		

If the mean analyses of the three groups be compared, it will be found that they agree very closely with one another; in fact the agreement is as close as could be expected for three successive analyses made upon the same material. But, as will be seen from what has already been said, the three samples were entirely *independent*, being taken from different parts of the ledge and differing in manner of association; the agreement between them thus becomes very striking. The ratio obtained for each

$$R_2O : R_2O_3 : SiO_2 = 1 : 1 : 4$$

is the same as that of spodumene, from which it differs only in this: that one-half of the lithium has been removed and its place (chemical equivalent) taken by sodium. The formula is then:—



It is shown below that the formula given in (2) is the correct one.

The facts stated thus far would seem to be sufficient to prove that the mineral was homogeneous and had a definite composi-

tion; there are, however, other facts which have an important bearing upon this point.

It was found by Mr. Penfield that, although the mineral gelatinizes with acid, it is not entirely decomposed. On the contrary, it is divided into two portions by the treatment with hydrochloric acid, viz:—a soluble portion (A), and an insoluble remainder (B), the latter including also the silica extracted from the soluble part. The results of three analyses gave

	A. Soluble in HCl.	B. Insoluble in HCl, with SiO ₂ from A.
No. 1	(17·97)	82·03 = 100·
2	16·65	83·01 = 99·66
3	17·91	82·18 = 100·09

In the case of No. 2, complete analyses of both the soluble and insoluble portions were made; these were independent of the total analyses of the same sample already given. The method of analysis was, briefly, as follows:—A gram of the mineral was digested with HCl, evaporated to dryness, then moistened with HCl and a second time evaporated to dryness. After being again moistened with HCl the soluble portion, A above, was filtered off and the alumina and alkalis determined in it by the usual methods. The insoluble portion, which included the silica extracted from A, after being weighed, was boiled with Na₂CO₃ and (in the case of No. 3) with a little KOH. By this means the soluble silica of A was dissolved out and the insoluble remainder being weighed, the amount of the soluble silica was determined by the difference. Finally, the insoluble part was analyzed in full by the usual methods. The results of the analyses were as follows:

	No. 2.
B. Insoluble in HCl with silica of A	83·01
Insoluble remainder after treatment with soda	67·56
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	15·45
A. Soluble in HCl (16·65), plus silica extracted by soda from B	32·10

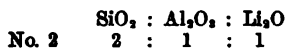
The two parts, therefore, into which the original mineral is divided by hydrochloric acid, are:—

	No. 2.
A. Soluble portion	32·10
B. Insoluble portion	67·56
	<hr/>
	99·66

The composition obtained for A was as follows:—

	A. Soluble portion.		
	No. 2.	Calculated to 100.	Calculated from formula.
SiO ₂	15·45	48·13	47·51
Al ₂ O ₃	13·00	40·50	40·61
Li ₂ O	3·50	10·90	11·88
K ₂ O	0·15	0·47	----
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	32·10	100·00	100·00

For the above analysis the ratio is, nearly:—



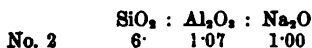
This corresponds to the formula, $\text{Li}_2\text{Al}_2\text{Si}_2\text{O}_8$, the percentage composition of which, given above, agrees well with the analysis.

The composition obtained for B was:—

B. Insoluble portion.

	No. 2.	Calculated to 100. No. 2.	Calculated from formula.
SiO_2	46.06	68.18	68.62
Al_2O_3	13.56	20.07	19.56
Na_2O	7.94	11.75	11.82
	67.56	100.00	100.00

The ratio calculated from the preceding analysis is:—



This ratio is very closely that of *albite*, viz: 6:1:1, so that the formula for the insoluble portion is $\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_8$.

An analysis was also made of sample No. 3, but the separation was a little less complete than of No. 2; the first digestion in acid left behind a very little of the soluble mineral, as shown by the presence of lithia in B, and then in the subsequent treatment of the insoluble part (in which also KOH was employed) there seemed to have been a slight decomposition of the albite. The results, although for the reason given hardly worth putting on record, were satisfactory in this, that they confirmed those of No. 2.

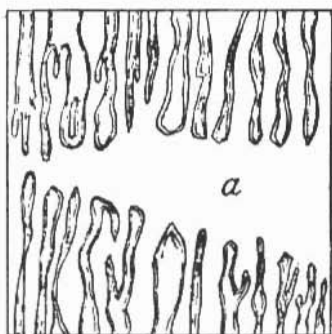
The point thus far established may be stated as follows: A chemical examination proves that the substance, called provisionally β spodumene, is not a distinct species, but only a very uniform mixture of two minerals; one of these, called by us *eucriptite*, dissolves with gelatinization in hydrochloric acid, and has the composition, $\text{Li}_2\text{Al}_2\text{Si}_2\text{O}_8$; the other, not attacked by acid, is *albite*, $\text{Na}_2\text{Al}_2\text{Si}_2\text{O}_8$. The true expression of the chemical composition of the substance is, therefore, seen to be that (2) given above. That the mixture is truly mechanical, and not a molecular one broken up by the acid (if that were possible), is proved by this significant fact: the insoluble residue (B above), left after the digestion in sodium carbonate, was in one case examined under the microscope, and found to be *crystalline*, and to have by the way the regular semi-fibrous structure belonging to the pseudomorphous *albite* as described below.

The microscopic examination of thin sections of β spodumene confirms the results reached from the chemical side as to

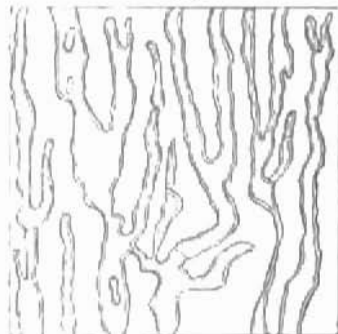
the complex nature of the substance, and gives, in addition, a very satisfactory determination of the crystalline character of the new lithia mineral. A series of thin sections were prepared, some parallel to the fibrous structure, that is at right angles to the original mineral (spodumene), and others transverse to the fibers and consequently parallel to the original prism. The sections parallel to the fibers, when examined under the microscope, seemed at first sight to give no proof of want of homogeneity. The fibers, seemingly of rounded form, and though in general parallel yet quite wavy in outline, are packed so closely together that the question of the presence or absence of any substance between the fibers and enclosing them could not be answered; the whole gave the effect of aggregate polarization. The above statement is true for the greater portion of each of the slides—the result thus far was negative.

Occasional irregularities, however, in the usually parallel fibrous structure, which may not inaptly be compared in appearance to the grain of wood-fiber in the neighborhood of a knot, as seen in a smooth board, gave better results. The fibers in such cases are much curved and irregular in outline, and so separated from one another that they are seen to be merely enclosures in a surrounding matrix. In other cases, this enclosing material forms open spots, where the structure (in polarized light) is found to be that of ordinary albite, and into this the needle-like fibers of the other mineral project (this is illustrated in fig. 15, *a* = albite). Still again, on the edges of the sections

15.



16.

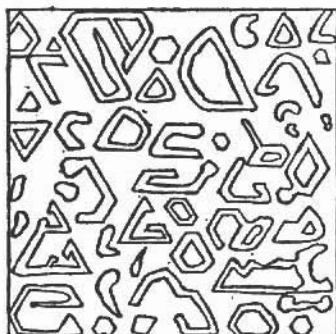


where a degree of thinness impossible for the whole slide is sometimes attained, a satisfactory result is reached. The fibers in such sections are distinctly seen, independently of each other and of the enclosing albite. They are generally nearly straight and parallel, but not infrequently the shape is more or less irregular; branching forms recalling some kind of coralline

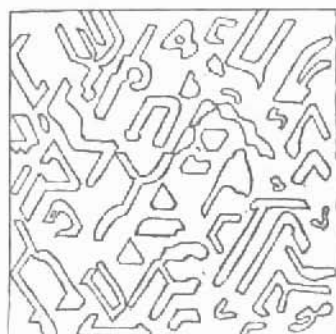
structure are common. The latter forms are shown in fig. 16; the fibers here are much more irregular and coarser than is generally true. (Compare also fig. 19.) The fibers are apparently rounded but the outlines are usually indistinct, and the form can be made out only by repeatedly changing the focus of the microscope. The explanation of all these irregularities in outline is given by the result obtained on examining the sections cut transverse to the fibers. Several additional facts were brought out in the study of the sections now described. It was found that, when examined between crossed Nicols, the extinction of the light took place *parallel* to the length of the fibers; moreover, the fibers have not infrequently a transverse fracture, probably indicating cleavage. The form of the terminations of the needles could not be certainly observed. In cases like those above described (fig. 15), the extremities seem to be given entire, but no absolute assertion can be made in regard to them. In many cases, probably the majority, they taper out gradually to a fine point, while in others they seem to be terminated by a low pyramid.

The examination of the other set of sections, cut across the fibers, was even more satisfactory and conclusive. The appearance in polarized light, as the plate is revolved on the stage of the microscope, is at once striking and beautiful. The section as a whole is divided into irregular patches (albite), changing from dark to light and the reverse with the revolution, giving the whole a strangely mottled look. Distributed closely and

17.



18.



uniformly through this matrix are seen also minute areas of another substance, sometimes curved but generally bent at an angle of 60° or 120° ; they are *unchanged* by the revolution between the crossed Nicols. The effect will be best appreciated from the accompanying sketches (figs. 17, 18). When a high power is employed (say 600 diam.) and the attention is confined to a small portion at once, it is seen that these narrow bands, which

in a cursory glance under a low power seem to be quite irregular in form, are, on the contrary, approximately in parallel position. The solid portions are triangular or hexagonal in outline, and the bands are bent at angles of 60° and 120° , sometimes so as to form complete rings;—they are all more or less rounded. In short, the structure is that of the most regular pegmatite or “graphic granite,” and the explanation is the same. These regular forms, like those of the quartz in the feldspar in the other case, are due to the restricted crystallization in the albite of the new mineral in question. They mark the mineral as belonging to the hexagonal system, and the result of the optical examination both parallel and transverse to the fibers confirms this conclusion.

Taking the section as a whole, there are portions in which the directions of the new mineral are quite irregular, but for the greater part there is an obvious tendency toward regularity, sometimes leading to most perfect forms. As would be expected, the axial directions (60°) change at small distances, so that a given set of directions belongs only to a limited area; this is obviously determined by the enclosing albite.

We are now able to connect the results of the microscopic examination with those of the earlier chemical investigation. The enclosing material in which the fibers lie is the *albite*; this is proved indeed by what has been stated, and moreover by the fact that it, whenever distinctly separate, has the same structure as in undoubted cases of the same pseudomorphous material; it is also shown by the examination of the insoluble portion alluded to before, for in this the fibers have been removed and the matrix left unattacked. The enclosed mineral is that which with the albite makes up the β spodumene, having the composition $\text{Li}_2\text{Al}_2\text{Si}_2\text{O}_6$.

In view of the fact that this lithia-bearing mineral is thoroughly defined, as well crystallographically as chemically, and considering, moreover, the important part it plays in the history of the spodumene, we feel obliged to give it a distinctive name. We call it *eucryptite*, from *εὖ* well, and *κρυπτός* concealed.

EUCRYPTITE crystallizes in the hexagonal system, with probably basal cleavage. Its specific gravity, calculated from that of β spodumene, 2.647 and that of the pseudomorphous albite 2.687, is 2.667. It gelatinizes with hydrochloric acid and fuses easily. It is a unisilicate, and its chemical composition is expressed by the formula $\text{Li}_2\text{Al}_2\text{Si}_2\text{O}_6$ = silica 47.51, alumina 40.61, lithia 11.88 = 100.00. Its mineralogical relations are not very certain; still, in form, and essentially in composition, it is analogous to nephelite. It also might be viewed as a lithia-anorthite, it having the same ratio as anorthite; though it is different crystallographically. On the other

hand, the fact that it changes so readily into muscovite, and has the same ratio as the normal varieties of that species, might seem to place it near it; but it certainly has no micaceous structure. The true lithia mica (lepidolite) has a very different composition.

2. *Cymatolite.*

The name cymatolite was given in 1867 by Prof. Shepard to a mineral found at Goshen and Norwich, Mass., a result of the decomposition of spodumene. The analysis given by him left the composition of the supposed new mineral in question, and this doubt was not removed by a subsequent analysis by Mr. B. S. Burton. Mr. Julien gives in his paper several analyses of cymatolite which agree well together and which correspond to a simple chemical formula. In our earlier investigations we assumed it to be an established point that the species was a good one and had a definite composition. This assumption was confirmed by two closely agreeing analyses (given below) made upon the Branchville material. Further study, however, which was made necessary by the results reached in the case of β spodumene—for the cymatolite is directly derived from the β spodumene—has convinced us that the supposed species is only a remarkably uniform and intimate *mechanical mixture of muscovite and albite*. We shall, however, throughout this paper retain the name cymatolite as a convenient way of designating this interesting compound substance, and shall describe it first as if it were a true species.

The *physical* characters of the cymatolite of Branchville are as follows:—It has a distinct fibrous structure, sometimes straight but more generally wavy. It is also at times confusedly fibrous and again scaly. The specific gravity = 2.692–2.699. The color is generally white, but it is often slightly discolored and occasionally it has a faint pink hue.

As has been stated on p. 258, the crystals of spodumene, which have been altered to cymatolite, are numerous and often very large. The way in which the fibrous structure is developed is seen in fig. 2, which is a section across the prism. It is usually true, as seen here, that the direction of the fibers at the edge is at right angles to the bounding surface. In the interior the structure is more irregular and the fibers interlace in an intricate manner, giving sometimes a feather-like appearance. Usually all trace of the original prismatic structure and cleavage of the spodumene has disappeared. In rare cases, however, in the interior of a crystal this longitudinal structure is still apparent, although the direction of the fibers remains transverse. (Compare also other figures in the Plate, in which *c* = cymatolite.)

Two analyses of cymatolite have been made by Mr. Penfield. Number 1 was made from a portion of an entirely altered crystal; it was perfectly white and apparently free from any impurities. The results are as follows:—

No. 1, G.—2062.	I.	II.	III.	Mean.	Ratio.
SiO ₂	59.38	----	----	59.38	.989 4
Al ₂ O ₃	26.67	----	----	26.67	.259 1.05
CaO	0.62	----	----	0.62	.011
Na ₂ O	----	7.66	7.70	7.68	.124
K ₂ O	----	3.53	3.49	3.51	.037
H ₂ O	2.01	----	----	2.01	.111
				99.87	

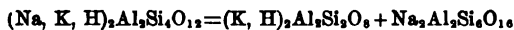
The second analysis was made on the pure mineral associated on the same crystal, which afforded sample 2 of β spodumene. The results afforded are, as follows:—

No. 2, G.—2066.	I.	II.	Mean.	Ratio.
SiO ₂	60.61	60.49	60.55	1.009 4
Al ₂ O ₃	26.37	26.39	26.38	.256 1.016
MnO	0.08	0.06	0.07	
Na ₂ O	8.08	8.16	8.12	.131
K ₂ O	3.33	3.35	3.34	.035
Li ₂ O	0.17	0.17	0.17	.006
H ₂ O	1.65	1.66	1.65	.091
	100.29	100.28	100.28	

The agreement between these two analyses is as close as could be expected; the ratio obtained from No. 2 is nearly

$$\text{H}_2\text{O} : \text{Al}_2\text{O}_3 : \text{SiO}_2 = 1 : 1 : 4.$$

This is the same ratio as that obtained for spodumene and β spodumene. The formula is therefore



Since the cymatolite is certainly derived from the β spodumene, while the latter substance has been proved to be a mixture of albite and what—as was shown—has the composition of a lithia muscovite, the fact that the formula of cymatolite can be written as a compound of one molecule *muscovite* and one molecule *albite* is significant. Were no other facts at hand the conclusion that cymatolite also must be a mechanical mixture could hardly be questioned. The facts, however, are in themselves sufficient to prove this, independent of any other considerations. It may be mentioned that the chemical method of attacking the problem, employed in the case of the β spodumene, is not here applicable, since the muscovite is not decomposed by hydrochloric acid. A preliminary examination was made with sulphuric acid, which resulted in showing that the cymatolite was attacked by it, as was the mica of the locality, while the albite was barely so. This method was, however, not carried further, for the microscope gave all the solution that could be desired.

A considerable number of sections of cymatolite, both in its purest normal varieties, and in its transition forms from β spodumene on the one hand and to albite on the other, were examined. The result not only proved the fact of the mixture of muscovite and albite, but also gave the explanation for the remarkable uniformity of the analyses, for in most cases the mixture is in the highest degree intimate. A section of cymatolite like that represented in fig. 1c (Plate), when examined in polarized light, is found to consist of long, slender, somewhat curved fibers, giving very brilliant colors and showing the characteristic structure of mica, and between them grayish portions of albite. In some cases the fibers of mica are so close together that the albite is invisible, but in others they spread out divergent and then the background of the other mineral is clearly seen. Still again, the mica needles are few and run out in brilliant lines over a broad surface of albite.

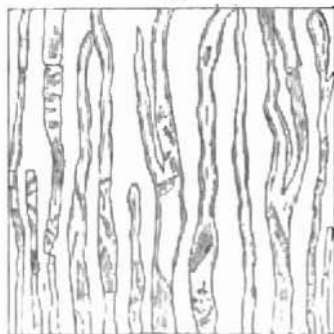
The sections increase in beauty with the irregularity of the structure of the cymatolite. For example, two sections were made from the crystal represented in fig. 2 (Plate). One of these was, like the figure, transverse, and the other was vertical, and showed something of the prismatic structure of the original spodumene. All the details of the structure came out most clearly in the sections in polarized light. The feather-like structure was particularly distinct and beautiful: a deeply colored rib of mica, and from this diverging regularly on both sides the narrow fibers of the same mineral, the albite between them becoming more and more distinct as their distance apart increased. Other sections were examined of the scaly varieties of cymatolite, where the mica scales were parallel to the surface. In these the albite had the mottled appearance in polarized light, mentioned under β spodumene, and the mica was scattered very uniformly as brilliantly colored scales through it. Other sections transverse to the fibers, in the distinctly fibrous kinds, gave somewhat different effects. Many details could be added, but enough has been said to make the character of the observations apparent on which the statement as to the compound nature of cymatolite is based. The mica and albite are always distinct from one another. In some cases they both appear in larger masses having segregated together in the process of alteration. More is said about this later.

The only foreign mineral observed in the slides was one which occurs in hexagonal prisms, and can hardly be anything but *apatite*, as it agrees optically and crystallographically with that species. It is seen scattered through the cymatolite sometimes rather abundantly, occasionally also in the β spodumene, it is, however, not for a moment to be confounded with eucryp-

tite. The presence of apatite would explain the lime found in analysis 1 of cymatolite.

Certain of the sections which show the transition from β spodumene to cymatolite are most interesting and instructive. While in much of the cymatolite there seems to have been a tendency to the partial separation of the mica and albite, there are other specimens in which the two are as intimately mixed as the eucryptite and albite in the β spodumene. In cases like those last named, the structure of the cymatolite is exactly that of the β spodumene, only that the rounded fibers of eucryptite have been replaced by the thin elongated scales of mica, proving that the one has been formed from the other. In still other cases we may pass on the same slide from normal cymatolite on the one side to normal β spodumene on the other. Between them is a zone where the two substances shade off into one another, in other words where the change of the eucryptite is only partial. This will be understood from fig. 19. As

19.



here seen, some of the fibers are apparently unchanged, while others are partly altered, the last containing many minute scales of mica, often packed closely together. These small scales are irregularly situated, often across the original fiber of eucryptite: the direction can always be observed both by the cleavage line and too by the direction of the extinction of the light between crossed Nicols. Where the process has been completed, however, the scale of

mica is generally parallel to the line of the original eucryptite. The eucryptite fibers along this intermediate zone, even when mica scales are not visible, have generally lost their smoothness of outline, and sometimes have separated into lines of minute, irregular, transparent granules.

The transition of β spodumene into cymatolite can also often be seen by the unaided eye, along the line of contact. In such cases the silvery lines of mica, though the scales are too minute to be distinguished, can be seen shooting up into the compact β spodumene.

3. *Albite.*

The albite, which occurs pseudomorphous after spodumene, appears in several rather distinct varieties. It is sometimes finely granular, showing no crystalline structure. Again it has a fibrous structure, similar to that of β spodumene and cymatolite, the fibers transverse to the prism. Still again it is

found forming parts of altered crystals, in which it has the curved and wavy laminated structure which is characteristic of the mineral that makes up so large a part of the vein; it also appears as rosettes implanted on the surfaces of many crystals, evidently owing its origin in such cases to the alteration.

An analysis of the fibrous variety of the species afforded Mr. Penfield the following results:—

G.—2687.	I.	II.	Mean.	Ratio.	
SiO ₂	67·61	67·59	67·60	1·127	6·
Al ₂ O ₃	20·07	20·11	20·09	1·195	1·03
MgO	·16	·14	·15	} ·193	1·02
Na ₂ O	11·71	11·66	11·69		
K ₂ O	·11	·11	·11		
Ignition	·14	·14	·14	} ·001	
	99·80	99·75	99·78		

This analysis corresponds closely to the formula Na₂Al₂Si₂O₁₀, or that of albite.

The occurrence of albite pseudomorphs after spodumene is mentioned by Mr. Julien, but among the Massachusetts specimens they seem to play a comparatively unimportant part. Mr. Julien speaks of the albite as mixed with a little muscovite and quartz, and states that these pseudomorphs are “a mere variety” of the coarse agglomerates of quartz, feldspar and mica, which he calls pseudomorphs of *vein granite*.

At the Branchville locality the albite as an independent mineral occupies a more common and perhaps more interesting place among the products of the alteration of the original spodumene.

The fibrous albite, of which the above analysis was made, formed the whole of a perfectly distinct crystal. A section was made of it and examined microscopically. It was found to be essentially pure, with only traces of mica (note the potash in the analysis). The structure was rather indistinctly fibrous and it was most interesting to note that its appearance was very closely that of the albite with the mica in cymatolite, as too with eucryptite in β spodumene. A number of the groups of fibers were found to consist of two parts optically, and the angle between the extinction of the light for them was from 10°–11°. As this is the angle for albite twins examined parallel to the basal plane, the agreement can hardly be accidental, and is a point of some interest.

A number of other sections of what we have called albite were also examined. The result proves that pure albite is rather rare, and that most of the granular albite in the crystals contains a considerable quantity of mica, and hence verges toward cymatolite. This qualification is to be remembered in examining the plate. In many cases the albite is found to be in broad plates characteristically twinned, and with them are

found scales of mica, large too as compared with those in normal cymatolite.

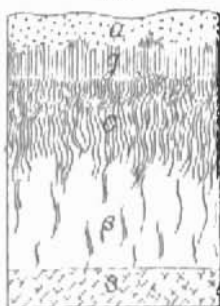
4. *Muscovite.*

As a distinct mineral, independent of its usual associate the albite, the potash-mica, muscovite, plays an unimportant part among the spodumene pseudomorphs at Branchville. It occurs very commonly in thin scales coating fracture-surfaces in the interior of the altered crystals. It is also found in small segregated masses, or as scattered plates imbedded in the mass of the crystal itself. It occurs in this way more particularly in the complex pseudomorphs where the feldspars (albite and microcline) are also present in distinct masses. Its presence is indicated in figs. 6 and 8 (Plate, g =mica). This mica is commonly of a light greenish-yellow color and has a greasy luster; in some cases though more rarely it is pink in color, but is not a lithia-mica. It was not found possible to obtain enough pure material for an analysis.

The occurrence of the mica with the albite, forming the cymatolite, has already been described under that head. The analyses of the cymatolite show that the mica has the formula of normal muscovite, viz: $(K, H), Al, Si, O_2$. Taking the ratio of $K_2O : H_2O = 1 : 3$, corresponding approximately to analysis 2, the calculated composition of this muscovite is:—

SiO ₂	46.23
Al ₂ O ₃	39.52
K ₂ O	9.35
H ₂ O	5.20
	100.00

The complex nature of cymatolite having once been established, it is easy to find many specimens in which the mica and albite are so distinct that their independent existence can be proved by the unaided eye. The occurrence of albite containing small quantities of mica has been mentioned. Conversely, we find specimens in which the mica is more or less completely separated from the albite. Fig. 20 shows a part of a section across a crystal, with the nucleus of spodumene (s), then β spodumene (β), next cymatolite (c) graduating into pure and soft silvery mica (g), and finally a coating of albite (a). Such a case shows the extent to which the segregation of the constituents of the cymatolite can go on.



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In the Massachusetts specimens, the mica, as an independent mineral, is, according to Mr. Julien, much more abundant. We quote, on a following page, a remark of his on this point.

6. *Microcline.*

A second potash mineral, arising from the alteration of the spodumene, is a potash feldspar having the composition and optical character of microcline. This is a much rarer occurrence than that of the albite pseudomorphs. The microcline, where it occurs alone, which is seldom, has a fine granular structure, showing no cleavage whatever. The color is yellow, and under the microscope it is resolved into independent grains having the characteristic appearance of microcline in polarized light. In the best specimen observed, the crystalline planes, both prismatic and terminal, are perfectly distinct, but nothing was left of the original mineral. This pseudomorph consisted, for the most part, of the potash feldspar, but a small portion of one side was soda feldspar (or albite). The relation of these two minerals is shown in fig. 10, a case in which the albite is present in much larger quantities than in that described, it making up about half the crystal.

The composition of the yellow granular feldspar is shown by the following analysis by Mr. Penfield:—

G.—7448.	I.	II.	Mean.	Ratio.	
SiO ₂	64.55		64.55	1.076	6
Al ₂ O ₃	19.70		19.70	.191	1.07
K ₂ O	15.66	15.59	15.62	.166	} .176 .98
Na ₂ O	0.53	0.64	0.58	.010	
Ignition	0.12	0.12	0.12		
			100.57		

It will be seen that the above analysis corresponds very closely with the normal composition of microcline, $K_2Al_2Si_2O_{10}$.

Figures 3 and 4 show further the manner in which the potash feldspar is contained in the interior of the soda feldspar, both forming part of perfectly distinct pseudomorphous crystals of spodumene. In addition to this method of occurrence, the microcline is also observed in broad cleavage plates forming sometimes almost entire crystals of the original mineral. Here, too, it is commonly associated with albite, as shown in figs. 11 and 13. One most interesting and significant fact in connection with this is that the separate fragments of microcline scattered through a single crystal at different points, though sometimes several inches apart, are uniformly in *parallel position*. The angles of the cleavages of the microcline differ in different specimens, so that their position seems to have no definite relation to the axes of the spodumene crystals.

It is worth while to call attention here to the fact that the potash feldspar, microcline, occurs in very large quantities at this locality. Several hundreds of tons have already been taken out by the Messrs. Smith for use in making porcelain. The

feldspar is obtained in cleavage masses as large as can be handled, and nearly pure; a single continuous cleavage surface ten feet long has been observed in the ledge.

6. *Killinite.*

Killinite is a hydrous silicate of aluminum and potassium ordinarily included among the pinite group of minerals. It was first described from Killiney Bay, Ireland, and a series of analyses is published in the Mineralogy of Greg and Lettsom. It was described as occurring in granite associated with spodumene, and has its cleavage. The same mineral is described by Mr. Julien as occurring at Chesterfield, Mass. Our results, which we give here, are for the most part identical with his.

The killinite from Branchville is sometimes compact and structureless, but more generally it has an indistinct fibrous structure parallel to the prism of the original mineral. Many specimens show distinctly the cleavages of the original spodumene. The color ranges through various shades of green, from light bluish-green to oil-green and dark grass-green.

Two analyses, on independent material, have been made for us; the first, number 1, is by Mr. S. L. Penfield, of the prismatic variety; and the other, number 2, is by Mr. F. P. Dewey, of the compact variety.

	No. 1.	No. 2.
SiO ₂	48·93	53·47
Al ₂ O ₃	34·72	32·36
Fe ₂ O ₃	0·54	0·79
FeO	0·33	0·42
MnO	0·64	0·72
CaO	----	0·17
K ₂ O	9·64	7·68
Na ₂ O	0·35	0·44
Li ₂ O	----	0·04
H ₂ O	5·04	4·07
	100·19	100·16

The two analyses show a rather wide variation in composition between the material analyzed in the two cases. If, moreover, the analyses referred to above as published by Greg and Lettsom be compared together, and with that of Mr. Julien from Chesterfield Hollow and those here given, it will be seen that they vary between quite wide limits. It cannot be doubted, however, that essentially the same material was under examination in the several cases, and that the difference noted is probably due to a want of homogeneity.

Killinite gives water in the closed tube. B. B. glows and fuses at about 5 to a white enamel. Not decomposed by hydrochloric acid.

Several sections of killinite were examined in the microscope. The parallel fibrous structure is there clearly seen and

in addition there appear to be scales inclined at equal angles in opposite directions on either side of each parallel line. They exert a considerable action on polarized light. Most of the specimens are of so fine a texture as not to allow of satisfactory resolution. One section, however, which was somewhat coarser, seems to offer an explanation. This one appeared to consist mostly of minute scales having all the appearance of *mica*. These scales were strikingly similar to those of unquestioned character formed from the alteration of eucryptite and illustrated by fig. 19. There seems to be but little doubt that this is the true resolution of the mineral. In addition to these scales, there are small portions which do not polarize light, which may be amorphous silica, and occasional other particles less easily defined.

The idea of a relation, between the minerals of the pinite group and those potash micas which yield water on analysis, is not a new one, but was long since advanced. It is recognized by Professor J. D. Dana, in the 5th edition of his *System of Mineralogy* (1868), p. 447.

If analysis 1 of killinite be compared with the composition of muscovite on p. 272, and also with the analyses of muscovite in Dana's *Mineralogy*, 5th edition, the correspondence will be at once recognized. The variation of analysis 2 of killinite would be explained by supposing the presence of several per cent of free silica; the correspondence would then be quite close. Moreover, the observations with the microscope have already independently led to the suggestion of the probable presence of amorphous silica. In view of the part played by mica in the alteration of the spodumene the suggestion here made certainly seems plausible, although the want of perfect homogeneity in the killinite makes it impossible to give it a definite formula.

7. *Pseudomorphs of Vein-granite.*

We employ the same term, as Mr. Julien, to describe certain pseudomorphous crystals of spodumene, which consist of a more or less coarse agglomeration of feldspar (albite and microcline), and mica. In such cases, which seem to be rarer at Branchville than at Chesterfield, the constituent minerals are well developed and have the same character as in the vein as a whole. The feldspar, for example, is not granular and without apparent cleavage, as is generally true of the special cases before described, but occurs in rather broad cleavage fragments. The surfaces of these crystals are very rough, often covered with rosettes of albite, and yet the general form of the original spodumene can always be distinctly seen. It is to be noted that quartz is almost entirely absent in these com-

plex pseudomorphs, in which they differ essentially from the Chesterfield specimens.

II. RELATION IN METHOD OF OCCURRENCE BETWEEN THE VARIOUS MINERALS PRODUCED BY THE ALTERATION OF THE SPODUMENE.

The individual characters of the several minerals produced from the change of the spodumene have already been given, and something has been said as to their mutual relations; it seems best, however, to add a few more general remarks as to their method of occurrence.

Spodumene and β Spodumene.—The way in which these two minerals occur together will be better understood from fig. 5. As indicated in this case, the alteration product, β spodumene, forms a more or less thick crust about the original mineral, and also penetrates in bands which follow the directions of the cleavage surfaces, and which are sometimes mere lines and again have considerable thickness. It is worthy of note, that in all cases the line of separation between the two is perfectly distinct, and the spodumene so associated seldom shows at most more than a trace of alteration. The direction of the fibers is, as stated, transverse to the neighboring surface of spodumene in each case, though in some cases it is so compact as to show little structure.

In one very interesting case the crystal consisted in part of β spodumene and in part of the original mineral, but the latter though unchanged in other respects had already taken the transverse structure of the former, and the longitudinal prismatic structure was nearly obliterated. This must evidently be an early step in the process of change.

β Spodumene and Cymatolite.—Many crystals and fragments of crystals which do not show a trace of spodumene exhibit these two minerals in very distinct relations. The aspect of them is such as to leave no doubt that the first passes gradually into the other, the blades of cymatolite interlacing with the less distinct fibers of β spodumene wherever the two come in contact (see fig. 1*b*). The appearance, however, is always that of two distinct substances, even when the line of union is examined under the microscope. It is consequently necessary to conclude that while the alteration went on gradually there was chemically an abrupt change from the one substance to the other. As already remarked, the analysis 2 of β spodumene was made of a portion, which, though apparently pure, immediately adjoined the cymatolite, and the result is identical with the others, where the idea of a regular gradation could not be suggested. Many of the large crystals of cymatolite, when examined carefully, show a trace of the other mineral, and we are forced to believe that at least for this locality it always preceded it.

Spodumene, β Spodumene and Cymatolite.—It only remains to speak of the cases in which all three of the minerals named occur together in the same crystal. Many instances could be given, but it will be sufficient to describe a single striking case. In figs. 1a, 1b, 1c, there are represented three sections across the same crystal. This crystal had a length of 15 inches, a width of $4\frac{1}{4}$, and was 1 inch in thickness; it was well terminated at one extremity. The sections, taken in order from the terminated end down, divide the crystal into three approximately equal parts. No. 1 (fig. 1a) shows the β spodumene (β) forming the mass of the crystal, with original spodumene (s) as a band on the lower surface, and the cymatolite (c) as a thin coating more or less continuous around the whole. No. 2. (fig. 1b) shows no spodumene, but the β spodumene forms the greater part, though the cymatolite has increased much beyond the first section. No. 3 (fig. 1c) shows only the cymatolite.

Figure 5, referred to above, shows all the three minerals, though the cymatolite is only sparingly present, and that on the edges. In figures 8 and 14 the spodumene forms a few points and small isolated portions having surfaces parallel to the cleavage. It is surrounded by β spodumene and cymatolite, the latter radiating out from the centers of spodumene. Crystals, in which only spodumene and cymatolite are present, are rare. In fig. 14 a single narrow band is shown which is still β spodumene, while all the rest is changed to cymatolite and albite.

Albite and Cymatolite.—The albite, as has already been remarked, is a common mineral among these pseudomorphs. In some cases it makes up almost the entire crystal, and again it is present only in small isolated portions. The commonest form is that which is very finely granular, although the fibrous form is not rare. It is to be remembered, however, that between the normal cymatolite (1 mol. albite + 1 mol. muscovite) and the pure albite on the one hand, and the pure muscovite on the other, there are many gradations.

Figure 3 is a vertical section of a portion of a crystal, the exterior of which is fibrous cymatolite (c), and the interior granular albite (a) with some bands of microcline (m). Fig. 7 is a section across a large crystal in which the two minerals are similarly disposed. Fig. 10 shows the albite and microcline, as also 11 and 13. Figs. 6, 8, 12, 14 show the way in which the granular albite is intermixed with the other species which have been mentioned. In still other cases, the albite is in broad curved plates, which would seem to have nothing of a pseudomorphous character except that the outlines of the spodumene crystals, of which they form a greater or less part, are still distinct.

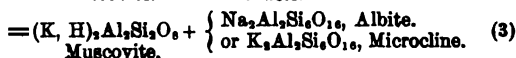
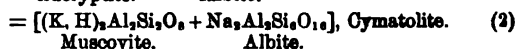
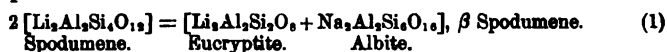
Occurrence of Killinite and Cymatolite.—In many of the massive specimens, the spodumene is changed in part to killinite and in part to cymatolite, the two minerals being intimately associated with each other. This association is illustrated by fig. 9, in which *c* is the fibrous cymatolite and *k* the killinite. The latter makes up the mass of the specimen, and the cymatolite, with its usual transverse fibrous structure, is in thin bands following nearly the original cleavage lines.

It is the confusedly massive variety of the spodumene which has furnished nearly all of the killinite. In the distinct crystals it rarely appears, though here it is sometimes seen, as indicated by fig. 12, as a more or less irregular surface covering.

III. GENETIC RELATION BETWEEN THE ORIGINAL SPODUMENE AND THE VARIOUS PRODUCTS OF ITS ALTERATION.

The general character of the process of alteration, by which the spodumene was changed into the various products already described, was, in a word, as follows:—it consisted essentially in the substitution of sodium and potassium for the original alkali lithium. The interesting facts, that have been detailed, in regard to the compound nature of the substances called β spodumene and cymatolite, taken in connection with the occurrence of the two feldspars and the muscovite, make the whole process tolerably clear and simple. The fact that two molecules of spodumene would, with a change in alkalies, yield one molecule of muscovite and one of albite, was clearly brought out by Mr. Julien; and he uses it to explain the occurrence of the complex pseudomorphs consisting of distinct individuals of albite and muscovite. The study of the specimens from Branchville enables us to extend and complete this explanation.

The relations of the various minerals involved in the change are presented in the following table, showing what may be derived from the spodumene, assuming the change in alkalies to take place.



The first step in the process of alteration was the formation of the β spodumene, by the substitution of sodium for one-half the lithium and the breaking up of the original spodumene, so as to form equal parts molecularly of *albite* and the new mineral which we have called *eucryptite*. The true nature of this second mineral has already been detailed. It would seem to be a

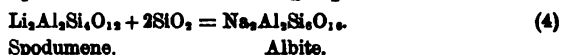
comparatively unstable compound, since it changes so readily to muscovite.

The second step in the alteration was the formation of cymatolite out of β spodumene; this change consisting in the substitution of potassium (and hydrogen) for the remaining equivalent of lithium in eucryptite, and the consequent formation of muscovite. The result is a compound, in equal molecular proportions, of *muscovite* and *albite*. It is certainly most striking that this compound substance, as derived from different localities, should be of so uniform chemical character. The explanation for this is to be found in the nature of the chemical process by which the alteration was brought about, the reaction going on uniformly through the mass, without, in the majority of cases, any distinct segregation of the two constituents formed. The change to β spodumene must have been produced by the action of a soda solution, and the subsequent change to cymatolite by that of a solution containing potash.

We have now to speak of the pseudomorphs in which the resulting minerals, mica and feldspar, appear in distinct form, and not as almost irresolvable aggregates. It was first remarked in regard to the cymatolite that in its usual varieties the mixture between the muscovite and albite was an extremely close and uniform one. This is ordinarily the case with respect to the normal material, as is exhibited in hundreds of specimens. There are others, however, of which this is not true, but where the silvery luster due to the mica is more or less absent, and the substance approximates in character to pure albite; and, on the contrary, there are others where the albite is nearly absent and the mica is nearly pure (see fig. 20). The conclusion to which these facts have led us is that there are many gradual transition cases between the normal cymatolite and the pure albite and muscovite, that is, cases, where there has been a decided separation and segregation of these two minerals. These cases, however, require no especial explanation, for that the conditions should be such as to lead occasionally to such segregations was to have been expected. It is rather remarkable that they are comparatively rare, and that normal cymatolite is the rule.

The scheme, presented above, obviously requires that the muscovite and albite should be formed in equal parts molecularly, and by weight in the ratio of 1 : 2 nearly. The question now arises, independently, as to the almost entire absence of mica not infrequently observed in connection with large masses of albite. It appears, to be sure, in separate form as a scaly covering of fracture-surfaces through the altered crystals, and occasionally in small segregated masses, but the amount so observed is much smaller than the equation requires.

We are obliged to conclude that either the muscovite, if formed at the same time with the albite, has entirely disappeared, or else that the method of formation of the albite was sometimes different from that previously explained. It can hardly be questioned that in the cases mentioned it must have been formed independently of its associate, the muscovite. Where the albite has a distinct fibrous structure it must have been formed from the β spodumene (compare also figs. 8 and 12). The albite was probably made from this by the action of a solution of sodium silicate changing the remaining lithium of the eucryptite to sodium and introducing two molecules of silica. It may also have been formed immediately from the spodumene, as expressed in the following equation :



Besides the albite pseudomorphs, there are also those consisting of the potash-feldspar, microcline, which require explanation. In regard to them, as has already been stated, there are the cases where the granular microcline is enclosed in albite, again others where it forms substantially the whole crystal, and still others where it is scattered through in large cleavage masses. Reference to formula (3) above shows that the explanation given for the albite and muscovite will answer for the microcline and muscovite, the only difference being in the alkali exchanged for the lithium. Generally, however, the mica is absent and then we must write, as in the case of the albite, taking into account the change of alkali,

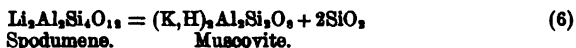


There is no reason to think that the microcline was not formed directly from the spodumene ; no trace of any potash series to correspond to the β spodumene and cymatolite was observed.

But little additional explanation is needed beyond what has been given, in the case of the coarse complex pseudomorphs, consisting of mica and the two feldspars. The method of their formation is involved in what has been given, the only essential difference being that the conditions were such as to lead to the segregation and simultaneous crystallization of the resulting minerals in large masses instead of as intimate mixtures. In connection with these it is interesting to call attention again to the fact that the masses of microcline in a single crystal, though often isolated and apparently quite independent, are yet in most cases in parallel position. This is a significant fact in its bearing upon the conditions of formation.

These agglomeration pseudomorphs seem to be more abundant at the Massachusetts localities, as described by Mr. Julien,

than with us. Moreover, they differ from those of Branchville in that they contain much more mica and also quartz, which latter mineral with us is practically absent. Mr. Julien, besides his general explanation of the relation of the soda feldspar and muscovite to the original spodumene (which as stated above we have adopted), calls attention to the fact that by an exchange of alkali and the loss of two molecules of silica, spodumene would yield muscovite—that is



He remarks upon the free quartz present in the pseudomorphs as evidence that this process actually went on.

It is interesting to note in this connection the following statement made by Mr. Julien, he says: "Many pseudomorphs were found in the Chesterfield vein which consist in large part or entirely of a greenish-yellow muscovite with peculiar greasy luster. In fact all stages of intermixture of cymatolite were observed, from the almost pure pseudomorphs of the latter mineral in which muscovite occurred only in minute or even microscopic scales lying mostly parallel to the axis of the crystal—to others in which the mica was so abundant as to have imparted a yellow or greenish color to the mixture, and at last to micaceous pseudomorphs perfectly free from cymatolite retaining the form and superficial striation of the spodumene even to its terminations." He also speaks of the occurrence of large quantities of quartz in the pseudomorphs.

In the specimens we have studied the case is reversed, quartz is nearly entirely absent, mica occurs in separate form only sparingly, and in the formation of the two feldspars there has often been an assumption of silica from some outside source.

Thus far we have said nothing in regard to one important pseudomorphous mineral—the killinite. It seems impracticable to give this a certain place in such a scheme as that given above, for the good reason that its true composition is somewhat in doubt. It is certainly a more or less impure material, having the same want of homogeneity and definite composition that is so often observed among the minerals of the pinitic group. The microscopic structure, and, too, the results of the analysis, seem to justify us in the suggestion that it may be essentially a hydrous potash mica, not very unlike that in the cymatolite. In this case its presence is not strange, for the distinction between it and the other would be more in its state of aggregation than in composition. The chemical process which led to the formation of the killinite is in any case clear, for the change consisted essentially in the introduction of potassium and hydrogen in place of lithium, with the loss of silica. It may consequently be expressed by equation (6),

given above, and the silica thus set free may have played a part (see equation 4) in the formation of albite. It is interesting to note that the killinite was probably always formed immediately from the original spodumene, since it so commonly shows its cleavages.

General Summary.—The remarks in the preceding paragraphs may be summed up as follows:—The spodumene was subjected to the action of solutions containing respectively soda and potash. The first action of the soda solution, by the partial exchange of alkali, resulted in the formation, from the spodumene, of an apparently homogeneous but really complex substance, consisting of equal parts molecularly of albite and a new lithia silicate (eucryptite.) A further action of the soda solution (sodium silicate), by the complete change of alkali and the accompanying assumption of silica, led in some cases to the formation of albite. On the other hand, the action of the potash more frequently changed the lithia silicate, above named, into normal muscovite, so that another apparently homogeneous but really complex substance resulted, cymatolite, consisting of muscovite and albite in equal molecular proportions; again, the segregation of these two minerals produced, in place of normal cymatolite, a mixture of separate masses of albite and mica. Still further the action of the potash, by an exchange of alkali and simultaneous assumption of silica, led to the formation of potash-feldspar or microcline. In some cases the result was a coarse mixture of the mica and the two feldspars. Finally, the action of the potash solution, and the simultaneous loss of silica, led to the formation from the original spodumene of a mineral very closely related to mica, namely, killinite.

Two questions arise here, to neither of which we can give a very satisfactory answer. The first is as to the source of the soda and potash involved in the changes that have been described—to this nothing more can be said than that they were probably furnished by the previous decomposition of feldspars, though under just what conditions we are unable to say.

The other question is as to the final disposition of the lithia removed from the spodumene—this seems to have disappeared entirely, unless the fact that some of the biotite in the vein now carries lithia may account for some of it. In this connection it should be stated that the manganese triphylite—lithiophilite—is certainly an original mineral of the vein, and occurs rather abundantly with the massive spodumene. Its decomposition has also led to an increase of this supply of lithia. Furthermore, it is more than possible that the formation of the remarkable series of phosphates of manganese, described by us from this locality, was connected with the extensive changes in the spodumene. The fact that two of the phosphates are almost

unique among that group of minerals in containing alkalis, (see analyses of dickinsonite and fillowite in our earlier papers) would almost prove this. The lithiophilite may be then the original phosphate of manganese from which the others have been derived. We shall return to this last subject at some future time.

A few additional remarks remain to be made. The cymatolite has been subjected to further change beyond that already described. The result is to lead to the formation of a soft soapy white mineral, filled with scales of mica, and obviously an impure kaolin. This is not at all a surprising result; for it is known that kaolin is formed from the soda-feldspar as well as the potash-feldspar, and the finely divided state in which the albite exists in the cymatolite would make it very liable to undergo the well understood change leading to kaolin.

Associated with the soft, partially kaolinized cymatolite, is an interesting pink clay-like mineral, closely related to *montmorillonite*. It also occurs coating the cleavage surfaces of the partially altered spodumene. It is most abundant, however, in independent deposits of considerable extent in the vein not far from the point where the spodumene occurs. It forms soft masses, easily dug out with a spade, and enough of it was found in one spot to fill an ordinary cart. It also penetrates the vein material, filling cavities in the unaltered albite and quartz. It is quite impure, often blackened in spots with manganese oxide, and contains crystals of apatite.

When first exposed it was moist and soft, easily crushed between the fingers, and in the purest parts entirely free from gritty material when placed in the mouth. Upon being exposed to the air for some weeks it lost much of its moisture and hardened considerably.

The color is a delicate rose-pink, growing somewhat lighter on being exposed to the air. It is easily fusible, B. B.

An analysis of the air-dried material was made by Mr. Horace L. Wells, with the following results:—

	I.	II.	Mean.	Ratio.	
SiO ₂	51.27	51.19	51.20		.853
Al ₂ O ₃	22.07	22.20	22.14		.118
FeO	tr.	--	tr.		
MnO	0.16	0.20	0.18	.002	} .130
MgO	3.76	3.68	3.72	.091	
CaO	3.55	3.51	3.53	.030	
Li ₂ O	tr.	--	tr.		
Na ₂ O		0.18	0.18	.003	
K ₂ O		0.38	0.38	.004	
H ₂ O	17.11	17.04	17.08		.955
P ₂ O ₅	1.40	1.43	1.42		
			99.83		

The phosphoric acid shows that a little apatite was present, and the corresponding amount of lime (1.86) should consequently be deducted. The analysis agrees reasonably well with the analyses of montmorillonite from Montmorillon, France. It is also closely related to a similar clay described by Helmhacker, from Macskamezö, Transylvania.*

It has been stated that this mineral was, as first found, very moist and coherent. It seemed a matter of some interest to determine the way in which it lost its water, and consequently two grams of air-dried mineral were taken and placed in the desiccator over sulphuric acid. Repeated weighings showed that it continued to lose weight gradually for a period of six or seven weeks, the loss being then 9.80 p. c. The total loss after ignition was about 17 p. c.

The exact relation of this montmorillonite to the spodumene pseudomorphs cannot be given. The fact that it occurs so intimately with the spodumene, and too with the cymatolite, seems to imply that it owes its origin to the former. It belongs, however, to a later part of the process, for it is almost entirely free from alkalis. The suggestion that it may have been made from feldspar and thus have afforded the alkalis involved in the alteration of the spodumene would seem at first sight plausible. But in the first place the feldspar of the vein with which it occurs is entirely fresh and unaltered, and then, as far as our observations have yet gone, the quantity is much too small. It would rather seem to be a local result of the further alteration of the cymatolite. We do not feel able at present, however, to speak with decision about it.

In concluding our paper, we would express our acknowledgments to Mr. Penfield, and to Messrs. Wells and Dewey, to whom we are indebted for the analyses here published.

DESCRIPTION OF PLATE.

In the figures the letters employed have the following signification:—*a* = albite, though here it is to be remembered that (as remarked earlier) most of the albite contains scales of muscovite, and hence shades into cymatolite; *c* = cymatolite; *g* = muscovite; *k* = killinite; *m* = microcline; *s* = spodumene; β = β spodumene.

1*a*, 1*b*, 1*c*: Three sections across a single crystal, 1.5 inches wide and 4½ long, at intervals of about 5 inches. 1*a*, from near the terminated extremity, consists principally of β spodumene (β), with cymatolite (*c*) along the edges, and a little glassy spodumene (*s*) on the lower side. 1*b* shows only β spodumene and cymatolite, the latter occupying a larger portion than in 1*a*. 1*c*, from the lower extremity of the crystal shows cymatolite only.

2. Section across a crystal, 4½ inches wide, now entirely altered to cymatolite. The intricate wavy structure of this mineral is shown, as also the tendency of the fibers to be at right angles to the edges.

3. Partial section taken longitudinally; the central portion consists of finely granular albite (*a*), with lines of coarsely granular, and cleavable, microcline (*m*); the exterior is cymatolite (*c*).

* Tschermak. Min. u. Petro. Mitth. 1879, p. 251.

4. Fragment of a crystal showing the granular albite (*a*) inclosing microcline (*m*).
5. Section across a large crystal; the exterior fractured and irregular. It consists mostly of clear pink spodumene (*s*) with bands of β spodumene (β) passing through it, following the directions of the cleavage; also some cymatolite (*c*) on the exterior.
6. Consists of granular albite (*a*), and cymatolite (*c*), also some plates of mica (*g*).
7. Section across a large crystal (natural size), the interior consisting of fibrous albite (*a*) and the exterior cymatolite (*c*).
8. Section showing some of the original spodumene (*s*) in detached points, with cymatolite (*c*) radiating from them, also some β spodumene, granular albite (*a*), and a few plates of mica (*g*).
9. A fragment consisting of killinite (*k*) with narrow bands of cymatolite (*c*) following approximately the original cleavage directions of the spodumene.
10. Section across a large crystal ($7\frac{1}{4}$ inches wide), consisting of albite (*a*) and granular microcline (*m*).
- 11, 13. Fragments showing granular albite (*a*) and imbedded in it broad cleavage plates of microcline; in each crystal these plates are all in parallel direction.
12. Fragment of a crystal, showing β spodumene (β) inclosed in albite (*a*), the exterior portion consisting of killinite.
14. Portion of a crystal with the spodumene (*s*) cymatolite (*c*) radiating from it, and granular albite (*a*); one band through the spodumene is still β spodumene.

ART. XXX.—*Floating Magnets*; by R. B. WARDER and
W. P. SHIPLEY.

IN repeating Professor Mayer's beautiful experiments with floating magnets,* we have modified the field of magnetic force by sending an electric current through a coil surrounding the vessel of water to repel the floating magnets to the center, either with or without the fixed central magnet. With these modifications, we still have radial lines of force (counting the horizontal component only), the intensity of which varies with the distance from the center of the bowl, but according to two very different functions of this distance. Assuming the solenoidal distribution of magnetism as a sufficient approximation for our present purpose, it may be readily shown that

$$F_1 = k_1 \left(\frac{r}{(r^2 + A^2)^{\frac{3}{2}}} - \frac{r}{(r^2 + B^2)^{\frac{3}{2}}} + \frac{r}{(r^2 + C^2)^{\frac{3}{2}}} - \frac{r}{(r^2 + D^2)^{\frac{3}{2}}} \right) \quad (1)$$

in which F_1 = the attraction of each floating magnet towards the center;

k_1 = the force acting between a pole of the central magnet and a pole of a floating magnet, when they are at unit distance;

r = the horizontal distance of the floating magnet from the center of the field, and

A, B, C and D are vertical distances which remain constant in each experiment.

* This Journal, xv, 276, 477, and xvi, 247; 1878.