II.

ON BERYLLITE AND BERTRANDITE FROM THE ILÍMAUSSAQ ALKALINE INTRUSION, SOUTH GREENLAND

CONTRIBUTION TO THE MINERALOGY OF ILÍMAUSSAQ, No. 5

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WITH CHEMICAL ANALYSES

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Abstract

The two beryllium silicates beryllite and bertrandite and their mode of occurrence are described from the Ilímaussaq alkaline intrusion. Optical and X-ray data are presented for the two minerals together with chemical analyses of two beryllite samples.

The data for bertrandite correspond closely to those given for bertrandite from other localities. The identification of the beryllite is based on the similarity in X-ray data with the Lovozero type mineral. Pronounced differences from the latter are found in the refractive indices which are $1.50 < n < 1.52$, and in the water content which varies in different samples from Ilímaussaq.

The two minerals are associated with the beryllium minerals epididymite, eudidymite, chkalovite and sorensenite. The beryllium minerals are found in analcite veins and pockets formed in a late stage of the development of the complex.

It is argued that differences in the partial water pressure of hydrothermal fluids govern the formation of the two minerals.

INTRODUCTION

During field work in the Kvanefjeld area in the northern part of the Ilímaussaq alkaline intrusion in 1964 and 1965 a number of samples containing rare beryllium silicates were collected.

The sample containing bertrandite was found in the summer of 1965 by Mr JOHN HANSEN. Attention was drawn to the rock during beryllometer work, and as a rapid investigation carried out in Greenland indicated the presence of an unknown mineral, the sample was sent to the author for further determination.

Beryllite has been identified in samples containing chkalovite, epididymite and sorensenite.

The author wishes to thank Mr JOHN HANSEN, Dr HARRY MICHEELSEN and Professor HENNING SØRENSEN, the leader of the investigations in Ilímaussaq, for discussions and help during the work. The investigations in Ilímaussaq form part of the activities of Grønlands Geologiske Undersøgelse (the Geological Survey of Greenland) in South Greenland. The author is grateful to the Director of the Survey for permission to publish these results. Mr T. C. R. PULVERTAFT kindly corrected the English of the manuscript.

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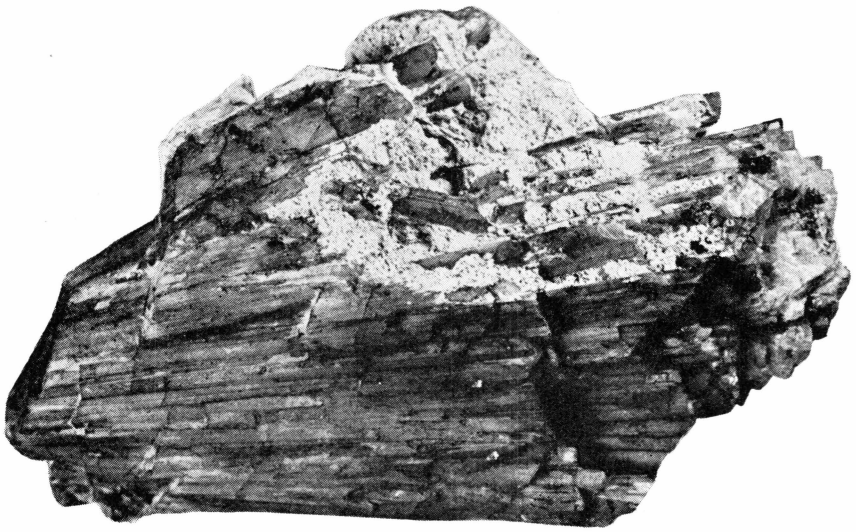

Fig. 1. Beryllite intergrown with sorensenite. Natural size. (P. NIELSEN photo).

BERYLLITE

Occurrence and description

Beryllite has been discovered in analcite-rich veins in the Kvanefjeld area in the northern part of the Ilímaussaq alkaline intrusion. It is associated with the Be-bearing minerals sorensenite, chkalovite and epididymite. (See SEMENOV *et al.*, 1965, for further details).

The beryllite, in its purest form, occurs as powdery, white masses found as cavity-fillings of approximately 1 cm size spread over the veins. The cavities are usually surrounded by analcite crystals and single sorensenite laths are often found in the beryllite mass. Besides, beryllite occurs as surface coatings on the other beryllium minerals or in zones penetrating these. These coatings may be greyish and porous, sinter-like.

When intergrown with sorensenite, beryllite is intimately mixed with analcite and occurs in lenses and wedges between bundles of sorensenite crystals (fig. 1). Under the microscope it is seen that the single laths of sorensenite are bent and broken as if they have been pressed aside to make room for the beryllite (plate 1, fig. 1 and 2). The sorensenite is apparently chemically unaltered.

Pigmentation is very pronounced in the beryllite of the cavities, the beryllite mass being almost opaque, and varies in the sorensenite-beryllite intergrowth. The pigmentation is probably largely due to ZnS and Fe-Ti-oxide.

Another mode of occurrence is seen in the association of beryllite and chkalovite. In one sample (no. 65302) pure beryllite grades into a

beryllite-chkalovite intergrowth, the latter showing the following microscopic features:

Beryllite occurs especially along the chkalovite grain boundaries and only the larger chkalovite crystals are cut by irregular beryllite veins; the texture thus formed is mortar-like. At the contact between the larger grains of chkalovite and to some extent inside these, smaller grains of chkalovite occur with an orientation slightly different from the adjacent large grains (*cf.* SØRENSEN, 1960). However, both kinds of chkalovite grains are replaced from the borders by scaly masses of beryllite. Only the beryllite veins are pigmented and these are seen as an almost opaque network with colourless, partly recrystallized chkalovite in between the mesh.

A few grains of twinned epididymite are found. These have been corroded by beryllite, which sends veins and tongues into them.

Under high magnification three crystallographic varieties of beryllite can be distinguished.

1. The best crystallized beryllite is found in tiny spherulites built up of fine, radiating needles about 10 μ (maximum 30 μ) long and a fraction of a μ thick (plate 1, fig. 3).

2. Single spherulites or small groups of spherulites are sometimes found enclosed within a crust of layered beryllite, the single layers being a few μ thick. Layered beryllite also forms veins. The extinction is parallel to the layers, but the elongation changes sign in the different layers. This contrasts with the needles of the spherulites, which are invariably length-slow.

3. The third modification consists of scaly, micro- to cryptocrystalline aggregates (plate 1, fig. 2).

Optical properties

Due to the small dimensions of the beryllite fibres, no single beryllite crystal could be separated for accurate optical determination.

The constant positive elongation of the spherulitic fibres (type 1) probably indicates that the optical γ-direction is parallel to the axis of these fibres.

The refractive indices of the Ilímaussaq mineral fall in the range 1.50–1.52. These values are distinctly lower than the values obtained for the Lovozero beryllite: $n\gamma = 1.560$ and $n\alpha = 1.541$ (KUZMENKO, 1954, quoted in VLASOV *et al.*, 1959).

The interference colours of the spherulites are greyish-yellow corresponding to a birefringence $\geqq 0.01$ as an average of $n\gamma$-$n\alpha'$. The birefringence given for the type beryllite is 0.019.

X-ray diffraction

X-ray data were obtained by a Guinier camera and a 9 cm diameter Bradley camera. d-values and estimated intensities are presented in table 1, columns 1 and 2 along with the data for Lovozero beryllite, column 3. The coincidence is found to be satisfactory.

Table 1. *X-ray data for beryllite.*

Beryllite from Ilímaussaq						Beryllite from Lovozero			Gelbertrandite from Lovozero		
9 cm camera			Guinier camera			Vlasov *et al.*, 1959 p. 446			Vlasov *et al.*, 1959 p. 449		
No.	d	Int.	No.	d	Int.	No.	d	Int.	No.	d	Int.
1	6.35	4	1	6.37	5	1	6.43	5	1	4.81	1
2	5.59	4	2	5.62	2				2	4.31	10
			3	4.34	1				3	3.15	10
3	4.08	7	4	4.07	8*	2	4.01	10	4	2.53	10
			5?	3.67	7	3	3.64	9	5	2.31	8
4	3.41	10	6	3.43	7	4	3.39	7	6	2.20	
			7?	3.18	7	5	3.19	7	7	1.998	4
5	3.03	5	8	3.05	2				8	1.714	2
6	2.98	5	9	2.99	8				9	1.651	2
7	2.90	5	10	2.93	6	6	2.90		10	1.555	4
			11	2.60	4	7	2.66	3	11	1.454	6
8	2.48	2	12	2.50	4	8	2.50		12	1.310	4
9	2.32	10	13	2.34	10*	9	2.34	10	13	1.261	2
			14	2.20	1	10	2.20	2	14	1.224	3
10	2.11	4				11	2.12	7	15	1.171	2
						12	2.03	7			
						13	1.937	7			
11	1.79	1				14	1.807	5			
12	1.73	1				15	1.754	1			
13	1.70	1				16	1.703	6			
14	1.63	1				17	1.649	1			
15	1.59	1				18	1.599	2			
16	1.54	1				19	1.547	4			
						20	1.451	1			
						21	1.396	1			
17	1.35	8				22	1.351	8			
						23	1.333	1			
						24	1.308	1			
18	1.28	7				25	1.287	5			
						26	1.259	2			
19	1.21	1				27	1.221	4			
						28	1.171	4			
						29	1.151	5			
						30	1.121	3			
						31	1.078	2			
						32	1.071	1			

*) Diffuse line. ?: Coincides with line of epididymite.

The optical properties of the hydrous beryllium silicate gelbertrandite (VLASOV *et al.*, 1959, quoting SEMENOV, 1957) agree with those obtained on the Ilímaussaq mineral. However, when comparing d-values of gelbertrandite (table 1, column 4) with the values in columns 1 and 2, pronounced differences are noticed. These are substantiated by a direct comparison of the powder photographs of the Ilímaussaq mineral with photographs of beryllite and gelbertrandite from Lovozero, samples of which were kindly supplied by Professor E. I. SEMENOV, Moscow.

In identifying the Ilímaussaq mineral as beryllite, preference is given to X-ray data. However, the large and varying water content which has been found (see below), indicates that the mineral "beryllite" has to be investigated in greater detail and probably redefined.

Chemistry

Chemical analyses were undertaken by IB SØRENSEN on beryllite in intergrowth with sorensenite and chkalovite. The samples were dried for two hours at 110° before the analyses were carried out. The results of the analyses are presented in table 2. Spectrographic analyses, carried

Table 2. *Chemical analyses of Beryllite.*

	Associated with chkalovite [1]		Associated with sorensenite [1]		From Lovozero [2]	
	Wt %	Cation proportion	Wt %	Cation proportion	Wt %	Cation proportion
SiO_2 ...	31.0	1.00	30.7	1.00	34.10	1.00
TiO_2 ...	trace		trace		trace	
Fe_2O_3 ..	0.2		0.4		0.12	
BeO ...	38.0	2.93	39.2	3.07	40.00	2.66
H_2O+ ..	22.7		22.0		18.95	3.50
H_2O- ..	6.8		5.6		3.25	
Total ..	98.7		97.9			
Analyst IB SØRENSEN, 1965					M. E. KAZAKOVA, 1952	

[1] The two Ilímaussaq samples were dried for two hours at 110° C to obtain the values of H_2O-. The chemical analyses were made on the dried samples. H_2O+ presented in the table was determined by the Penfield method. Determination of loss of weight by heating to approx. 1000° C gave 26.0 and 25.4 % respectively. The true values for the H_2O+ content may be intermediate between the figures obtained by the different methods, which may explain the low totals of the analyses. However, for reasons given in the text the temperature 110° C has little significance in describing the beryllite.

The beryllium content was also determined by Mrs MARGRETHE JENSEN, the Chemical Department of the Danish Atomic Energy Commission. She found 33.5 and 38.9 Wt % BeO, respectively.

[2] The following elements were found in addition to those given in the table: Al_2O_3: 1.63, CaO: 0.50, Na_2O: 2.42 Wt. %. Al_2O_3 and Fe_2O_3 are included in the SiO_2 value 1.00.

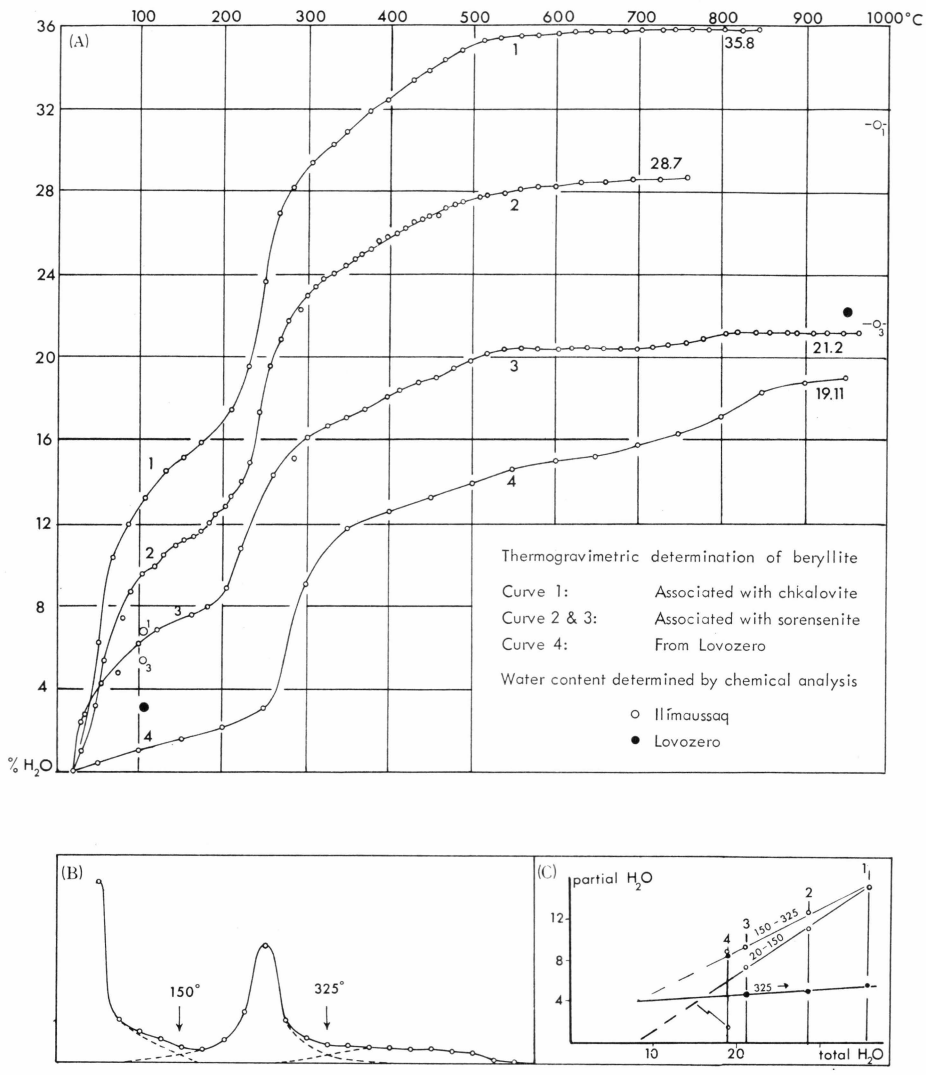

Fig. 2. Thermogravimetric analyses of beryllite. See text for explanation.

out by HALDIS BOLLINGBERG, showed that the amounts of other elements present (Mg, Al) are negligible. TiO_2 and Fe_2O_3 were found in the constant proportion 1 :10 and probably originate from the pigmentation. They are not considered in the calculations.

The formula first proposed by KUZMENKO (1954) for beryllite was $Be_3SiO_4(OH)_2.H_2O$. Later BEUS (1960), suggested $Be_5Si_2O_7(OH)_4.2H_2O$ by analogy with spherobertrandite. Regarding the Be:Si proportion, the Ilímaussaq mineral fits with the former formula.

Further examination of the water content was carried out by thermogravimetric analyses. In fig. 2A curve 1 is for beryllite from the chkalovite association used in the chemical analysis. Curves 2 and 3 represent beryllite from different intergrowths with sorensenite. Curve 4 is redrawn from VLASOV *et al.*, 1959, and is for Lovozero beryllite.

Fig. 2A illustrates the pronounced difference in water content found in different samples from Ilímaussaq, the lowest being of the same order of magnitude as in the Lovozero beryllite, the highest having almost twice that amount of water. The forms of the curves are, however, very similar and show three different, overlapping reactions: Reaction I occurs in the interval 20° — ca. 200°C, reaction II occurs in the interval ca. 100° — ca. 400°C, and reaction III in the interval ca. 300° — ca. 600°C. Reaction I and II are assumed to be the losses of two, structurally distinct kinds of water molecules, whereas reaction III is assumed to be the decomposition of OH groups. In order to determine the weight loss in each of these reactions the first derivative of the thermogravimetric curve No. 1 was drawn — fig. 2B. This DTGA curve can be divided into three peaks indicated by the dashed lines in fig. 2B, the areas of which are the weight losses of the three reactions. If the DTGA curve, however, is cut into three parts by vertical lines at ca. 150°C and 325°C the three areas obtained are nearly identical to those of the peaks. In order to simplify the use of the thermogravimetric curves 1–3, these two temperatures have been used as boundaries in the calculation of the weight losses in the three reactions. It should be stressed, however, that notably the distinction between reaction II and III is uncertain and likely to be in error. The results thus obtained are given in table 3 and illustrated in fig. 2C. Within the limits of accuracy the weight loss of reaction III is constant and corresponds to one OH group per Be_3Si. The weight losses of reaction I and II vary strongly, but they are roughly of the same size

Table 3. *Recalculated water content.*

	Temperature interval	Weight loss				Proportions: Be= 3.00, Si = 1.00			
						Calculated as			
Curve no.		1	2	3	4		1	2	3
	20°–150°C	15.0	11.1	7.3	1.5	H_2O	1.75	1.17	0.69
	150°–325°C	15.2	12.7	9.3	9.0	H_2O	1.78	1.34	0.89
	325°–upwards	5.6	4.9	4.6	8.6	OH	1.30	1.04	0.88
Total ..		35.8	28.7	21.2	19.1				

within one sample. Reaction I gives a slightly smaller weight loss than reaction II, but this may be due to a zeolithic nature of the water of reaction I, part of the water being lost corresponding to an atmospheric humidity below the point of saturation. The strong variations of reaction I and II show that a definite formula for the Ilímaussaq beryllite does not exist. From the ratio of Be/Si = 3/1, we can within the limits of accuracy propose the following formula for beryllite:

$$Be_6Si_2O_9(OH)_2 \cdot (2+x)H_2O^{II} \cdot (2+x)H_2O^{I},$$

where $x \sim 0$ for curve 3, $x \sim 1$ for curve 2 and $x \sim 2$ for curve 1. It should be noted that the experimental results do not prove that x is an integer.

BERTRANDITE

The sample containing bertrandite was found by Mr JOHN HANSEN in the north-western part of the Ilímaussaq alkaline intrusion a few hundred metres north of the beryllite locality.

The host rock of the bertrandite is made up of massive, coarse-grained analcite aggregates which form pockets in a naujaite pegmatite. The only unusual feature of the rock is a lesser degree of transparency due to small patches of a fine-grained, white material.

Under the microscope twinned tablets of eudidymite and epididymite in the analcite are found to be the hosts of small bertrandite crystals. The former two minerals are present in rather large amounts in the analcite matrix, which has corroded their ideal rectangular shape. The few crystals of the beryllium mineral sorensenite found in the rock are free of bertrandite.

The bertrandite is developed in fine laths averaging 100×10 μ in size. The laths found within a single host crystal display a pronounced tendency to growth in two sets of parallel individuals at an angle of approximately 60°. In the intergrowth the single crystals of the two sets usually penetrate each other. In some places, however, they do not touch each other, but are then probably linked by laths above or below the plane of the section. As no relation has been found between the crystallographic directions of the host minerals and the bertrandite, this mode of occurrence is probably due to twinning.

Usually the single crystals of bertrandite are evenly distributed in the host mineral, but all transitions in spacing exist up to dense plates made up of several laths in parallel or twin position. An irregular, vermicular development is met with, often with a weak indication of the two twin directions.

The bertrandite is virtually restricted to the crystals of epididymite and eudidymite. Only two crystals of the mineral, both of larger size, have been observed to cross the boundaries into analcite. This restriction is also evident where the host mineral is partly replaced by analcite.

In thin section the bertrandite from Ilímaussaq is an easily identified mineral due to the typical occurrence in twins of length-fast laths with moderate relief and birefringence. A more detailed description of the crystallographic, optical and X-ray data is given in the following sections.

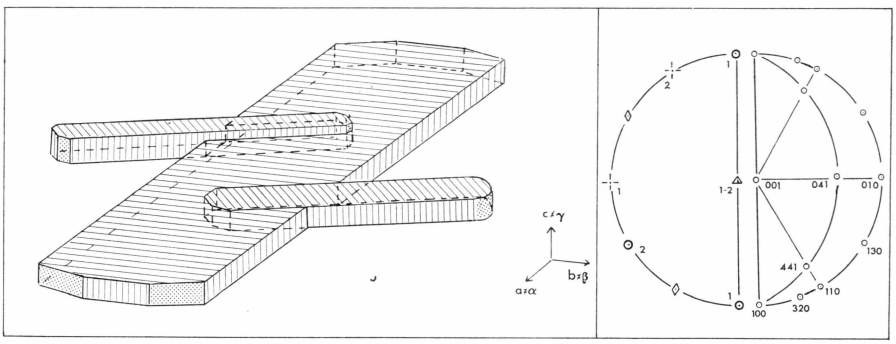

Fig. 3. Left: Schematic drawing of bertrandite twins. Right: Stereographic projection showing position of indicatrices in a twin (left) and crystal faces found corresponding to individual 1 (right).

Crystallography

Bertrandite crystallizes in the orthorhombic hemimorphic class mm, space group $Cmc2_1$ (ITO and WEST, 1932; SOLOVIEVA and BELOV, 1961, quoted by Ross, 1964).

Several morphological settings have been proposed by different authors. Most widely used is the setting by PENFIELD ($a \parallel \alpha$, $b \parallel \beta$, $c \parallel \gamma$; a:b:c: = 0.5688:1:0.5973. PENFIELD, 1889), which is also followed here. The setting corresponds to a doubling of the c axis found in structural determination and an interchange of the a and b axes of ITO and WEST.

In determining the crystallographic forms of bertrandite use was made of the universal stage and powder mounts. Due to the small dimensions of the crystals, the measurements were rather inaccurate.

The laths of bertrandite are elongated in the direction [100] with $\{00\bar{1}\}$ and $\{001\}$ as the dominating forms followed by $\{010\}$. The laths may be terminated by $\{100\}$ but are often rounded. Cleavage is well developed parallel to all the forms mentioned above. Additional forms found are: $\{320\}$, $\{130\}$, $\{041\}$ and $\{441\}$ (?).

As mentioned, penetration twins of the bertrandite are almost invariably found. When investigated on the universal stage $\alpha \wedge \underline{\alpha}$ was found to be 59°, $\gamma \parallel \underline{\gamma}$ ($\pm 5°$, 8 measurements). This relationship could correspond to twin-planes $\{110\}$ and $\{130\}$, $\alpha \wedge \underline{\alpha} = 59.3°$ and 60.7° respectively; it has not been possible to decide which of these is the more likely. The twinning is illustrated in fig. 3.

Optical properties

In powder mounts obtuse axial figures are most commonly observed with optic-normal figures next in abundance. The refractive indices were therefore easily obtained by using different liquids and monochromatic

light of varying wavelength. n_D for the liquids were obtained by a Jelley micro-refractometer. Interpolated to $\lambda = 589$ nm the refractive indices are

$$n_\alpha = 1.593 \pm 0.005$$
$$n_\beta = 1.607 \pm 0.005$$
$$n_\gamma = 1.614 \pm 0.005$$

Determined on the universal stage $2V_\alpha = 72°$ ($\pm 5°$, 9 measurements). VOGT (1912) gives $n_\alpha = 1.5914$, $n_\beta = 1.6053$, $n_\gamma = 1.6145$; $2V_\alpha = 74°41'$.

X-ray investigation

X-ray data were obtained by a Guinier camera. The results obtained are presented in table 4 along with the values cited by VLASOV (1964).

In the table values followed by an asterisk (*) were obtained on a mixture of bertrandite, eudidymite and epididymite by subtraction of the lines of the latter two minerals. The unmarked values were also found on an exposure of hand-separated bertrandite. The amount of this material was, however, so small, that all lines were weak even after a 70 hours' exposure.

Table 4. *X-ray data for bertrandite*

Ilímaussaq Guinier technique			VLASOV, ed. (1964) p. 102			ASTM Powder Diffraction File. 1963. 12–452.		
no.	d	Int.	no.	d	Int.	no.	d	Int.
1	7.60 *	2				1	7.56	10
			1	5.177	1.5			
2	5.04 *	1						
			2	4.884	1.5			
			3	4.665	4			
3	4.36	9	4	4.375	7	2	4.385	55
						3	4.350	35
			5	3.934	3	4	3.914	20
4	3.82 *	3	6	3.828	1	5	3.807	>100
5	3.61 *	2						
6	3.49 *	1	7	3.510	2.5			
7	3.34	7	8	3.321	5			
8	3.17	4	9	3.174	10	6	3.161	45
9	3.06	4						
10	2.97 *	1						
						7	2.925	4
11	2.91 *	1				8	2.913	4
						9	2.876	6
						10	2.865	8
						11	2.850	6

(continued)

Tabel 4 (continued).

Ilimaussaq Guinier technique			Vlasov ed. (1964) p. 102			ASTM Powder Diffraction File 1963. 12–452		
no.	d	Int.	no.	d	Int.	no.	d	Int.
12	2.75	9						
			10	2.600	5			
13	2.55 *	2				12	2.543	75
14	2.52	10	11	2.527	6	13	2.521	40
15	2.42 *	1				14	2.417	4
16	2.34 *	1						
17	2.32 *	1						
18	2.29	8	12	2.285	5	15	2.283	20
19	2.22	6	13	2.220	7	16	2.222	14
20	2.20 *	7				17	2.208	6
21	2.18	1				18	2.177	4
						19	2.102	4
			14	2.028	2.5	20	2.021	4
22	1.980*	2	15	1.981	4	21	1.978	6
23	1.930*	8				22	1.917	4
						23	1.907	12
24	1.816	3						
			16	1.790	2	24	1.790	2
						25	1.761	2
			17	1.699	2.5	26	1.699	2
			18	1.652	2	27	1.648	4
						28	1.579	2
						29	1.563	4
						30	1.556	6
			19	1.554	4	31	1.551	6
25	1.463*	2	20	1.463	5			
			21	1.362	1.5			
			22	1.341	2.5			
26	1.304*	1	23	1.305	7			
			24	1.250	2.5			
27	1.225*	1	25	1.218	3.5			
28	1.168*	1	26	1.170	3			
			27	1.145	1			
29	1.115*	1	28	1.120	3			
			29	1.105	1			
			30	1.090	1			
			31	1.075	2			
			32	1.055	1.5			
			33	1.039	1			
			34	1.014	1			
			35	1.003	1			
			36	0.939	0.6			

(continued)

Table 4 (continued).

Ilímaussaq Guinier technique			Vlasov, ed. (1964) p. 102			ASTM Powder Diffraction File 1963. 12–452		
no.	d	Int.	no.	d	Int.	no.	d	Int.
			37	0.898	1			
			38	0.858	2			
			39	0.842	1			
			40	0.836	2			
			41	0.827	1.5			
			42	0.819	1			
			43	0.811	1			
			44	0.809	0.6			
			45	0.802	3			
			46	0.798	1			
			47	0.791	0.6			
			48	0.788	1			
			49	0.782	0.6			
			50	0.778	1			

DISCUSSION OF GENESIS

The minerals bertrandite and beryllite described above are members of a very interesting beryllium mineral assemblage. No thorough account of this can be given at the moment, and only some details regarding the genesis of beryllite and bertrandite are discussed.

Common to the two minerals is their occurrence in analcite veins, which represent a very late stage in the formation of the Ilímaussaq intrusion. In the veins both minerals are found in association with and partly replacing other beryllium-bearing minerals.

Both minerals are pure beryllium silicates, mainly differing in their water content. This suggests that a difference in water pressure was the main factor governing their formation. This can be substantiated by their textural relationship to the minerals they replace.

The formation of bertrandite was a very gentle process as shown by the undeformed twin-lamellae of the host minerals epididymite and eudidymite. This process may have been contemporaneous with the replacement of the epididymite and eudidymite by analcite, but the uniform distribution of the bertrandite in the host crystals is in no way affected in the vicinity of analcite.

In contrast to this, strong mechanical effects have accompanied the formation of the beryllite, a fact best shown by the breaking-up of sorensenite crystals by beryllite. As the sorensenite crystals are chemically unaltered, this mode of occurrence is best explained by a forceful injection of Be-rich solutions, possibly of a rather local origin, into a consolidated rock. At the same time recrystallization of analcite took place so that loosened fragments of sorensenite were enclosed well inside the analcite matrix. The variations in the water content of beryllite were probably the result of local fluctuations in partial water pressure.

This process of formation agrees with the regional geological setting of the beryllite-bearing analcite veins in a coarse-grained lujavrite, thought to be a late pegmatoid differentiate in the uppermost part of the intrusion (Sørensen and Østergaard, in preparation).

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Plate 1.

Fig. 1. Photomicrograph showing the intergrowth of beryllite and sorensenite laths. 2 nicols at ca. 80°. ×100.

Fig. 2. Upper central part of fig. 1 enlarged. The main mass of beryllite has a scaly appearance. ×225.

Fig. 3. Beryllite spherulites. + nicols. ×225.

Fig. 1.

Fig. 2.

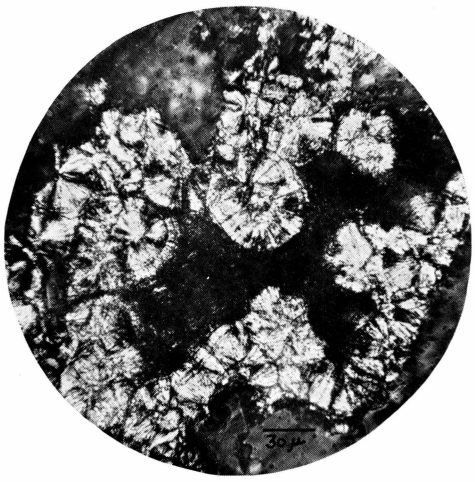

Fig. 3.