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ON BABINGTONITE

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In the course of a study of augite, acmite, aegirite, and other pyroxenes it became advisable to study the relationships of babingtonite to the monoclinic pyroxenes.

ARENDAL BABINGTONITE. Through the kindness of Dr. Shannon we obtained from the collection of the U. S. National Museum a specimen (No. 47035) of babingtonite from Arendal, Norway, the original locality. The mineral occurs as small (up to 1 mm. long) black glistening crystals, which occupy ramifying solution cavities in large microcline crystals. The cavities appear to have been once filled with albite.

The crystals of babingtonite are in habit stoutly prismatic nearly normal to the perfect cleavage; there is a less perfect cleavage in this prismatic zone. We have used Dauber's orientation which makes this zone vertical, the more perfect cleavage is the base *c*(001) and the less perfect cleavage is the side pinacoid *b*(010). This is the orientation used by Palache and Fraprie,[1] in their description of the Somerville babingtonite, and by Manjirô Watanabé for babingtonite from the Yakuki Mine, Japan.[2] They give tables of angles which we have used in determining the optical orientation. Dana's orientation relates the cleavages and certain parameters with those of the monoclinic pyroxenes, but the axial angles based on this orientation are not in good agreement. The planes *c*(001), *b*(010), *a*(100), *h*(110), and *g*$(2\bar{1}0)$ of Dauber's orientation correspond to *M*$(1\bar{1}0)$, *m*(110), *c*(001), *h*(221), and *g*$(11\bar{1})$ of Dana's orientation.

The following optical orientation was determined for yellow light. One optic axis, *A*, emerges from the base at an angle in air of 37°, and the optic axial plane emerges from it at an angle in

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[1] Palache and Fraprie, *Proc. Am. Acad. Arts and Sci.*, **38,** 383 (1902).

[2] *Am. Journ. Sci.*, **4,** 159 (1922).

air of 35°. The trace of the plane of the optic axes upon the base makes an angle of 35° with the trace of the less perfect cleavage. From the interference figure seen in a basal section $+2V$ appears to be about 70° and the acute bisectrix is roughly midway between *c*(001) and *g*(2$\bar{1}$0). The other optic axis, *B*, and likewise the plane of the optic axes, emerges from the face *g*(2$\bar{1}$0) at an angle in air of 14°. The trace of the axial plane makes an angle of 21° with the trace of the less perfect cleavage and of 69° with that of the basal cleavage.

The angles, reduced when necessary to angles within the crystal, were plotted on a Nikitin hemisphere with the necessary crystallographic data. The optic axial angle thus found was 76° ± 3°. The φ and ρ values for the extremities of the ellipsoidal axes in the upper hemisphere are as follows:

	α	β	γ
ϕ	−36°	−147°	108°
ρ	44°	71°	53°

Thus, α emerges nearly midway between *c*(001) and *k*($\bar{1}$10); β about 19° toward *c*(001) from *h*($\bar{1}\bar{1}$0); and γ nearly midway between *c*(001) and *g*(2$\bar{1}$0). Measured from the cleavage traces the extinction on *c*(001) is practically zero; on *b*(010) it is 41°, with elongation positive in both cases.

Crossed dispersion of the optic axes and dispersion of the bisectrices are discernible in white light but are not very noticeable microscopically. At the axis *B* the dispersion is about twice as strong as *A*, but of the same character. At *B* within the crystal the axis for red is 2° beyond that for blue, with respect to the acute bisectrix; also, the axial plane for red is 4° nearer the normal to *g*(2$\bar{1}$0) than the plane for blue. Thus, $2V_r - 3° = 2V_b$, and the bisectrices are dispersed about 1°.

One of the most characteristic features of babingtonite is its strong pleochroism. The axes which represent the greatest contrasts in hue are nearly coincident with the axes of the index ellipsoid. In grains about .07 mm. thick α is deep green (about 37'''i or 37''k Ridgway), β is a slightly purplish gray (about 67'''''b or 67'''''l) and γ is an orange gray (about 16''''c). These color comparisions were made by placing the Ridgway colors on the table beside the microscope, covering them closely with a white paper having an opening somewhat smaller than one of the color rectangles, and then tilting the page away from the window until the white paper was illuminated approximately the same as the field of the microscope. In grains about 15 to 20 mm. thick α is nearly black, β is dull orange (about 9′′′′b), and γ is dull orange yellow (about 15′′′h or 15′′′′h).

The refractive indices were measured microscopically by the immersion method. It was found that β is variable from 1.728 to 1.733. When this variation is taken into account the following refractive indices are probably representative: $\alpha=1.717$, $\beta=1.730$, $\gamma=1.752$; from which $+2V=75°$.

The density of the Arendal babingtonite was determined by finding pycnometrically the density of Clerici's solution[3] in which several crystals of the mineral were suspended. The density (grams per c. c.) at 26° is 3.359, with a variation of only ±.001. This result is between the values obtained by Rammelsberg and by Silvia Hillebrand, which were 3.366 and 3.351 respectively.

SOMERVILLE BABINGTONITE. Some of the babingtonite studied by Palache and Fraprie was placed at our disposal by Prof. Palache through Dr. Fenner. This was found to vary in refractive indices between the same limits as the mineral from Arendal. It also showed the same optical aspects of cleavage fragments, of color, and of pleochroism. The density (at 25°) of the Somerville babingtonite was determined by the same method as that used with the Arendal material and was found to be 3.355, with a variation of ±.003.

For the four occurrences which have been studied the refractive indices of babingtonite are practically identical:

	α	β	γ	±
Arendal and Somerville	1.717	1.730	1.752	.002
Arendal[4]	1.713	1.725	1.746	.003
Baveno[4]	1.713	1.727	1.746	.003
Yakuki Mine[2]	1.715	1.725	>1.74	.005

CHEMICAL COMPOSITION. An analysis was made of our specimen of the Arendal babingtonite, the material having been carefully purified from feldspar and epidote by means of heavy solutions and the magnet. About 4.45 grams were available; the powder was dried at 110° before analysis.

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[3] Enrico Clerici, *Rend. Accad. Lincei*, 16, 187, (1907).

[4] E. S. Larsen, *U. S. Geol. Survey*, **Bull. 679**, 43, (1921).

TABLE I. ANALYSES OF BABINGTONITE

	1	2	3	4	5	1a	2a
SiO_2	52.80	52.25	52.48	51.22	52.57	.880	.871
TiO_2	0.29	0.18	trace	n.d	n.d.	.004	.002
Al_2O_3	2.41	5.27	1.93	n.d.	n.d.	.024	.052
Cr_2O_3	none	n.d.	n.d.	n.d.	n.d.		
Fe_2O_3	13.17	7.49	23.24	11.00	15.03	.083	.047
FeO	7.68	11.05	n.d.	10.26	6.61	.107	.154
MnO	1.89	1.94	0.37	7.91	6.62	.027	.027
MgO	0.92	0.46	1.55	0.77	n.d.	.023	.012
CaO	19.19	20.36	19.31	19.32	19.85	.343	.363
Na_2O	0.39	0.22	n.d.	n.d.	n.d.	.006	.004
K_2O	0.09		n.d.	n.d.	n.d.	.001	.....
H_2O+	0.91	0.29	1.03	0.44	n.d.	.050	.015
	99.84	99.51	100.02	100.92	100.68		
Density	3.359	3.355		3.366	3.351		

1. Babingtonite, Arendal, Norway. Washington analyst.
2. Babingtonite, Somerville, Massachusetts. Fraprie analyst. Palache and Fraprie, *Proc. Am. Acad. Arts. Sci.*, **38**, 391, (1902).
3. Babingtonite, Buckland, Massachusetts. Schneider analyst. B. K. Emerson, *U. S. Geol. Survey*, **Bull. 126**, 32, (1895), Includes $H_2O- = 0.11$. FeO not determined for lack of material.
4. Babingonite, Arendal. Rammelsberg analyst. *Pogg. Ann.*, **103**, 287, 304, (1858).
5. Babingtonite, Arendal. Silvia Hillebrand analyst. *Tsch. Min. Pet. Milth.*, **32**, 256, (1914).

1a. Molecular ratios of No. 1.
2a. Molecular ratios of No. 2.

Our analysis of the Arendal mineral closely resembles those by Fraprie and by Schneider of the two New England occurrences in all essential respects, except the iron oxides. The relations of these in No. 2 are inverse to those in No. 1, and it would appear that in No. 2 more Al_2O_3 replaces Fe_2O_3. The total amounts of Al_2O_3, Fe_2O_3, and FeO are about the same in both. The small amount of material at hand did not permit Schneider to determine FeO, but making allowance for the presence of this the total amount of the same three oxides in his analysis is about the same as in the first two analyses.

The analysis by Rammelsberg is chiefly of historic interest; in the figures for SiO_2, CaO, MgO, and total iron oxides it resembles ours, but MnO is inordinately high and the ratio of the iron oxides is different. At the time when Rammelsberg made his analysis there was no good method for the determination of FeO in silicates, and the methods for manganese were also very uncertain in their results as they are apt to be now. Silvia Hillebrand's analysis is so incomplete as to be of no value for discussion of the constitution of the mineral. It is similar to ours in SiO_2, the iron oxides and CaO, but MnO is here also very high, Al_2O_3 is undetermined, probably included in her "MnO," and the determination of magnesia, water, and the alkalies would raise the summation to a very unsatisfactory figure.

None of the few other analyses of babingtonite that have been published[5] merit serious consideration. Those by Arpe and Thomson were the first made of the mineral and date from the 40's. Those by Forbes and by Heddle of minerals from Devonshire and from Ben Bhreck are poor and they are possibly not of babingtonite. That by Jehn of the Nassau babingtonite is a student's analysis and of little value. There is no analysis of the Baveno, of the Yakuki, or of the Passaic County, N. J.,[6] babingtonite.

The chemical composition and the correct formula of babingtonite are not exactly known and there has been much diversity of opinion in the matter.[7] A reason for this is obvious when the incompleteness and generally unsatisfactory character of the earlier analyses are considered. However, the better analyses agree as to certain main features. They show about 52 per cent of SiO_2, about 20 per cent of iron oxides in varying proportions, about 20 per cent of CaO, and from about one-half to one per cent of H_2O+. Babingtonite is therefore essentially a silicate (presumably a metasilicate) of calcium and ferric and ferrous iron.

Babingtonite is commonly considered a triclinic member of the pyroxene group. Rammelsberg[8] regarded it as a mixture of the molecules $(Ca, Fe, Mn)O.SiO_2$ and $Fe_2O_3.3SiO_2$ in varying amounts. In this interpretation he has been followed by Dana,[9] Groth,[10] Naumann-Zirkel,[11] Lacroix, [12] Palache and Fraprie,[13] and

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[5] See Hintze, Handbuch der Mineralogie, **2**, 1171, (**1897**); and Doelter, Handbuch der Mineralchemie, **2**, (2), 968, (**1917**).

[6] C. N. Fenner, *Jour. Washington Acad. Sci.*, **4**, 552, (1914).

[7] For an account of some of the various views see Doelter, Handbuch der Mineralchemie, **2**, (2), 969-972, (1917).

[8] Rammelsberg, Handbuch der Mineralchemie, **2**, 404, (**1875**).

[9] Dana, System of Mineralogy, 383, (**1892**).

[10] Groth, Tabell. Uebers. Mineralien, 4th. ed., 147, (**1898**).

[11] Naumann-Zirkel, Elemente der Mineralogie, 700, (**1898**).

[12] Lacroix, Mineralogie de la France, **1**, 540, (**1895**); **4**, 780, (**1910**).

[13] Palache and Fraprie, *op. cit.*, 391.

by most other authors. Tschermak[14] and Jannetaz[15] give somewhat different formulae. Doelter[16] considered that it is composed of the molecules $CaO.(Fe, Mn)O.2SiO_2$, $CaO.Fe_2O_3.4SiO_2$, and $CaO.SiO_2$. Silvia Hillebrand[17] suggests a quite different constitution. According to her, babingtonite is a mixture of $2CaO.3SiO_2$ and $(Ca, Fe)O.Fe_2O_3.2SiO_2$, that is dicalcium trisilicate and an iron anorthite. In support of this view she points out close crystallographic analogies between babingtonite and anorthite. Zambonini[18] concludes from a study of four of the older analyses that Rammelsberg's interpretation is applicable with slight modification. He considers babingtonite a triclinic analogue of hypersthene, the two differing chemically in the presence of CaO and $(Fe,Al)_2O_3$ in the former.

If the bases shown in the better analyses are calculated as metasilicates an excess of SiO_2 remains unsatisfied. This led to Miss Hillebrand's assumption of the presence of the hypothetical dicalcium trisilicate, while Doelter[19] regarded this excess silica as present in solid solution. If, however, the H_2O+ that is found in the better analyses be regarded as hydroxyl, entering an acid silicate molecule, the mineral may be regarded as a metasilicate and Miss Hillebrand's and Doelter's suppositions may be disregarded.

The data for analyses Nos. 1, 2, and 4 are given below on the basis of metasilicate ratios.

	R_2O_3	RO	SiO_2 Calc.	SiO_2 found	Excess SiO_2	H_2O+
Arendal (H. S. W.)	.107	.507	.828	.884	.056	.050
Somerville (Fraprie)	.099	.560	.857	.873	.016	.015
Arendal (Rammelsberg)	.069	.549	.825	.854	.029	.024

A calculation which may more or less perfectly represent the two most complete analyses of babingtonite in terms of end members of a complex mixed crystal series is given in Table II. If these end members are named by analogy with pyroxenes the Arendal babingtonite contains about 49 per cent of "acmitic molecules," about 13 of "diopsidic molecules," and about 37 of "wollastonitic molecules."

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[14] Tschermak, Lehrbuch der Mineralogie, 515, (**1905**).

[15] Jannetaz, Les Roches et leurs Elements Mineralogiques, 357, (**1911**).

[16] Doelter, *Tsch. Min. Pet. Mitth.*, **2**, 198, (1880).

[17] S. Hillebrand, *Tsch. Min. Pet. Mitth.*, **32**, 264, (1914).

[18] Zambonini, *Atti Accad. Sci. Napoli*, **16**, 24, (1914); *Zeits. Kryst.*, **55**, 153, (1915).

[19] Doelter, Handbuch der Mineralchemie, **2**, (2), 972, (**1917**).

TABLE II. RECALCULATED COMPOSITION OF BABINGTONITE

	ARENDAL			SOMERVILLE		
	FOUND	100%		FOUND	100%	
$FeO.Fe_2O_3.4SiO_2$	35.87	36.05	49.29	20.30	20.40	43.90
$FeO.Al_2O_3.4SiO_2$	9.94	10.00		21.53	21.64	
$Na_2O.Fe_2O_3.4SiO_2$	3.23	3.24		1.85	1.86	
$CaO.MgO.2SiO_2$	4.97	4.99	13.43	2.59	2.60	24.00
$CaO.FeO.2SiO_2$	1.73	1.74		14.63	14.70	
$CaO.MnO.2SiO_2$	6.67	6.70		6.67	6.70	
$CaO.SiO_2$	27.38	27.52	37.28	29.00	29.16	32.10
$CaO.H_2O.2SiO_2$	9.71	9.76		2.93	2.94	
	99.50	100.00		99.50	100.00	
Excess SiO_2	.36			0.01		
	99.86			99.51		

GENERAL RELATIONSHIPS OF BABINGTONITE. In the case of triclinic, chemically complex minerals like babingtonite so ill-defined are the limits of unlikeness permissible in what is called a group of minerals that classification is largely arbitrary. In our opinion babingtonite it too unlike anorthite chemically to be classed with it although they are sufficiently alike crystallographically, as was pointed out by Miss Hillebrand. On the other hand babingtonite is chemically much like the acmitic pyroxenes, although they are not known to form extensive mixed crystal series, and crystallographically they are too unlike to be classed together. Through the kindness of Dr. R. W. G. Wyckoff we are able to present evidence of the structural unlikeness of babingtonite and acmite, shown by the X-ray diffraction spectra from the powdered minerals (Fig. 1). The relative positions of the lines are measured horizontally from the central vertical line, and their relative intensities are represented by the lengths of the lines.

The triclinic acid sodium-manganese-calcium metasilicate schizolite has been compared with babingtonite by Bøggild,[20] who found the two to differ about as much as do babingtonite and the monoclinic pyroxenes. Pectolite and manganopectolite,[21] which are rather closely related to schizolite, differ considerably from babingtonite. All of these minerals have two cleavages about as perfect as those of babingtonite and inclined at about the same angle. The range is from 84°40′ in pectolite to 88°24′ in babingtonite.

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[20] O. B. Bøggild, Meddels. om Groenland, **26**, 121, (1904).

[21] J. F. Williams, *Arkansas Geol. Survey, Ann. Rep.* (1890), **2**, 253, (1891); *Zeits. Kryst.*, **18**, 386, (1891).

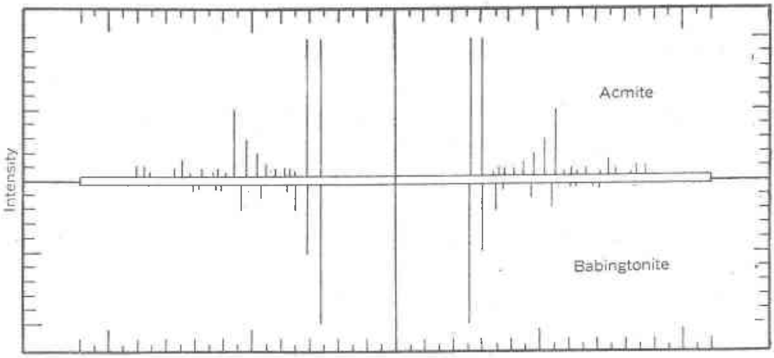

FIG. 1. X-ray Diffraction Spectra of Babingtonite and Acmite

By general agreement rhodonite and babingtonite have usually been grouped together. Another mineral, pyroxmangite, should be in this group, it seems to us, although its discoverers, Ford and Bradley,[22] questioned such relationship. The angle between the two cleavages, which are similar to those of babingtonite, is 88°10′, almost identical with that in babingtonite. Optical differences, which Ford and Bradley considered important, we consider unimportant.

The chemical composition, determined by two closely agreeing analyses, was expressed by them as follows:

SiO_2	0.786	
Al_2O_3	.023	
FeO	.394	.717
MnO	.290	
CaO	.033	
H_2O	.018	

The ratio RO:SiO_2 is far from that of a metasilicate if the Al_2O_3 is assumed to be present in the Tschermak molecule, $RO.Al_2O_3.SiO_2$, as was done by Ford and Bradley. If, however, we assume the presence of $FeO.Al_2O_3.4SiO_2$, as was done with babingtonite, the exact metasilicate ratio is obtained, if the water is disregarded.[23] According to our interpretation the molecular composition of the pyroxmangite may be expressed as follows:

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[22] Ford and Bradley, *Am. Jour. Sci.*, **36**, 169, (1913).

[23] The pyroxmangite was intimately associated with an alteration product to which the composition $3MnO_2.2Fe_2O_3.6H_2O$ was assigned.

$FeO.Al_2O_3.4SiO_2$	9.52
$FeO.SiO_2$	48.97
$MnO.SiO_2$	37.99
$CaO.SiO_2$	3.83
H_2O	0.37
	100.68

Two other triclinic substances appear also to belong to the rhodonite-babingtonite group. One is the mineral sobralite,[24] a metasilicate of manganese, iron, lime, and magnesia, and the other is a slag product, called vogtite,[25] which is apparently like the triclinic babingtonite-like slag crystals described by Vogt.[26] These crystals have pyroxene-like cleavages and angles and were thought by their discoverers to belong with rhodonite and babingtonite.

SUMMARY

New determinations of the chemical and optical properties and the density of babingtonite have been made. Its unlikeness to the monoclinic pyroxenes has been discussed. The arbitrary character of the boundaries of mineral groups, especially triclinic groups, is mentioned, and it is suggested that babingtonite, rhodonite, pyroxmangite, and sobralite are sufficiently alike, and also unlike the pyroxenes and other mineral groups, to be grouped by themselves.

MAGNESITE CRYSTALS FROM ORANGEDALE, NOVA SCOTIA

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The unusual rarity of euhedral crystals of magnesite led the writer to make a special study of some obtained from Ward's Natural Science Establishment by Dr. A. F. Rogers a few years ago. The crystals come from a magnesite deposit near Orangedale, Inverness County, Nova Scotia, the occurrence of which was described by A. O. Hayes in 1916.[1]

According to Hayes, the deposit was discovered by Alexander McLeod on the farm of John Martin, McLean Point road, about

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[24] J. Palmgren, *Bull. Geol. Inst. Univ. Upsala*, **14**, 109, (1917).

[25] C. Hlawatsch, *Zeits. Kryst.*, **42**, 590, (1907).

[26] J. H. L. Vogt, Studier over Slagger, **1**, 37, (1884); Mineralbildung in Schmelzmassen, **71**, (1892); Die Silikatschmelzlosungen, **1**, 47, (1903).

[1] Sessional Papers of the Canada Department of Mines, Vol. LII, No. **17**, p. 277, (**1917**).