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NORSETHITE, $BaMg(CO_3)_2$, A NEW MINERAL FROM THE GREEN RIVER FORMATION, WYOMING*

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Abstract

Norsethite, $BaMg(CO_3)_2$, was found in dolomitic black oil shale below the main trona bed in the Westvaco trona mine in Wyoming, associated with shortite, labuntsovite, searlesite, loughlinite, pyrite, and quartz. It also occurs there in gray shale with abundant shortite and northupite, some searlesite and loughlinite, in a fine-grained matrix consisting essentially of quartz and pyrite.

Norsethite occurs as clear to milky-white circular plates or flattened rhombohedral crystals, 0.2–2.0 mm. across. The mineral is insoluble in water but is readily decomposed by cold dilute hydrochloric acid. Norsethite has hardness about 3.5; density 3.837 ± 0.005 (meas.), 3.840 (calc.); luster vitreous to pearly; fracture hackly; good rhombohedral cleavage. It is infusible before the blowpipe. Norsethite is uniaxial negative, and the indices of refraction are $\omega = 1.694$ and $\epsilon = 1.519$. *X*-ray crystallographic studies show that the crystals are rhombohedral and have the following characteristics: possible space groups, $R\bar{3}m$, $R3m$, or $R32$, the most probable being $R32$ (D_3^7), a subgroup of $R\bar{3}c$, the space group of calcite; hexagonal $a = 5.020 \pm 0.005$ Å, $c = 16.75 \pm 0.02$; rhombohedral $a_{rh} = 6.29 \pm 0.01$ Å, $\alpha = 47°02' \pm 05'$; volume 365.6 Å^3 (hex.); cell contents: $3[BaMg(CO_3)_2]$, in the hexagonal unit. Crystal forms observed are $c\{10001\}$, $a\ \{11\bar{2}0\}$, $m\ \{10\bar{1}0\}$, and $r\ \{10\bar{1}1\}$. The strongest *x*-ray lines are: 3.015 Å (100), 3.860 (35), 2.656 (35), 2.512 (35), 2.104 (35), 1.931 (35), 1.864 (35).

Norsethite has a structure similar to that of calcite. The structural relations of norsethite, dolomite, and calcite are discussed.

Chemical analysis of a 0.1 gm. sample gave: BaO 52.9, CaO 0.5, MgO 13.9, FeO 0.4, MnO 0.1, CO_2 31.2, Na_2O 0.2, SiO_2 0.3, insoluble 0.4, total 99.9 per cent.

Norsethite is named in honor of Mr. Keith Norseth, engineering geologist of the trona mine at Westvaco, Sweetwater County, Wyoming.

Introduction

The new mineral norsethite, $BaMg(CO_3)_2$, was discovered during the investigation of the authigenic minerals of the Green River formation of Wyoming, Utah, and Colorado. It occurs in microscopic quantities at the Westvaco trona mine which is about 18 miles west of Green River, Wyoming. So far, norsethite has not been found at any other Green River locality.

The specimens that contained the crystals of norsethite were collected by Charles Milton who first observed this new mineral and named it in honor of Mr. Keith Norseth, engineering geologist at the Westvaco trona mine, in grateful acknowledgment of his friendly assistance in the mineralogical studies of these authigenic minerals.

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Occurrence of Norsethite

Norsethite first was observed as clear to milky-white plates flattened parallel to the basal pinacoid (Figs. 1 and 4) in the dolomitic black oil shale which underlies the main trona bed at the Westvaco trona mine in Wyoming. There the mineral has been found associated with shortite [$Na_2Ca_2(CO_3)_3$], labuntsovite [$(Na,K)_2(Ba,Mg)(Ti,Al,Fe,Nb)_2Si_4O_{11}(OH)_6$], searlesite [$NaBSi_2O_6 \cdot H_2O$], loughlinite [$Na_2Mg_3Si_6O_{16} \cdot 8H_2O$], pyrite, and quartz. Norsethite also occurs at the Westvaco mine in a gray shale that consists largely of quartz and a small amount of pyrite; the associated minerals are abundant shortite and northupite [$Na_3MgCl(CO_3)_2$], and lesser amounts of searlesite and loughlinite. The water-insoluble residue of trona core from an unknown depth, drilled in the area of the Westvaco trona mine, yielded discoid masses of norsethite (Fig. 2). In addition, good crystals of the type shown in Figs. 1 and 3 were obtained from the waste sodium-carbonate "mud" discharged from the soda-ash processing plant at Westvaco, along with pyrite, shortite, dolomite, calcite, labuntsovite, barytocalcite [$CaBa(CO_3)_2$], leucosphenite [$Na_3CaBaBTi_3Si_9O_{29}$], and witherite [$BaCO_3$].

Thus far, norsethite has not been found in the dolomitic oil shales of Utah or Colorado.

Mineral Separation

Norsethite crystals were isolated from the rock specimens, the trona core, and the waste sodium-carbonate "mud" by heavy-liquid separation (bromoform), followed by hand-picking under the binocular microscope. Associated with norsethite in the waste "mud" were crystals of barytocalcite and witherite, nearly identical in habit with those of norsethite. Norsethite could not be distinguished readily from barytocalcite and witherite by means of indices of refraction, or by specific gravity, since Clerici solution attacks carbonates. It was necessary to check each individual crystal of such habits under the microscope; norsethite is uniaxial negative, whereas barytocalcite and witherite are both biaxial negative with small 2V.

The material submitted for the chemical analysis (0.1 gm.) was obtained from a single specimen of dolomitic shale which was free from barytocalcite and witherite. In this instance only bromoform separation was required.

Physical and Optical Properties

Norsethite occurs as clear to milky-white circular plates or flattened rhombohedral crystals with diameters ranging from 0.2 to 2.0 mm. (Figs. 1–4). Some crystals, as well as irregular grains, show corrugated

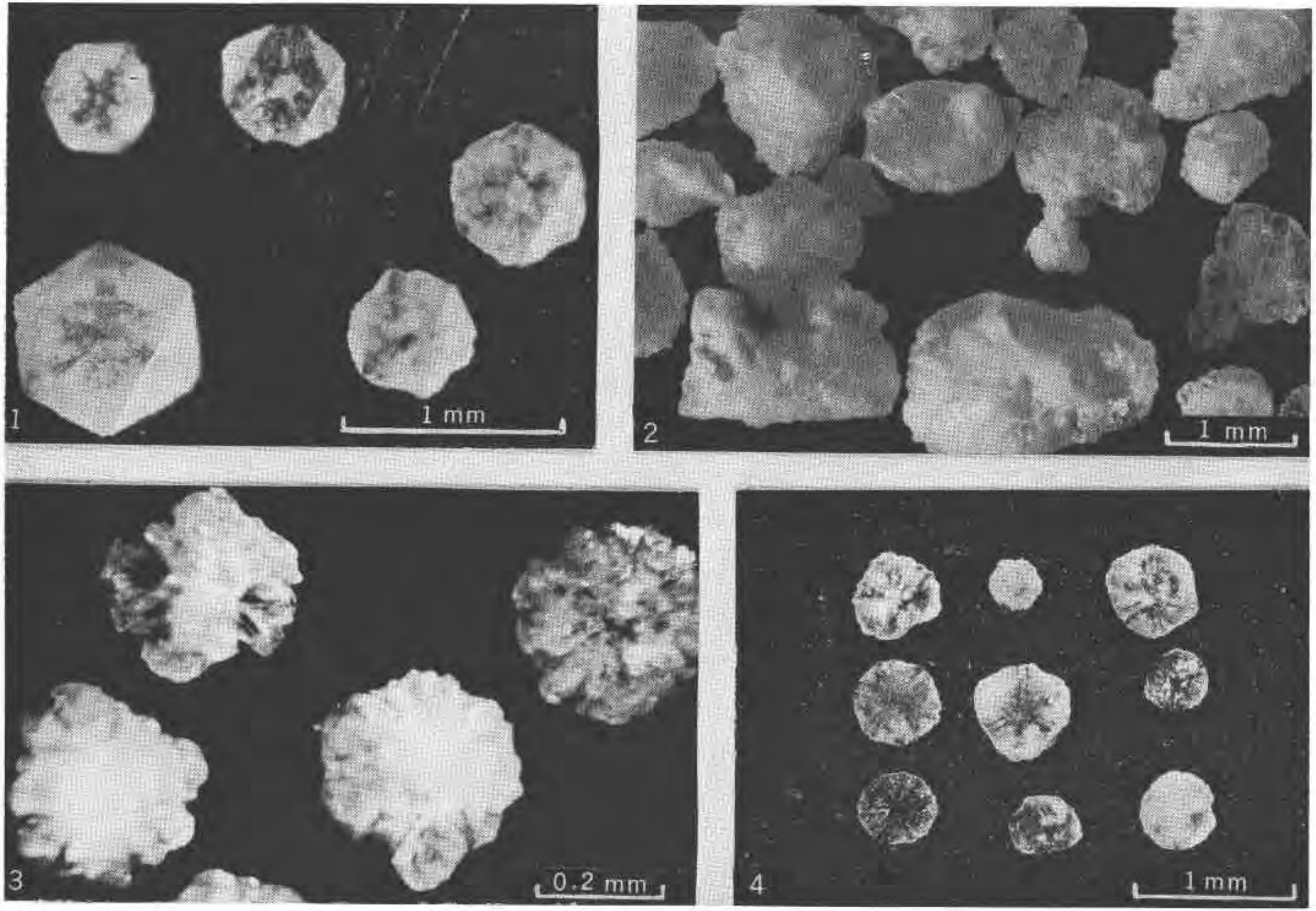

FIG. 1. Norsethite crystals of average size showing well-developed rhombohedral faces and basal pinacoid.
FIG. 2. Irregular platy crystals of norsethite showing corrugated edges.
FIG. 3. Pumpkin shaped crystals of norsethite.

or flattened edges; the thick corrugated grains are pumpkin-shaped. The mineral has a vitreous luster, a hackly fracture, and good rhombohedral cleavage $\{10\bar{1}1\}$. Its hardness is about 3.5. Norsethite is insoluble in water but is readily decomposed by cold dilute hydrochloric acid. It is infusible before the blowpipe. The specific gravity, determined on small crystals of norsethite on the Berman microbalance, using toluene as the immersion liquid, is 3.837 ± 0.005 (an average of six different determinations); for large crystals, 3.810 ± 0.005; the calculated specific gravity is 3.840. Most of the crystals of norsethite that were examined

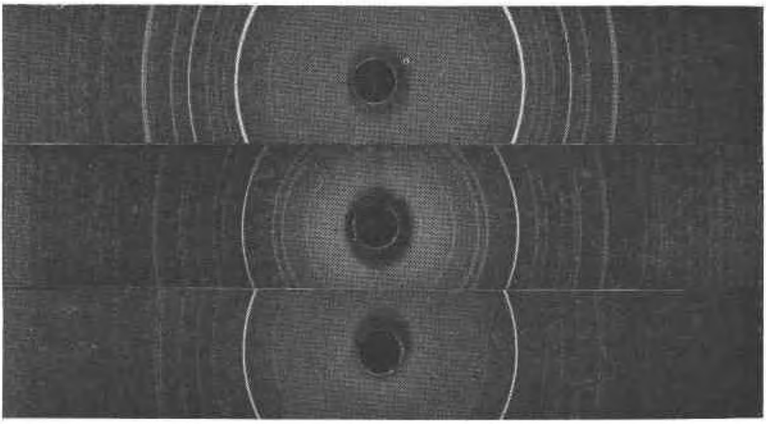

FIG. 5. *X*-ray powder photographs (Cu Kα radiation). (above) Calcite, Westvaco trona mine, Sweetwater County, Wyoming. (middle) Norsethite, Westvaco trona mine. (below) Dolomite, Binnental, Switzerland.

under the microscope showed fluid inclusions or cavities; some appear as channels normal to, and in between, the rhombohedral faces, as shown in Fig. 1 and 4. The presence of cavities and channels in the large crystals undoubtedly accounts for the difference between the observed and calculated values.

Optically, norsethite is uniaxial negative. The mineral is colorless in transmitted light. The indices of refraction were determined by the immersion method using sodium light and were corrected to 25° C. The error of measurement probably is not greater than ± 0.001; $\omega = 1.694$ and $\epsilon = 1.519$; $\Delta = 0.175$ (Na).

The rule of Gladstone and Dale $[(n-1)/d = K]$ was found to hold surprisingly well for norsethite. Norsethite with $d = 3.837$ (meas.) and $K = 0.16632$ (based on the recalculated chemical analysis in Table 3) gives $dK + 1 = 1.638$ for the calculated mean index and $(2\omega + \epsilon)/3 = 1.636$ for the measured mean index.

Crystallography

Morphology

The faces on the well-formed crystals of norsethite gave only fair signals on the optical goniometer. The forms observed were identified readily from goniometric measurements correlated with the single-crystal x-ray results. The morphology of the largest crystals measured (averaging 1.0 mm. in diameter) consists only of a well-developed base {0001} and the rhombohedron $\{10\bar{1}1\}$. The small crystals (less than 0.5 mm. in diameter) showed, in addition, the first order prism $\{10\bar{1}0\}$ and the second order prism $\{11\bar{2}0\}$, as very narrow faces.

The notable absence of a bipyramidal form on any of the numerous crystals examined made it impossible to determine the crystal class from morphological considerations alone. The crystals are holohedral in habit. They gave no positive piezoelectric response on the Giebe-Scheibe apparatus. This evidence would suggest that the crystal class is either rhombohedral ($\bar{3}$) or scalenohedral ($\bar{3}2/m$). Both these possibilities were eliminated and the crystal class was established as trigonal-trapezohedral (32) from a consideration of the space group criteria and the structural relation of norsethite to calcite (see discussion on page 426).

X-ray powder data

An x-ray powder diffraction pattern of norsethite (film no. 11793) was taken in a 114.59 mm. diameter Debye-Scherrer camera with nickel-filtered copper radiation ($\lambda = 1.5418$ Å), using both the Straumanis and Wilson techniques (Fig. 5). Film measurements were corrected for shrinkage. All interplanar spacings and intensities for the observed lines are given in Table 1, column 2. The intensities were estimated visually by comparison with a calibrated intensity strip. Interplanar spacings were calculated from the x-ray cell constants down to a value of $d_{hk.l} = 1.005$ Å on a digital computer using a program developed and carried out by Daniel E. Appleman. All calculated spacings for $d_{hk.l} \geq 1.000$ Å for norsethite are listed in Table 1, column 1.

Single-crystal x-ray data

A thin, tabular, hexagonal-shaped crystal of norsethite (approximately 0.5 mm. in diameter) was examined by the Buerger precession method. A quartz-calibrated precession camera was used with zirconium-filtered molybdenum radiation ($\lambda = 0.7107$ Å) to obtain the $h0 \cdot l$, $h1 \cdot l$, $hk \cdot 0$, $hk \cdot 1$, and $hh \cdot l$ net planes. These photographs established the lattice as rhombohedral and, together with the film measurements (corrected for horizontal and vertical shrinkage), led to the crystallographic data given in Table 2.

TABLE 1. COMPARISON OF X-RAY POWDER DATA FOR NORSETHITE, DOLOMITE, AND CALCITE

Norsethite, $BaMg(CO_3)_2$ Westvaco trona mine, Sweetwater Co., Wyoming Present Study				Dolomite, $CaMg(CO_3)_2$ Ross Township, Haley, Ontario Howie and Broadhurst, 1958		Calcite, $CaCO_3$ Synthetic Swanson and Fuyat, 1953	
(1) Calculated[a]		(2) Measured[b]		(3) Measured[c]		(4) Measured[d]	
hk.l	$d_{hk.l}$	$d_{hk.l}$	I	$d_{hk.l}$	I	$d_{hk.l}$	I
00.3	5.583	5.584	25				
10.1	4.208	4.210	30	4.025	3		
01.2	3.859	3.860	35	3.690	5	3.86	12
10.4	3.016	3.015	100	2.886	100	3.035	100
00.6	2.792	2.795	3	2.670	10	2.845	3
01.5	2.654	2.656	35	2.540	8		
11.0	2.510	2.512	35	2.405	10	2.495	14
11.3	2.289	2.290	25	2.192	30	2.285	18
02.1	2.156	2.154	25	2.066	15		
20.2 10.7	2.104 2.096	2.104	35	2.015	15	2.095	18
02.4	1.929	1.931	35	1.848	5	1.927	5
01.8	1.886	1.890	25	1.804	20	1.913	17
11.6 00.9	1.867 1.861	1.864	35	1.786 1.781	30	1.875	17
20.5	1.824	1.824	3				
21.1	1.635	1.636	6	1.567	8	1.626	4
12.2 02.7	1.612 1.609	1.612	18				
10.10	1.563	1.563	6	1.496	2	1.587	2
21.4	1.530	1.530	25	1.465	5	1.525	5
20.8	1.508	1.510	6	1.445	4	1.518	4
11.9	1.495	1.496	6	1.431	10	1.510	3
12.5	1.475	1.475	9	1.413	4	1.473	2
03.0	1.449	1.448	9	1.389	15	1.440	5
01.11	1.437	1.437	2				
03.3 30.3	1.403	1.404	6				
00.12	1.396	1.398	6	1.335	8	1.422	3
21.7	1.355	1.356	9	1.297	4	1.356	1
02.10	1.327	1.328	9	1.269	4	1.339	2
12.8	1.293	1.295	9	1.238	5	1.297	2
03.6 30.6	1.286	1.286	9			1.284	1
22.0	1.255	1.256	6	1.202	3	1.247	1
20.11	1.247	1.248	4				
10.13	1.235	1.237	3				
22.3 11.12	1.224 1.220	1.222	9	1.168	4	1.235	2
13.1	1.203	1.203	3				

[a] Calculated from cell data for norsethite given in Table 2.

[b] Film corrected for shrinkage. Camera diameter, 114.59 mm. CuK_α radiation, Ni filter ($\lambda = 1.5418$ Å). Lower limit 2θ measurable, approximately 7.0° (12.6 Å).

[c] Powder data obtained on diffractometer with CuK_α radiation.

[d] Pattern made with a high-angle Geiger-counter spectrometer, using a sample of exceptionally high purity. CuK_α radiation ($\lambda = 1.5404$ Å at 26° C.).

(*Continued on next page*)

TABLE 1 (*Continued*)

Norsethite, $BaMg(CO_3)_2$ Westvaco trona mine, Sweetwater Co., Wyoming Present Study				Dolomite, $CaMg(CO_3)_2$ Ross Township, Haley, Ontario Howie and Broadhurst, 1958		Calcite, $CaCO_3$ Synthetic Swanson and Fuyat, 1953	
(1) Calculated[a]		(2) Measured[b]		(3) Measured[c]		(4) Measured[d]	
$hk.l$	$d_{hk.l}$	$d_{hk.l}$	I	$d_{hk.l}$	I	$d_{hk.l}$	I
31.2	1.193	1.193	4	1.144	2		
21.10	1.173	1.173	4	1.123	5	1.1795	3
13.4	1.159	1.160	9	—*		1.1538	3
01.4	1.154	1.154	3				
22.6	1.145 }						
03.9	1.144 }	1.144	4	1.096	3		
30.9	1.144 }						
31.5	1.135	1.135	6				
00.15 } 12.11 }	1.117	1.119	3	1.068	1	1.1244	<1
02.13	1.108	1.108	3				
40.1	1.084	1.086	3				
04.2	1.078 }	1.077	6				
13.7	1.077 }						
40.4	1.052	1.051	3	1.008	4	1.0473	3
20.14	1.048	1.046	6			1.0613	1
31.8	1.042 }	1.042	3	1.001	5	1.0447	4
22.9	1.041 }						
04.5	1.034	1.033	3				
11.15	1 020	1.020	4				
10.16	1.018 }	1.015	3	0.973_5	3	1.0352	2
21.13	1.014 }					1.0234	<1
03.12 } 30.12 }	1.005	1.006	6	0.962	5	1.0118	2
		0.9893	3	0.949	1	0.9895	<1
		0.9799	3	0.930	1	0.9846	1
		0.9717	6	0.926	3	0.9782	1
		0.9683	6	0.923	3	0.9767	3
		0.9559	3	0.913	1	0.9655	2
		0.9499	3	0.909	2		
		0.9469	3	0.903	1		
		0.9343	4	0.894	2		
		0.9223	3	0.835	4		
		0.9117	3	0.821	2		
		0.9017	4				
		0.8989	6				
		0.8961	3				

* This line was obscured by a line of the Si standard.

Structural relation to calcite and dolomite

A search of *Crystal Data* (Donnay and Nowacki, 1954) showed that dolomite [$CaMg(CO_3)_2$] and calcite [$CaCO_3$] have c/a ratios remarkably close to that of norsethite [$BaMg(CO_3)_2$]. This, coupled with the fact that these three minerals have remarkably similar crystallographic data (Table 2) as well as physical and optical properties, strongly suggested that norsethite must be a member of the same structure group as dolomite and calcite. Comparison of the *x*-ray powder films (Fig. 5) and the powder diffraction data (Table 1) for the three minerals indicated a strong structural resemblance between norsethite and calcite (space group $R\bar{3}c$), and between norsethite and dolomite (space group $R\bar{3}$).

The Buerger precession photographs of norsethite indicated only three possible space groups for the mineral: $R\bar{3}m$, $R3m$, or $R32$. Neither $R\bar{3}m$ nor $R3m$ is a possible sub-group of $R\bar{3}c$ or of $R\bar{3}$. Since evidence indicates that norsethite has a structure similar to that of calcite, and since $R32$ is the only one of the three possible space groups for norsethite which is listed as a sub-group of $R\bar{3}c$ (the space group of calcite), it follows that the space group of norsethite must be $R32$.

In order to elucidate the relation of the norsethite structure to the calcite and dolomite structures, a determination of the structure of norsethite has been undertaken and will be published in detail at a later date.

TABLE 2. COMPARISON OF CRYSTALLOGRAPHIC DATA FOR NORSETHITE, DOLOMITE, AND CALCITE

Mineral	Norsethite	Dolomite	Calcite
Locality	Westvaco mine, Sweetwater Co., Wyoming	Ross Township, Haley, Ontario	Synthetic
Reference	Present Study	Howie and Broadhurst, 1958	Swanson and Fuyat, 1953
Symmetry	Hexagonal-R; trapezohedral-32	Hexagonal-R; rhombohedral-$\bar{3}$	Hexagonal-R; scalenohedral-$\bar{3}2/m$
Cell Constants			
a	5.020 ± 0.005 Å	4.810 ± 0.002 Å	4.989 Å
c	16.75 ± 0.02	16.02 ± 0.001	17.062
c/a	3.337	3.330	3.420
a_{rh}	6.29 ± 0.01 Å	6.020 Å	6.375 Å
α	$47°02' \pm 05'$	$47°07'$	$46°04'$
Space Group	$R32$	$R\bar{3}$	$R\bar{3}c$
Volume (hex.)	365.6 Å^3	321.0 Å^3	367.8 Å^3
Cell Contents (hex.)	$3[BaMg(CO_3)_2]$	$3[CaMg(CO_3)_2]$	$6[CaCO_3]$
Density (calc.)	3.840	2.872*	2.711
(obs.)	3.837 ± 0.005	2.86*	—

* Quoted from Zen (1956).

CHEMISTRY

Except for the determination of CO_2, the classical procedures of Hillebrand *et al.* (1953) were followed in the chemical analysis of norsethite which was made on a 0.1 gm. sample obtained from a single specimen. Carbon dioxide was determined volumetrically by measuring the gas evolved when the sample was treated with (1+3)HCl and, after reducing to standard conditions, applying the factor to convert volume of CO_2 to mass (Fahey, 1946).

The quantitative spectrographic analysis for minor elements in norsethite, cited below, was made by Harry Bastron of the U. S. Geological Survey:

Ca	0.40	Sn	0.002
Na	0.2	Ti	0.001
Fe	0.15	Cu	0.0005
Mn	0.049	Cr	0.0004
Sr	0.022	Be	0.0002
Al	0.016		

Looked for, not found: Ag, Au, Hg, Ru, Rh, Pd, Ir, Pt, Mo, W, Re, Ge, Pb, As, Sb, Bi, Te, Zn, Cd, Tl, In, Co, Ni, V, Ga, Sc, Y, Yb, La, Zr, Th, Nb, Ta, U, Li, P, and B.

The chemical analysis of norsethite is given in Table 3. The formula derived from this analysis is $BaMg(CO_3)_2$. The recalculated chemical analysis is in good agreement with the theoretical composition.

TABLE 3. CHEMICAL ANALYSIS OF NORSETHITE, $BaMg(CO_3)_2$
Analyst: J. J. Fahey

	Determined Per Cent	Recalculated	Molecular Ratios	Theoretical Composition
BaO	52.9	53.5	1.00	54.44
CaO	0.5	0.5		
MgO	13.9	14.0		14.31
FeO[a]	0.4	0.4	1.00	
MnO	0.1	0.1		
CO_2	31.2	31.5	2.01	31.25
Na_2O[b]	0.2			
SiO_2[c]	0.3			
Insol.[d]	0.4			
Total	99.9	100.0		100.00

[a] Total iron as FeO.
[b] Determined spectrographically by Harry Bastron.
[c] Soluble in (1+3)HCl.
[d] Insoluble in (1+3)HCl.

Using the measured specific gravity determination of 3.837, the chemical analysis in Table 3, and the cell constants for norsethite, the experimental molecular weight of the unit cell is 844.6. The calculated cell contents approach very closely the formula $3[BaMg(CO_3)_2]$.

Acknowledgments

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