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SAHAMALITE, A NEW RARE EARTH CARBONATE MINERAL¹

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ABSTRACT

Sahamalite, $(Mg, Fe)(Ce, La, Nd, Pr)_2(CO_3)_4$, a new rare earth mineral, occurs in barite-dolomite rock near Mountain Pass, San Bernardino County, California. The mineral is monoclinic, $2/m$; space group $P 2_1/a$; $a:b:c = 0.3635:1:0.2857$; $a_0 = 5.92 \text{ \AA}$, $b_0 = 16.21 \text{ \AA}$, $c_0 = 4.63 \text{ \AA}$, $\beta = 106^\circ 45'$. Crystals are tabular, parallel to $\{201\}$; dominant forms are $\{201\}$, $\{\bar{1}31\}$, $\{120\}$, $\{110\}$, $\{010\}$, and $\{011\}$. Cleavage (010) is poor; $\alpha = 1.679$, $\beta = 1.776$, $\gamma = 1.807$; biaxial negative, $2V = 57^\circ$; $Z \wedge c = 29^\circ$, $Y = b$; $G = 4.30$. The mineral is named for Th. G. Sahama, contemporary Finnish geochemist.

INTRODUCTION

In the summer of 1951 the senior author was assigned to make a detailed study of the mineralogy of the bastnaesite-bearing deposits near Mountain Pass, San Bernardino County, California. At this time, several rock specimens previously collected by D. F. Hewett, J. C. Olson, and W. N. Sharp, all of the U. S. Geological Survey, were made available for preliminary study. One thin section of dolomite, collected from the Sulfide Queen deposit, contained numerous small (0.01–0.2 mm.) prisms of an unidentified colorless mineral intimately associated with parisite and altered bastnaesite. After examination of the powdered mineral by the immersion method revealed unique optical properties, the mineral was purified for further studies. Subsequent spectrographic, x-ray, and chemical analyses have established the mineral to be a new anhydrous carbonate of the cerium earths, magnesium, and iron. The composition of the new mineral is expressed by the formula $AB_2(CO_3)_4$, where A is magnesium and bivalent iron and B is the cerium earth group—dominantly cerium, lanthanum, and neodymium.

The new mineral, sahamalite (sä'hä-mä-lit), is named for Thure Georg Sahama, contemporary Finnish geochemist, who has contributed much to our knowledge of the association and the abundance of the rare earths in eruptive rocks and in minerals.

¹ Publication authorized by the Director, U. S. Geological Survey.

MINERALOGY

Separation and purification

The sahamalite was difficult to separate and purify because of its fine grain size and intimate association with parisite and bastnaesite. The rock containing it was ground to minus 40 mesh, and the powder was then further sized on 60, 100, 200, and 270 mesh sieves. Microscopic studies of the different fractions showed that the sahamalite grains could not be liberated for concentration in sizes coarser than 100 mesh. The optimum concentration of the mineral amenable to separation occurred in the 100–200 mesh fraction (0.075–0.15 mm.). Sahamalite finer than 270 mesh could not be separated successfully.

Heavy-liquid separation of the sized sample was made using methylene iodide having a density of 3.3. This separation gave a light fraction composed essentially of dolomite and a minor amount of quartz, and a heavy fraction composed of barite, sahamalite, altered bastnaesite, parisite, and hematite. Barite, the chief mineral component of the heavy fraction, was removed on the Franz isodynamic magnetic separator. The barite remained nonmagnetic at the highest intensity, 1.5 amperes, and was easy to remove after several passes. Sahamalite was found to be slightly more magnetic than bastnaesite and parisite, and slightly less magnetic than hematite. Both separations had to be made at differences of only 0.1 ampere. About 50 passes on the magnetic separator were necessary to remove the altered bastnaesite, parisite, and hematite from the sahamalite. The final magnetic concentrate of sahamalite was examined microscopically and still showed a minor amount of small adhering particles of dolomite and a little red stain on some of the sahamalite grains. These impurities were removed by treating the concentrate with tartaric acid after solubility tests were made. Sahamalite is insoluble in boiling tartaric acid, whereas dolomite is completely soluble, (see solubility). Examination of the concentrate before and after the tartaric acid treatment was made by x-ray diffraction and immersion studies. The x-ray spacings and optical properties remained precisely the same. A final product of 200 mg. of sahamalite was obtained for further studies. A microscopic grain count of the final concentrate indicated 99 per cent purity.

Space group and unit cell

A single (100–200 mesh) grain of sahamalite, with the aid of its external crystal habit, was mounted on a glass fiber with the monoclinic *b*-axis oriented roughly normal to the fiber. From this crystal, photographs of the zero layer reciprocal lattice planes normal to (110) and (010), and a first layer normal to (010), were made with the Buerger

TABLE 1. X-RAY CRYSTALLOGRAPHY OF SAHAMALITE

<i>Crystal class:</i> Monoclinic, $2/m$		
<i>Space group:</i> $P2_{1/a} = C_2^5h$		
<i>Lattice dimensions:</i> $a = 5.92 \pm .02 \text{ \AA}$		
$b = 16.21 \pm .05 \text{ \AA}$	$\beta = 106^\circ 45'$	
$c = 4.63 \pm .02 \text{ \AA}$	Cell volume = 425.6 \AA^3	
<i>Cell contents:</i> 2 formulas of $(Mg, Fe)Ce_2(CO_3)_4$		
<i>Density:</i> pycnometer = 4.30		
calculated = 4.30 (Mg:Fe = 85:15)		

precession camera using $Mo/K\alpha$ radiation. The x-ray crystallographic data obtained by Howard T. Evans are given in Table 1.

X-ray powder diffraction pattern

An x-ray powder diffraction pattern was taken by F. A. Hildebrand with a Debye-Scherrer camera (114.59 mm. diameter) using $Cr K\alpha$ radiation with $\lambda = 2.2909 \text{ \AA}$. All the lines measured, down to $d = 1.81$, were indexed on the basis of the data given in Table 1. The x-ray powder diffraction data are given in Table 2. The pattern is reproduced in Fig. 1.

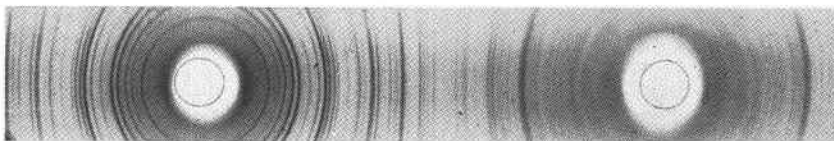


FIG. 1. X-ray powder diffraction pattern of sahamalite taken with a 114.59 mm. diameter camera using $Cr K\alpha$ radiation.

Morphology

Three grains not larger than 0.2 mm. were mounted on glass fibers and studied with the optical goniometer. The crystals were found to be rather richly developed, each showing 11 to 24 measurable faces giving fair to good signals. The data were plotted on a gnomonic projection normal to (010) and the various forms identified by comparison with the x-ray lattice. The morphological data obtained by Howard T. Evans are summarized in Table 3.

Fifteen forms were identified. The crystals are tabular parallel to $\sigma\{\bar{2}01\}$, which is by far the most prominent form. The edges are beveled by the forms $e\{120\}$ and $s\{\bar{1}31\}$. These together with other minor forms result in the characteristic habit shown in Fig. 2. Under the microscope, the crystals lie habitually on the large $\sigma(\bar{2}01)$ face and present the characteristic appearance shown in Fig. 3. The peculiarly tapering outlines of the bevel faces at the edges of the crystal are thus readily explained. The

TABLE 2. X-RAY POWDER DIFFRACTION DATA FOR SAHAMALITE

<i>d</i> (obs.)	<i>I</i>	<i>d</i> (calc.)	<i>hkl</i>	<i>d</i> (obs.)	<i>I</i>	<i>d</i> (calc.)	<i>hkl</i>
8.0	4	8.105	020	2.02	2	2.026	080
5.33	7	5.352	110			2.018	171
4.64	5	4.646	120			2.002	142
4.41	2	4.436	001			1.995	222
4.26	7	4.278	011	1.98	2	1.979	231
4.02	4	4.052	040			1.956	260
		3.990	111			1.945	042
3.90	10	3.912	130	1.94	3	1.941	261
		3.891	021			1.940	311
3.65	10	3.670	121	1.93	2	1.923	232
3.41	$\frac{1}{2}$	3.428	031			1.908	180
3.28	5	3.297	140	1.90	2	1.899	321
		3.274	131	1.88	3	1.883	241
3.03	7	3.034	111			1.877	152
2.98	1	2.992	041			1.876	112
2.87	10	2.888	141			1.853	171
		2.886	121	1.84	2	1.843	081
2.82	2	2.835	200			1.842	122
		2.814	150			1.841	320
		2.793	210			1.837	331
2.78	4	2.780	201			1.835	242
2.76	4	2.740	211	1.83	6	1.830	052
2.69	4	2.702	060	1.82	6	1.818	181
		2.681	131	1.81	2		
2.67	4	2.676	220	1.784	2		
		2.629	221	1.748	$\frac{1}{2}$		
2.60	4	2.617	051	1.707	5		
		2.547	151	1.688	3 <i>B</i>		
		2.510	230	1.663	3 <i>B</i>		
		2.472	231	1.629	4 <i>B</i>		
2.45	2	2.456	141	1.610	2		
2.42	3	2.439	160	1.595	1		
2.32	3	2.323	240	1.573	2		
2.28 <i>B</i>	6	2.292	241	1.534	2		
		2.280	112	1.514	4		
2.25	1	2.259	161	1.486	3		
		2.253	151	1.475	4		
2.21	2	2.218	002	1.437 <i>B</i>	2		
		2.215	122	1.393	5		
2.19	2	2.197	012	1.378	5		
		2.144	170	1.361	1		
		2.140	022	1.353	1		
		2.134	250	1.332 <i>B</i>	3		
2.12 <i>B</i>	7	2.127	201	1.317 <i>B</i>	1		
		2.118	132	1.302	4		
2.10 <i>B</i>	7	2.110	251	1.295 <i>B</i>	5		
		2.109	211	1.267 <i>B</i>	2		
2.05 <i>B</i>	6	2.058	202	1.244 <i>B</i>	1		
		2.057	221	1.233 <i>B</i>	2		
		2.053	071	1.222 <i>B</i>	2		
		2.052	032	1.2048 <i>B</i>	2		
		2.042	212	1.1914 <i>B</i>	1		
		2.033	161	1.1845 <i>B</i>	1		

B = broad.

TABLE 3. MORPHOLOGICAL CRYSTALLOGRAPHY OF SAHAMALITE

<i>Crystal class:</i> Monoclinic, $2/m$							
<i>Elements (from Table 1)</i>							
Axial ratio $a:b:c=0.3635:1:0.2857$,			$\beta=106^{\circ}45'$				
Projection: $x_0'=0.3010$; $p_0'=0.8169$; $q_0'=0.2857$							
Polar: $p_0=0.7162$; $q_0=0.2505$; $v_0=73^{\circ}15'$							
<i>Forms observed:</i>							
b	010	f	011	q	$\bar{1}11$	s	$\bar{1}31$
e	120	d	021	γ	$\bar{1}42$	n	$\bar{2}11$
m	110	σ	$\bar{2}01$	G	$\bar{3}23$	x	$\bar{2}51$
l	230	k	$\bar{1}12$	a	$\bar{3}43$		
Dominant forms (descending rank):							
σ, s, e, m, b, f							

upper and lower corners of the crystal are usually truncated at a shallower angle by the form $m\{110\}$ which is generally striated in oscillatory growth with $e\{120\}$. It may be noted that two of the three measured crystals gave projections corresponding to the normal habit, but the third showed a number of poorer reflections grouped around the principal forms. These poorer reflections appear to correspond to vicinal forms produced by etching and partial solution of some of the faces.

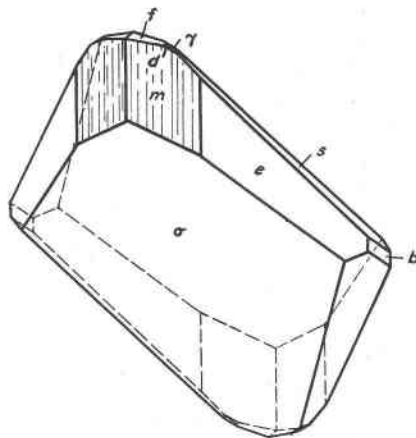


FIG. 2. Typical crystal habit of sahamalite showing forms $\sigma(\bar{2}01)$, $m(110)$, $e(120)$, $b(010)$, $s(\bar{1}31)$, $f(011)$, $d(021)$, and $\gamma(\bar{1}42)$.

Optical properties

Sahamalite is colorless and nonpleochroic in thin section and in fragment mounts. Grains lying on the prominent $(\bar{2}01)$ face give a birefringence of 0.028; those lying on (010) give the maximum birefringence of 0.128. Cleavage is poor parallel to (010) , and traces may be observed

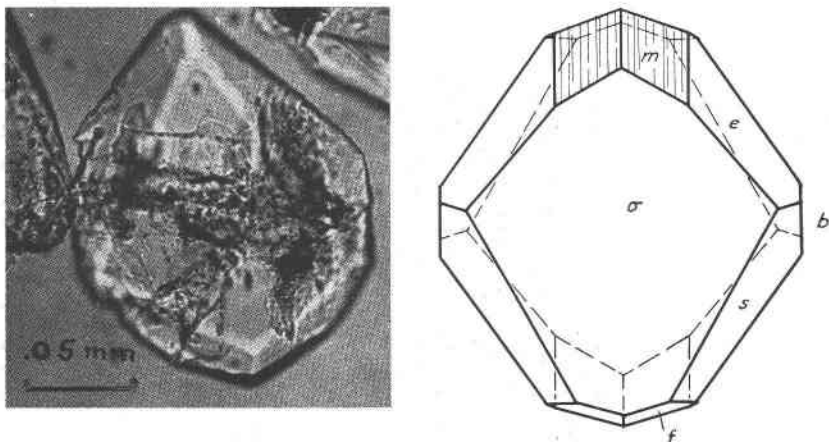


FIG. 3. Appearance of crystal of sahamalite resting on $\sigma(201)$ face.

occasionally on grains lying on $(\bar{2}01)$. The optical constants measured by H. W. Jaffe are given in Table 4, and the optic orientation is illustrated in Fig. 4.

TABLE 4. OPTICAL PROPERTIES OF SAHAMALITE

Index of refraction (± 0.002)	Orientation
$\alpha = 1.679$	$X \wedge a$
$\beta = 1.776$	$Y = b$
$\gamma = 1.807$	$Z \wedge c = 29^\circ$
$2V$: (Universal stage) = $57^\circ(-)$	
(Calculated) = $57^\circ(-)$	
Dispersion: $r < v$ (perceptible)	

The intermediate and maximum indices of refraction were measured with the index oils prepared and described by Meyrowitz and Larsen (1951). Index oils were checked with a Leitz-Jelley microrefractometer at the time the indices were measured.

CHEMISTRY

Solubility

In the course of the separation and chemical analysis of sahamalite, some data were obtained on its solubility. The mineral is more resistant to acids than most normal carbonates. This is illustrated in Table 5, where sahamalite is compared with the National Bureau of Standards sample #88 dolomite.

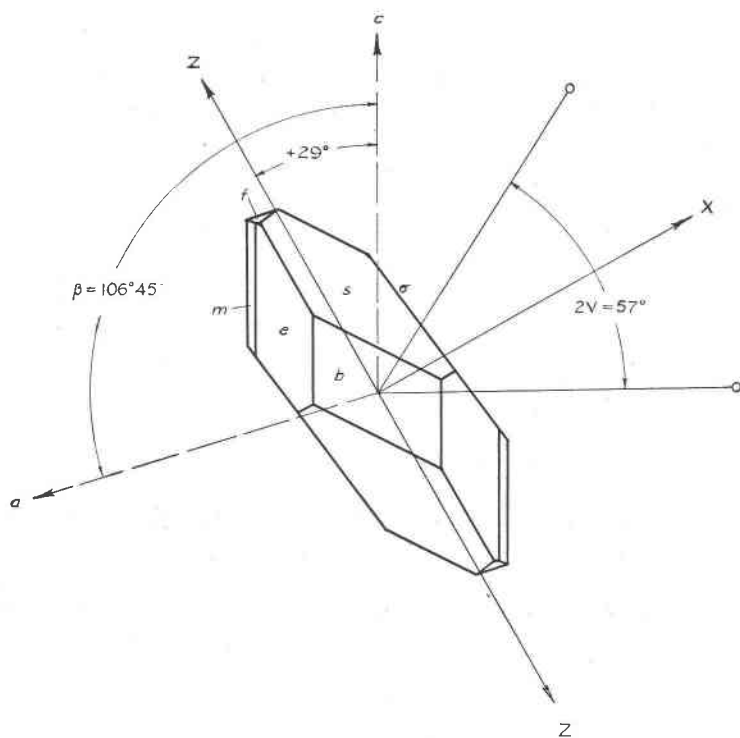
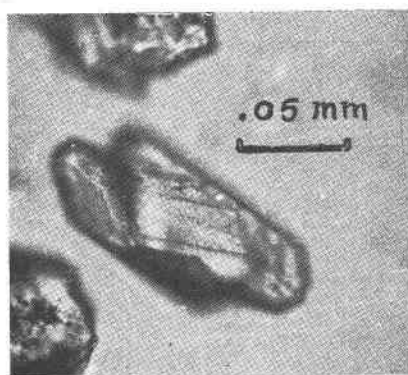


FIG. 4. Optical orientation of sahamalite.

TABLE 5. RELATIVE SOLUBILITIES OF SAHAMALITE AND DOLOMITE

Acid	Dolomite	Sahamalite
Boiling tartaric	soluble	insoluble
Boiling 1N HCl	soluble	insoluble
Boiling 3N HCl	soluble	soluble

TABLE 6. SPECTROGRAPHIC ANALYSIS OF SAHAMALITE

X0.	La, Ce
X.	Mg, Fe, Nd
.X	Mn, Ba, Si
.0X	Pb, Al, Ca, Y
.00X	Cu, Sr
.000X	Ag, Be

Looked for, not found: Au, Pt, Mo, W, Ge, Sn, As, Sb, Bi, Zn, Cd, Tl, Co, Ni, Ga, Cr, V, Yb, Ti, Zr, Th, U, Nb, Ta, B, F, K, and Na.

TABLE 7. CHEMICAL ANALYSIS OF SAHAMALITE (ROBERT MEYROWITZ, *analyst*)

Oxide	Deter- mined	Recalcu- lated	Mol. ratios	Oxygens	Metals	Cations on basis of 12 O
Ce ₂ O ₃	31.4	31.7	966	2898	1932	1.06
(La, Nd) ₂ O ₃	27.8	28.1	848	2544	1696	.93
MgO	6.1	6.2	1538	1538	1538	.85
FeO	2.0	2.0	278	278	278	.15
CO ₂	31.7	32.0	7271	14542	7271	4.00
Insol.	0.5	—				
	99.5	100.0				

Density = 4.30 (pycnometer)

Notes:

1. Cerium was determined volumetrically by titrating with 0.01N ferrous ammonium sulfate after oxidation with sodium bismuthate. The size of the sample was approximately 10 mg.

2. The figure for the rare-earth oxides other than cerium was obtained by subtracting the sum of the percentages of Fe₂O₃ and CeO₂ from that of R₂O₃.

3. Magnesium was determined as the pyrophosphate. Size of the sample was approximately 23 mg.

4. Iron was determined colorimetrically with o-phenanthroline. Size of the sample was approximately 2 mg.

5. CO₂ was obtained by loss on ignition, using a sample of approximately 8 mg. A CO₂ determination by the macroabsorption train method gave 30 per cent.

6. No H₂O was found by the Penfield method.

7. Rare earths other than cerium were determined by quantitative spectrochemical analysis, H. J. Rose, Jr., analyst. La₂O₃ 17.4, Nd₂O₃ 7.3, Pr₂O₃ 2.3, Sm₂O₃ 0.7; total 27.7. Rare earth ratio is Ce:La:Nd:Pr:Sm = 53:30:12:4:1.

Composition

Prior to quantitative chemical analysis, the sample was submitted for semiquantitative spectrographic analysis. The spectrogram obtained by H. J. Rose, Jr., gave the percentages shown in Table 6. The complete chemical analysis of sahamalite is given in Table 7.

The formula derived from the chemical analysis given in Table 7 is written as follows: $(\text{Mg, Fe})(\text{Ce, La, Nd})_2(\text{CO}_3)_4$ or $\text{AB}_2(\text{XO}_3)_4$

where A Mg^{+2} Fe^{+2}
 B Ce^{+3} , La^{+3} , Nd^{+3}
 X C^{+4}

Sahamalite is not related to any of the known carbonate mineral groups or miscellaneous types listed in the *Dana's System of Mineralogy* (Palache et al., 1951). No naturally occurring anhydrous normal carbonates of the $\text{AB}_2(\text{XO}_3)_4$ type are known. Using the Dana System classification, sahamalite might be categorized as follows:

Carbonates
 Class 14. Anhydrous normal carbonates
 Type 4. $\text{AB}_2(\text{XO}_3)_4$.

The presence of essential magnesium and bivalent iron in A and the various members of the cerium earth group in B suggests that appreciable substitution may be expected in the sahamalite type, $\text{AB}_2(\text{XO}_3)_4$. The theoretical composition for Mg and Fe^{+2} end members are compared with the composition of sahamalite in Table 8.

TABLE 8. COMPOSITION OF SAHAMALITE AND Mg , Fe^{+2} END MEMBERS

	1	2	3
Ce_2O_3	30.2	31.7	28.6
$(\text{La, Nd, Pr})_2\text{O}_3$	30.0	28.1	28.3
MgO	7.4	6.2	—
FeO	—	2.0	12.5
CO_2	32.4	32.0	30.6
	100.0	100.0	100.0

1. Theoretical Mg end member, with Ce:La 1:1.
2. Sahamalite, Mountain Pass, California.
3. Theoretical Fe^{+2} end member, with Ce:La 1:1.

Relation between composition, index of refraction, and density

The application of the law of Gladstone and Dale (1864) to mineralogy, suggested by Larsen and Berman (1934), has not been sufficiently exploited by mineralogists. The simple equation $(n-1)/d=K$, where n

is the mean index of refraction, d is the density, and K is the sum of the specific refractive energies of the component oxides (k), proved very useful in establishing the composition of sahamalite during the early stages of this investigation.

The spectrographic analysis was followed by a preliminary chemical analysis to determine whether sahamalite was a normal carbonate or a fluocarbonate, and to establish the methods best suited for the analysis of the small sample available. The preliminary analysis gave:

R ₂ O ₃	59%
MgO	6
FeO	2
CO ₂	21
	<hr style="width: 10%; margin: 0 auto;"/>
Total	88%

After qualitative tests for fluorine and H₂O proved negative, the spectrogram was reexamined. No additional metallic constituents could be found, and a second spectrographic analysis was made with the same results. Using the indices of refraction, the pycnometer density, the analytical data, and the specific refractive energies of the oxides (k) given by Larsen and Berman (1934), it was calculated from $(n-1)/d = K$ that the missing oxide or element had a specific refractive energy (k) near .20. Eliminating the elements previously not detected with the spectrograph, this left only CO₂ ($k=0.217$), Br ($k=0.214$), I ($k=0.226$), and O ($k=.203$) to account for the 12 per cent missing from the analytical total. The CO₂ determination was repeated by two different methods and the correct value was obtained bringing the analytical total to 99 per cent. The original CO₂ determination was low because the macroabsorption train had recently been set up and was not in equilibrium.

Crystal chemistry

From the data now available, the coordination of the various cations in sahamalite may be predicted from Pauling's (1929) electrostatic valency principle. In sahamalite, each oxygen should be common to:

1 C ⁺⁴ in threefold coordination equal to	1 $\frac{1}{3}$
1 (Mg, Fe) ⁺² in sixfold coordination equal to	$\frac{2}{3}$
1 (Ce, La) ⁺³ in ninefold coordination equal to	$\frac{1}{3}$

Total positive charge = 2

In this manner, the total strength of the valency bonds that reach an oxygen ion from all neighboring cations is equal to a positive charge of 2, satisfying Pauling's rule. Mg⁺² and Fe⁺² are normally expected to assume sixfold coordination, and C⁺⁴ would normally be in threefold coordination in minerals. Ce⁺³ and the other large trivalent rare-earth

ions would be expected to assume a coordination in the range of eight to twelve. From a consideration of Pauling's rule, Ce^{+3} should be in nine-fold coordination in sahamalite.

OCCURRENCE

Geological environment

The geology of the Mountain Pass district is described by D. F. Hewett, J. C. Olson, et al. (U. S. Geological Survey Bulletin, in preparation). Carbonate-rich rocks, composed essentially of calcite, dolomite, barite, quartz, and bastnaesite, occur as veins and irregular bodies in foliated metamorphic rocks and in alkalic igneous rocks including shonkinite, syenite, and quartz syenite. The largest of the irregular carbonate-rich bodies, locally referred to as the Sulfide Queen, contains barite and bastnaesite throughout; but thus far, sahamalite has been detected in only about one acre of area in the southwestern part of the exposed Sulfide Queen body.

Mineral association

Sahamalite occurs in a medium- to coarse-grained, light- to dark-brown barite-dolomite rock. Three modal analyses of the rock (Table 9) show a variable mineralogical composition. The Modes for samples 123 *A* and *B* were obtained from two thin sections cut from the same rock specimen.

TABLE 9. MODES OF SAHAMALITE-BEARING BARITE-DOLOMITE ROCK

	123A	123B	123C
Dolomite	46*	40*	60*
Barite	39	25	22
Sahamalite	8	13	4
Parisite	5	20	10
Bastnaesite			
Quartz	1	1	3
Hematite	1	1	1
	100	100	100

* Contains approximately 1 per cent ankerite+calcite.

The thin sections show well-developed rhombs of dolomite, 0.5 to 2.0 mm. in diameter, in a matrix of fine- to medium-grained barite. The barite is commonly strained and the dolomite rhombs commonly broken. Sahamalite characteristically occurs in subparallel, radiating clusters of singly terminated prisms, 0.01 to 0.2 mm. in size (Fig. 5). Parisite and

altered bastnaesite are intimately associated with sahamalite, and all three of the rare-earth minerals form fringes around the dolomite grains (Fig. 6). Sahamalite also embays the dolomite rhombs along cleavage traces. The accessory minerals are quartz, hematite pseudomorphous after pyrite, calcite, and ankerite. Fine- to medium-grained, granular,



FIG. 5.



FIG. 6.

FIG. 5. Well-developed elongate crystals of sahamalite in quartz. Small, well-formed hexagon at bottom of photograph is parisite. Dirty, mottled material at top of photograph is altered bastnaesite. Center of photograph shows barite being replaced by quartz. Pl. pol. lt. $\times 100$.

FIG. 6. Rhombic grains of dolomite partly replaced by barite (gray-white), quartz (clear white), and the rare earth minerals: sahamalite, parisite, and altered bastnaesite (dark grains with high relief). Opaque grains are hematite. Pl. pol. lt. $\times 50$.

strained barite occurs in lenticular masses and veinlets replacing dolomite and frequently isolating patches of dolomite grains. Where the dolomite is badly deformed, the rhombs take on a strained plumose habit characteristic of dolomitic rocks elsewhere in the Sulfide Queen deposit. Bastnaesite is badly altered and could not be positively identified by microscopic means. Its identity was confirmed by x -ray powder diffraction analysis. The altered bastnaesite exhibits a fine-grained, dirty appearance, commonly showing a brown stain. In contrast to the bastnaesite, sahamalite and parisite form fresh, moderately well-developed prisms and plates.

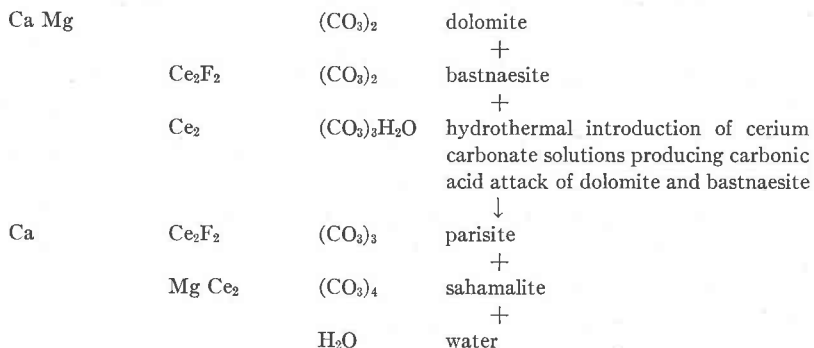
Paragenesis

In thin sections *A* and *B* of specimen 123 the dolomite is interpreted to be the oldest mineral. Formation of dolomite was followed by the introduction of bastnaesite and barite. Sahamalite and parisite accom-

TABLE 10. THEORETICAL COMPOSITIONS OF DOLOMITE, BASTNAESITE, PARISITE, AND SAHAMALITE

Mineral	Ce-earth oxides	F	CaO	MgO	CO ₂
Dolomite	—	—	30.4	21.9	47.7
Bastnaesite	74.8	8.69	—	—	20.2
Parisite	60.8	7.07	10.4	—	24.6
Sahamalite	59.2	—	—	7.4	32.4

panied by quartz are believed to be the last minerals to crystallize. The order of rare-earth mineral crystallization—bastnaesite, parisite, and sahamalite—is consistent with a decreasing availability of fluorine as indicated in Table 10. Bastnaesite and parisite contain essential fluorine, whereas sahamalite has none. It is inferred that parisite and sahamalite have formed from dolomite and bastnaesite under hydrothermal conditions. The following reaction is suggested as a potential explanation for the formation of parisite and sahamalite:



All the available calcium from the dolomite would enter parisite, and all the magnesium would enter sahamalite. The data in Table 10 clearly show that the CaO:MgO ratio in theoretical dolomite is nearly equal to the CaO:MgO ratio in theoretical parisite plus sahamalite. The ratio, 30.4 CaO:21.9 MgO is virtually the same as 10.4 CaO (parisite):7.4 MgO (sahamalite). This would suggest that no calcium or magnesium need be introduced for the formation of parisite and sahamalite from dolomite and bastnaesite. The only introduction required is cerium, carbon dioxide, and water, the latter to generate carbonic acid for the alteration of dolomite and bastnaesite. If additional fluorine were added, the suggested reaction would not have occurred, and additional bastnaesite should have crystallized. Inasmuch as the rock does not contain any

fresh bastnaesite, the larger crystals of sahamalite associated with late quartz are further suggestive of local hydrothermal activity in the barite-dolomite rock.

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