

# BURBANKITE AND CALKINSITE, TWO NEW CARBONATE MINERALS FROM MONTANA\*

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## ABSTRACT

Burbankite and calkinsite, two new rare-earth-bearing carbonates, have been discovered in veins in the Bearpaw Mountains of Montana. Burbankite is an anhydrous carbonate with the general formula  $Q_6(\text{CO}_3)_6$ , where Q represents Na, Ca, Sr, Ba, and rare earths. Calkinsite is a hydrous carbonate with the formula  $(\text{RE})_2(\text{CO}_3)_3 \cdot 4\text{H}_2\text{O}$ , where RE represents the summation of the rare earths. Burbankite is unlike any other carbonate, and calkinsite resembles lanthanite but has less water.

The physical properties of burbankite are: Hexagonal; color, grayish yellow; H,  $3\frac{1}{2}$ ; Sp. gr., 3.50; uniaxial (-);  $\omega$ , 1.627;  $\epsilon$ , 1.615; cleavage, prismatic. The physical properties of calkinsite are: Orthorhombic; color, pale yellow; H,  $2\frac{1}{2}$ ; Sp. gr., 3.28; habit, platy, {010}; biaxial (-);  $2V$ ,  $57.2^\circ$ ;  $\alpha$ , 1.569;  $\beta$ , 1.657;  $\gamma$ , 1.686; cleavage, {010}, perfect, {101} distinct; parting (?), {001}.

X-ray crystallographic data for burbankite:  $a_0 = 10.53 \text{ \AA} \pm 0.05 \text{ \AA}$ ,  $c_0 = 6.47 \text{ \AA} \pm 0.02 \text{ \AA}$ , space group  $P6_3/mmc$  or  $D_{6h}^4$ , number of formula units in the unit cell is 2. X-ray crystallographic data for calkinsite:  $a_0 = 9.57 \text{ \AA} \pm 0.02 \text{ \AA}$ ,  $b_0 = 12.65 \text{ \AA} \pm 0.08 \text{ \AA}$ ,  $c_0 = 8.94 \text{ \AA} \pm 0.02 \text{ \AA}$ , space group  $P2_1 2_2 1$  or  $D_2^8$ , number of formula units in the unit cell is 4; a:b:c=0.757:1:0.707. Morphological crystallography for calkinsite:  $p_0:q_0:r_0 = 0.934:0.707:1$ ; forms c {001}, b {010}, a {100}, d {102}, q {122}, r {132}; twinning plane {101}; crystal class, probably P 2/m 2/m 2/m.

Burbankite occurs with intimately intergrown ancylite as irregular masses or veinlets younger than calcite, and as separate crystals in calcite, in hydrothermal deposits composed essentially of silicates, carbonates, and sulfides. Calkinsite is a late mineral associated with barite in vugs and associated with lanthanite, barite, and goethite in porous areas of weathered burbankite and ancylite.

The minerals are named after W. S. Burbank and F. C. Calkins, of the U. S. Geological Survey.

## INTRODUCTION

A number of rare-earth-bearing carbonates have been identified during the study of a group of silicate-carbonate-sulfide deposits in the Bearpaw Mountains of Montana. Two among them are recognized as new minerals and their description is the purpose of this paper. The deposits themselves will be described in a later publication as another of a series developing from current geological investigations in the Bearpaw Mountains. The two new minerals, *burbankite* and *calkinsite*, are named after W. S. Burbank and F. C. Calkins, geologists of the U. S. Geological Survey, in recognition of their contributions to the geology of mineral deposits of the Western States.

Both burbankite and calkinsite are well-defined minerals for which the

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optical and x-ray data that have been determined have a high order of reliability. Very fine grained intergrowths with other minerals, unfortunately, have not permitted satisfactory purification of samples for an equally reliable interpretation of chemical analysis. The type material has been deposited in the U. S. National Museum, Washington, D. C.

#### LOCATION

The deposits containing burbankite and calkinsite are located in south-eastern Hill County, Montana, at the head of Big Sandy Creek in sec. 19, T. 28 N., R. 16 E. The group of prospects, locally known as "Vermiculite Prospects," are in the Rocky Boy's Indian Reservation and can be reached from the town of Boxelder on U. S. Highway 87 by traveling eastward about 24 miles, and from the city of Havre on U. S. Highway 2 by traveling southward about 30 miles.

#### GEOLOGICAL OCCURRENCE

The mineral deposits at the Vermiculite Prospects occur in shonkinite, mafic monzonite, and syenite that are a part of the Rocky Boy composite stock, briefly described by Pecora (1942, p. 398) and correlated with

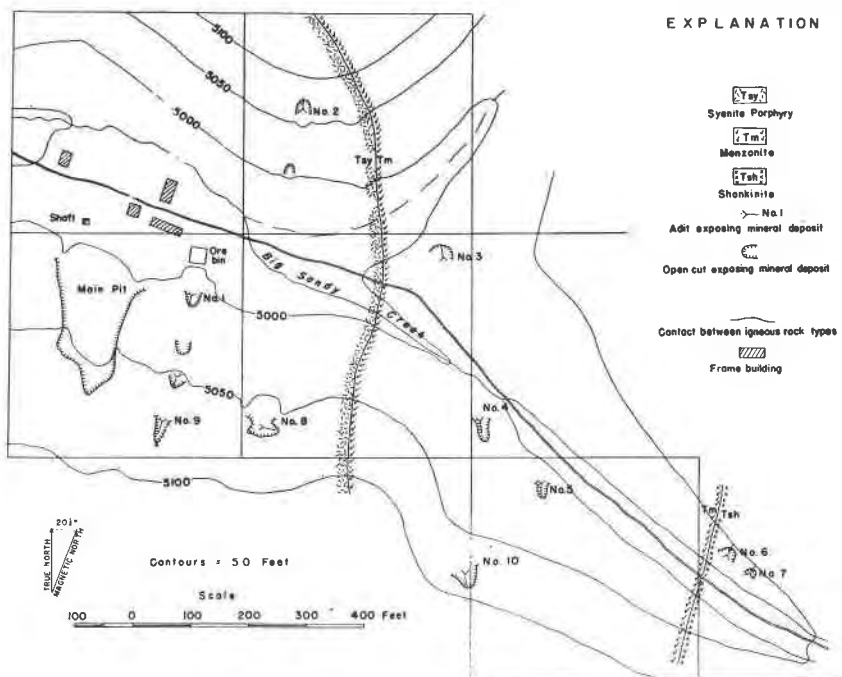


FIG. 1. Sketch map of the Vermiculite Prospects on Big Sandy Creek.

volcanic rocks of Eocene age (Brown and Pecora, 1950). Six minerals in varying abundance essentially make up these deposits; they are sanidine, biotite, aegirite, calcite, pyrite, and pyrrhotite. The two most easterly prospects on Big Sandy Creek, numbered 6 and 7 in Figure 1, have more burbankite and calkinsite than any of the others.

Specimens from prospect number 6 provided the material prepared for chemical analysis. At this locality, shonkinite is irregularly fractured and is host to a random network of interconnecting veins that define a fracture zone about 12 feet wide. The veins range in thickness from a fraction of an inch to 8 inches. Calcite is the dominant mineral of the vein material; and the other minerals, in addition to burbankite and calkinsite,

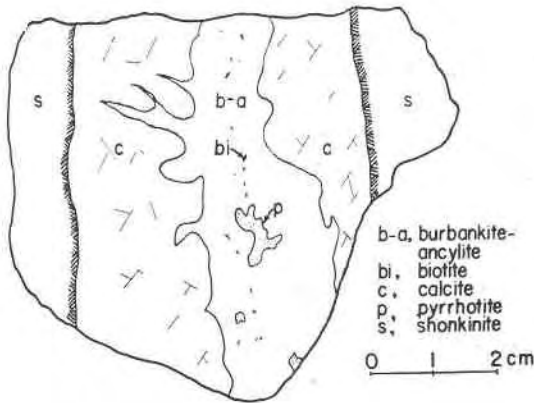


FIG. 2. Sketch of carbonate vein in shonkinite showing distribution of the principal minerals associated with burbankite.

include sanidine, biotite, aegirite, pyrrhotite, pyrite, chalcopyrite, galena, tetrahedrite, ilmenite, barite, ancylite, lanthanite, and a number of unidentified alteration products. A crude zoning is apparent in some of the veins, with sanidine and aegirite concentrated at their margins; and a streaked or banded feature is apparent in others and is suggestive of re-opened fractures.

Irregular stringers and patches, as much as 5 cm. wide, within the calcite-rich vein material (Fig. 2) are composed almost entirely of rare-earth-bearing minerals or their weathering products. In unweathered specimens these portions of the veins are essentially burbankite that is intricately veined by very fine grained ancylite and subordinate amounts of calcite and biotite. The largest burbankite crystals are 3 cm. across. Burbankite is also disseminated in calcite as anhedral crystals commonly less than 0.02 mm. in largest dimension.

As a result of weathering, the burbankite-ancylite intergrowth is altered to a porous, flaky, powdery material containing plates of calkingsite and lanthanite, fine-grained barite, goethite, and some other unidentified, fine-grained minerals. Calkingsite is most abundant in the partly altered area adjacent to unweathered burbankite; and lanthanite and barite are most abundant in completely altered material. Both calkingsite and barite are present also in rare vugs that show no evidence of weathering. The plates of calkingsite are less than 1 mm. in maximum dimension and their average maximum dimension is about 0.2 mm.

### BURBANKITE

#### *Physical Properties*

Powdered burbankite has a grayish-yellow color. In freshly broken hand specimens, the burbankite-rich material has a pale-yellow color. Burbankite effervesces strongly in cold dilute (1:5) HCl, has a hardness of about  $3\frac{1}{2}$ , and a specific gravity (pycnometer method) of 3.50. Its cleavage is prismatic, {100}, distinct to imperfect. Its optical properties, compared with those of associated ancylite, are given in Table 1.

TABLE 1. OPTICAL PROPERTIES OF BURBANKITE AND ANCYLITE  
FROM THE BEARPAW MOUNTAINS

	Burbankite	Ancylite
Indices of refraction	$\omega = 1.627$ } Na $\epsilon = 1.615 \pm 0.001$	$\alpha = 1.615$ } Na $\beta = 1.695$ } $\pm 0.003$ $\gamma = 1.730$
Birefringence	0.012	0.115
Optical character	(-)	(-)
Optic angle		$70^\circ \pm 5^\circ$
Dispersion		r < v
Crystal system	Hexagonal	Orthorhombic

The very low birefringence (0.012) for burbankite is noteworthy in view of its composition. Winchell (1931, p. 204) records a birefringence as low as 0.050 for some synthetic carbonates of the alkalis and alkaline earths. No carbonate is known analogous to burbankite in composition that has so low a birefringence.

#### *Chemical Composition*

*Purity of the analyzed sample:* The sample of powdered burbankite prepared for chemical analysis was determined by grain counts in immersion to contain about 96 per cent burbankite, 3 per cent ancylite, and one per

cent biotite, sulfides, and other minerals. It was prepared from 30 grams of hand-picked fragments that were crushed, sieved, washed, and purified by means of methylene iodide and the Frantz isodynamic separator. This method removed most of the impurities but unfortunately also concentrated admixed ancyllite. Despite repeated heavy liquid separations and some 400 passes in the Frantz separator, at different settings, it was impossible to improve the purity of the final sample in the size range of 200–400 mesh beyond 96 per cent burbankite.

*Chemical analysis:* The chemical analysis of the original sample of burbankite by M. K. Carron is given in Table 2, column 1, and a recalcu-

TABLE 2. CHEMICAL ANALYSIS OF BURBANKITE  
M. K. Carron, Analyst

	1	2	3	4	5
	Original sample	Recalculated to 100% pure	Moles	Cation ratios	Atoms based on 5CO <sub>3</sub> and 6 cations
CO <sub>2</sub>	32.55	33.39	0.7587	0.7587	
CaO	13.46	13.68	0.2439	0.2439	1.611 Ca
SrO	19.42	19.70	0.1901	0.1901	1.255 Sr
BaO	13.56	14.02	0.0914	0.0914	0.603 Ba
La <sub>2</sub> O <sub>3</sub>		2.34	0.0072	0.0144	0.095 La
Ce <sub>2</sub> O <sub>3</sub>		4.65	0.0142	0.0284	0.188 Ce
Pr <sub>2</sub> O <sub>3</sub>		0.37	0.0011	0.0022	0.015 Pr
Nd <sub>2</sub> O <sub>3</sub>	9.48	1.40	0.0042	0.0084	0.055 Nd
Sm <sub>2</sub> O <sub>3</sub>		0.10	0.0003	0.0006	0.004 Sm
Gd <sub>2</sub> O <sub>3</sub>		0.08	0.0002	0.0004	0.003 Gd
Y <sub>2</sub> O <sub>3</sub>		0.10	0.0004	0.0008	0.005 Y
Na <sub>2</sub> O		9.69	10.17	0.1640	0.3280
K <sub>2</sub> O	0.15	100.00			6.000
SiO <sub>2</sub>	0.16				
Al <sub>2</sub> O <sub>3</sub>	0.25				
Fe <sub>2</sub> O <sub>3</sub>	0.03				
MgO	0.14				
P <sub>2</sub> O <sub>5</sub>	0.12				
H <sub>2</sub> O ±	0.18				
S	0.24				
	99.43				
Less O=S	0.12				
	99.31				

Na<sub>2</sub>O and K<sub>2</sub>O by flame photometer by E. A. Nygaard.  
Rare-earth distribution by spectrograph by H. J. Rose.

lation to 100 per cent purity by allowance for the impurities is given in column 2. The alkalis were determined by E. A. Nygaard on a part of the original sample and the distribution of the rare-earth elements was determined by H. J. Rose on the precipitate of the total rare earths. The mean index of refraction calculated from the chemical composition and density after the Law of Gladstone and Dale is 1.632. This is in close agreement with the mean index of 1.625 calculated from the measured indices of refraction.

*Formula of burbankite:* As shown by the data listed in Table 2, columns 3, 4, and 5, the ratio of cations to  $\text{CO}_3$  is 6:5 and the calculated cation formula is  $(\text{Na}_{2.17}\text{Ca}_{1.61}\text{Sr}_{1.26}\text{Ba}_{0.60}\text{RE}_{0.36})(\text{CO}_3)_5$ , where RE is the total of the rare earths. The general formula may be thus expressed as  $\text{Q}_6(\text{CO}_3)_5$ , where Q is the summation of the cations. The corresponding chemical formula weight is 658, or about one-half the unit cell weight (1310) that is calculated from cell dimensions and density.

The total positive charge of the cations, as stated above, slightly exceeds the negative charge of the  $\text{CO}_3$ . If, as is possible, the given amount of rare earths is too high and sodium too low, the general formula could be expressed as  $\text{Na}_2\text{R}_4(\text{CO}_3)_5$ , where R is Ca, Sr, Ba, and rare earths, and an amount of Na equal to the amount of rare earths.

### *X-ray Crystallography*

*Powder pattern:* X-ray powder data for burbankite are given in Table 3. The calculated interplanar spacings are based on cell dimensions:  $a_0 = 10.53 \text{ \AA} \pm 0.05$  and  $c_0 = 6.47 \text{ \AA} \pm 0.02$ , which were determined from the indexing of an x-ray powder photograph taken with Fe radiation and an Mn filter. These values are in close agreement with those determined in the later single crystal work, and they are probably more accurate because the powder photographs were corrected for film shrinkage by use of the back reflections. The cell volume calculated from the above cell dimensions is  $621 \text{ \AA}^3$ . If two or more planes contribute to a line on the powder photograph, all are listed in Table 3.

*Single crystal data:* An anhedral crystal of burbankite measuring  $0.5 \times 0.3 \times 0.3$  mm. was oriented with the  $c$  crystal axis ( $c = E$  vibration direction) parallel to the goniometer axis. Orientation was completed by taking x-ray oscillation photographs. A rotation photograph and Weissenberg photographs (zero, first, and second layers) were then taken in this orientation. The rotation photograph permitted the determination of a  $c_0$  cell dimension of  $6.48 \text{ \AA} \pm 0.03$ ; and an  $a_0$  cell dimension of  $10.46 \text{ \AA} \pm 0.08$  was determined from the zero layer Weissenberg photograph. A primitive hexagonal lattice is indicated by these photographs.

The only systematic omission noted is  $h h l$ , where  $l$  is odd. This makes

TABLE 3. INDEXED X-RAY POWDER LINES WITH OBSERVED AND CALCULATED INTERPLANAR SPACINGS FOR BURBANKITE

Cu/Ni Radiation U.S.G.S. Film #9105		Fe/Mn Radiation U.S.G.S. Film #3943		d Å Calculated	Probable <i>hkl</i>
I	d Å	I	d Å		
2	9.10	2	9.16	9.12	100
5	5.26	7	5.28	5.28	101
				5.27	110
1	4.55	1	4.56	4.56	200
5	3.719	6	3.729	3.728	201
1	3.431	1	3.442	3.447	210
2	3.240	3	3.246	3.237	002
6	3.034	8	3.041	3.043	211
				3.040	300
3	2.748	3	2.758	2.758	112
				2.752	301
10	2.630	10	2.639	2.640	202
				2.633	220
$\frac{1}{2}$	2.524			2.530	310
1	2.350	1	2.358	2.360	212
				2.356	311
1	2.272	$\frac{1}{2}$	2.281	2.280	400
1	2.213	$\frac{1}{2}$	2.218	2.216	302
5	2.145	7	2.150	2.151	401
				2.158	003
1	2.100	1	2.107	2.100	103
				2.093	320
2	2.040	2	2.045	2.043	222
2	1.986	2	1.990	1.990	410
				1.991	321
2	1.951	2	1.956	1.951	203
$\frac{1}{2}$	1.895			1.902	411
1	1.860	1	1.864	1.864	402
$\frac{1}{2}$	1.827			1.829	303
				1.824	500
3	1.754	2	1.757	1.757	322
$\frac{1}{2}$	1.691			1.695	412
3	1.662	2	1.664	1.666	421
$\frac{1}{2}$	1.640			1.638	510
				1.641	313
				1.618	004
$\frac{1}{2}$	1.619			1.588	511
1	1.585	$\frac{1}{2}$	1.588	1.588	
1	1.566	$\frac{1}{2}$	1.569	1.567	
$\frac{1}{2}$	1.525	$\frac{1}{2}$	1.530	1.525	
1	1.518	$\frac{1}{2}$	1.519	1.520	
$\frac{1}{2}$	1.499	1			
1	1.458				
$\frac{1}{2}$	1.422				
$\frac{1}{2}$	1.380				
$\frac{1}{2}$	1.376				
1	1.346				
$\frac{1}{2}$	1.314				
$\frac{1}{2}$	1.282				
$\frac{1}{2}$	1.277				
$\frac{1}{2}$	1.248				
$\frac{1}{2}$	1.238				
$\frac{1}{2}$	1.231				
$\frac{1}{2}$	1.217				
1	1.208				
$\frac{1}{2}$	1.178				
$\frac{1}{2}$	1.166				
$\frac{1}{2}$	1.128				
$\frac{1}{2}$	1.121				

the space group  $P6_3/mmc$  or  $D_6^4h$ . The symmetry requirements of this space group do not allow all the  $CO_3$  groups to occupy similar positions. The low birefringence of burbankite, moreover, would suggest that the  $CO_3$  groups are not coplanar.

#### CALKINSITE

##### *Physical Properties*

Calkinsite is pale yellow and has a typical platy habit parallel to  $\{010\}$ . The plates are commonly twinned, compound, and elongate parallel to the  $a$  axis (Figs. 3 and 4). The mineral effervesces strongly in cold dilute (1:5) HCl. Its hardness is about  $2\frac{1}{2}$ , and its specific gravity (pycnometer method) is  $3.28 \pm 0.01$ . The optical and cleavage data for calkinsite are given in Table 4. Lanthanite, which occurs with calkinsite, has many similar physical properties but can be readily distinguished from it by the indices of refraction obtainable on the cleavage plates (see Table 4), as well as by its powder pattern. Lanthanite also has a lower specific gravity and higher water content than calkinsite.

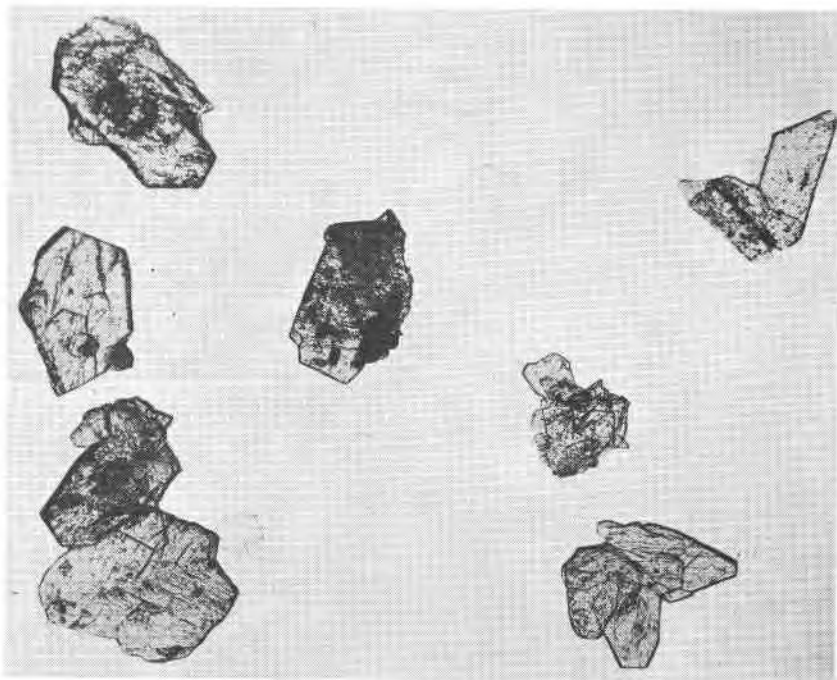


FIG. 3. Photomicrograph ( $\times 110$ ) of calkinsite crystals in immersion, showing variation in crystal habit.



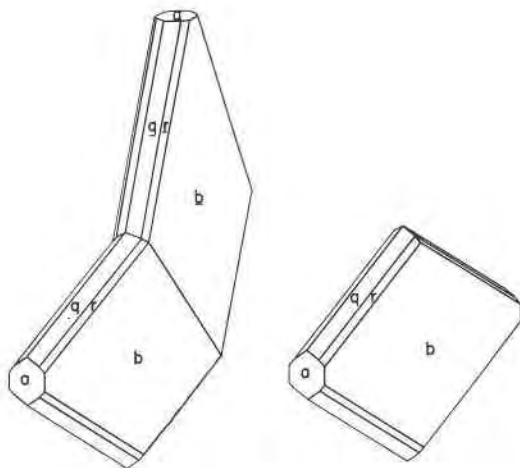


FIG. 4. Clinographic projection of twinned (left) and untwinned (right) crystals of calkinsite.

TABLE 4. OPTICAL DATA FOR CALKINSITE AND LANTHANITE FROM THE BEARPAW MOUNTAINS, MONTANA

	Calkinsite	Lanthanite
Indices of refraction ( $n_a \pm 0.002$ )	$\alpha = 1.569$ $\beta = 1.657$ $\gamma = 1.686$	1.587
2V (Universal stage) (Calculated) (Estimated)	$54^\circ, (-)$ $57.2^\circ, (-)$	$60^\circ, (-)$
Dispersion	$r < v$ , perceptible	$r < v$ , perceptible
Crystal system	Orthorhombic	Orthorhombic
Cleavage	{010}, perfect {101}, distinct {001}, parting (?)	{010}, perfect {101}, distinct
Twin plane	{101}	{101}
Orientation and pleochroism	X=b (yellow) Y=c (colorless) Z=a (colorless)	X=b Y=c Z=a

*Chemical Composition*

*Purity of the analyzed sample:* A sample of 1.4 grams containing at least 85 per cent calkinsite was submitted for chemical analysis. This was recovered from an original hand-selected sample of 50 grams of powdery material that contained less than 5 per cent of calkinsite; the treatment included gentle crushing, sieving, riffing on sheet stationery, and repeated treatment in the Frantz isodynamic separator. The identified impurities include burbankite, ancylite, lanthanite, barite, biotite, calcite, and some unidentified sulfate mineral. Heavy liquids were not used because of the potential danger of decomposition.

*Chemical analysis:* The chemical analysis of the impure sample of calkinsite is given in Table 5, column 1, and approximate recalculation to 100 per cent purity by estimating the per cent and composition of the impurities is given in column 2. The alkalies and the rare earths were

TABLE 5. CHEMICAL ANALYSIS OF CALKINSITE

	1	2	3	4	5
	Original sample	Recalculated to 100% pure	Moles	Mole ratios	Theoretical analysis
La <sub>2</sub> O <sub>3</sub>	54.42	19.82	0.608	1	19.48
Ce <sub>2</sub> O <sub>3</sub>		32.05	0.0976		31.51
Pr <sub>2</sub> O <sub>3</sub>		2.89	0.0088		2.86
Nd <sub>2</sub> O <sub>3</sub>		7.97	0.0237		7.84
CO <sub>2</sub>	22.40	23.93	0.5437	2.85	24.78
H <sub>2</sub> O	12.00	13.34	0.7405	3.88	13.53
MgO	0.96	100.00			100.00
CaO	1.46				
SrO	0.54				
BaO	4.23				
Fe <sub>2</sub> O <sub>3</sub>	0.47				
MnO	0.08				
Al <sub>2</sub> O <sub>3</sub>	0.97				
SiO <sub>2</sub>	0.92				
Na <sub>2</sub> O	0.26				
K <sub>2</sub> O	0.18				
SO <sub>3</sub>	1.58				
	100.47				

M. K. Carron, Analyst.

Na<sub>2</sub>O and K<sub>2</sub>O by flame photometer by E. A. Nygaard.

Rare-earth distribution by spectrograph by H. J. Rose.

TABLE 6. INDEXED X-RAY POWDER LINES (WITH ESTIMATED INTENSITIES AND INTERPLANAR SPACINGS) FOR CALKINSITE

Cu/Ni radiation film 9158		Fe/Mn radiation film 9185	Calculated $d$ Å Probable hkl	
I	Measured $d$ Å			
10 broad	6.54	6.52 $\beta$ 6.57	6.32	020
4	4.78	4.77 $\beta$ 4.76	4.78	200
4	4.49	4.47 $\beta$ 4.45	4.47	002
$\frac{1}{2}$	4.24	4.27	4.22	030
			4.22	012
2	3.87	3.87	3.86	112
			3.82	220
2	3.71	3.71	3.65	022
5	3.27	3.27 $\beta$ 3.26	3.27	202
1 broad	3.17	3.16	3.16	040
			3.16	212
			3.16	230
$\frac{1}{2}$		3.02	3.03	140
			3.00	301
3 broad	2.931	2.940	2.981	041
			2.923	311
			2.921	132
2	2.897	2.899	2.902	222
$\frac{1}{2}$	2.713	2.708	2.714	321
$\frac{1}{2}$	2.654	2.650	2.638	240
1	2.595	2.596	2.595	123
			2.582	042
			2.582	232
$\frac{1}{2}$	2.433		2.434	033
$\frac{1}{2}$	2.393	2.393	2.392	400
			2.402	322
$\frac{1}{2}$	2.338	2.336	2.359	133
$\frac{1}{2}$	2.281	2.283	2.272	242
			2.273	411
1	2.248	2.245	2.238	420
			2.235	004
			2.246	340
$\frac{1}{2}$	2.207		2.201	014
			2.211	332
$\frac{1}{2}$	2.179	2.181	2.176	104
			2.178	341
			2.171	421
			2.169	043
			2.169	233
3	2.128	2.127	2.145	114
			2.146	313
3	2.115	2.113	2.109	402
			2.108	060
			2.107	024

TABLE 6—(continued)

Cu/Ni radiation film 9158		Fe/Mn radiation film 9185	Calculated $d$ Å Probable hkl	
I	Measured $d$ Å			
3	2.074	2.070	2.115	143
			2.052	061
			2.059	160
			2.059	323
			2.081	412
			2.081	430
			2.058	124
$\frac{1}{2}$	2.029	2.028	2.025	204
			2.027	431
3	2.009	2.008	2.001	422
			2.000	214
			2.006	161
			2.007	342
			1.975	034
$\frac{1}{2}$	1.985		1.975	243
			1.934	134
3	1.945	1.944	1.935	333
1	1.925	1.921	1.929	224
2	1.902	1.899	1.908	440
1 broad	1.840	1.835	1.907	062
			1.830	304
			1.846	413
1	1.786	1.785	1.793	144
			1.794	343
			1.789	423
			1.755	442
			1.758	324
$\frac{1}{2}$		1.762	1.759	360
			1.633	404
1 broad	1.634	1.634		
$\frac{1}{2}$		1.626		
1	1.591	1.591		
$\frac{1}{2}$	1.570	1.568		
$\frac{1}{2}$	1.548	1.550		
$\frac{1}{2}$	1.527	1.531		
1	1.502	1.502		
1	1.466	1.463		
1	1.421	1.422		
1 broad	1.357			
$\frac{1}{2}$	1.319			
1	1.300			
$\frac{1}{2}$	1.262			
$\frac{1}{2}$	1.221			
$\frac{1}{2}$	1.176			

determined in the same manner as for burbankite. The mean index of refraction calculated by the Law of Gladstone and Dale is 1.619, and that calculated from the indices of refraction is 1.636.

*Formula of calkinsite:* As shown by the data in Table 5, column 4, the chemical formula derived from the mole ratios can be expressed as  $(RE)_2(CO_3)_3 \cdot 4H_2O$ . Recalculating the chemical analysis from theoretically perfect ratios would yield the weight per cents listed in column 5, which, in comparison with those in column 2, lends more credibility to the probable composition of pure calkinsite. The chemical formula can be given as  $(La_{0.64}Ce_{1.02}Pr_{0.09}Nd_{0.25})(CO_3)_3 \cdot 4H_2O$ . The calculated chemical formula weight is 533, which is almost exactly one-fourth the unit cell weight of 2140. Four formula units per unit cell are thus indicated. Lanthanite is chemically very closely related to calkinsite but is an octahydrate with the formula  $(RE)_2(CO_3)_3 \cdot 8H_2O$ .

#### *X-ray Crystallography*

*Single crystal data:* Single crystals of calkinsite suitable for x-ray study were initially mounted with the aid of a binocular microscope and oriented by successive oscillation photographs. Unfortunately, none of these crystals exceeds 0.1 mm. in maximum dimension. Rotation photographs were taken about the  $a$  and  $c$  axes on two different crystals; and zero, first, and second layer Weissenberg photographs were obtained in these orientations. The photographs, although imperfect, showed calkinsite to be orthorhombic. The cell dimensions obtained are:  $a_0 = 9.57 \text{ \AA} \pm 0.02$ ;  $b_0 = 12.65 \text{ \AA} \pm 0.08$ ; and  $c_0 = 8.94 \text{ \AA} \pm 0.02$ . The cell volume is  $1083 \text{ \AA}^3$ . The only systematic omissions were  $h00$  and  $00l$ , in which  $h$  and  $l$  are odd. This indicates the space group  $P2_1 22_1$  or  $D_2^3$ .

*Powder pattern data:* X-ray powder pattern data for calkinsite are given in Table 6. All of the lines on the photographs are indexed by use of the cell dimensions obtained from the single crystal study. The good agreement of the calculated and observed interplanar spacings for  $\{030\}$ ,  $\{040\}$ , and  $\{060\}$  support a satisfactory value for the  $b_0$  cell dimension. The poor agreement shown for  $\{020\}$  can perhaps be explained by absorption. Beta lines observed in the x-ray powder photograph taken with Fe radiation are due to a weak Mn filter.

#### *Morphological Crystallography*

Goniometric measurements were made on both crystals of calkinsite which were mounted for x-ray study with (001) and (100) polar. A third crystal was mounted with (010) polar and its faces were similarly measured. Because of the small size of the crystals and imperfection of the crystal faces, the signals were poor. Several forms were observed under

TABLE 7. MORPHOLOGICAL DATA FOR CALKINSITE (ORTHORHOMBIC, DIPYRAMIDAL, PROBABLY P2/m 2/m 2/m)

Calculated ratios		a:b:c = 0.757:1:0.707		p <sub>0</sub> :q <sub>0</sub> :r <sub>0</sub> = 0.934:0.707:1		q <sub>1</sub> :r <sub>1</sub> :p <sub>1</sub> = 0.757:1.071:1		r <sub>2</sub> :p <sub>2</sub> :q <sub>2</sub> = 1.414:1.321:1	
<i>Calculated angles</i>									
Form	Quality	$\phi$	$\rho = C$	$\phi_1$	$\rho_1 = A$	$\phi_2$	$\rho_2 = B$		
c {001} <sup>1</sup>		—	0°	0°	90°	90°	90°		
b {010} <sup>1</sup>	Fair	0°	90°	90°	90°	—	0°		
a {100} <sup>1</sup>	Poor	90°	90°	—	0°	0°	0°		
d {102} <sup>1</sup>	Poor	90°	25°02'	0°	64°58'	64°58'	90°		
q {122} <sup>1</sup>	Poor	33°28'	40°18'	35°16'	69°09'	64°58'	90°		
r {132} <sup>1</sup>	Poor	23°45'	49°14'	46°38'	72°14'	64°58'	57°23'		
{101} (cleavage)		0°	43°03'	0°	46°57'	46°57'	90°		
<i>Measured angles</i>									
Form (faces)	Quality	$\phi$	$\rho$	$\phi_1$	$\rho_1$	$\phi_2$	$\rho_2$		
b {010} 2	Fair	89°57'–89°55'	0°	89°54'–90°12'	89°36'–90°00'	64°11'–66°43'	0°06'		
q {122} 7	Poor	34°54'	40°16'	34°18'–38°40'	69°11'–71°25'	66°24'–68°15'	58°37'–60°00'		
r {132} 3	Poor	(90°)	42°30'	44°35'	72°45'		47°05'–47°45'		

<sup>1</sup> Forms observed on many crystals but not measurable in goniometric work.

<sup>2</sup> Measured with a petrographic microscope.

the microscope which could not be verified by goniometric measurements. Variation in crystal habit is shown in Figure 3 and clinographic projections are shown in Figure 4. The twinning and composition plane is  $\{101\}$ . The crystallographic data are summarized in Table 7. All the crystals observed appear to have full orthorhombic symmetry belonging to the class  $P2/m\ 2/m\ 2/m$ .

#### ORIGIN

In the sequence of mineral development, burbankite is younger than most of the calcite. Ancylicite was formed locally by a reaction on burbankite by a hydrothermal solution. In this reaction burbankite, an anhydrous complex carbonate, contributed to form a hydrous complex carbonate richer in rare earths. Both of these complex carbonates were decomposed to contribute to the formation of calkinsite and lanthanite, two hydrous simple carbonates richer still in rare earths. This final decomposition most probably was effected by weathering and further resulted in local deposition of barite, goethite, and an unidentified sulfate. Such decomposition by weathering of the vein material could provide sufficient sulfate radical by alteration of the sulfide minerals, particularly pyrrhotite, to lower the pH of the environment and to combine with barium and other cations released by the carbonates or other minerals. The occurrence of coarse barite and calkinsite in isolated vugs may possibly indicate the development of some or all of the calkinsite under late hydrothermal conditions, but the lanthanite certainly resulted from weathering alone.

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