

A RESTUDY OF BAKERITE, PRICEITE, AND VEATCHITE*

HENRY KRAMER, *U. S. Geological Survey, Washington, D. C.*,†

AND

ROBERT D. ALLEN, *U. S. Geological Survey, Claremont, California.*

ABSTRACT

Complete chemical analyses have been made on six specimens to clarify existing uncertainties in the formulas of bakerite, priceite, and veatchite. Previously published formulas are corroborated for all three minerals. Optical measurements clear up several ambiguities in the literature. Tabulated below are formulas (calculated from analyses), optical properties, specific gravities, and spectrographic determinations.

	<i>Bakerite</i>	<i>Priceite</i>	<i>Veatchite</i>
Chemical formula	$8\text{CaO} \cdot 5\text{B}_2\text{O}_3 \cdot 6\text{SiO}_2 \cdot 6\text{H}_2\text{O}$	$4\text{CaO} \cdot 5\text{B}_2\text{O}_3 \cdot 7\text{H}_2\text{O}$	$3(\text{SrO}, \text{CaO}) \cdot 8\text{B}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$
α_{Na}	$1.626 \pm 0.004^*$	1.573 ± 0.002	1.550 ± 0.002
β_{Na}	—	1.595 (calc.)	1.553 (calc.)
γ_{Na}	$1.655 \pm 0.003^*$	1.597 ± 0.002	1.621 ± 0.002
2V	—	$32^\circ \pm 2^\circ$	$25^\circ \pm 2^\circ$
Optical group	—	Biaxial negative	Biaxial positive
Specific gravity (25° C.)	2.885*	2.415*	Not determined
Trace elements (<1%)	Al, Mg, Fe, Na, Sr, Cu, Sn, Pb, Ag, Mn	Si, Al, Mg, Fe, Sr, Cu, Na	Ca, Si, Al, Mg, Fe, Ba, Cu, Mn

* Average value.

X-ray data confirm a striking similarity between bakerite and datolite patterns; a possible structural formula for bakerite, which agrees with the chemical analyses is $\text{Ca}_8\text{B}_8(\text{BO}_4)_2(\text{SiO}_4)_6(\text{OH})_6 \cdot 3\text{H}_2\text{O}$.

On the basis of mineralogical and chemical associations it is suggested that (1) priceite is sometimes derived from colemanite, (2) bakerite may be deposited by hydrothermal solutions.

INTRODUCTION

Bakerite, priceite, and veatchite are three borates whose reported chemical formulas are subject to review; and optical determinations available on these minerals are incomplete or inconsistent. The experimental results of examining California specimens are reported in this paper to help clarify several of these uncertainties. In addition, spectrographic analyses, x-ray diffraction data, and density determinations are included. A brief discussion of the origin of bakerite and priceite is based on mineralogical and chemical associations. Descriptions of the six specimens studied are presented below.

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† Present address: Pyrotechnics Laboratory, Samuel Feltman Ammunition Laboratories, Picatinny Arsenal, Dover, New Jersey.

<i>Specimen number</i>	<i>Locality</i>	<i>Occurrence</i>
Bakerite 1 (Collected by W. T. Schaller)	Corkscrew Canyon, Death Valley area, Inyo County, Calif. (Exact locality not known)	As irregular veins in altered volcanic rock. Pockets among veins are lined with acicular crystals of thomsonite and natrolite
Bakerite 2 (Collected by D. H. Kupfer)	Center of sec. 22, T. 26 N., R. 2 E., San Bernardino base and meridian, DeBely Wash, 1000 feet SW. of DeBely Mine, Death Valley area, Inyo County, Calif.	Float. Encrusted and veined by minute crystals of natrolite and thomsonite
Priceite 1 (Collected by F. M. Byers)	NW $\frac{1}{4}$ sec. 16, T. 26 N., R 2 E., San Bernardino base and meridian, 1450 feet N. 55° E. from U. S. Mineral Monument 40 (elev. 2191 feet); Monte Blanco area, Death Valley area, Inyo County, Calif.	White veins associated with colemanite in basaltic tuff. (Tuff consists of partly devitrified glass with average index of refraction near 1.50, nondescript anisotropic material, and basalt fragments)
Priceite 2 (Collected by J. F. McAllister)	SW $\frac{1}{4}$ sec. 9, T. 26 N., R. 2 E., San Bernardino base and meridian, 3900 feet N. 45° E. from U. S. Mineral Monument 40 (elev. 2191 feet), Corkscrew Wash, Death Valley area, Inyo County, Calif.	White veins in altered basalt
Priceite 3 (Collected by D. F. Hewett)	Same as Priceite 2	Megascopically translucent and pale olive-yellow.* Float presumably derived from veins in altered basalt
Veatchite (Collected by S. J. Muessig)	Center NE $\frac{1}{4}$ sec. 32, T. 5 N., R. 14 W., San Bernardino base and meridian, lower dump, Lang Borate district, Tick Canyon, Los Angeles County, Calif.	Silky fibrous crystals encrusting colemanite and clay on massive howlite

* Pale olive-yellow 10 Y 7/2, Rock-Color Chart, *Geol. Soc. Am.* (1951).

X-ray powder patterns were prepared by Arthur Chodos, Department of Geology, California Institute of Technology. Spectrographic analyses were made by H. W. Johnson, Pacific Spectrochemical Laboratory, Los Angeles, Calif. Datolite specimens were supplied by W. C. Oke of the California Institute of Technology. Borate specimens were collected by members of the U. S. Geological Survey whose names are given above.

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BAKERITE

Optical Properties

Palache, Berman, and Frondel (1951) describe bakerite as "Optically biaxial with moderate birefringence and a mean index of refraction of 1.642; in part spherulitic." The specimens used in the present investigation have permitted measurement of both alpha and gamma. It was not possible, however, to determine either beta or 2V because of its fine-crystalline habit.

TABLE 1. OPTICAL PROPERTIES OF BAKERITE

	Bakerite 1	Bakerite 2	Palache, Berman, and Frondel (1951)
α_{Na}	1.624 ± 0.002	1.628 ± 0.002	—
γ_{Na}	1.654 ± 0.002	1.656 ± 0.002	—
Birefringence ($\gamma - \alpha$)	0.030 ± 0.004	0.028 ± 0.004	Moderate
Average index	1.639	1.642	1.642
Habit _{micro}	Cryptocrystalline to submicroscopic; spherulitic extinction	Same as bakerite 1	In part spherulitic

Chemical Analyses

From two analyses of bakerite, Giles (1903) derived the following formula: $8CaO \cdot 5B_2O_3 \cdot 6SiO_2 \cdot 6H_2O$. No other published analyses are known to the writers. W. F. Foshag (1954) has obtained two bakerite analyses which are essentially the same as those published by Giles. Contrasting with the above formula is the one proposed by Palache, Berman, and Frondel (1951) "based on the structural resemblance to datolite, herderite, and homilite indicated by x-ray powder diffraction study": $Ca_4B_4(BO_4)(SiO_4)_3(OH)_3H_2O$. When the latter formula is recast as oxides and multiplied by two it becomes: $8CaO \cdot 5B_2O_3 \cdot 6SiO_2 \cdot 5H_2O$. Thus, the only difference between the formulas is in the number of molecules of water. Two bakerites have been analyzed to determine the water content as well as the cationic ratios.

The possibility that " $H_2O(-)$ " can be held in bakerite at temperatures in excess of $105^\circ C.$ has been explored by two methods. (1) A differential

TABLE 2. BAKERITE—CHEMICAL ANALYSES AND CALCULATION OF FORMULA

	Bakerite 1 (per cent)		Bakerite 2 (per cent)		Giles (1903)* (per cent)		Palache Berman, and Frondel (1951) theoretical per cent)
	Orig.	Recalc.	Orig.	Recalc.	Orig.	Recalc.	
CaO	35.14	35.42	34.47	35.24	35.05	35.38	35.97
B ₂ O ₃	27.58	27.79	26.57	27.17	27.30	27.56	27.92
SiO ₂	27.90	28.12	28.40	29.03	28.25	28.52	28.89
H ₂ O (+)	8.60	8.67	8.37	8.56	8.46	8.54	7.22
H ₂ O (-)	0.30		0.26				
R ₂ O ₃	0.65		1.93		0.94		
Total	100.17		100.00		100.00		
Less H ₂ O (-) and R ₂ O ₃	0.95		2.19		0.94		
Total	99.22	100.00	97.81	100.00	99.06	100.00	100.00
Specific gravity (25° C.)	2.88		2.89				2.88

Analyst: Henry Kramer

	Molecular proportions (Bakerite 1)	Oxygen atoms	Atomic ratios	Atomic ratios on basis of 40 O's
CaO	0.632	0.632	Ca 0.632	7.788
B ₂ O ₃	0.399	1.197	B 0.798	9.833
SiO ₂	0.468	0.936	Si 0.468	5.767
H ₂ O	0.481	0.481	H 0.962	11.854

Atomic ratios and formula on basis of 41 O's

Ca 7.983

Ca₂B₁₀Si₆O₃₅ · 6H₂O

B 10.080

or

Si 5.911

H 12.151

8CaO · 5B₂O₃ · 6SiO₂ · 6H₂O

* Average of two analyses.

thermal analysis curve of bakerite 2 was prepared with a portable apparatus, using maximum sensitivity and a heating rate of 30° C. per minute to obtain maximum thermographic response from the instrument. A single endothermic peak was recorded which commenced at an indefinite point between 400 and 500° C. and reached a maximum at 590° C. The sample was not heated above 600° C. (2) Bakerite 1 was heated in a muffle furnace at 200° C. for 30 minutes. Water loss was not appreciably greater than at 105° C. These results would indicate that the usual procedure for determination of "H₂O (-)" is applicable to bakerite.

The assumption of 41 oxygen atoms in the formula fits the analysis of bakerite 1 and verifies Giles' formula for bakerite. Although bakerite 2 was unsuitable for formula calculation because of impurities, its B₂O₃/H₂O ratio, calculated from weight per cents, also substantiates this formula:

	<i>Bakerite 1</i>	<i>Bakerite 2</i>
B ₂ O ₃ /H ₂ O	3.205	3.174

PRICEITE

Optical Properties

Although the indices of refraction of priceite are known with reasonable accuracy (Larsen, 1917; Foshag, 1924), the measured and calculated values of 2V are discordant (Palache, Berman, and Frondel, 1951). In fact, 2V has been previously measured only on priceite from Panderma, Turkey (also known as pandermite).

The direct measurement of beta on grains of priceite is exceptionally difficult because the orientation of the optical indicatrix is uncertain. Beta was determined, therefore, by calculation from alpha, gamma, and 2V measured on the universal stage, as well as by direct measurement.

Cryptocrystalline varieties of priceite (priceite 2 and 3) whose crystal diameter averages less than 5 microns appear to have a lower gamma index, and consequent lower birefringence, than the coarser crystallized type (priceite 1), whose crystal diameter averages more than 20 microns. This effect is probably caused by the nearly submicroscopic particle size rather than by variations in the chemistry of the mineral. Optical data from the coarser material are believed to be superior. The 2V measured on priceite 1 is exactly the same as that reported for priceite from Panderma (Larsen, 1917). Beta calculated is the same as beta measured (on grains "on edge"), limits of error considered.

Chemical Analyses

Foshag (1924) gives two possible formulas for priceite: (1) 4CaO · 5B₂O₃ · 7H₂O (after Van't Hoff); (2) 5CaO · 6B₂O₃ · 9H₂O. Either one

TABLE 3. OPTICAL PROPERTIES OF PRICEITE

	Priceite 1	Priceite 2	Priceite 3	Foshag (1924)
α_{Na}	1.573 ± 0.002	1.573 ± 0.003	1.573 ± 0.003	1.571
β_{Na} calc	1.595	—	—	—
β_{Na} meas.	1.594 ± 0.002	—	—	1.590
γ_{Na}	1.597 ± 0.002	1.595 ± 0.003	1.591 ± 0.003	1.593
Birefringence ($\gamma - \alpha$)	0.024 ± 0.004	0.022 ± 0.006	0.018 ± 0.006	0.022
Optic sign	Negative	—	—	Negative
$2V_{\text{meso.}}$	$32^\circ \pm 2^\circ$	—	—	Medium
Habit _{micro.}	Tiny "books" of plates with rhombic outline	Cryptocrystalline	Cryptocrystalline	—
Orientation	α angle long dimension of "plates on edge" varies between 60° and 70° . γ is at an angle with the bisectrix of the obtuse angle of a rhomb of about 5°	—	—	—

is in approximate agreement with published analyses. In this investigation three extremely pure priceites have been analyzed in an attempt to refine our knowledge of the stoichiometry. All three priceites gave negative tests for SO_3 and CO_2 . Priceites 1 and 2 contained virtually no insoluble material whereas priceite 3 contained a trace of insoluble material, microscopically identified as volcanic glass and clay. Calculations based on analyses of priceites 1 and 2 support the formula $4\text{CaO} \cdot 5\text{B}_2\text{O}_3 \cdot 7\text{H}_2\text{O}$.

VEATCHITE

Optical Properties

Published optical measurements on veatchite (Switzer, 1938; Stewart, Chalmers, and Phillips, 1954) present the following inconsistency: $2V$ (measured?) is reported as $37^\circ \pm 2^\circ$, but $2V$ calculated from the indices of refraction would be 20.4° .

The indices of refraction found for veatchite are close to those determined by Switzer, but $2V$ was measured as 25° , which is consistent with these indices. Because of its perfect side pinacoidal cleavage, beta was determined by calculation from alpha, gamma, and measured $2V$.

TABLE 4. PRICEITE—CHEMICAL ANALYSES AND CALCULATION OF FORMULA

	Priceite 1 (per cent)		Priceite 2 (per cent)		Priceite 3 (per cent)		Priceites 1 and 2 Average (per cent) Recalc.
	Orig.	Recalc.	Orig.	Recalc.	Orig.	Recalc.	
B ₂ O ₃	49.87	49.88	49.64	49.92	48.95	49.20	49.90
CaO	32.04	32.05	31.90	32.08	32.06	32.43	32.06
H ₂ O (+)	18.07	18.07	17.90	18.00	18.28	18.37	18.04
H ₂ O (-)	0.20		0.69		0.41		
Total	100.18		100.13		99.70		
Less H ₂ O	(-0.20)		0.69		0.41		
Total	99.98	100.00	99.44	100.00	99.29	100.00	100.00
Specific gravity (25° C.)	2.41		N.D.		2.42		

Analyst: Henry Kramer

	Molecular proportions	Oxygen atoms	Atomic ratios	Atomic ratios and formula on basis of 26 O's
B ₂ O ₃	0.713	2.139	B 1.426	9.988 Ca ₄ B ₁₀ O ₁₉ · 7H ₂ O
CaO	0.572	0.572	Ca 0.572	4.006 or
H ₂ O	1.001	1.001	H 2.002	14.022 4CaO · 5B ₂ O ₃ · 7H ₂ O

TABLE 5. OPTICAL PROPERTIES OF VEATCHITE

	Allen	Switzer (1938)	Stewart, Chalmers, and Phillips (1954)
α_{Na}	1.550 ± 0.002	1.551	1.551
β_{Na}	1.553 (calc.)	1.553	1.553
γ_{Na}	1.621 ± 0.002	1.621	1.621
Birefringence ($\gamma - \alpha$)	0.071 ± 0.004	0.070	0.070
Optic sign	Positive	Positive	Positive
$2V_{\text{meas.}}$	25° ± 2°	37° ± 2°	37°
Habit _{micro}	Platy cleavage frag- ments (parallel to 010)	—	—
Orientation	Angle between γ and “c” is about 30°	Angle between γ and “c” is -38°	Angle between γ and “c” is -30°

Chemical Analyses

An average of three analyses of veatchite from the Lang district indicates the formula $3\text{SrO} \cdot 8\text{B}_2\text{O}_3 \cdot 5\text{H}_2\text{O}$ (Switzer and Brannock, 1950). A microchemical analysis of veatchite from Aislaby, Yorkshire, gives the formula $\text{SrO} \cdot 3\text{B}_2\text{O}_3 \cdot 2\text{H}_2\text{O}$ (Stewart, Chalmers, and Phillips, 1954).

The present veatchite analysis is essentially in agreement with the average analysis of Switzer and Brannock (1950), and agrees approximately with the formula they proposed. Unfortunately, our veatchite specimen, which contained less than one per cent clay, was not sufficient for a second analysis or specific gravity measurement.

TABLE 6. VEATCHITE—CHEMICAL ANALYSES AND CALCULATION OF FORMULA

	Veatchite (per cent)		Switzer and Brannock (1950) (average of three recalculated analyses (per cent)	Stewart, Chalmers and Phillips (1954) (per cent)	
	Orig.	Recalc.		Orig.	Recalc.
SrO	30.50	30.72	30.0	} 30.0*	29.8*
CaO	1.68	1.69	1.6		
B ₂ O ₃	57.56	57.96	58.5	60.3	59.8
H ₂ O (+)	9.56	9.63	9.6	10.5	10.4
H ₂ O (-)	0.30				
CO ₂	nil				
SO ₃	nil				
Insoluble	N.D.				
Total	99.69				
Less H ₂ O (-)	0.39				
Total	99.30	100.00	99.7	100.8	100.0
Analyst Henry Kramer					
	Molecular proportions	Oxygen atoms		Atomic ratios	Atomic ratios and formula on basis of 32 O'S
SrO	0.296	0.296	Sr	0.296	} 3.107
CaO	0.030	0.030	Ca	0.030	
B ₂ O ₃	0.832	2.496	B	1.664	15.861
H ₂ O	0.535	0.535	H	1.070	10.199
					(Sr, Ca) ₃ B ₁₆ O ₂₇ · 5H ₂ O
					or
					3(SrO, CaO) · 8B ₂ O ₃ · 5H ₂ O

* Includes SrO and CaO.

SPECTROGRAPHIC ANALYSES

Spectrographic analyses for minor elements in bakerite, priceite, and veatchite are presented in Table 7.

TABLE 7. SPECTROGRAPHIC ANALYSES

Concentration range (per cent)	Bakerite		Priceite			Veatchite
	1	2	1	2	3	
0.X	Mg Al Fe	Mg Na	Si	Si Mg Sr	Si Mg Al Fe Na	Si Mg Ca
0.0X	Sr Cu Pb Na	Al Fe Pb	Mg Al Fe Sr	Al Fe	—	Al Fe Ba
0.00X	Ag Mn	Cu Sn	Cu	Cu	Cu	—
0.000X	—	—	—	—	—	Cu Mn

X-RAY DIFFRACTION DATA

X-ray powder patterns were prepared for all three minerals with nickel-filtered copper radiation over the range $2\theta = 0^\circ$ to 90° , the spectrum being scanned with a Geiger counter spectrometer at 1° per minute.

The similarity between powder patterns of bakerite and datolite has been noted by Palache, Berman, and Frondel (1951). In Table 8 the bakerite pattern is compared with patterns prepared from (1) finely crystalline datolite from Keweenaw Peninsula, Michigan (datolite 1), and (2) coarsely crystalline datolite from Hampden Quarry, Springfield, Maine (datolite 2). With respect to spacing, the patterns nearly coincide for all major peaks and for many minor peaks. The bakerite pattern, however, apparently represents a slight contraction of either datolite pattern. If the bakerite structure can be derived from that of datolite by partial substitution of B for Si, contraction would be expected. Undoubtedly, bakerite and datolite structures are nearly identical, but a structural formula must account for the bakerite composition. If the formula proposed by Palache, Berman, and Frondel (1951) were modified

as follows it would satisfy the water requirements indicated by oxide analysis: $\text{Ca}_8\text{B}_8(\text{BO}_4)_2(\text{SiO}_4)_6(\text{OH})_6 \cdot 3\text{H}_2\text{O}$.

The pattern for priceite 1 is apparently more completely developed than the pattern for priceite 2, probably because the former is more coarsely crystallized.

The veatchite pattern agrees fairly well with a pattern reported by Stewart, Chalmers, and Phillips (1954), especially with respect to diffraction maxima of strong and moderate intensity.

ORIGIN OF BAKERITE AND PRICEITE

Mineralogic and chemical evidence suggests that bakerite is deposited by hydrothermal or late-magmatic solutions: (1) bakerite is veined and encrusted with the zeolites natrolite and thomsonite; (2) bakerite contains trace quantities of such typically hydrothermal elements as Pb, Sn, Ag, and Mn, all of which are generally absent from borates.

Mineralogic and petrographic evidence suggests that priceite is derived from colemanite. A white translucent coating sometimes found on "cauliflower" colemanite in Gower Gulch, Death Valley, is characterized by an average index of refraction near 1.585 and moderate birefringence; this material is believed to be priceite, probably an alteration of the colemanite. White pisolitic nodules from the Thompson mine which is located 2.55 miles N. 83° W. of U. S. Mineral Monument 47, Death Valley, consist of comparatively fresh colemanite mingled with finely crystalline translucent alteration material with fibrous habit and indices of refraction intermediate between those of colemanite and priceite; if the alteration process had reached completion the end-product might have been priceite. Thin sections of priceite from the Monte Blanco area, Death Valley, show corroded euhedral inclusions of colemanite surrounded by fine-crystalline priceite.

Colemanite and priceite from the Death Valley area contain the same trace elements: Si, Al, Fe, Mg, Sr, Ma, and Cu. Principal differences in concentration are shown by Si and Cu as follows:

Per cent	0.X	0.0X	0.00X	0.000X
Colemanite		Si		Cu
Priceite	Si		Cu	

If priceite is derived from colemanite, the process might bring about enrichment in these elements.

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