UNIVERSITY OF CALIFORNIA PUBLICATIONS
BULLETIN OF THE DEPARTMENT OF
GEOLOGY
Vol. 5, No. 9, pp. 149-153 ANDREW C. LAWSON, Editor

BENITOITE, A NEW CALIFORNIA GEM MINERAL.

BY

GEORGE DAVIS LOUDERBACK,

WITH CHEMICAL ANALYSIS BY

WALTER C. BLASDALE.

UNIVERSITY OF CALIFORNIA PUBLICATIONS
BULLETIN OF THE DEPARTMENT OF
GEOLOGY
Vol. 5, No. 23, pp. 331-380, Pls. 27-39 ANDREW C. LAWSON, Editor

BENITOITE, ITS PARAGENESIS AND MODE OF OCCURRENCE.

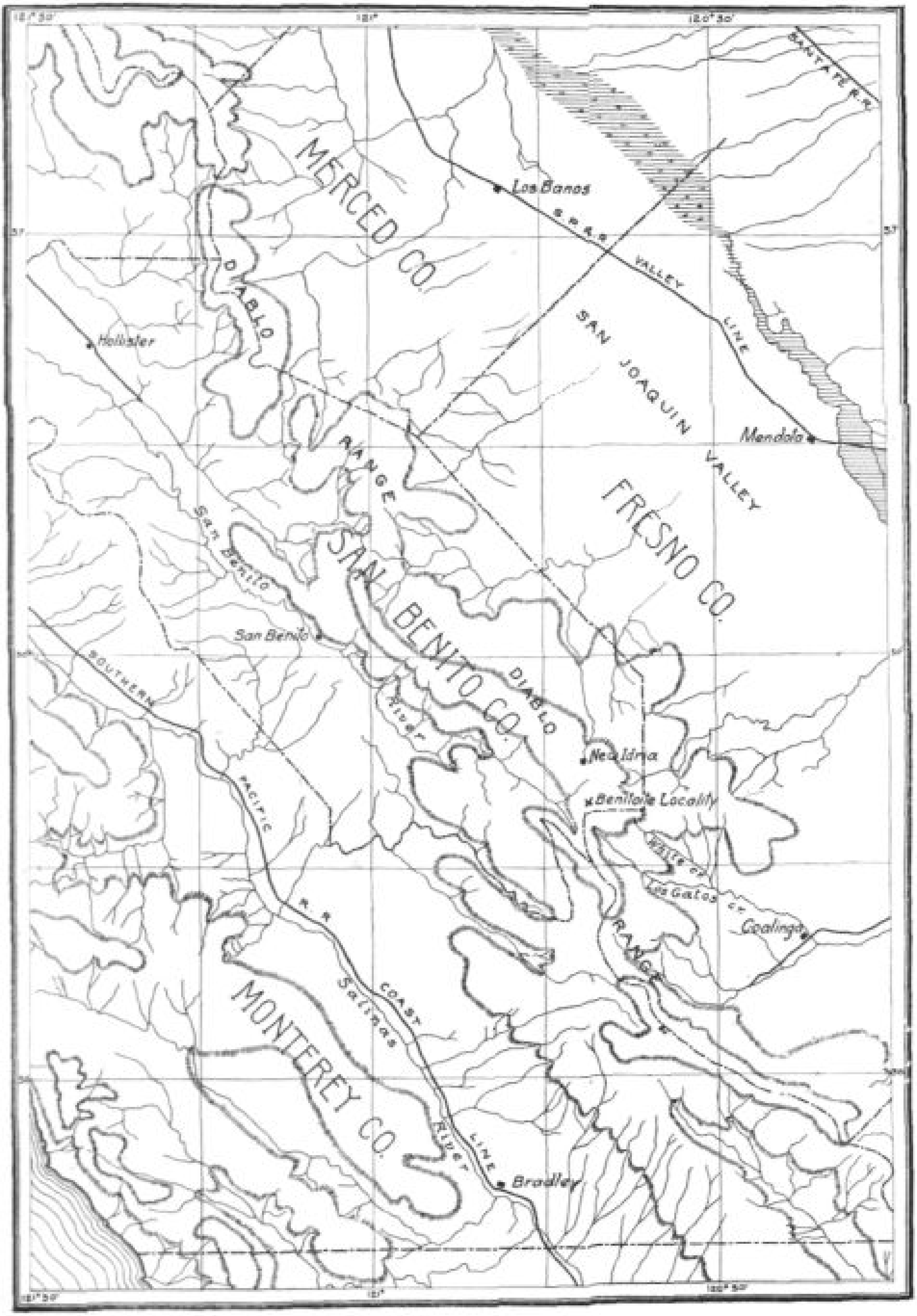
BY

GEORGE DAVIS LOUDERBACK.

WITH CHEMICAL ANALYSES BY

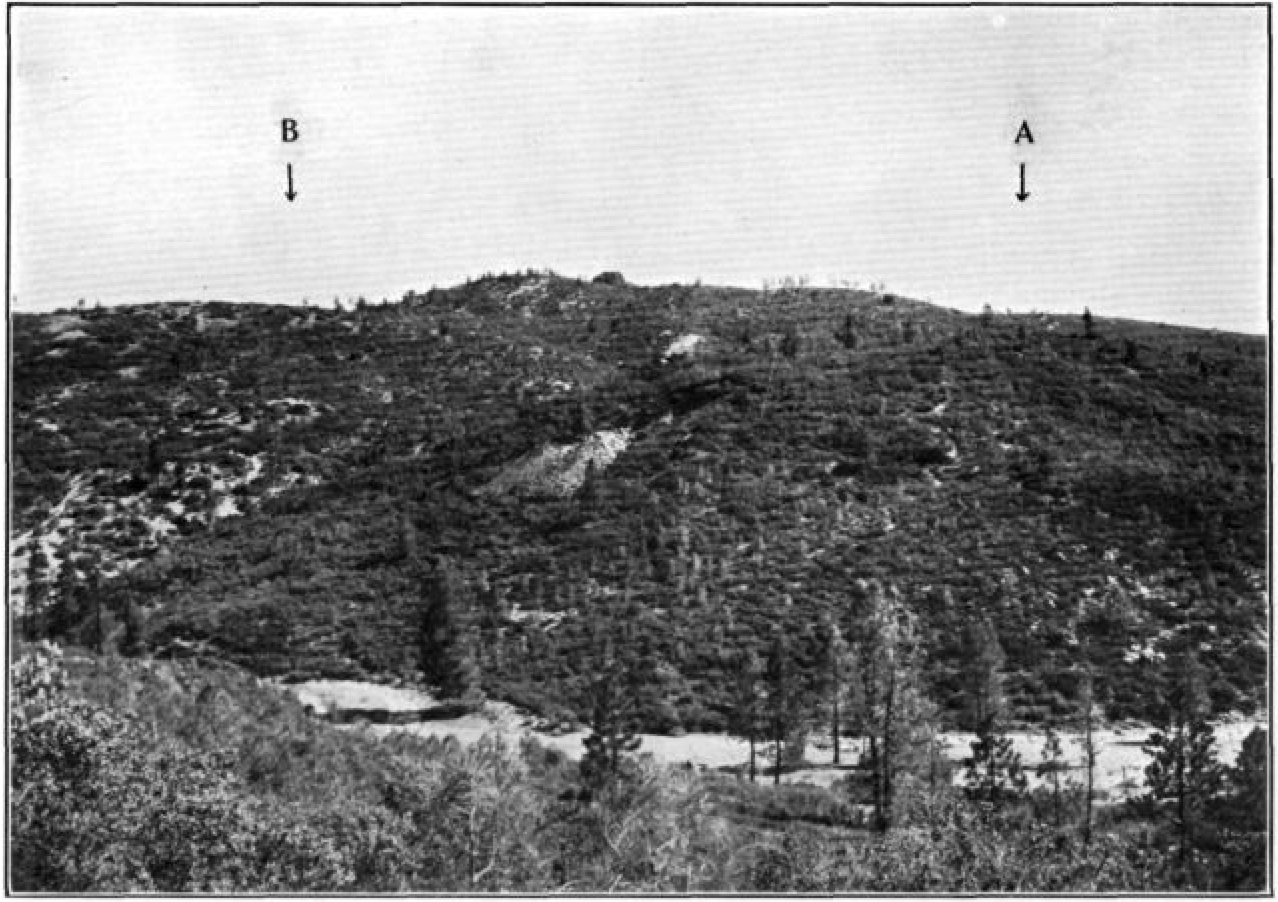
WALTER C. BLASDALE.

CONTENTS.

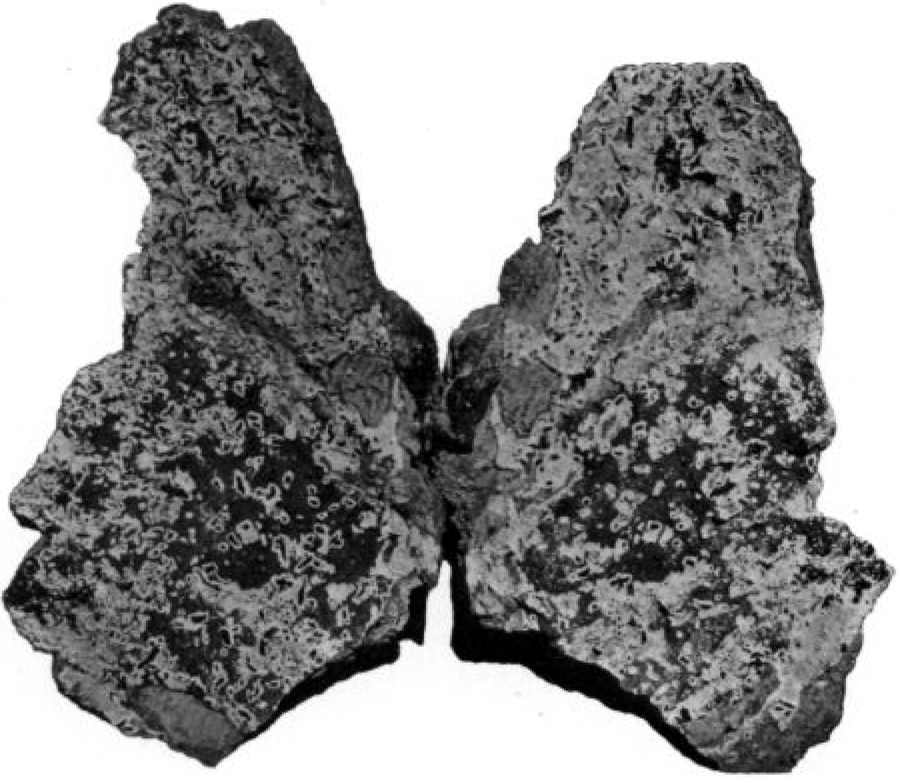


INDEX MAP.

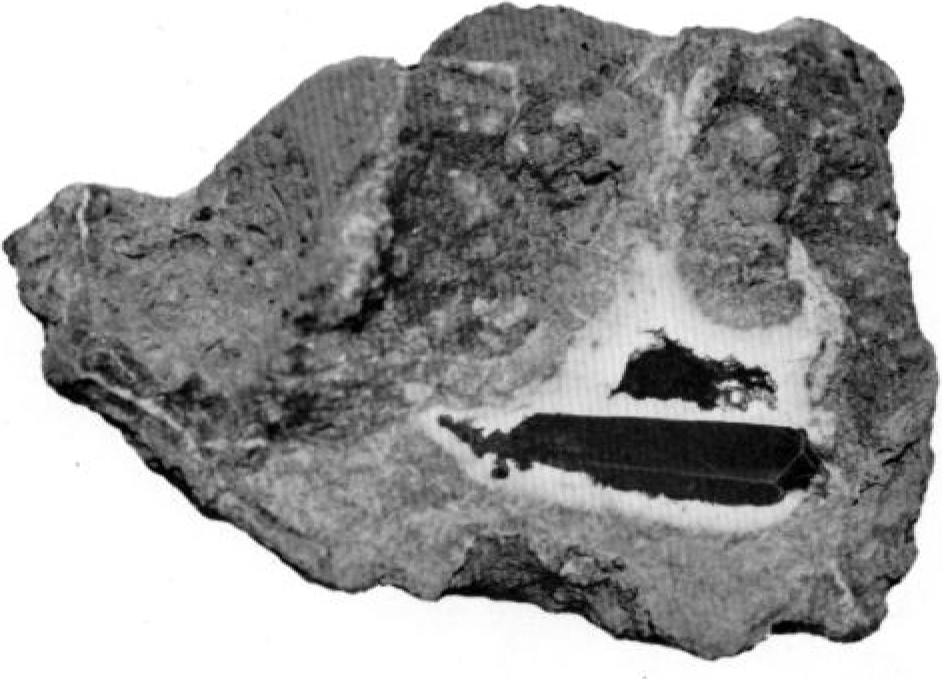
South Central Coast Ranges, California.



General view of benitoite locality and mine, August, 1908. B-A, limits of included rock mass in which the zone of mineralization occurs.



Portion of vein split open to show drusy interior. Benitoite and neptunite crystals, and white natrolite veinstone partially coated with a limonite film. About ½ natural size.



Neptunite prism in natrolite druse. The inner pure white natrolite is separated from the soda amphibole rock by a layer of greenish natrolite.

Detailed view face of open cut, benitoite mine, August, 1908. Sheeted zone on right, discontinuous masses of veinstone on left.

The elements according to the system of Goldschmidt, as $\underset{(10)}{a : c} = 1 : 0.7344$ (G_1), are as follows:

$c = 0.7344$	lg $c = 9.86593$	lg $a_0 = 0.37263$	lg $p_0 = 9.68984$	$a_0 = 2.3585$	$p_0 = 0.4896$	G_2

or by selection of the other set of axes,

$c = 1.2720$	lg $c = 0.10449$	lg $a_0 = 0.13407$	lg $p_0 = 9.92839$	$a_0 = 1.3617$	$p_0 = 0.8480$	G_1

TABLE OF ANGLES. G_1.

No.	Let.	G_1	G_2	Bravais	ϕ	ρ	ξ_0	η_0	ξ	η	x Prisms x y	ν	$d = tg\rho$
1	*c*	0	0	0001	——	0°00′	0°00′	0°00′	0°00′	0°00′	0	0	0
2	*a*	∞	∞0	$11\bar{2}0$	30°00′	90 00	90 00	90 00	30 00	60 00	0.5773	∞	∞
3	*m*	+∞0	+∞	$10\bar{1}0$	0 00	90 00	0 00	90 00	0 00	90 00	0	——	∞
4	*μ*	−∞0	−∞	$01\bar{1}0$	60 00	90 00	90 00	90 00	60 00	30 00	1.7321	∞	∞
5	*p*	+10	+1	$10\bar{1}1$	0 00	40 18	0 00	40 18	0 00	40 18	0	0.8480	0.8480
6	*π*	−10	−1	$01\bar{1}1$	60 00	40 18	36 19	22 59	34 04	18 52	0.7349	0.4240	0.8480
7	*r*	+½0	+½	$10\bar{1}2$	0 00	22 58	0 00	22 58	0 00	22 58	0	0.4240	0.4240
8	*d*	2	60	$22\bar{4}1$	30 00	71 12	55 45	68 32	28 15	55 04	1.4687	2.5440	2.9375

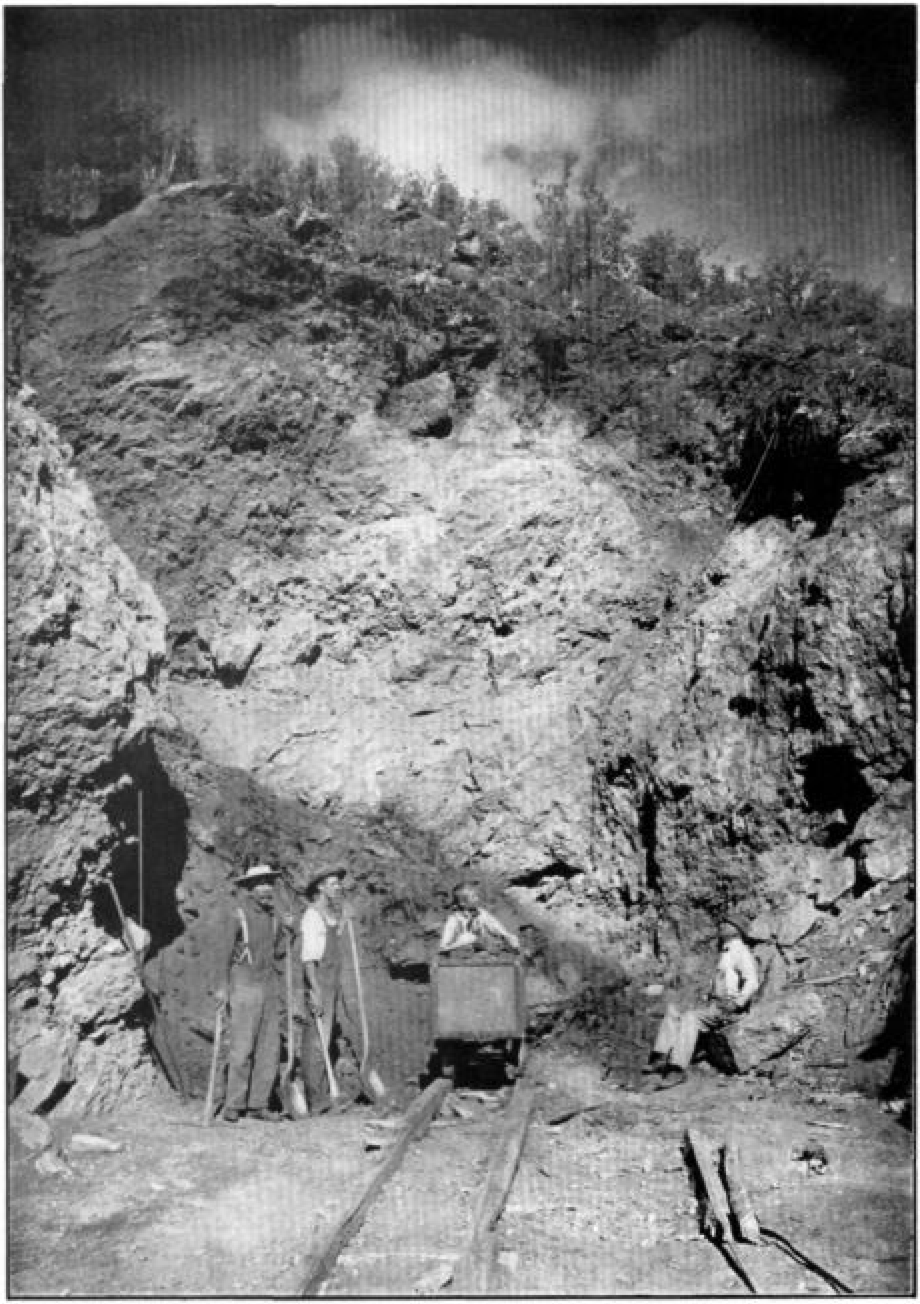
Crystal No. 3

	Measured.		Reflection.	Calculated.	
	ϕ	ρ		ϕ	ρ
p^1	0° 00′	40° 18′	excel.	0° 00′	40° 18′
π^2	59° 59′	40° 14′	poor	60° 00′	40° 18′
p^3	119° 56′	40° 18′	good	120° 00′	40° 18′
π^4	broken				
p^5	240° 00′	40° 18′	excel.	240° 00′	40° 18′
π^6	299° 54′	40° 18′	fair	300° 00′	40° 18′
m^1	0° 00′	90° 00′	good	0° 00′	90° 00′
m^5	240° 00′	89° 58′	fair	240° 00′	90° 00′

Crystal No. 1

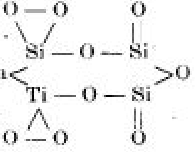
	Measured.		Reflection.
	ϕ	ρ	
p^1	0° 00′	40° 19′	excel.
π^2	60° 05′	40° 19′	poor
p^3	120° 04′	40° 22′	fair
π^4	180° 01′	40° 22′	good
p^5	239° 58′	40° 21′	good
π^6	300° 01′	40° 21′	fair
m^1	0° 00′	90° 00′	fair
μ^2	60° 04′	90° 00′	fair
m^3	120° 05′	90° 00′	fair
m^5	240° 01′	90° 00′	fair

		Measured.		Calculated.	
		ϕ	ρ	ϕ	ρ
r	$(10\bar{1}2)$	0° 02′	23° 00′	0° 00′	22° 58′
a	$(11\bar{2}1)$	89° 59′	30° 03′	90° 00′	30° 00′
		90° 00′	30° 04′		
d	$(22\bar{4}1)$	71° 07′	30° 03′	71° 12′	30° 00′
		71° 12′	30° 00′		



General view of end of open cut, benitoite mine, August, 1908.

Benitoite



The forms observed at the San Benito locality are *c*(001), *b*(010), *a*(100), *m*(110), *s*(111), *o*($\bar{1}$11), *i*($\bar{1}$12), *g*($\bar{2}$11), *r*($\bar{2}$21), *p*($\bar{3}$11).

	Measured.		Calculated.	
	φ	ρ	φ	ρ
c(001)	90° 00′	25° 38′	90° 00′	25° 38′
a(100)	90 00*	90 00*	90 00	90 00
m(110)	40 06	90 00*	40 07	90 00
s(111)	55 14	54 36	55 10	54 43
o($\bar{1}$11)	$\bar{1}4$ 06	39 53	$\bar{1}3$ 57	39 45
i($\bar{1}$12)	$\bar{1}9$ 08	23 04	$\bar{1}9$ 05	23 08
r($\bar{2}$21)	$\bar{2}8$ 27	61 25	$\bar{2}8$ 37	61 28
p($\bar{3}$11)	$\bar{6}2$ 25	60 20	$\bar{6}2$ 30	60 22

* Crystals set with prism zone at $\rho = 90° 00′$ and angles φ referred to *a* as 90° 00′

---

[11] The correct and usual pronunciation of place names of Spanish origin in California approximates the original Spanish pronunciation. In Benito the accent is on the penultimate syllable and the i has the sound of i in machine. In conformity with this, the name of the mineral is properly to be pronounced be-nï′-to-ite. Benito is a Spanish form of benedictus, blessed.

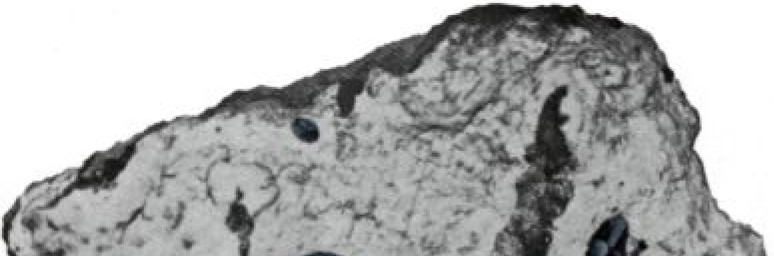
[12] Flink, *Zeit. für Kryst.*, 23 (1894), pp. 344-367; Nordenskiöld, *Geol. Fören. Förh.*, 16 (1894), p. 336; Wallenström, *ibid.*, 27 (1905), p. 149; Böggild, *Meddelelser om Grönland*, 33 (1907), pp. 95-120.


1


2


3


4

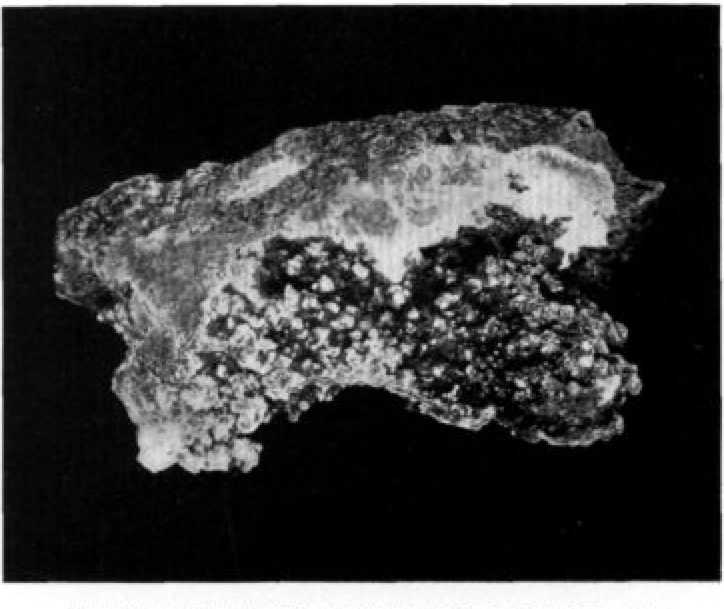

5

Benitoite.—1 and 2. Gem in ordinary reflected light, natural size; 3. in transmitted light, extraordinary ray; 4. in transmitted light, ordinary ray. 5. Crystals in matrix, ⅘ nat.

	Neptunite (Greenland)		California Mineral	Molecular ratios for
	I	II	III	III
SiO_2	51.53	51.93	53.44	.820
TiO_2	18.13	17.45	17.18	.213
FeO	10.91	10.23	11.23	.230
MnO	4.97	5.32	1.78	
CaO	—	0.71	0.25	
MgO	0.49	—	1.82	
K_2O	4.88	5.71	5.39	.204
Na_2O	9.26	9.63	9.14	
	100.17	100.98	100.23	

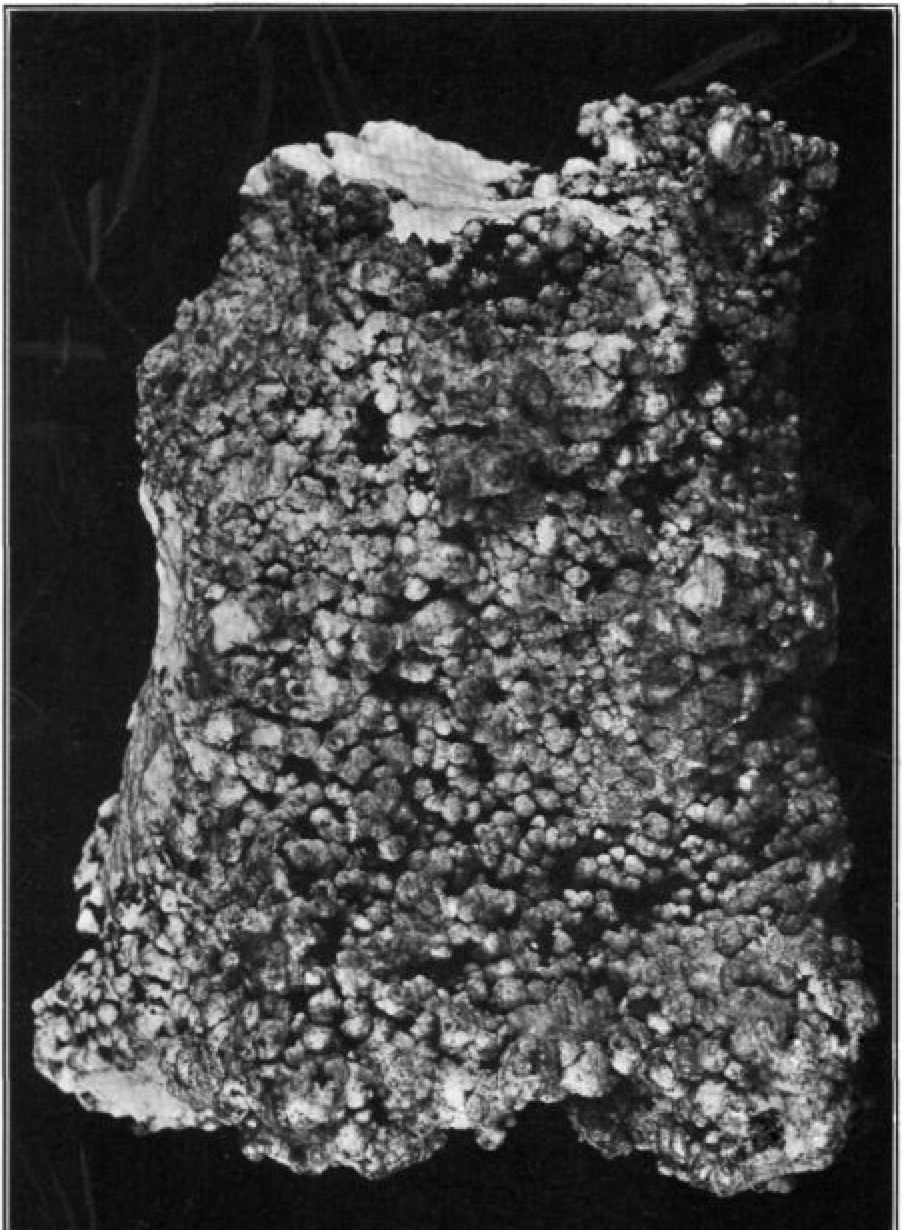
Natrolite, crystalline aggregate, tabular habit. Natural size.

Natrolite, crystal group, normal prismatic habit. Natural size.



Natrolite druse showing equant groups perched on soda amphibole fibers. Natural size.

	Matrix.	Natrolite calculated.
SiO_2	47.69	47.49
Al_2O_3	27.14	26.79
Na_2O	15.74	16.28
H_2O	9.56	9.44
	100.13	100.00



Natrolite, botryoidal aggregate. Slightly reduced.

	Amphibole of Druse	Crossite, North Berkeley (Smith)
SiO_2	52.94	55.02
Al_2O_3	3.76	4.75
Fe_2O_3	----	10.91
FeO*	13.40	9.45
MnO	1.44	trace
MgO	11.54	9.30
CaO	5.45	2.38
Na_2O	5.11	7.62
K_2O	0.43	0.27
H_2O at 110°	1.31	----
Ign	3.72	?
	98.67	99.70

*All Fe assumed to be ferrous.

over the region that if completely developed would be occupied by the faces *P* and $\underline{P}$, where they form the salient angle, and over part or all of the area of *l*, $\underline{l}$ (110). The re-entrant angle between the bases is therefore uniformly presented towards the observer and the basal planes are very decidedly the most lustrous faces on the crystals. The faces *o* and *p* are very largely developed, being sometimes longer than *M* and $\underline{M}$ and the crystal appears prismatic parallel *o*, *o*, *p*, *p*.

These dominant faces are modified by the following: *f* (130), *z* ($1\bar{3}0$), η ($1\bar{2}0$), *c* ($1\bar{1}1$), *x* ($\bar{1}01$), δ ($\bar{1}\bar{1}2$), Θ ($\bar{1}31$), *u* ($\bar{2}\bar{2}1$). The form *x* shows an unusual lack of prominence, occurring as a very narrow strip. Of the others, *u* ($\bar{2}\bar{2}1$) is a rather uncommon form for albite, and *c* ($1\bar{1}1$) and η ($1\bar{2}0$) are very rare. The former (*c*) is reported by Jeremejew[16] from the Lake Baikal region; the latter, η ($1\bar{2}0$) by Klockmann from the Riesengebirge granitic rocks.[17] As far as known to the writer Θ ($\bar{1}31$) has not been previously reported as occurring on albite. The form *c* is very narrow but bright; η, *u* and Θ are generally progressively broader in the order named, the last mentioned being sometimes over ½ millimeter wide. The relations of these planes are shown in figures 5 and 5a, plate 38, which were drawn from a crystal about 5 millimeters high.

The following measurements were obtained, the calculations being based on Brezina's elements for pure albite:

	Measured.				Calculated.			
	φ		ρ		φ		ρ	
P(001)	81°	56′	26°	50′	81°	51′	27°	01′
M(010)	set				0	00	90	00
l(110)	60	27	90	00	60	25	90	00
T($1\bar{1}0$)	119	54	set		119	52	90	00
η(120)	138	47	90	00	138	42	90	00
f(130)	30	16	90	00	30	23	90	00
z($1\bar{3}0$)	149	47	90	00	149	44	90	00
x($\bar{1}01$)	$\bar{8}0$	50	25	58	$\bar{8}0$	54	25	48
c($1\bar{1}1$)	108	28	57	35	108	18	57	27
o($\bar{1}\bar{1}1$)	$\bar{1}35$	26	34	07	$\bar{1}35$	21	34	11
δ($\bar{1}\bar{1}2$)	177	00	11	42	176	17	11	38
Θ($\bar{1}31$)	$\bar{1}63$	19	59	13	$\bar{1}63$	30	59	13
u($\bar{2}\bar{2}1$)	$\bar{1}25$	30	60	50	$\bar{1}25$	26	60	50

---

[16] *Zeit. für Kryst.*, 32 (1900), on albite, pp. 494-495.

[17] *Zeit. d. deutschen geol. Gesell.*, 34 (1882), on albite, pp. 416-426. This form is characterized as doubtful by Dana, System of Mineralogy (1892), p. 328; and as "nicht ganz sicher" by Hintze in his Handbuch der Mineralogie, 2 (1897), p. 1447.

SiO_2	54.51
Al_2O_3	6.55
Fe_2O_3*	19.34
MgO	3.47
CaO	5.90
Na_2O	5.95
K_2O	0.23
H_2O at 110°	0.74
H_2O ign	1.82
TiO_2	0.44
P_2O_5	0.30
MnO	0.52
	99.77

Specific gravity 3.104.

---

* Not able to effect complete decomposition of mineral for ferrous iron. At least 12 per cent. is ferric.

Crystal constants of benitoite. The average angle $(0001)\wedge(10\bar{1}1)$ is given by Rogers as 40° 10′; Palache 40° 12′; Hlawatsch 40° 14′, the value arrived at by the writer on his earlier material; Louderback 40° 18′; Baumhauer[23] 40° 19′ 37½″. These yield $c:a=0.7310$ (for 40° 10′); 0.7319 (P.); 0.7327 (H.); 0.7344 (L.); 0.7351 (B.). Palache apparently adopts the reference axes (G_2) and gives $p_0=.4879$ corresponding to $p_0=.4896$ (L.); Hlawatsch selects (G_1) and gives $p_0=.8461$ corresponding to $p_0=.8480$ (L.).

In his table of Goldschmidt elements (G_1) Hlawatsch gives $c=0.7327$ when, following Goldschmidt's practice, it should be $c=1.2690$[24] lg $c=0.10349$, corresponding to the writer's $c=1.2720$.

---

[20] Palache, C. Note on Crystal Form of Benitoite. *Am. Jour. Sci.* (4), 27 (1909), p. 398; also German translation with slight and unessential additions, *Zeit. für Kryst. u. Min.*, 46 (1909), p. 379.

[21] Hlawatsch, C. Die Krystallform des Benitoit. *Centralblatt für Min., Geol. u. Pal.*, 1909, pp. 293-302 and p. 410. Also *Zeit. für Kryst. u. Min.*, 46 (1909), p. 602.

[22] *Loc. cit.*, pp. 300-301.

[23] Baumhauer, H. Ueber die Winkelverhältnisse des Benitoit. *Centralblatt für Min., Geol. u. Pal.*, 1909, pp. 592-594. Results of measurements on some very small crystals giving simple, good reflections.

[24] The value given by Hlawatsch is, for (G_1), $\underset{(10)}{c}$, but it is Goldschmidt's practice to use uniformly in his Winkeltabellen $\underset{(1)}{c}$ and report it simply as c. $\underset{(1)}{c} = \underset{(10)}{c}\sqrt{3}$. The value 1.2708 for apatite given in his Winkeltabellen is therefore not a "Druckfehler," as stated by Hlawatsch (*loc. cit.*, p. 299) and should appear as printed.

Neptunite.[27] W. M. Bradley has recently published the following analyses of the San Benito neptunite[28] with values very close to those given by Blasdale.

	BRADLEY				BLASDALE	
	I	II	Mean	Mol. Ratios	Mean	Mol. Ratios
SiO_2	52.91	52.83	52.87	.875	53.44	.820
TiO_2	17.77	17.89	17.82	.222	17.18	.213
FeO	11.54	11.83	11.69	.235	11.23	.230
MnO	0.82	0.88	0.85		1.78	
CaO	1.59	1.53	1.56		0.25	
MgO	1.41	1.48	1.44		1.82	
K_2O	5.11	5.06	5.08	.208	5.39	.204
Na_2O	9.83	9.28	9.56		9.14	
	100.98	100.78	100.88		100.23	

Albite. A recent abstract in the Zeitschrift für Krystallographie[29] shows that Dreyer and Goldschmidt have studied some remarkably form-rich albites from Greenland, in which are found among others certain of the rare forms and the supposedly new form on the San Benito albite: $u(\bar{2}\bar{2}1) = u(\bar{2}\bar{2}1)$ (S.B.); $\alpha(1\bar{2}0) = \eta(1\bar{2}0)$ (S.B., following Klockmann); $\eta(\bar{1}31) = \Theta(\bar{1}31)$ (S.B.). It may be noted that the angles for the San Benito albite reported by the writer agree more closely with the values calculated by Dreyer and Goldschmidt from their newly determined elements, than they do with the angles calculated from the Brezina elements given above (p. 362).

	Measured San Benito Albite		Calculated (*Elements of Dreyer & Goldschmidt*)	
	ϕ	ρ	ϕ	ρ
$P(001)$	81° 56′	26° 50′	81° 59	26° 51′
$l(110)$	60 27	90 00	60 38	90 00
$T(1\bar{1}0)$	119 54	90 00	120 04	90 00
$\eta(1\bar{2}0)$	138 47	90 00	138 59	90 00
$f(130)$	30 16	90 00	30 24	90 00
$z(1\bar{3}0)$	149 47	90 00	149 50	90 00
$x(\bar{1}01)$	$\bar{8}0$ 50	25 58	$\bar{8}0$ 44	26 00
$e(1\bar{1}1)$	108 28	57 35	108 34	57 26
$o(\bar{1}\bar{1}1)$	$\bar{1}35$ 26	34 07	$\bar{1}35$ 3	34 16
$\delta(\bar{1}\bar{1}2)$	177 00	11 42	177 14	11 39
$\Theta(\bar{1}31)$	$\bar{1}63$ 19	59 13	$\bar{1}63$ 17	59 8

---

[27] A German translation of Ford's paper on neptunite cited above occurs in *Zeit. für Kryst. u. Min.*, 46 (1909), pp. 321-325.

[28] *Am. Jour. Sci.* (4), 28 (1909), pp. 15-16. Also German translation of the same, *Zeit. für Kryst. u. Min.*, 46 (1909), pp. 516-517.

[29] Über Albit von Grönland: *Meddelelser am Grönland*, 34 (1907), 1-60. Ref. *Zeit. für Kryst. u. Min.*, 46 (1909), p. 605.

ρ measured from c as pole face

p^1 76° 35′	p^1 striated blurred reflection
p^2 train 72° 56′-76° 20′	p^2 103° 22′ supplem. 76° 38′
p^3 76° 24′	p^3 striated, blurred band of light
p^4 76° 30′	p^4 103° 22′ supplem. 76° 38′

c as pole face

p^1 103° 15′ supplem. 76° 45′
p^2 103° 31′ to 40′ supplem. 76° 20-29′
p^3 103° 10′ supplem. 76° 50′
p^4 103° 12′ supplem. 76° 48′
average ρ=76° 37′
extremes 76° 20′-76° 50′

2ϕ measured 94° 52′, 94° 43′, 95° 01′, 94° 47′.

Average 94° 51′ or ϕ=47° 25′.

The pinacoid a was found on this crystal as a minute rhombus truncating the front and back solid angle of the four p faces. the signal was very faint and could not be set within 8 or 10 minutes.

	ϕ	ρ
Measured	89° 50′	89° 42′
Calculated	90° 00′	90° 00′

Cleavage is not distinct but appears to exist parallel to the basal plane and even less distinct perpendicular to it (possibly parallel to the two pinacoids). Whenever cleavage cracks appear under the microscope, the extinction is always straight with respect to them.

The optical orientation is $\mathfrak{a}=a$, $\mathfrak{b}=b$, $\mathfrak{c}=c$. $\mathfrak{c}$ is the acute bisectrix and in convergent light in sections perpendicular to the acute bisectrix (basal section), the optic axes emerge just at the edge of the field.

The refractive index is high (>1.73) and the double refraction strong. The mineral is transparent and has a honey yellow to brownish yellow color in fair sized fragments, very pale and transparent in thin section. In thicker pieces pleochroism is visible, $\mathfrak{c}$ ocreous or reddish yellow, $\mathfrak{b}$ light yellow, $\mathfrak{a}$ similar to $\mathfrak{b}$ but slightly paler. Absorption $\mathfrak{c}>\mathfrak{b}>\mathfrak{a}$. Hardness greater than glass (5.5); density determined on the largest crystal, between 3.85 and 3.9. Heated in closed tube it becomes paler colored.

in either set. The measurements therefore indicate orthorhombic symmetry.

The pyramid faces which in a mineral of so simple a habit as is here shown would be expected to have rather simple indices, give approximations to only very complicated titanite forms. The nearest *simple* possible titanite forms are $(\bar{2}21)$ and $(\bar{3}44)$ with $x \wedge (\bar{2}21) = 70°\ 37'$, $x \wedge (\bar{3}34) = 76°\ 37'$ the measured value being 76° 37′. The coincidence of the last figures is shown to have no meaning, as ϕ^4-ϕ^3 referred to x as pole is 79° 15′ in titanite, 85° 9′ measured. A closer approximation would be $(\bar{3}54)$ and $(\overline{17}\ 13\ 8)$. As regards the form called *a* above, the nearest approximation, with simple index, is titanite $(\bar{1}01)$ where $x \wedge (\bar{1}01)$ is 86° 56′, measured 89° 42′ orthorhombic should be 90° 00′. A closer titanite approximation would be $(\overline{17}\ 0\ 16)$.