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BENITOITE, ITS PARAGENESIS AND MODE OF OCCURRENCE.

BY

GEORGE DAVIS LOUDERBACK.

WITH CHEMICAL ANALYSES BY

WALTER C. BLASDALE.

CONTENTS.

INTRODUCTION.

A brief announcement of the recently discovered mineral benitoite was made in a preliminary paper issued in July, 1907.[1] The purpose of the present paper is to give a general description of the nature of the occurrence and a more complete account of the major minerals than was possible at that time. The writer is indebted to Mr. R. W. Dallas, vice-president and manager, and Mr. Thomas Hayes, superintendent of the Dallas Mining Company for permission to visit the mine and for assistance in obtaining material for study; and to Shreve and Company of San Francisco and in particular Mr. G. Eacret, head of the diamond department, for gem and other material and assistance in many ways during the progress of the work.

Since the public announcement of the discovery of this beautiful gem mineral many efforts have been made to find new occurrences of it, but so far without success. The writer has, in connection with another problem, examined several hundred occurrences of analogous deposits, and several other geologists who have worked in the Coast Ranges of California have taken

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[1] *Benitoite, a New California Gem Mineral*, by George Davis Louderback, with Chemical Analysis by Walter C. Blasdale. *Univ. Calif. Publ. Bull. Dept. Geol.*, V, No. 9 (July, 1907), pp. 149-153. Announcement was then made that new material had been received and a more complete report would follow. The main points of this latter report were presented before the Geological Society of America at its Albuquerque meeting in December, 1907. Various causes have contributed to the delay in publication of this material, in particular a severe illness which has kept the writer from the field of activity for the greater part of a year. In returning now to the completion of the manuscript for publication it is found that recently certain phases of the work have been duplicated by others. The results are presented here, however, as they were originally worked out by the writer and his co-worker and reference made to the other articles at the end of the paper.

particular notice of minerals and veins occurring in similar geologic surroundings without seeing either of the more characteristic minerals of this particular deposit. And it is not because these minerals are difficult to see, for on the contrary they are striking in appearance. They do not occur as microscopic forms, but always in distinctly visible crystals commonly of fairly good size. It would appear reasonable to conclude that the minerals have not been simply overlooked, but that they are really very restricted in their occurrence and are due to a special and unusual set of conditions—a peculiar variation, as the writer believes, of a type of geologic activity of rather general occurrence along the Coast Ranges. The locality and general geological surroundings therefore assume considerable interest.

THE LOCALITY.

The only locality of benitoite known at present lies in San Benito County, California, near the Fresno County line, on a short tributary of the San Benito River which joins the latter near its source. It is on the west side of the Diablo Range and not far from its summit line, and about twenty-five miles in a straight line (probably thirty-five miles by road) north of Coalinga, where the mining company that owns and works the property has its headquarters and from which it ships its supplies.[2] Its geographical position is represented on the index map, plate 27. The mine is located on section 25, township 18 south, range 12 east, Mount Diablo base and meridian.

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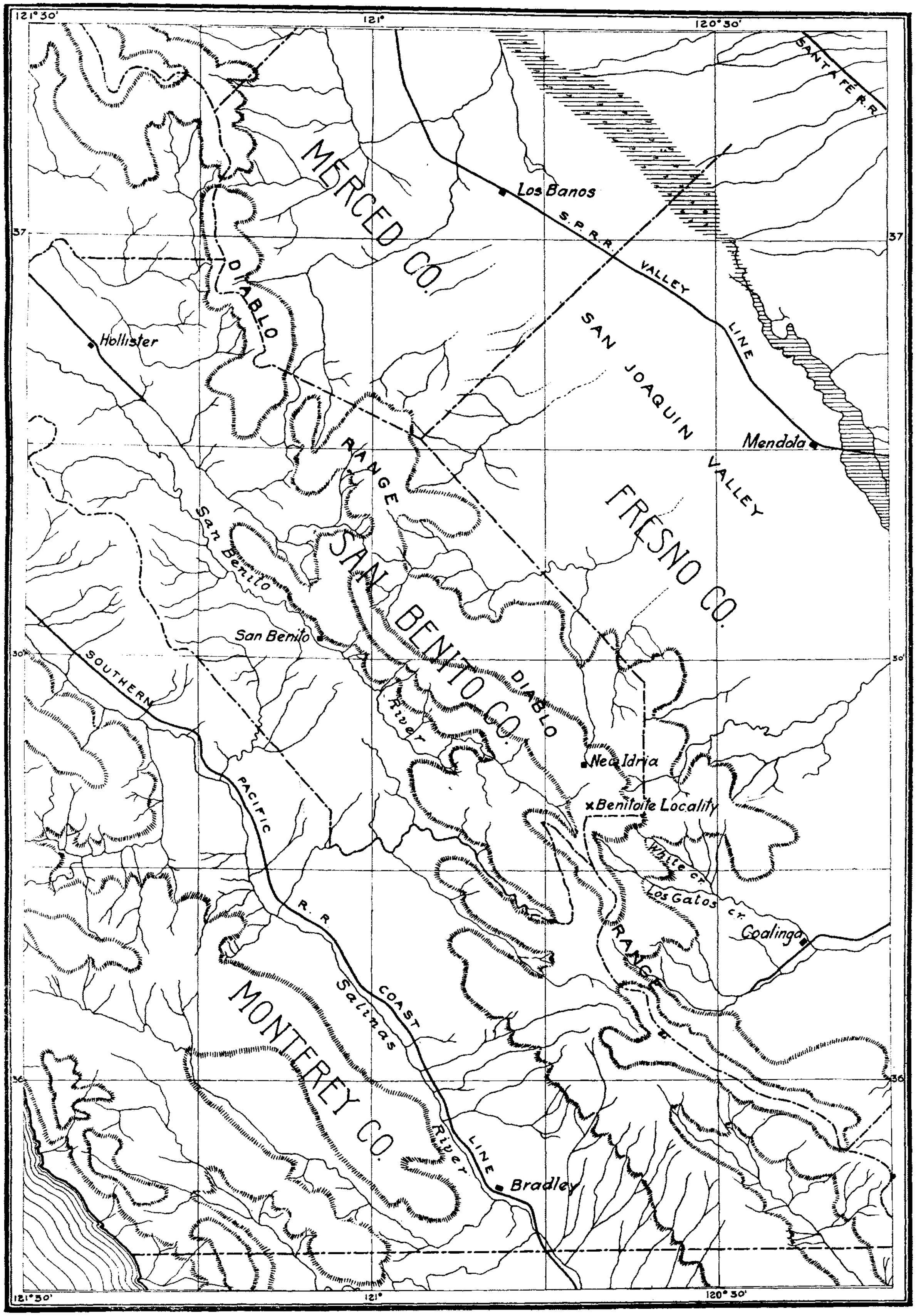
[2] It has been found very difficult to determine just who is the discoverer of this interesting deposit. Different individuals have laid claim to this title and a comparison of their various accounts shows that the ambition to be so called has led to misrepresentations of the facts. As the writer has already given names in his preliminary report and has found that the original accounts given him are not entirely correct, he feels that a further statement is due. Mr. J. M. Couch, a prospector of Coalinga, grubstaked by Mr. Dallas, had in December found some deposits that seemed to need further examination, and Mr. Dallas induced Mr. L. B. Hawkins of Los Angeles to accompany Couch into the mountains for that purpose. While out to examine some copper prospects they happened on the benitoite deposit and each claims to be responsible for the discovery. Having no idea of the nature of the material, they took some back to town for further enlightenment. At first the idea, expressed by some "expert" in Los Angeles, prevailed that the material was volcanic glass and of no value. Later some stones were cut in San Francisco, the lapidary believing that they were sapphires, and for some time the property was known as the Sapphire Mine.

GENERAL GEOLOGICAL SURROUNDINGS.

The Diablo Range is primarily a range of folding and is essentially anticlinal in its structure. The rock formations of which it is composed rise up from the "Great Valley" on the east exposing in the characteristic way, and chiefly through the effects of erosion, older and older strata as we approach the summit region, the rocks dipping to the west and appearing in reverse order as we descend the western slope. Often the general rise from the Great Valley is marked by one or more gentle or subsidiary folds, or it is modified by faulting, and such variations are especially common on the west side where the main range is flanked by a more or less mountainous country as far as the coast.

However, the Diablo Range is not in its general nature a single great anticline with axis practically coincident with the range line. It consists of a series of anticlinal axes arranged en echelon, their strikes lying generally more west of north and south of east than the topographic summit line. In contrast to the subsidiary or minor flanking anticlinal folds, these may be called the primary anticlinal components of the range. The noses of these component folds run out into the valley, gradually flattening down until they disappear. These anticlines are so placed with respect to each other that the summit divide runs along one for a greater or less distance, and then dipping down to a pass rises again to the next axis, and so on. The outcropping strata pass along the flank of the anticline, swing about the end and turn back into the range, then curve about in the opposite direction along the synclinal axis and out along the flank of the next succeeding anticline.

By reference to the map (plate 27) the general nature of the structure in the vicinity of the benitoite locality can be recognized by its influence on the topography. From some distance to the north of the mineral occurrence an axis of a primary anticlinal component occupies the summit region, and passing a short distance to the east of the gem mine continues in a southeasterly direction and runs out some miles into the valley, where it pitches below the plain just northeast of Coal-



INDEX MAP.

South Central Coast Ranges, California.

inga. This particular anticlinal lobe is of considerable interest in another way, for its lower portion near the valley has produced and is producing large quantities of petroleum, and it was along the nose of this anticline that the first important development of the Coalinga oil fields took place.

The next succeeding primary anticlinal component forms that part of the range to the west of Los Gatos Creek and Coalinga. The synclinal area between the two is well marked topographically by the depression in which flows Los Gatos Creek and its tributary, White Creek, the pass at the head, and the depression occupied by San Benito Creek on the western slope. These corresponding depressions (in part structural, but modified by erosion) and the saddle between them naturally determine the position of a road crossing the mountains from the interior valley towards the coast, and this is the road followed to reach the benitoite locality from Coalinga.

Ascending the mountains one sees a remarkable display of formations starting with the Recent of the valley, crossing in succession various divisions of the Quaternary, Pliocene, Miocene, Eocene, Upper and Lower Cretaceous and ending with the Franciscan which with its associated intrusives occupies the highest portions of the range. It is in these last named rocks that the minerals under discussion occur.

Owing to the general structure just described, the exposures of the Franciscan and their associated igneous rocks do not everywhere occupy the summit line of the main range, but extend out along the axes of the anticlinal components. Thus these rocks of the benitoite locality extend southward along the spur that runs into the valley northeast of Coalinga, while later rocks occupy the divide at the pass. The older rocks again appear at the surface along the range line farther south along the axis of the next anticlinal component.

All of the rock formations of this section down to and including the Knoxville (usually considered Lower Cretaceous), as is common in the Coast Ranges, are unaltered or but slightly altered sediments and show nothing in the nature of schist formation and very little in the way of veination—and this of superficial origin. The Franciscan series is in marked contrast.

It consists of more or less altered sandstones (often more properly graywacke), shales (frequently slates), radiolarian cherts and local areas of various types of more or less recrystallized rocks, which are frequently coarsely crystalline schists. This series is also intruded by various types of basic igneous rocks and by dikes and large (bathylithic?) masses of serpentine. A particularly large mass of serpentine occupies the summit region of the anticline north of Coalinga; and it is in the midst of this that the benitoite mine is located. It is the same mass that has been referred to in the literature as passing just back of the New Idria quicksilver mines which are situated about five or six miles north of the benitoite locality. In the vicinity of the gem mine it is several miles wide and extends down the range some distance to the southeast.

Scattered through this serpentine area are included patches of the Franciscan, sometimes of considerable size and sometimes only a few yards or even feet across. These patches may consist of any of the types of rocks mentioned above or any combination of them with or without associated basic igneous materials. Patches of schist are quite common and of considerable variety, including glaucophane, actinolite, hornblende, garnet, mica, chlorite and other schists, and they often carry well-developed crystals either as part of the body of the schist or in the veins by which they are frequently traversed. Attempts have been made to discover some regularity of strikes, or dips or other structural relations, but without success. These patches appear in general to be detached masses included at the time of the intrusion of the serpentine, and to bear no particular relationship in their attitude to the roof or country from which they were separated.

It is in one of these masses inclosed in the serpentine that the mineral deposits under consideration are found.

OCCURRENCE.

Benitoite occurs in a zone of narrow veins of natrolite, which traverses an irregular lens-shaped inclusion in the serpentine.[3]

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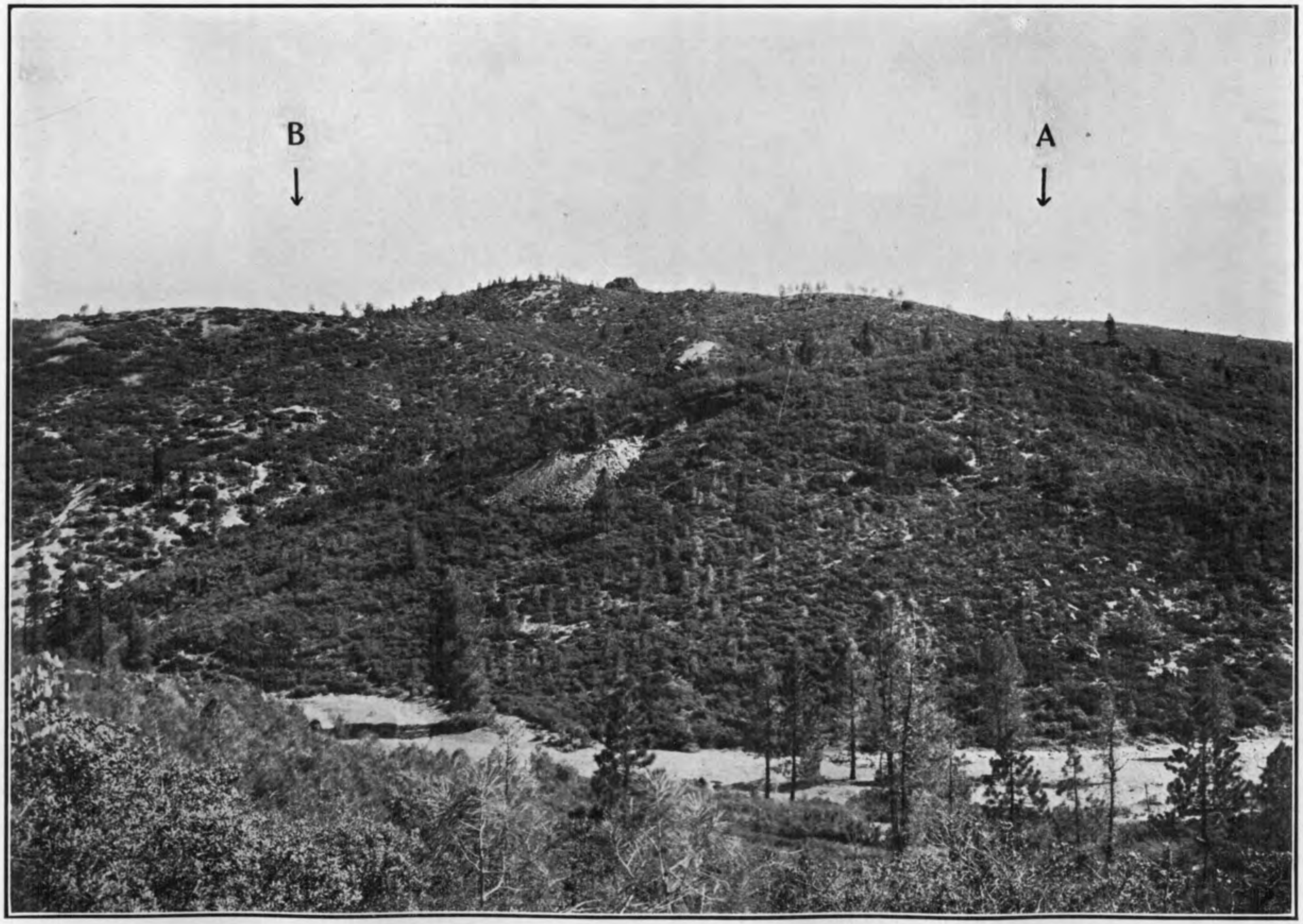
[3] The occurrence of the minerals is also discussed by Arnold: *Science*, n. s., Vol. XXVII (1908), pp. 312-314.



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

The outcrop occurs on a hill which, as shown in plate 28, is separated from the neighboring ridge by erosional depressions on all sides. Practically all of the country in view in this photograph, which was taken looking a little east of north, is serpentine, including the basal portion of the mine hill. The rock mass directly associated with the veins lies along the top of the hill from a point directly below A to one directly below B, and is about 520 feet long, and perhaps 400 feet in its widest part.

The outcrop of the mineralized belt lies entirely on the side of the summit visible in the photograph and extends along a line determined in the photograph by the right end of the cut and top of the dump. It is a zone of veination which consists of a large number of irregular stringer-veins running along together in the general direction of elongation of the zone, and connected by many branches and anastomosing laterals. The rock in the vicinity of the veins is altered by recrystallization, metasomatosis, and impregnation, in some places porous from solution of certain constituents, in others tough and cemented by natrolite impregnation.

EFFECTS OF EARTH MOVEMENT AND PRESSURE.

Considerable movement has taken place both before and since the mineral deposition, and it is distinctly concentrated along the mineralized zone. The great majority of the planes of movement and crushing lie in or near the plane of strike of the zone of mineralization, but a few are transverse.

The effects of pressure may be tabulated:

Genetically related to deposit.	1. Local schistosity. 2. Cracks and spaces giving loci of veins and druses.
Subsequent to deposit.	3. Sheeting, crushing, and brecciation. 4. Faulting and displacement of veins.

In the first three of these groups the planes lie approximately in the zone of mineralization. A few of the later fault-planes are transverse and have displaced the veins and rendered the deposits more or less discontinuous.

The appearance of schistosity in the massive rocks seems to be limited to the immediate vicinity of the zone of veination and the planes of schistosity lie roughly parallel to the outcrop. This is especially noticeable at the east end of the zone where the rock is a fine-grained greenstone, and along the line of the zone shows incipient schistosity and is traversed by narrow veins of natrolite lying chiefly in the planes of foliation.

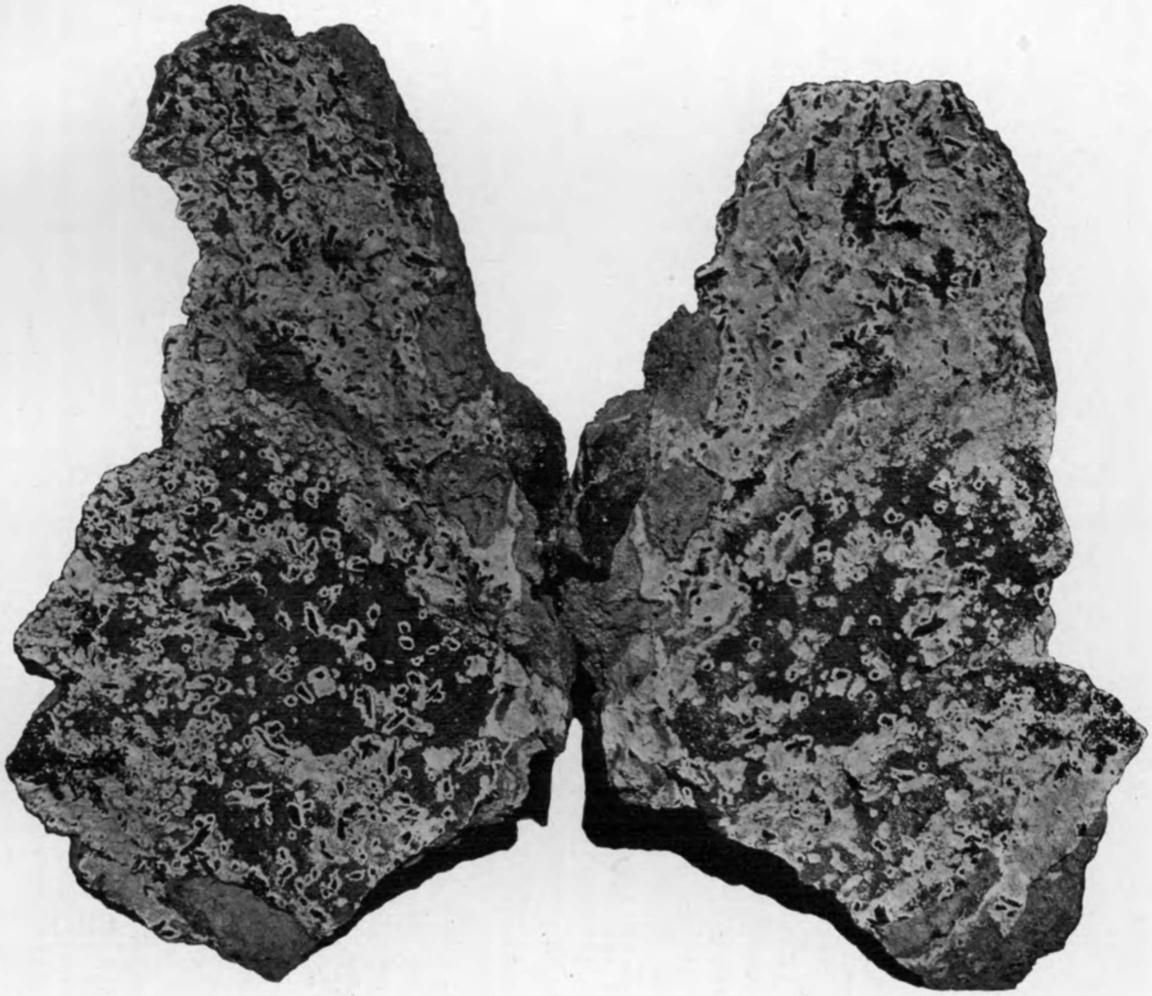
The cracks and spaces in which the veins have been deposited are not always completely filled, and drusy cracks and geodal cavities are quite common. As might be expected, many of the best crystals, and almost all of the better specimens, are obtained from such drusy spaces. Often the filling has proceeded so far that while a number of the crystals from opposite walls have united, the majority are still free. These may be split open. Plate 29 shows a slab three feet long and eighteen inches maximum width which has been so opened, exhibiting the corresponding drusy surfaces. Plate 30 and plate 33 show smaller surfaces more in detail.

Sheeting is very marked in the face of the open cut, as can be distinctly seen in plate 31. To the right of the rope it is very well developed with vertical planes. It occurs in other parts of the mine also. Crushing is evident here and in other places where sheeting is not developed.

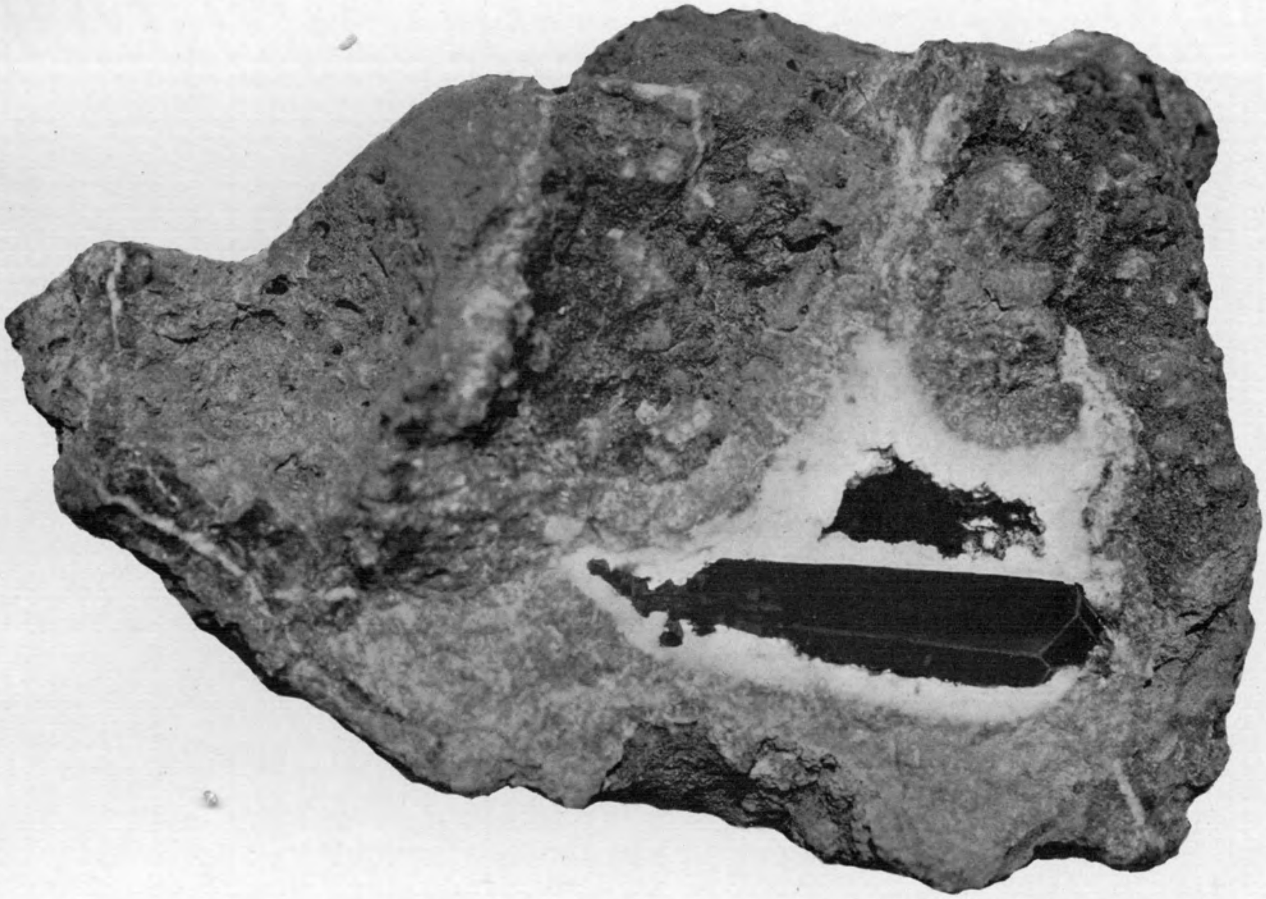
It is interesting in this connection to note that eastward beyond the limits of the vein-bearing rock-lens, and in continuation of the direction of the zone of mineralization, the serpentine is badly brecciated.

Evidences of movement are very plentiful—both fault-planes and displacements. In the face of the open cut (plate 31) the rope lies on a very distinct plane of movement. To its right is crushed, sheeted, and altered greenstone; to the left the veinstone and tough impregnated wall-rock is seen broken into separate blocks.

This crushing and faulting of the mineralized zones allows the ready seepage of water, and therefore favors decomposition. The rock outside the impregnation zone has suffered the most from this, and especially in the sheeted areas has suffered so from oxidation and other changes that it is often impossible to get a definite idea of its original nature. In the mineral druses, where permeable, the waters have deposited a layer of limonite



Portion of vein split open to show drusy interior. Benitoite and neptunite crystals, and white natrolite veinstone partially coated with a limonite film. About 1/9 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.

over the natrolite, and disfigured its shining pure white surface. The general dark areas in plate 29 are due to limonite films. Fortunately, the benitoite and most of its associates are very resistant to weathering, and besides they are generally well enclosed in impregnated blocks that shed the water into their more porous neighbors. Plate 32 is a more general view of the face of the cut, and the distribution of vein-stone can be there better followed. The rope lies on the fault-plane, and to its right is the sheeted greenstone. Starting from the curve in the rope, to the left a number of harder blocks are to be seen lying almost on a level. These are all ''ore''. Above them is a greenish blue, porous, highly altered country, characterized by an extensive development of green to blue amphiboles. At the left edge of the photograph is a large mass extending to the floor of the cut. It is evidently a breccia, and is highly impregnated. It also is ''ore'', if in part low grade. This mass extended out originally into the cut, where it was separated from the vein-stone in the face as a result of a transverse fault. The zone here dips to the left. Its irregularity is evident. The highest visible point of the rim is thirty-seven feet above the floor of the cut.

We may consider briefly the practical bearings of these post-veination movements. They have increased the difficulty of mining by producing irregularity and discontinuity of the gem-bearing matrix, by leaving the rock in a weakened condition so that movement and caving are always imminent, and by affording ready access of surface water into the workings.

The workings are at present so shallow that there is not sufficient evidence on which to base an opinion as to whether these conditions will change or not with increasing depth.

SIZE AND ATTITUDE OF OUTCROP.

The outcrop of the mineralized zone is not very extensive. At its widest point it is about sixty-four feet. Its length is not over four hundred feet. Of this the easternmost part carries barren natrolite veinlets and the wall-rock shows a minimum of metasomatic alteration. Benitoite has been found at the surface along only about 230 feet of the zone, and at the extremes of this distance only in very small quantity.

The general trend of the outcrop is north 64° west. In the cut the western part dips about 68° north, while in the face it dips 65° north. At the east end of the mineralized zone the greenstone with incipient schistosity and the barren veins of natrolite lying in these planes strike north 59° west and dip 75° north. In other words, the zone turns slightly to the south before dying out.

GENERAL RELATIONS OF MINERALS IN VEINS.

The most abundant mineral of the veins is natrolite, which occurs chiefly in granular aggregates. Indications of crystal form are largely limited to the drusy cavities, and even there the natrolite generally forms in peculiar groups, projecting in small roof-shaped ridges or coxcomb-like forms, and only very rarely developing the prismatic forms usually characteristic of natrolite. Some of the druses are filled with very small needles of green or blue-green amphibole, and lying in the midst of the cavity supported by these needles the natrolite often occurs as equant[4] polyhedral aggregates of from 1 to 3 millimeters in diameter, not at all suggestive of the mineral natrolite. Most conspicuous and beautiful in this white ground of the natrolite gangue are the scattered idiomorphic crystals of the blue equant or somewhat tabular benitoite and the brilliant black neptunite prisms, showing here and there a touch of deep red. These minerals are the characteristic and more abundant minerals of the benitoite-bearing veins.

In plate 30 it is apparent that surrounding the drusy cavity is a layer of white (natrolite) and that it is followed by a layer of darker color. This outer layer is of variable thickness—from a fraction of an inch up to several inches—and is usually present between the white vein material and the more definitely recognizable wall-rock. It has a bluish or greenish tint, and looked at closely is seen to show a granular structure with luster and cleavage much like the vein-stuff. It is indeed natrolite which is loaded with numerous microscopic

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[4] Used in the sense of equidimensional or nearly so, in contrast to tabular or prismatic, as suggested by Cross, Iddings, Pirrson and Washington, *Journ. Geol.,* XIV (Dec., 1906), p. 698.

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

needles of greenish or bluish amphibole, etc., and recalling in its general nature the ''Eisennatrolith'' of Norway.

Following this is the more or less altered wall-rock, which along the central part of the deposit is made up largely of bluish or greenish amphibole in minute prisms or needles or irregular tangled mats. It often has a rather porous and irregular texture, as the result of considerable leaching of the original rock substance.

THE MINERALS OF THE DEPOSIT.

BENITOITE.

Crystallography.

Benitoite crystallizes in the trigonal division of the hexagonal system and, as will be more fully shown below, it belongs to the twenty-second or ditrigonal-bipyramidal group of Groth, the trigonotype group of Dana—the first actual example of this type of symmetry. This is the highest symmetry group of the trigonal division—too high to exhibit rhombohedra which are so characteristic of this division that it is often called the rhombohedral division or system.

The axial ratio $c:a$ is 0.7344, determined as the average of 27 direct measurements of the angle between p $(10\bar{1}1)$ and c (0001) with the two-circle goniometer.

The detailed data obtained from 7 crystals are as follows:

40° 14′ —2 good, 1 fair.
16½′—1 good, 1 poor.
18′ —4 excellent, 3 good, 7 fair, 2 poor.
19′ —1 excellent, 1 poor.
21′ —1 good, 1 fair.
22′ —2 fair.

Giving weights of 4, 3, 2, and 1 for excellent, good, fair, and poor reflections, respectively, the average is 40°17′.94; a simple average, all readings being given same weight, gives 40° 18′.04. The closeness to the value for apatite (Dana, 0.7346[5]) is striking, but the symmetry is different and the relationship otherwise not apparent.

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[5] Baumhauer in *Zeit. für Kryst.*, XVIII (1891), p. 40, has collected the various values for the axial ratio of apatite and gives values from 0.7294 to 0.7353.

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

$c = 0.7344$	$\lg c = 9.86593$	$\lg a_o = 0.37263$	$\lg p_o = 9.68984$	$a_o = 2.3585$	$p_o = 0.4896$	G_2

or by selection of the other set of axes,

$c = 1.2720$	$\lg c = 0.10449$	$\lg a_o = 0.13407$	$\lg p_o = 9.92839$	$a_o = 1.3617$	$p_o = 0.8480$	G_1

TABLE OF ANGLES. G_1.

No.	Let.	G_1	G_2	Bravais	ϕ	ρ	ξ_0	η_0	ξ	η	x Prisms $\frac{x}{y}$	y	$d = tg\rho$
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*	$+\frac{1}{2}0$	$+\frac{1}{2}$	$10\bar{1}2$	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

A number of crystals show a more complicated form that lies vicinal to π and in the angle where π, m and p meet. These faces may occur complete for the symmetry as far as one face π and its corresponding face vertically below are concerned—that is, one in each of the corresponding p, π, m corners; but they have not yet been found corresponding to the complete symmetry of a whole crystal. They are uniformly dull, and give no opportunity for accurate measurement. Many attempts at measurement were made with unsatisfactory results, and the following approximation may be given: $x = -1\frac{1}{10}$ ($\overline{10}\ 1\ 9\ 10$). At least one other was observed, and recognized as different by the different triangular trace that it produces, but it is so near π in its attitude and so dull that no approximation is attempted. x seems to be the more common of the vicinal forms and was observed on a number of crystals. It is of interest as the best-defined representative of a general form yet observed.

The positive set of planes give much better reflections than the negative set. μ ($\bar{1}010$) gives generally unsatisfactory reflections. The unit pyramid faces ± should show the simple relation that one appears at each $(\phi + n\,60)°$ with the same

ρ=40° 18′; likewise a prism face at each (ϕ+n 60)° with ρ = 90°. To illustrate the nature of the measurements obtained, results are here given for two crystals. In general it has been found that all of the individual faces of a form are not measurable on the same crystal.

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′		

For *a* and *d* the two sets of readings are averages from two crystals.

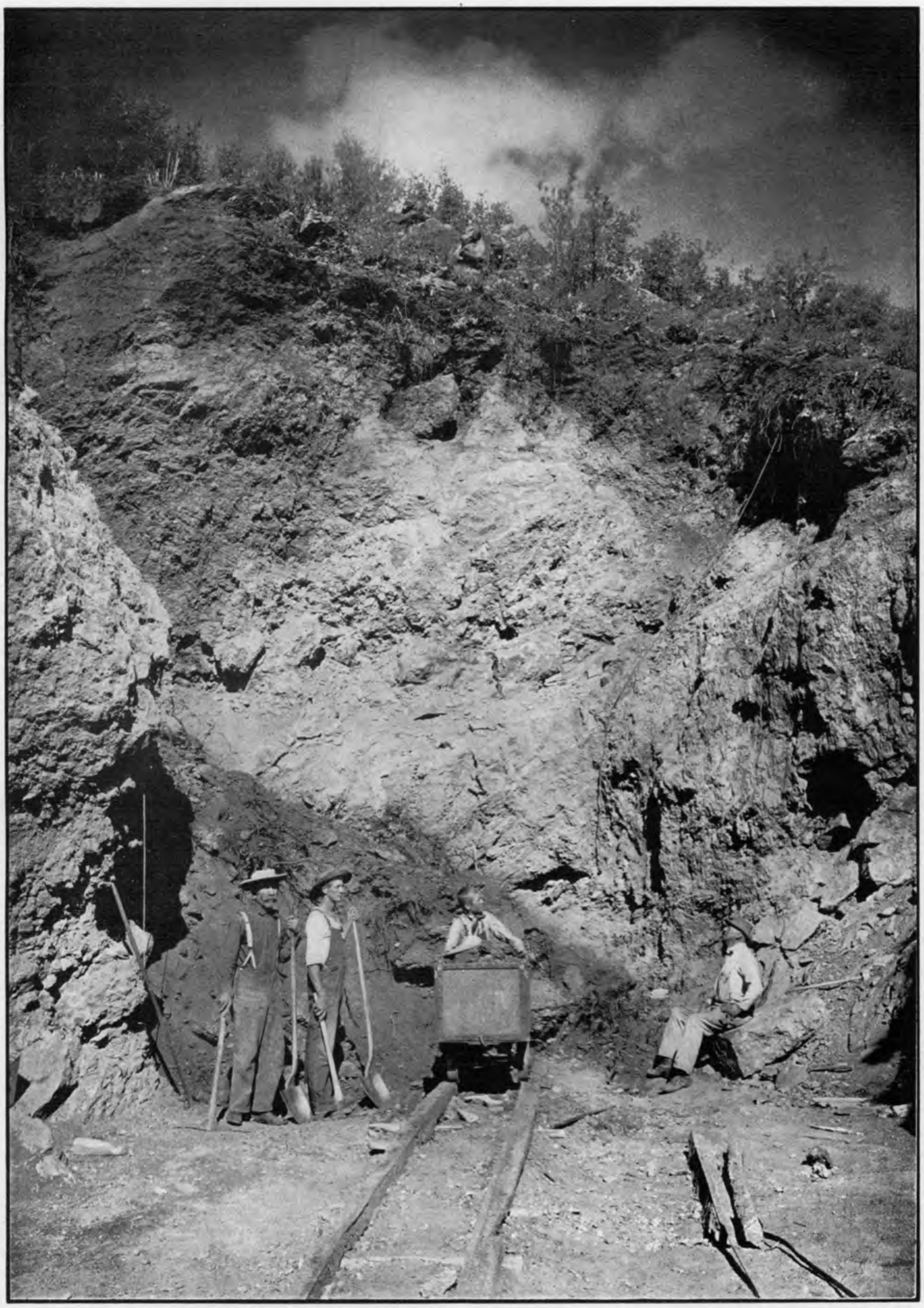
For *x* the average on one crystal was ϕ=55° 22′ ρ=41° 48′; on another ϕ=54° 49′ ρ=41° 39′. The calculated angles for $-1\frac{1}{10}$ are ϕ=55° 07′ ρ=41° 48′.

Habit.—The most common habits are distinctly trigonal and pyramidal. Although prism faces are almost universally present they are always comparatively small, and no approach to a prismatic habit has yet been observed. The largest crystal yet seen is about two and a half inches across, but is of unusual size. The majority are less than one inch across. The negative pyramid generally shows the largest faces, p commonly not reaching to c, and thus giving a triangular outline to the basal plane. The prisms appear as narrow bands. The basal plane may more rarely be absent, and p is then quite small. This gives the two habits shown in figures 1 and 2, plate 37. The positive pyramids reach the basal plane in about 20 per cent. of the crystals and then a hexagonal outline is produced, the edges generally being distinctly in two alternate groups (pl. 37, fig. 3). Only one crystal was seen wherein was produced a pseudo-hexagonal symmetry. A peculiar habit that has been found in a few crystals is produced by a predominant basal plane, the crystal being very thin, and, if growing from one side, has the appearance of an orthorhombic table.

Only one crystal was found not showing prism faces. The positive prism m may be narrower than the negative prism as in plate 38, figure 1, and in about 3 per cent. of the crystals examined it was absent, as in plate 38, figure 4. On the other hand, it may be considerably broader than the latter, even when its corresponding pyramid p is smaller than the negative pyramid π, as in figure 2.

The form r $(10\bar{1}2)$, has been found on considerably less than half of the crystals in which p does not reach the basal plane, and then always as a narrow truncation of the π edges. This is shown in figure 4, plate 37, together with x $(\overline{10}\ 1\ 9\ 10)$ which is here represented as complete for the crystal, although actually it is not found in all the sectants, and occurs only on a few crystals. In a certain number of crystals the place of r is then taken by a strip of horizontal striations or narrow planes due to oscillatory growth. The striations are shown in plate 38, figure 3, and in figure 4 is represented a set of coarser oscillations showing the origin of the striations as alternations of c and p.

The prism of the second order a $(11\bar{2}1)$ was observed in



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

about fifteen crystals in a lot of about 500 examined. It is always small and may occur without other planes of the second order, as in plate 38, figure 4, but it is commonly associated with *d* $(22\bar{4}1)$ as in figure 3 of this plate. This form, *a,* may be dull, and if bright is not so lustrous as either *m* or μ. The second order pyramid, *d* $(22\bar{4}1)$ was found on eleven crystals in the same lot. It is always small and with luster inferior to that of *a*. It generally accompanies *a,* but on two crystals showing an oscillatory growth between *c* and *p,* it occurs without *a.*

The basal plane is generally a very brilliant face, as also the pyramid *p.* The negative pyramid is frequently dull, and even when at its best is never as smooth and brilliant as the positive. Its surface is almost always uneven and often irregularly curved. This results sometimes in the production of a wedge-like form for the prism face, the edges $\pi \wedge \mu$ and $\bar{\pi} \wedge \mu$ converging towards the right or left. The prisms are generally quite bright, and if any difference appears, *m* shows a better surface than μ. Vertical striations of oscillatory growth are common on μ.

Symmetry.—The habit of benitoite is very characteristic of its trigonal symmetry, and of the presence of a plane of symmetry parallel to the base. The planes at each end of the vertical axis are always similarly developed, and the identity of the planes in the upper half with those vertically below are clearly shown, both by geometrical development and physical character. There may still be a doubt, however, as to whether the symmetry is that of the trigonal-bipyramidal or the ditrigonal-bipyramidal group. The simple forms that characterize the benitoite crystals are common to both groups. The planes of the second order occurring in like development at the end of each lateral axis, and vicinal form *x,* which is occasionally found, would indicate the group of highest symmetry.

Etch Figures.—Etching was also resorted to in the investigation of the symmetry. Good figures may be obtained on the base and the positive unit forms by treatment with hydrofluoric acid, and also with fused caustic potash, the results being similar in both cases. The figures with the acid are somewhat sharper and easier to handle and will be especially described.

These etch figures are illustrated by figure 5, plate 37, wherein the basal plane remaining fixed, the pyramidal planes of the upper half of the crystal and the prisms are supposed turned on their upper horizontal edges until brought into the plane of the drawing. This gives the actually observed forms of the figures on each face, and exhibits clearly the symmetry. The broken lines are the traces of the three lateral planes of symmetry.

The basal plane remains brilliant and gives very distinct figures. These most commonly show the outline of equilateral triangles in position reversed with respect to the similar triangular outline of the basal plane, and with its sides parallel to the edges $c \wedge \pi$. On one crystal treated with very dilute acid hexagonal figures were obtained, but the face was also dotted by numerous small reversed equilateral triangles representing depressions of regular trigonal pyramidal form.

The negative unit pyramid π is the most readily attacked form on the crystal, and very soon becomes dull without showing any distinct figures. Under very favorable circumstances, peculiar figures are obtained, the upper boundaries of which are very indefinite, but which are distinctly symmetrical with respect to the projection of the c axis.

The negative unit prism (μ) shows generally rod-like or ellipsoidal depressions with sides or elongation parallel to the c axis. Where exceptionally developed figures of hexagonal outline are produced, two opposite sides are parallel to the c axis and the whole figure is symmetrical with respect to a horizontal and to a vertical line.

The positive unit pyramid p remains quite bright and gives good figures, usually quadrilateral and symmetrical to a diagonal parallel to the projection of the c axis on p. In some cases this quadilateral is truncated by a line parallel to the edge $p \wedge m$ at its upper angle, sometimes at its lower angle also. In a specimen treated with hot acid, depressions were obtained corresponding to a truncated hexagonal pyramid (not regular) as shown in fig. 5, plate 37.

The positive unit prism (m) is with difficulty attacked and generally shows only small pits with sides parallel to the

c axis; occasionally minute lozenge-shaped figures may be seen in certain light, symmetrical with respect to the edges $\mu \wedge m$ and $c \wedge m$.

The figures on the basal plane show conclusively the trigonal character, and those on the prisms the presence of the horizontal plane of symmetry. It is also evident that three planes of symmetry pass through the vertical axis and bisect the pyramidal and prismatic faces, fixing the symmetry as that of the ditrigonal-bipyramidal group, and making benitoite the type of the highest grade of trigonal symmetry.

Natural Etching.—A large number of the crystals of benitoite show natural etching. The negative pyramids commonly show various degrees of dulling. This sometimes produces very striking results, especially when the crystal shows a large development of these planes with the other planes quite small, when the bulk of the surface may be very dull and even covered by a film of decomposition, in the midst of which the small faces may appear clear and brilliant. Triangular figures on the basal plane occasionally occur, sometimes as depressions when the triangle is in reversed position with respect to the triangle of $\pi \wedge c$, sometimes elevations when they are placed in the same attitude as triangle of $\pi \wedge c$. Occasionally hexagonal figures occur outlined by grooves parallel to the basal edges.

Physical Properties.

Hardness $6\frac{1}{4}$-$6\frac{1}{2}$; distinctly above orthoclase and labradorite, and below chrysolite and quartz. Density 3.64-3.67. The highest value obtained was on a flawless gem stone of moderately deep color weighing 1.53243 grams, and giving a value of 3.667. The clearest obtainable colorless fragment gave 3.65. A number of intermediate values were obtained on clear blue material and as low as 3.64. Material with flaws, cloudy white specimens, etc., in general give lower values.

Fracture, conchoidal to sub-conchoidal; cleavage very imperfect, pyramidal.

Refractive index by prism method referred to D line: $\omega =$ 1.757; ϵ about 1.804. Double refraction strong, and positive.

Basal sections show a perfect uniaxial cross which gives a distinct positive reaction with the mica plate.

Color, most commonly pale to deep blue, generally with a slightly violet tint; transparent. Colorless crystals occur, but are more rare. The variation in color frequently occurs on the same crystal, and the writer has many in which part of the crystal is blue and part colorless. The transition is sometimes gradual and irregular; sometimes it is sharp, the zones being separated by crystallographic planes. The writer has a slab cut parallel to the vertical axis to exhibit the pleochroism in which the line separating the blue from the colorless portion is parallel to that crystallographic axis. On another crystal a colorless layer 2 mm. thick lies at the top, and is separated from the bulk of the crystal which is blue by a plane parallel to its base. The physical properties of the colorless material are, except for those dependent on color, the same as those of the most highly colored ones.

An effort has been made to determine the source of the blue color of most of the material, but the results have so far been negative. Some of the colorless material was carefully separated and submitted to Professor Blasdale for chemical analysis, but it shows but slight variation (if any) from that of the blue, as may be seen by referring to the analyses given farther on. He also made a careful qualitative examination of a two-gram portion, but failed to detect any appreciable amounts of any element that might be reasonably supposed to influence the color of the minerals. That practically all of the titanium is in the highest state of oxidation was also shown by dissolving the material in hydrofluoric acid in an atmosphere of carbon dioxide. A colorless solution was obtained which failed to reduce potassium permanganate. In the preliminary report the writer suggested that the color might be due to a small amount of titanium in the reduced condition in solid solution in the benitoite molecule. A comparison of the analyses of colorless and blue samples shows that the TiO_2 of the former is a half per cent. or more less than in the latter, and if this can be accepted as an essential difference it at least is in consonance with that view. The violet-tinted blue of the extraordinary ray is also very suggestive of the color given by the sesquioxide of titanium. The reduction test stands opposed to this idea unless the quantity in the material used for the test was very small—or, in other words, unless very small quantities can give distinct colors.

The color is apparently quite stable. No evidence of fading has been noticed in the cut stones and fragments heated to a bright red, just short of fusion, for five or six minutes showed no change whatever after they were again cooled.

Pleochroism is very intense in the deep colored varieties and is probably the most important test applicable to cut stones. In the lighter parts the extraordinary ray is a very slightly greenish blue, inclining to indigo as it becomes darker, and is very similar to one of the axial colors shown by some cordierites. In the deeper colored crystals and the thicker layers it is an intense purplish blue. The ordinary ray is white. The color of the mineral in ordinary light is therefore merely the color of the extraordinary ray diluted with the white of the ordinary ray. The extraordinary ray shows strong absorption of sodium light, and renders a determination of the refractive index for that light difficult.

An attempt has been made to represent the pleochroism in plate 33, figures 2 to 4, as shown in a large cut stone. Figure 2 shows the natural color, and figures 4 and 3 the colors of the ordinary and extraordinary rays. The stone used is of only moderate depth of color. Dark colored specimens, if fairly thick, give such very strong absorption along the extraordinary ray that the depth of color is hardly reproducible.

It fuses quietly to a transparent glass at about 3.

Chemical Characters.

In hydrochloric acid it is practically insoluble, and this permits us to dissolve crystals out of their natrolite matrix without injury to the crystal faces. The natrolite dissolves, leaving the benitoite in a matrix of hydrous silicic acid which is easily removed. Sulphuric acid has also been used for this purpose at the mine. The mineral is attacked by hydrofluoric acid, and dissolves readily in fused sodium carbonate. Blasdale also finds it but slowly attacked by molten potassium pyrosulphate.

The chemical analysis was kindly undertaken by Professor Blasdale. A and B were made on the blue material and C on the white.

	A.	B.	Av.	Mol. Ratios.	C.
SiO_2	43.56	43.79	43.68	.723	43.61
TiO_2	20.18	20.00	20.09	.250	19.50
BaO	36.34	36.31	36.33	.237	37.01
	100.08	100.10			100.12

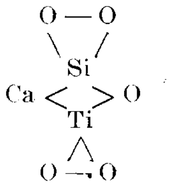
From these is derived the formula $BaTiSi_3O_9$ which yields the following calculated values.

SiO_2	43.71
TiO_2	19.32
BaO	36.97

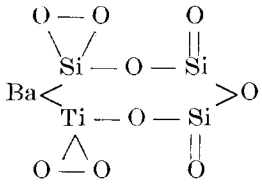
In an attempt to account for the color of the mineral Blasdale made various qualitative tests, and reports: "A more careful examination of a two-gram portion of the blue mineral failed to show the presence of appreciable amounts of iron, cobalt, manganese, copper or chromium. Very minute quantities of sodium and aluminum were obtained, but the amounts were so small as to render it probable that they were derived from the action of the reagents on the glass vessels employed rather than from the mineral itself. Conclusive evidence of the presence of the rarer earths, especially zirconium, tantalum and columbium, could not be obtained. Careful examination of some of the mineral in a delicate electroscope gave no indications of radioactivity." "It was also shown that all the titanium was present in the higher degree of oxidation. On dissolving the mineral in hydrofluoric acid in an atmosphere of carbon dioxide a colorless solution was obtained which failed to reduce potassium permanganate."

Benitoite is considered by both of us a very acid titanosilicate. Blasdale notes that the formation of salts of an extremely acidic character is not unusual when the acid concerned possesses very weakly acidic properties and the base very strongly basic ones, also that silicon dioxide possesses a remarkable tendency for the formation of complex poly-acids and that it is not improbable that the very closely related titanium dioxide might partially replace it atom for atom in such a compound as the mineral under consideration. He suggests that the relationship of benitoite to titanite may be represented by the following formulae:

TITANITE



BENITOITE



Professor Kraus has recently stated objections to this view,[6] which was expressed in our preliminary paper. He considers the chemical composition of beryl and benitoite sufficiently similar to consider the compounds isomorphous, and interprets the composition of the latter as a metasilicate of barium and titanium of the formula $Ba_2Ti_2(SiO_3)_6$. The facts that it is associated paragenetically with the basic metasilicate natrolite and that the deposit is formed in basic rocks are also considered of weight in deciding the metasilicate character in contrast to that of an acid titano-silicate.

A general survey of the compounds of TiO_2 shows that it normally possesses the properties of a weak acid, and its common formation of titanates and titano-silicates is well known. That it may act as a base in combination with a strong acid is probable, but as far as known to the writer, no evidence that it may hold this relation to silicic acid has been found. It readily forms compounds in which it acts as an acid with only moderately basic oxides. In the present case, the temperature conditions for the production of the deposit being considered limited by the conditions for the formation of natrolite, SiO_2 may be looked upon as acting as a weak acid, while barium is a strong base. Without specific evidence to the contrary, then, it would be expected that the TiO_2 would act as an acid forming a titano-silicate. The intimate association of neptunite with the benitoite would suggest that the TiO_2 played the same rôle in each. In the latter the very strong bases soda and potash are present, and its character as an acid titano-silicate is gen-

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[6] *Science*, n. s., XXVII (1908), pp. 710-711. Blasdale has discussed this point in Science, n. s., XXVIII (1908), pp. 233-234; on p. 234, line 19, the word ''base'' unfortunately appears where ''acid'' was intended.

erally admitted; in fact, a few years ago it was characterized by Groth as "das Kieselsäurereichste aller Silikate," being considered a salt of pentasilicic acid, one of the five silicon atoms being replaced by titanium.

The association with contemporaneous natrolite can hardly be taken as indicating the basic character of the generating solutions—in fact, quite a different interpretation may be given. For many years Tschermak[7] has held that natrolite is an acid ortho-silicate of the formula $Na_2Al_2Si_2O_8.H_4SiO_4$. Doelter adopted this view and presented some suggestive evidence of it derived from its decomposition and synthesis, and secondary origin from nepheline.[8] Recently this matter has again been taken up experimentally by Tschermak[9] and Baschieri[10], and, as I believe, it has been very satisfactorily proven by the dehydration curve of the separated acid that natrolite is a salt of orthosilicic acid, the formula then indicating an excess of silicic acid in the solution. In regard to the basic characters of the country-rock as affecting the nature of the minerals in the veins, it may be noted that the polysilicate albite commonly occurs in veins in the glaucophane and other basic schists of the Coast ranges and in the schists themselves, associated paragenetically with glaucophane, actinolite and other metasilicates. Contrary to the inference drawn by Kraus, the effects of basic rocks on solutions carrying TiO_2, if the minerals of these rocks become involved in the action, should be to develop the acid characters of the TiO_2. As a matter of observation, titanite is a very common mineral in the glaucophane and associated basic schists. In some of the highly siliceous veins occurring in these rocks the main mass being quartz, the TiO_2 is found in the form of rutile, the basic elements not being present in sufficient quantity to permit its entering into combination. It does not, however, in such circumstances form a compound exhibiting a basic character toward silicic acid and, as Blasdale

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[7] See for example his *Lehrbuch der Mineralogie* (1st edition), Wien, 1884, and repeated in his later editions.

[8] *Neues Jahrbuch für Mineral.*, etc., 1890, I, p. 134.

[9] *Sitzungsber. Akad. Wissensch. Wien.*, Math. Naturwiss. Klasse, Band 114, Abt. I (1905), pp. 455-466.

[10] *Rivista di Min., e Crist. ital.*, 36 (1908), pp. 37-48.

has pointed out, the entire lack of such a compound, considering the frequent association of the oxides in the same formation, is striking.

Aside from these general considerations bearing on its chemical character, the symmetry and physical constants of benitoite do not appear to the writer to indicate any close relation to beryl.

Benitoite as a Gem.

Benitoite forms a beautiful gem stone, but only a small proportion of the crystals are suitable for cutting. It is generally cut as a brilliant to bring out both its color and the brilliancy and fire due to its high refractive power. The deep violet-tinted blue of the finer stones is very attractive and by many it is considered more beautiful than that of the sapphire, which it distinctly surpasses in fire and brilliancy. The color varies from colorless to very deep blue, the two extremes being the least common. The finest stones are those with a moderately deep color. Considerable judgment has to be used in getting the proper attitude and proportions to bring out the full color-value while preserving the brilliancy. Both color and brilliancy vary materially in different directions and the color is often distributed unevenly or zonally. Quite a number of stones which have been cut by various lapidaries do scant justice to the possibilities of the gem. A common result is the production of a sort of dull leaden, or in the darker varieties blackish appearance.

The large stones have a general run from a carat and a half to about two carats, only a few exceeding the latter value. The largest flawless gem yet obtained weighed a little over seven and a half carats when first cut, though it has since been repolished and brought down to a little below this value. It has a moderately deep blue color and is about 14.5 mm. long, 10.5 mm. wide at the girdle, and 8 mm. deep. It is the property of Mr. G. Eacret of San Francisco. This stone is remarkable in that it is about three times as heavy as the next largest flawless stone so far obtained, and also that it was found in the early days of the mine almost at the surface. It is shown actual size in plate 33, figures 1-4.

Lately some very good results have been obtained by the use of the emerald cut which gives good color-value with but slight loss of brilliancy. A number of the stones have also been cut *en cabochon.* This allows the use of the less perfect material and also of that which varies considerably in color in the same piece, containing perhaps with the deep blue certain areas without color. The results have been quite satisfactory.

Name. The name of the mineral was taken from San Benito, the name of the county in which the mine lies, of the river, at the headwaters of which the deposit occurs, and of a nearby peak of the range.[11]

NEPTUNITE.

Crystallography.

Neptunite is an abundant and characteristic mineral of the deposit. Prior to its discovery in California it had been reported only from Greenland.[12] In the original benitoite material a small section of a prism without terminal faces was suspected to be a new mineral and the name carlosite suggested for it. Soon after the mine was visited satisfactory material was obtained and its identity with neptunite recognized.

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′

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[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.

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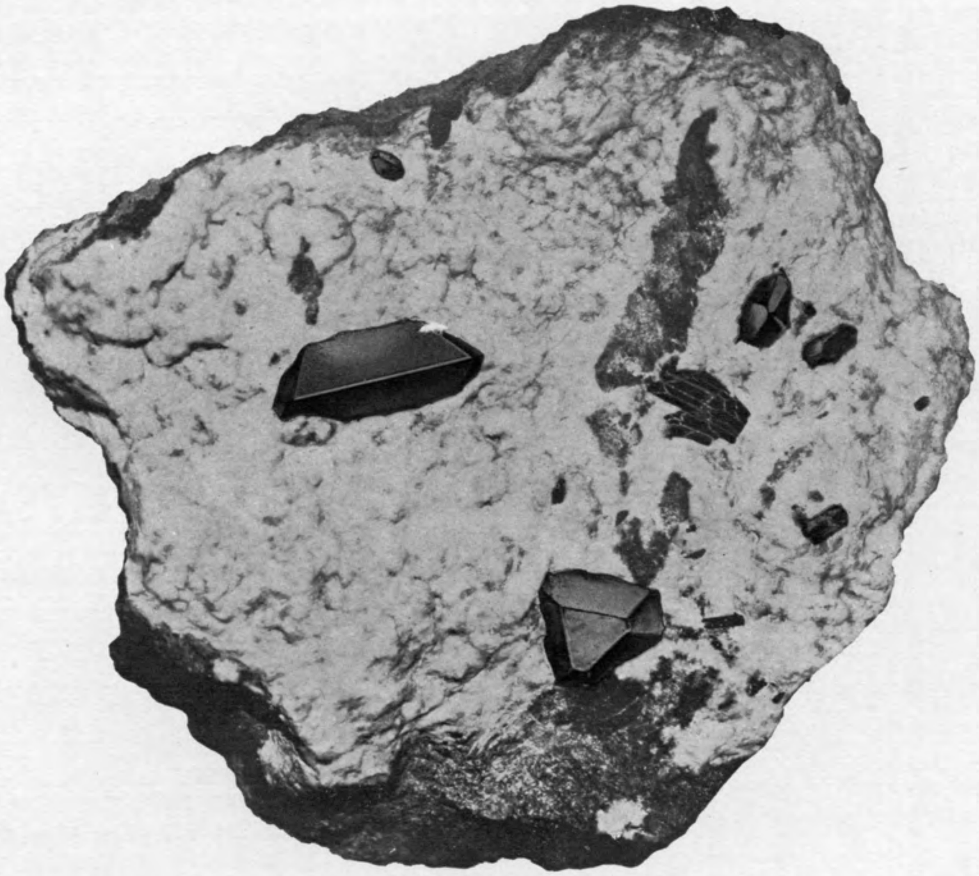

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Benitoite.—1 and 2. Gem in ordinary reflected light, natural size; 3. in transmitted light, extraordinary ray; 4. in transmitted light, ordinary ray. 5. Crystals in matrix, $4/5$ nat.

b(010) is always narrow and strongly striated vertically and difficult to get readings on. Its position in the prism zone is definite and its even truncation of the angle $110\wedge 1\bar{1}0$ leaves no doubt as to its identity.

As a constituent form of the crystals *g* is quite definite and generally present, but its attitude is somewhat variable. It is always more or less curved and generally dull. While in general it lies in the zone of ($\bar{1}11$) and ($\bar{3}11$), it appears to be sometimes curved in such a way that its traces with ($\bar{1}11$) and ($\bar{3}11$) are not parallel, and in such cases the distance between these edges is always greater along the edge $g^3\wedge g^4$ and diminishes outwards in both directions. Where most simply developed it is a narrow band and lies sensibly in the zones $\bar{1}11$-$\bar{3}11$, $\bar{2}21$-$\bar{2}\bar{2}1$ and $\bar{1}\bar{1}2$-$\bar{1}10$ corresponding to the symbol ($\bar{2}11$); but where more broadly developed the lower portion approaches in attitude to ($\bar{9}44$).

Measurements made on the poor reflections of the lower portions of curved faces gave

	Measured.		Calculated.		
	ϕ	ρ		ϕ	ρ
(1)	52° 07′	52° 49′	($\bar{9}44$) =	52° 28′	52° 58′
(2)	51 17	51 31	($\bar{2}11$) =	47 29	50 5
(3)	51 43	52 47			

Habit. By far the larger number of neptunite crystals are attached at one end and grow out as comparatively slender prisms six or eight times or even ten times as long as broad. A moderate number show development of faces at both ends of the prism axis, but the habit is always prismatic, and is somewhat similar to that described by Wallenström, but in the Greenland prismatic neptunite the orthodome is the most important terminal form, and occurs also in the first found prismatic type of the mineral described by Nordenskiöld. In the California neptunite as far as known both ortho- and clino-domes are entirely lacking.

The basal plane is always small and brilliant and in outline commonly developed obliquely to the symmetry plane; *g* is very commonly dull and *p* frequently so; o^4, $\bar{1}11$ is generally, s^2, $1\bar{1}1$ frequently and i^4, $\bar{1}12$ sometimes striated parallel to the edges of the diagonal zone $1\bar{1}0$-$1\bar{1}1$-001-$\bar{1}12$-$\bar{1}11$-$\bar{1}10$; o^3, $\bar{1}\bar{1}1$, i^3, $\bar{1}\bar{1}2$, s^1, 111 to edges of the corresponding zone, 110-001-$\bar{1}\bar{1}0$. The front pinacoid and the prism (110) are always present and the planeness of their surface is very generally impaired, *a* showing vertical striations and sometimes slight curvature horizontally, and *m* is striated both vertically and in the zone (001)-(110) respectively $(\bar{1}10)$. The pyramid $r(\bar{2}21)$ occurs only on a minority of crystals and is generally small and usually bright.

A rather common type is illustrated in figure 1, plate 39, which was drawn from a doubly terminated crystal free from the matrix and 42 mm. long by 8 mm. wide. The slight curvature in *g* is not shown. This illustrates about the average proportional length of the prisms. It is very common for the front planes to be rather small and the back planes to cut much farther down on the prism. The width of *g* is very variable and the planes *p* are frequently the largest of the terminal planes.

Figure 2 is from a stout prism some 12 mm. wide and shows a high development of the unit pyramids. The *g* faces are narrow and the "edges" $g\wedge p$ curved and of varying distance from the $o\wedge g$ edges.

Figure 3 shows a peculiar asymmetric development and was drawn from a doubly terminated prism 8 mm. long by 3 mm. wide, though only the planes at one termination are shown. It illustrates the usual ways in which $r(\bar{2}21)$ appears, either as a small triangular face between *g* and the prisms, or less commonly as a rhomboidal form bounded by the prisms, and by *o* and *p* when *g* is narrow or absent.

Only one crystal of the type shown in figure 4 was found. It shows the front faces *s*(111) largely developed and cutting down much farther on the prisms than the back faces. Both $i(\bar{1}12)$ and *g* are absent, and *r* and *p* occur as narrow strips bordering *o*.

Physical Characters.

Hardness between 5 and 6. Density 3.18-3.19. Cleavage perfect, prismatic parallel to *m*(110), with normal angle of 80° 18′.

The crystals are black and lustrous; in thin sheets or splinters, deep blood red. Cleavage plates show strong pleochroism: $\mathfrak{c}$ deep ocreous yellow to brownish red; $\mathfrak{a}$ pale yellow to reddish yellow in thicker sections; $\mathfrak{c}'\wedge c=14^{\circ}5$.

Chemical Characters.

It is practically insoluble in hydrochloric acid and may therefore be chemically separated from the natrolite matrix as is the case with the benitoite.

Professor Blasdale's quantitative analysis is here given, and for comparison, two made on the Greenland neptunite, the first by Flink, the second by Sjöström.[13]

	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	

He says "The results show a substantial agreement in the composition of the mineral from the two localities, the most marked differences apparently resulting from the substitution of magnesium and iron for some of the manganese in the Greenland specimens. Sjöström represents the composition of the mineral by the formula $ROR_2O.TiO_2.4SiO_2$ and the same form can be applied with equal degree of success to the new analysis."

NATROLITE.

Natrolite is the gangue in which the benitoite and neptunite occur, and it is also found in veinlets without associates.

Fracture of the solid vein-stone shows a mass of xenomorphic crystals exhibiting a good cleavage that yields more or less curved surfaces. The general texture is granular but with common development of radiate forms quite different from the usual radiate arrangement of natrolite and not showing such distinct straight-line boundaries to the components.

Where open spaces occur in the veins allowing the formation of crystal faces, peculiar aggregates are found entirely unlike the

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[13] *Geol. Fören. Förh.*, 15 (1893), p. 393.

ordinary natrolite. Instead of the usual prisms with square pyramidal terminations there are formed small roof-shaped ridges as shown in plate 34, commonly with curved or more strictly broken roof lines and coxcomb-like groups. These are made up of elements that are bounded by a basal plane and unit prism. The smaller angle of the prism generally projects out into the open cavity. In other words, the tendency is to place the *b* axis at right angles to the wall. The apex of the roof-shaped form is then a prism edge. The radiate groups are produced by laying the elements together along the diverging basal planes whose intersections are roughly parallel.

More complicated aggregates are common. In certain druses lined with greenish amphibole needles the natrolite occurs as small equant groups looking in the distance as if individual crystals perched on the ends of the amphibole fibres, as shown in figure 2, plate 35. A close examination shows them to be complex aggregates in which the tabular elements described above can frequently be observed. This mode of occurrence is undoubtedly closely related to the botryoidal groups which are occasionally found and which are illustrated in plate 36. Under the microscope the structure of the natrolite gangue is rather complex. As viewed on a fracture surface or in section, the radiate groups described show divergent strips that are elongated at right angles to the vertical axis. As the axis is perpendicular to the basal plane the elongation in thin section will always be optically negative. This is just the reverse of that usually seen in divergent natrolite groups and a positive elongation is generally looked upon as a character of diagnostic importance.[14]

In sections parallel to the base is often seen the twinning described by Lacroix,[15] with (110) as twinning plane forming, as it were, a sort of irregular mosaic when viewed with the aid of a gypsum plate.

A group of natrolite crystals, rare for this occurrence, was found showing the normal development of habit and planes. The

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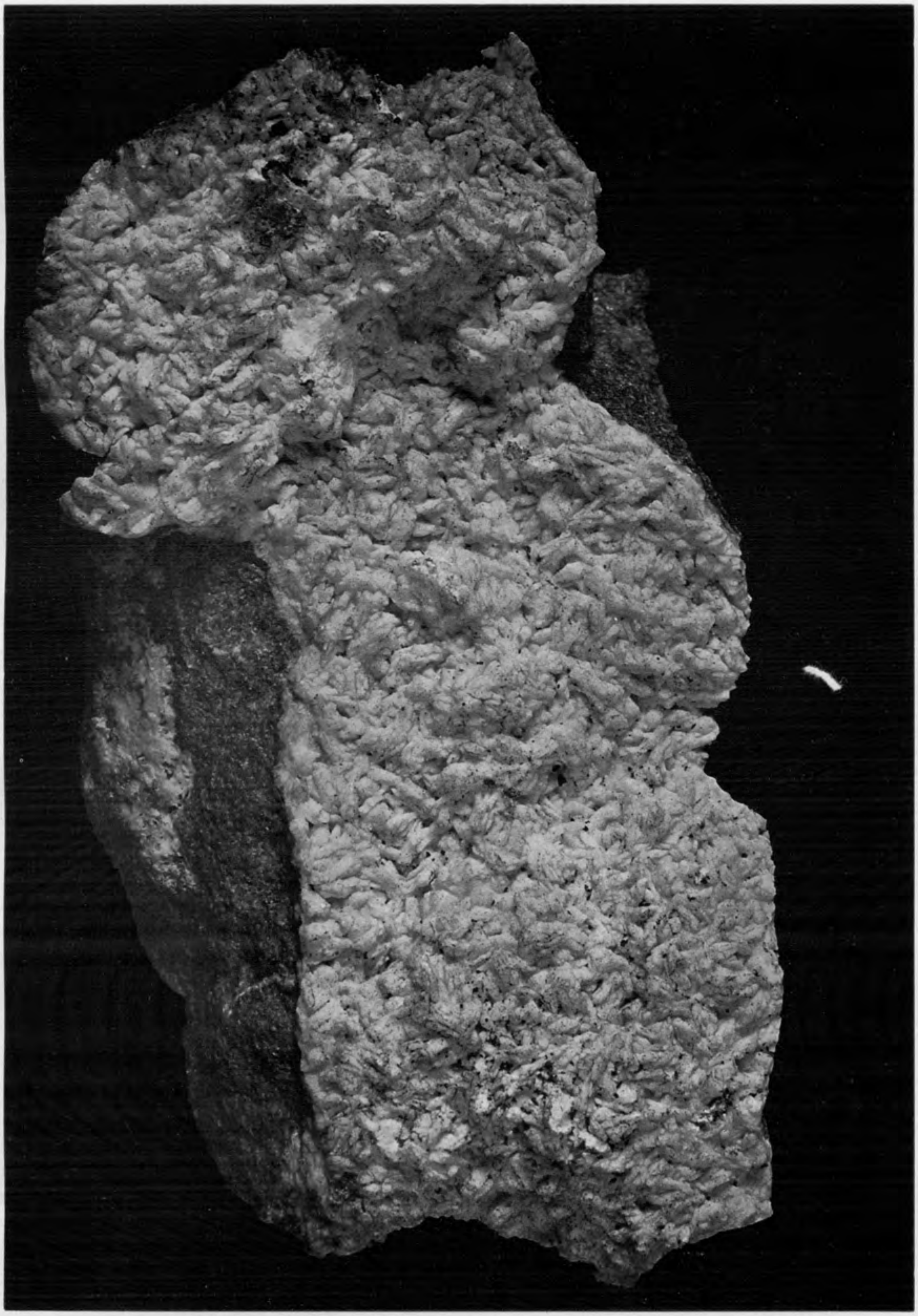
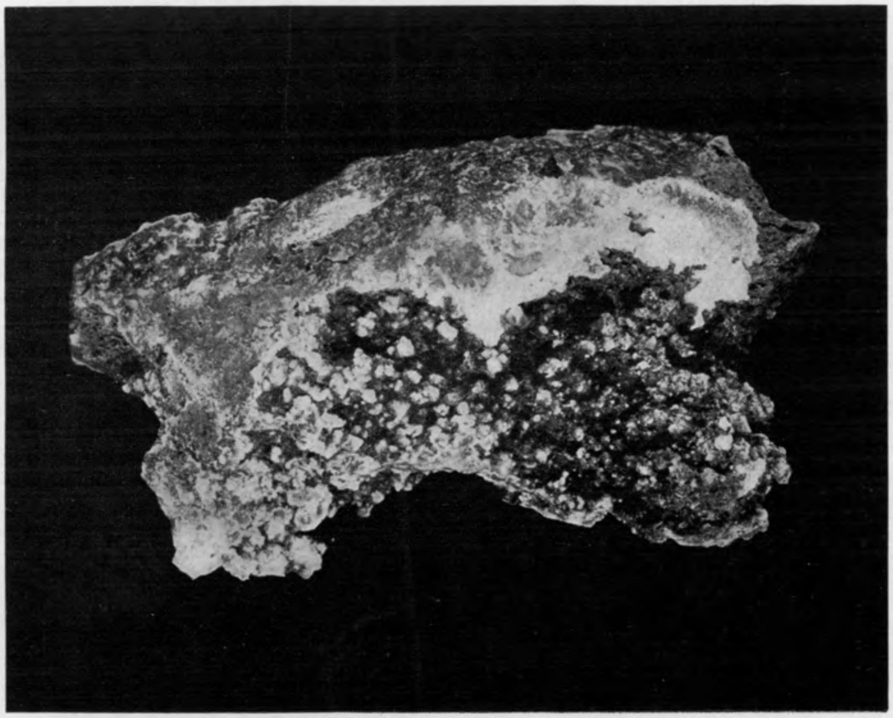
[14] Cf. Rosenbusch, *Mikoskopische Physiographie*, etc., Bd. I, 2 (1905), p. 178.
Lacroix, *Mineralogie de France*, Vol. II, p. 267.

[15] *Loc. cit.*, p. 265.



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.

individuals are large—two to four centimeters long—with prism faces 6 to 10 mm. broad, and show a combination of the unit prism *m*(110) and unit pyramid *o*(111). The faces are somewhat dull, but they show a very perfect cleavage, yielding lustrous surfaces. A distinct zonal structure is present, appearing to the eye as layers of different degrees of translucency lying parallel to the faces of the external form. These prisms show straight extinction and in a section perpendicular to prism edges an acute positive bisectrix, the axial plane bisecting the cleavage at the obtuse angle, that is, ‖(010). It does not seem probable that these crystals formed under the same conditions as the natrolite matrix of the titano-silicates. The peculiarity of the prevailing habit may be considered as dependent on the unusual composition of the solutions giving rise to the benitoite and neptunite. No crystals of benitoite or neptunite were found with or near the group showing this prismatic habit. Plate 35, figure 1, is from a photograph of one of these prismatic groups.

A chemical analysis of the pure white benitoite matrix was made by Professor Blasdale showing it to be pure natrolite.

	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

A somewhat careful search failed to show the presence of even traces of titanium, barium, manganese, or potassium.

COPPER MINERALS.

In some parts of the deposit the copper sulphide chalcocite is not infrequent. It occurs enclosed in the natrolite in dark gray or black anhedral grains several millimeters in diameter. Occasionally on fractured surface it shows distinct and characteristic crystal outline, occurring then as a flat table with the trace of a hexagon elongated parallel to one pair of sides. It is to be considered an original mineral of the veins.

In the same part of the deposit is found the copper silicate chrysocolla. It occurs in small quantity as a stain or thin coating here and there, probably as a result of the alteration of the chalcocite, but also as individual grains 4-6 mm. across in the granular natrolite matrix. These may represent original chalcocite grains that have been replaced by solutions percolating through the natrolite and thus becoming charged with silica, but from the freshness of the surrounding natrolite and neighboring chalcocite it may be that some of the copper in the original solutions was held as silicate and separated out primarily as chrysocolla.

Both of these copper minerals occur side by side with the titano-silicates.

OTHER MINERALS.

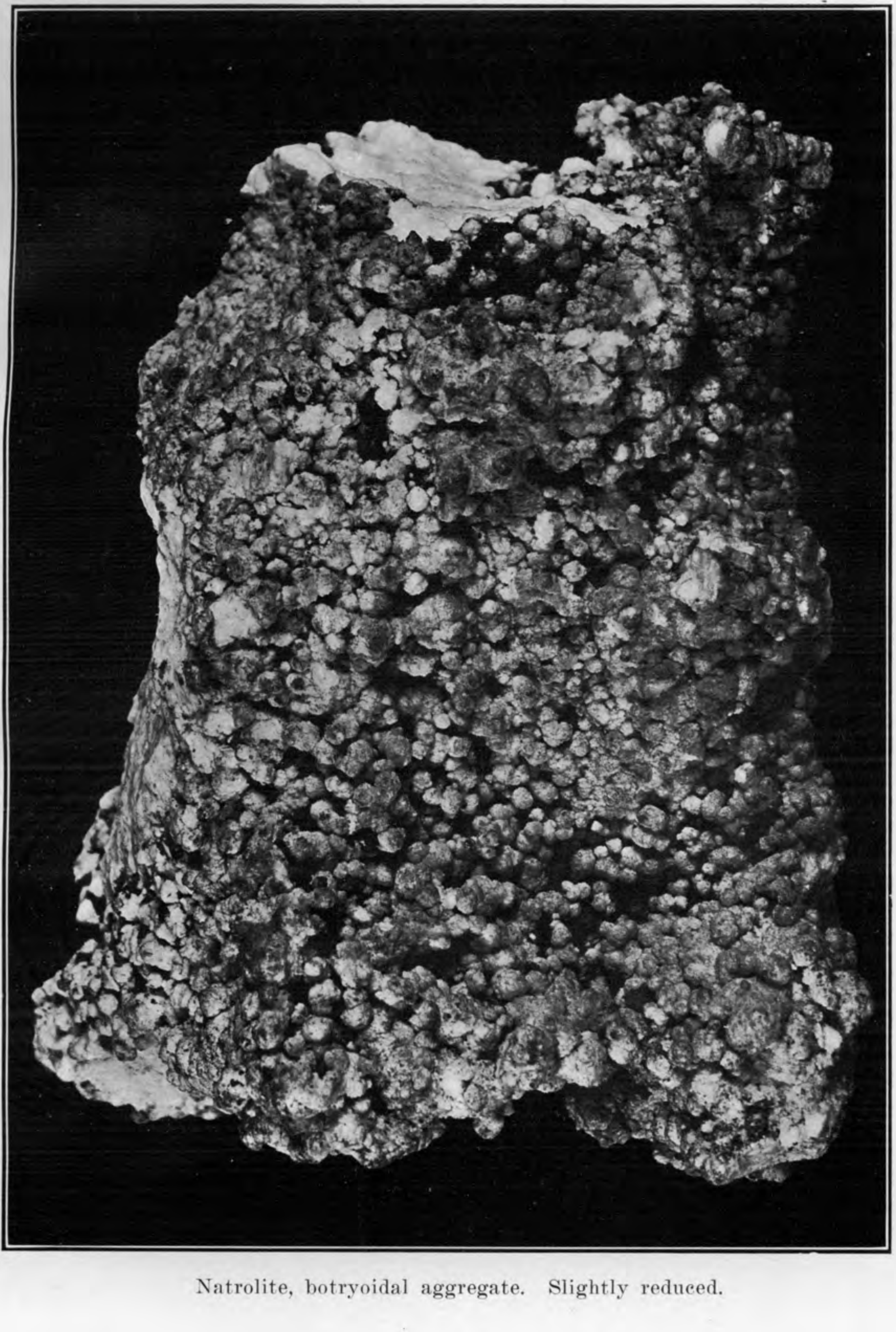
Amphiboles.

Some of the drusy surfaces are coated with green or bluish green amphibole needles, and the natrolite and albite crystals often carry them in sufficient quantity to give a greenish or bluish tint. These amphiboles vary from place to place and even the same needle may show different optical properties along its length.

A common type is actinolite. This has been observed in thin needles growing out into open spaces as a newly formed mineral in the wall rock and in veins. Occasionally it develops as asbestos films or exceedingly fine hair-like bunches. It shows pleochroism in pale green and yellow, the 𝔠 sometimes having a bluish tint. It gives a distinct sodium reaction in the blowpipe flame.

Another common amphibole is bluish green in color and shows under the microscope 𝔞 greenish yellow, 𝔟 gray violet, 𝔠 bluish green. The axial plane is transverse to the plane of symmetry and the dispersion is so great that it shows no extinction in plane (010) with white light. The extinction for red light is about 25°-30°, for violet some 5° greater. Its properties would indicate a soda amphibole with considerable iron in the molecule —perhaps intermediate between crossite and crocidolite, but nearer the crossite type.

A member of the glaucophane group is sometimes present. 𝔠 blue, 𝔟 violet, 𝔞 yellow; $\mathfrak{c} \wedge c$ about 8°.



Natrolite, botryoidal aggregate. Slightly reduced.

To get a more definite idea of the chemical nature of the amphibole occurring in the druses carrying the perched natrolites, a separation was attempted. The material is essentially of the type just described as related to crossite, but contained a small amount of actinolitic and other amphibole material in spots and zones on the crystals, and also a very small amount of natrolite that could not be entirely separated. Professor Blasdale's analysis follows:

	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.

Albite.

Albite has not been found in direct association with benitoite or neptunite. It is common in minute veins in some of the surrounding rock, where it is generally granular and determinable only by means of the microscope. But in places it is developed in druses in the zone of mineralization and appears as crystals 5 to 10 mm. long growing from the blue-green amphibole wall. These crystals are generally translucent grayish or greenish in hue, due to included amphibole fibres.

Most commonly the crystals are twinned according to the albite law. Simple twins are the rule, but sometimes there are several very thin polysynthetic lamellae intercalated between the two main halves of the twin. The habit is defined by the dominance of $M, \underline{M}$ (010); $l, \underline{l}$ (110); $T, \underline{T}$ $(1\bar{1}0)$; $o, \underline{o}$ $(\bar{1}\bar{1}1)$; $p, \underline{p}$ $(\bar{1}11)$ and $P, \underline{P}$ (001). The forms are named in order of size. *M* is the largest though never so large as to produce a distinctly tabular habit, *T* and *o* about the same, and *P* distinctly smallest. The general mode of growth is such that the crystals are attached 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*, $\underline{o}$, *p*, $\underline{p}$.

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 $(\bar{1}\bar{3}1)$, *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 $(\bar{1}\bar{3}1)$ 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
$\eta(1\bar{2}0)$	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
$\delta(\bar{1}\bar{1}2)$	177 00	11 42	176 17	11 38
$\Theta(\bar{1}\bar{3}1)$	$\bar{1}63$ 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

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[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.

$p(\bar{1}11)$ on lower side of twin was determined as being in zones $\bar{1}\bar{1}1$-$\bar{1}\bar{3}1$-010, and 001-$1\bar{1}0$.

The extinction on cleavage flakes parallel to (010) is +18°; on (001) +4°+.

Aegyrine.

At one point there was found in the albite a belt several inches long of stellate groups referred to aegyrine. The color is greenish black. The individuals, sometimes as much as 6 or 8 mm. long, do not show crystal form and are exceedingly thin in one dimension, corresponding to the tendency of aegyrine to form needles very flat parallel to (100). They were determined under the microscope by their high refractive index, negative elongation with maximum angle of extinction 2° or 3°; pleochroism, $\mathfrak{a}$ deep grass green, $\mathfrak{b}$ lighter green, $\mathfrak{c}$ brown to yellow; absorption $\mathfrak{a} > \mathfrak{b} > \mathfrak{c}$. The needles melt readily before the blowpipe, with a strong sodium flame, to a black magnetic globule.

Calcite and Aragonite.

Crystallized calcium carbonate has not been observed in the benitoite-natrolite veins, but is not uncommon in the adjoining rocks, especially in the altered basic rocks on the south side. It occurs as stringers and bunches. While calcite is the more common form, specimens of aragonite were obtained in radiate groups of columns 1 to 4 mm. thick. They are translucent and have a slightly brownish tint and while not showing terminal planes, the prismatic and pinacoidal cleavages are well developed. They carry on their surfaces small, white, more opaque calcite rhombohedra.

Manganese dioxide.

Thin stringers and coatings of manganese dioxides are common in the country on the north side just below the cut. It generally shows the character of psilomelane and is frequently in fine globular and botryoidal aggregates.

While it may sometimes be found in the same hand-specimen that carries the benitoite veins, it does not actually occur in these veins in which the manganese is limited to the neptunite.

COUNTRY IN WHICH THE VEINS ARE FORMED.

As already stated, the chief rock of the surrounding country is serpentine. This is of a type common in the Coast ranges and in general derived from the alteration of a peridotite. Small areas of a pyroxenic facies occur. Nowhere so far as known do the veins under discussion occur in actual contact with the serpentine, although it surrounds the deposit and is frequently not many yards distant from them.

The rocks immediately associated with the veins are all more or less altered, and this alteration is greatest close up to the zone of veination. In the less altered parts both igneous and sedimentary types are recognized. The more common type has in the field the usual appearance of the Franciscan greenstones. Under the microscope it is seen to have originally possessed a diabasic structure. In some specimens the augite is still largely intact. The feldspars however are recrystallized into a fine granular mass. Yet they often show very clearly by the outline of the granular areas the lath-shaped forms of the original feldspars and the relationship to the augites that characterize the diabase structure. Some titanite is present. In a somewhat altered specimen the augite is more or less altered into chlorite, while in the feldspathic layers small greenish or bluish needles are commencing to form in some cases actinolite, occasionally glaucophane, or some other geologically related amphibole. The new feldspar is at least in large part albite.

On the south hillslope below the east end of the deposit is a spheroidal gabbro. The grains and prisms of monoclinic pyroxene are in part altered to chlorite. The labradorite is more or less decomposed and otherwise altered and the rock is impregnated with calcite. It does not come in contact with the veins at any point.

Other rocks are found having the characteristics commonly displayed by the more altered Franciscan sandstones or greywackes. Under the microscope the light colored constituents which make up the bulk of the rock are seen to be entirely recrystallized into very fine granular aggregates. The original structure is preserved by the dark films of ferruginous or carbonaceous matter that followed the lamination. The new feldspar as determined in several places is also albite. Throughout the rock small needles are beginning to develop, the more common one observed being actinolite. Some very small colorless ones also occur.

A peculiar rock occurs towards the western part of the zone. It is dark colored, aphanitic, dense and fine banded, as if from the effects of original lamination. Manganese dioxide stringers are common. Under the microscope it is seen to be a fine microcrystalline aggregate, consisting in part of dark patches made up largely of a brown mineral in short minute prisms with apparently straight extinction, negative elongation, high refractive index and moderately strong double refraction. In the preparations at hand it was not determinable. In parts veinlets and areas are numerous, carrying albite, chlorite, glaucophane, etc.

In the hope that its origin might be indicated by the chemical composition, Dr. Blasdale undertook the analysis with the following results.

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.

It is not entirely clear what type of rock this represents. The alumina is remarkably low and the iron high as associated with the other constituents. It has considerable similarity to the analysis of amphibole given on a previous page, and appears to point to considerable metasomatic alteration which conceals the original nature of the rock.

The writer inclines to the belief that this rock was originally a facies of the Franciscan radiolarian chert. He has seen distinctly altered cherts that have a somewhat similar texture and mineral appearance under the microscope. The Franciscan cherts grade over insensibly into siliceous iron ores and in a number of localities have associated with them deposits of manganese dioxide. This would explain the high iron and low alumina content and the association with manganese stringers. Much or all of the soda and other oxides in part may have been introduced during the metamorphism, as in the case of certain crocidolite schists of the Coast Ranges which the writer has found to have been derived from ferruginous cherts by a similar process.[18]

Of the rocks described as associated with the veins the greenstone (altered diabase) is the most abundant and the one most commonly in contact with the veins in moderately altered condition—especially towards the east end. On approaching the central part of the zone of veination, however, the alteration increases very greatly, the original pyroxenic constituents disappear and the chief constituents are the new-formed amphiboles. The old structures are entirely lost. In part we may refer to the material as soda-amphibole schist.

A still further alteration is caused by the leaching out of the feldspathic constituents, leaving the rock in a more or less porous condition, as occurs on the left side of the cut shown in plate 32.

This rather porous rock near the veins may be thoroughly impregnated with natrolite for a fraction of an inch or several inches from the vein; also it is in this rock that the spaces occur covered with free-growing amphibole needles on which the natrolite groups are perched as already described.

SEQUENCE OF EVENTS.

The field relations and lithologic characteristics indicate that the rocks in which the benitoite-bearing veins occur are a detached mass of the Franciscan series, showing both igneous and sedimentary facies, that was included in the serpentine at the time of its intrusion.

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[18] Louderback and Sharwood: *Bull. Geol. Soc. Am.*, 18 (1906), abstract p. 659.

The rocks of the inclusion have all suffered more or less alteration affecting throughout the feldspathic constituents and characterized by the production of newly formed albite and, as the alteration proceeds, by the production of soda-bearing amphiboles from the ferro-magnesian constituents. Both the igneous and sedimentary types of the inclusion share in the alteration, which is remarkable in that the central portions are more strongly affected than the periphery. This can be explained by considering that emanations from below passed upward through the central portions of the rock-mass, and diffused out into the peripheral portions. Open channels may have existed in this central avenue, for it must have been an easier pathway than either the peripheral portions or the rock beyond. But if so the conditions at that time were not favorable to deposition along such channels. Furthermore, the extent and character of the alterations cannot be accounted for by such diffusion as often takes place in the formation of veins. One would expect the pressure to have been rather high and the temperature of the rocks undergoing alteration at least a few hundred degrees above the normal to favor the wide diffusion and production of albite and the amphiboles.

At least towards the end of this period of metamorphism we have the leaching of feldspathic material along portions of the central tract that produces the porous amphibole rock and the drusy spaces lined with amphibole needles in which the sodium-aluminum silicates are later deposited. This may be the same solution that, diffusing farther into the rocks, causes the recrystallization.

The first deposition along the zone of veination is probably that of albite, which is separated out in crystals over and about the amphibole druses and is accompanied at least in one place by aegyrine. Only a comparatively slight change is necessary to change a solution from a condition where it will slowly take up albite to one in which it will slowly deposit it in small quantity.

Before the natrolite deposition takes place important changes must have been brought about. The action is one of active deposition and is limited to the vein except where the wall-rock is porous. It is then impregnated for a short depth with natrolite and sealed, and the deposition in the vein continues with no further interchange or passage of material from or to the rocks. The setting up of active deposition, the stopping of metamorphogenic diffusion into the wall-rock, and the substitution of natrolite for albite as the precipitated molecule, all point to a marked lowering of temperature both of ascending solutions and of the country rock.

The benitoite and neptunite do not appear anywhere to follow the natrolite into the wall-rock. In a few places the neptunite appears to be partially surrounded at its base with amphibole-natrolite matrix but it is practically limited to the confines of the vein proper. Both benitoite and neptunite are attached directly to the wall so that they often commence to deposit before the wall received any coating of natrolite. They also occur in the central portion of the vein entirely surrounded by natrolite, showing that at these points the latter commenced depositing first. They also occur in the natrolite druses and project freely from the surface, showing that they were among the last materials to separate. We conclude therefore that benitoite, neptunite, and natrolite were deposited contemporaneously throughout the period of vein filling.

The order of crystallizing power—the crystalloblastic order—arranged in decreasing magnitude is neptunite, benitoite, natrolite. Natrolite is found in abundance surrounding neptunite and benitoite, molding itself to suit their form and showing the smooth surfaces of their imprint when separated. A few cases were observed where benitoite crystals are pierced by neptunite prisms or have partially grown around them.

The next events recognized are those of descending solutions, decomposition, etching, limonite coatings, etc., as already referred to elsewhere.

DISTRIBUTION OF MINERALS IN VEINS.

The workings are so shallow at the mine that there are no data at hand to indicate the distribution of the various minerals with depth. But it is of some interest to note that the distribution is not uniform along the surface. The benitoite is most abundant along the east central portion of the zone of veination. Passing eastward the titano-silicates decrease in abundance until the stringers, as judged in the outcrops, appear to contain nothing but natrolite and then play out and disappear.

Going westward the proportion of neptunite to benitoite increases until the latter practically disappears before the stringers die out in that direction.

THE RELATION TO THE SERPENTINE.

It would be interesting to determine whether the serpentine intrusion has had any direct effect on the production of the phenomena described. General considerations seem to the writer to indicate that it had.

The most suggestive characters of the deposit in this connection are perhaps the similarity in nature of the general metamorphism of the enclosing rock-lens to the more active alteration in immediate proximity to the vein on the one hand; and on the other hand the correspondence of the albitic alteration, the albite stringers of the country, the albite of the thin zone, and the natrolite in the benitoite veins which are all related chemically and by field relations. In other words, the general rock changes which seem to demand a general elevated temperature for their consummation, appear genetically related forerunners of the local action along the veins. Such a general elevation of temperature was undoubtedly supplied by the peridotite intrusion, and that occasion is most naturally taken as the period of metamorphism.

As regards the more extreme metasomatosis and later mineralization, it would seem that the rocks of the included mass were more favorable to the production and maintenance of channels than the surrounding peridotite, and acted as a vent pipe for the escape of solutions from the more highly heated lower portions of the peridotite mass to the overlying rocks, or possibly to the surface.

In considering the possibility of an origin of the deposit previous to the peridotite intrusion, the close relationship of the distribution of the veins and the present form of the included mass is suggestive. The veins run along in the direction of elongation of the lens and become smaller, less mineral-bearing and play out just before reaching the serpentine in either direction.

GENERAL DISCUSSION.

The Franciscan series extends with various interruptions for about six hundred miles along the Coast Ranges of California and Oregon and in it and its associated eruptives are found a very great number of occurrences of vein deposits that lie among similar surroundings, and a comparison of these with the deposit now under consideration yields some general analogies along with the striking differences.

Very often in traversing the serpentine areas, so frequently associated with the Franciscan, we come across included masses of partly recrystallized basic rocks or irregular areas or lenses of glaucophane, hornblende, or other basic schists. These are often cut by veins of quartz, but of particular interest in the present connection are the abundant veins of albite. Natrolite, so far as known to the writer, has not been found under these conditions except at the benitoite locality, but the analogous albite veins are very common.

Titanium is often found in the recrystallized rock, occasionally in the veins, and occurs most commonly as titanite, sometimes as rutile.

While minerals containing potassium (usually muscovite), magnesium and iron (such as chlorite or more rarely talc) are also found in veins cutting such rocks, an association representing so many metallic elements in essential quantities as occur in the benitoite veins is exceptional: sodium, potassium, magnesium, iron, manganese, copper, aluminum, barium. With this variety it seems peculiar that calcium is practically absent within the veins proper. It is found generally in the veins in the schists as lawsonite or the amphiboles.

The occurrence of barium as an essential constituent is without precedent. The only barium mineral that the writer has found associated with such formations is barite in veins in the serpentine of Mt. Diablo. While suggestive of the presence and possible concentration of barium in such rocks, it is not an analogous occurrence.

Apart from the chemical differences, a comparison of the chief gangue materials, albite and natrolite, would indicate that the benitoite-bearing veins are exceptional in the lower temperature and perhaps more moderate pressure under which they were formed. The crystallization of complex and highly acid titanosilicates at the comparatively low temperature suitable for the production of natrolite demand the presence and activity of crystallizing agents (*agents mineralisateurs*) whose nature is not indicated by an analysis of the vein materials.

RECENT PAPERS.

A. F. Rogers: Note on the Crystal Form of Benitoite. *Science* n.s., 28 (1908), p. 616. He gets an average of 40° 10′ for the pole angle of the unit pyramid. He discusses the possible symmetry and inclines to the ditrigonal bi-pyramidal class.

W. E. Ford: Neptunite Crystals from San Benito County, California. *Am. Jour. Sci.* (4) 27 (1909), pp. 235-240, 8 figs. Describes the crystallography and optical properties of neptunite. Finds optic axial plane in plane of symmetry; $c \wedge \mathfrak{c} = 24°$; $b = \mathfrak{b}$; $\mathfrak{a}$ yellow, $\mathfrak{b}$ red, $\mathfrak{c}$ red. $\beta = 1.7$; $2V = 48° 40'$; optically +. Dispersion of optic axes $v > \rho$.

The common habit described by Ford is practically the same as that described by the writer; the less usual types are somewhat different. He notes the form *g* as new, and the drawings for this paper were changed to adopt this symbol. *r* was not reported.

Received May 19, 1909.

SUPPLEMENTARY NOTES.

To the proof of the above paper the writer is permitted to add the following notes on contributions to the study of benitoite and neptunite during the past summer.

The symmetry of benitoite. The writer notes that no evidence has been published unfavorable to the view of the strictly trigonal[19] symmetry of benitoite presented by the writer in the

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[19] Not rhombohedral, as the writer is reported to have said, in the Referat of his paper, *Zeit. für Kryst. u. Min.*, 46 (1909) pp. 386-387. In the original paper (*loc. cit.* p. 150) he says "It crystallizes in the hexagonal system, trigonal division. The observed forms are the basal plane, the plus and minus trigonal pyramid and the corresponding trigonal prisms. . . . The development of faces at one end of the principal axis always corresponds so well with those at the other, that it gives the impression that the horizontal plane of symmetry is present." Trigonal bipyramids and corresponding trigonal prisms can only occur in the ditrigonal bipyramidal and in the trigonal bipyramidal symmetry classes in which the rhombohedra are not possible, and the Referent therefore misrepresented the writer's view of the symmetry relations when he wrote:

p. 386 line 4 from bottom, rhomboëdrisch for trigonal
Rhomboëder for trigonale Pyramiden
line 3 " " Rhomboëder for trigonale Pyramide.

preliminary paper, and in particular its reference to the ditrigonal bipyramidal group announced by him at the December, 1907, meeting of the Geological Society of America, chiefly on the basis of the etch figures. Recently C. Palache and C. Hlawatsch have independently arrived at the same conclusion, the former[20] basing his conclusion on the hexagonal development of the second order forms, $(11\bar{2}0)$ and $(22\bar{4}1)$ and the latter[21] on the same ground and from a consideration of the etch figures. Hlawatsch also discovers[22] certain natural irregularities on the faces of the negative (Louderback) pyramid which might indicate a pseudo-trigonal symmetry (possibly orthorhombic hemimorphic trillings), but finally decides in favor of the trigonal.

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 $c = 1.2720$.

Crystal forms of benitoite. The following table gives the correspondences of planes reported on benitoite by the various writers:

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[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.

Louderback.	Palache.	Hlawatsch.	Rogers.
$c(0001)$	$c(0001)$	$c(0001)$	(0001)
$a(11\bar{2}0)$	$a(11\bar{2}0)$	$a(11\bar{2}0)$	....
$m(10\bar{1}0)$	$\mu(01\bar{1}0)$	$m(01\bar{1}0)$	$(01\bar{1}0)$
$\mu(01\bar{1}0)$	$m(10\bar{1}0)$	$M(10\bar{1}0)$	$(10\bar{1}0)$
$p(10\bar{1}1)$	$\pi(01\bar{1}1)$	$p(01\bar{1}1)$	$(01\bar{1}1)$
$\pi(01\bar{1}1)$	$p(10\bar{1}1)$	$P(10\bar{1}1)$	$(10\bar{1}1)$
$r(10\bar{1}2)$	$e(01\bar{1}2)$	$r(01\bar{1}2)$	$(01\bar{1}2)$
$d(22\bar{4}1)$	$x(22\bar{4}1)$	$d(22\bar{4}1)$	....

Hlawatsch gives also $D(22\bar{4}3)$ as dull faces on one crystal, and also $s(11\bar{2}1)$ and $\alpha(3.\overline{19}.16.12)$. These are reported as "unsichere Flächen," and of the two latter he says, p. 296, "es können leicht Abformungen von den begleitenden Neptunit Kristallen gewesen sein." This is easily possible as neptunite has the stronger crystallizing force and benitoite is often found molded against or around it. The writer's form of doubtful index $x=(\overline{10}.1.9.10)$ is not reported by the others.

The fundamental form of benitoite. The three authors cited above agree in selecting μ (Louderback) as the positive unit pyramid and their positive forms correspond to the writer's negative forms and vice versa. While they do not discuss the point, they were apparently led to the selection by the fact that this form is usually developed at this locality in broader faces than the complementary pyramid. The designation of positive unit form ought to be applied whenever possible to the physically most fundamental pyramid. It is well known that the relative size of faces is a very variable matter and commonly determined by the character of the solution from which the crystal separates. Calcite is an excellent example. The cleavage rhombohedron is very appropriately taken as the positive unit form but other rhombohedra both positive and negative are often developed in larger faces and the fundamental rhombohedron is frequently not present among the growth planes at all. Furthermore negative rhombohedra may dominate the positive even to their complete exclusion. The peculiar symmetry of the trigonal pyramids is such that a cleavage if present would be of no value in discrimination, for m^1 is parallel to $\underline{\mu}^4$; $\mu^2 \parallel \underline{m}^5$, etcetera.[25]

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[25] Numbers superscript refer to sextants counted clockwise; a bar below signifies a lower dodecant, the upper one being unmarked, as used by Goldschmidt.

The following consideration decided the writer in the choice of the positive unit form and seems to him to indicate its more fundamental character than the complementary pyramid of the same parameters. In growth the positive pyramid produces more perfect planes and more brilliant faces, the negative pyramid showing most commonly uneven, curved, influenced and otherwise less perfect forms even when it is areally about equal to the positive form. In the attack of corrosive agents, the positive pyramid is much more resistant than the negative. In concentrated hydrofluoric acid the negative faces immediately become dull and are rapidly corroded, the positive planes remain bright and show the production of small well-formed etch figures. The positive faces must eventually be attacked over their whole surface but this was not observed during the progress of the experiment which lasted at least two hundred times and more as long as it took to entirely destroy the original surface of the negative pyramids. That this same relative resistance of the positive planes exists under very varying conditions is shown by the facts that it was observed (1) in the natural weathering process, (2) in hydrofluoric acid, both hot and cold, concentrated and dilute, and (3) in fused caustic potash.

Goldschmidt and Wright[26] in their work on that form-rich mineral, calcite, found that the more fundamental planes give the best etch figures, and suggest it as a possible general method for their determination. In benitoite there is a very marked superiority in this respect of the form selected as positive by the writer over the corresponding negative form. Altogether, then, the different lines of evidence are consistent and definite and indicate the writer's positive unit form as the more fundamental.

Refractive index of benitoite. Hlawatsch has also determined the refractive index of benitoite by the prism method (*loc. cit.*, p. 301) with results almost identical with the writer's.

	Hlawatsch.	Louderback.
ω	1.756	1.757
ϵ	1.802	1.804

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[26] *Neues Jahrb. für Mineral., etc.* (1903), Beilage-Band 17, p. 365.

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); $\eta(\bar{1}\bar{3}1)=\Theta(\bar{1}\bar{3}1)$ (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
$\Theta(\bar{1}\bar{3}1)$	$\bar{1}63$ 19	59 13	$\bar{1}63$ 17	59 8

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[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.

Joaquinite. Associated with the minerals of the benitoite-bearing veins is occasionally found a honey yellow or light brown substance in small generally individual crystals or crystal grains rarely over one millimeter in diameter which is believed to be a new mineral. On account of its rarity, minute size and the general imperfectness of its crystals, its investigation has been attended with considerable difficulty. A preliminary statement of its properties is here presented. Some recently acquired material containing this mineral is being worked over for its separation with a view to a more complete study and for purposes of a quantitative chemical analysis which has not heretofore been possible and the writer expects to present a more complete description of the mineral in the near future.

The crystals are generally equant, occasionally slightly tabular, and always show two parallel almost square smooth faces, the other larger faces being strongly striated. The evidence so far obtained indicates that the mineral is orthorhombic and the two broad smooth faces are taken as the basal plane, and the eight lateral inclined planes, the only pyramidal planes so far observed, are taken as the unit pyramid. We have the combination $c(001)$ and $p(111)$ and on one crystal $a(100)$. The axial ratios based on the position angles for p of $\phi=76° 37'$, $\rho=47° 25'$ are $a:b:c=2.8440:1:0.9190$.

ELEMENTS.

$a=0.9190$	$\lg a=9.96332$	$\lg a_0=9.50939$	$\lg p_0=0.49061$	$a_0=0.3231$	$p_0=3.0946$
$c=2.8440$	$\lg c=0.45393$	$\lg b_0=9.54607$	$\lg q_0=0.45393$	$b_0=0.3516$	$q_0=2.8440$

Two crystals and part of a third were studied goniometrically, but only one of the crystals was satisfactory. Measurement is interfered with in two ways. The basal faces are commonly somewhat curved (concave), and the pyramid faces are strongly striated horizontally. As a result measurements could not be trusted on two of the crystals within one or two degrees. On one of the crystals the basal faces are quite plane and can be set very satisfactorily within a few minutes, and the majority of the pyramid faces show plane strips broad enough to get definite reflections. For this crystal I am indebted to Mr. R. M. Wilke of Palo Alto.

ρ measured from c as pole face

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

$\underline{c}$ 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.

loses luster in part and yields a little water but does not fuse. Fuses readily in lower part of bunsen flame (2.5) with intumescence to a brown glass, practically colorless in thin bubbles.

It resists hot hydrochloric and nitric acids and may therefore be separated from the natrolite matrix by these agents. It is easily attacked by hydrofluoric acid which leaves a white film of decomposition products on its surface.

Qualitative chemical tests have shown the presence in reasonable quantity of silica, titanium and calcium. Iron is also present and probably determines the color.

When first observed in small particles without definite crystal form the mineral was thought by the writer to be titanite. It answers to all the tests usually applied to titanite in small irregular particles in thin sections. In particular may be mentioned its color, high refractive index, strong double refraction, biaxial positive character, its pleochroic colors and absorption scheme, the tests for silica, titanium, and calcium. Its fusibility is exceptionally low and its density somewhat higher than the usual range of titanite. The crystal form is most distinctive. It has a characteristic orthorhombic habit unlike any of the titanites hitherto described. So very different in their general appearance however are the various habits of titanite that already in its history it has been given a number of different names. It seemed possible then that this might be a new and pseudo-orthorhombic habit of this protean mineral. After considering various possible orientations, the closest approximation was found, in considering the apparent basal plane to be $x(102)$ and the symmetry plane to bisect the obtuse angles of the pyramid. This would give the proper optical orientation, as in titanite $\mathfrak{c}$ is almost perpendicular to x and lies in the symmetry plane. In this arrangement the two back faces (p^3, p^4) and the front faces (p^1, p^2 as described above) must belong to different forms and would be expected to show some systematic difference in their angular relation to x and in the angles where they meet in the plane of symmetry. If orthorhombic each set of angles should have the same values. An examination of the detailed figures given above will show that the differences are only a few minutes and that the slight variations are not systematic or symmetrical 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 $x\wedge(\bar{2}21)=70^\circ\ 37'$, $x\wedge(\bar{3}34)=76^\circ\ 37'$ the measured value being $76^\circ\ 37'$. The coincidence of the last figures is shown to have no meaning, as ϕ^4-ϕ^3 referred to x as pole is $79^\circ\ 15'$ in titanite, $85^\circ\ 9'$ 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 $86^\circ\ 56'$, measured $89^\circ\ 42'$ orthorhombic should be $90^\circ\ 00'$. A closer titanite approximation would be $(\overline{17}\ 0\ 16)$.

The attempt to make this crystal combination a habit of titanite is not successful and leads to very improbable results, while all of its properties so far determined consistently fit into the orthorhombic scheme. It may be noted here that under the microscope its most marked divergence from titanite is its inferior cleavage and straight extinction wherever cleavage cracks are observable.

This mineral may contain some other elements not shown in the preliminary microchemical tests, but it may also be a dimorphous form of titanite, or an orthorhombic end member of an isomorphous series.

The name is taken from the ridge (primarily anticlinal component) of the Diablo range on which the mineral occurs. The ridge received its name from the prominent Joaquin rocks—a landmark of the region.[30] It also borders the great San Joaquin valley.

Joaquinite is found enclosed in the natrolite, both at the edge of the veinlets and touching the wall rock, and also in the central portion of the vein. It is also found enclosed in the neptunite and seems especially to occur in those parts of the deposit rich in neptunite. Both the natrolite and neptunite are molded about it xenomorphically.

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[30] See further Arnold and Anderson, *Bull. U. S. Geol. Survey*, No. 357 (1908), 13.

Octahedrite. Palache in the paper cited above reports octahedrite as occurring in the benitoite-natrolite veins and gives the following description. ''It appears in groups of pale-brown crystals, combinations of unit pyramid and base; the crystals are small and present facetted and curved faces so that they could not be measured but chemical tests showed the presence of titanic oxide alone.'' The writer has not observed octahedrite in any of the specimens he has studied and suggests that the mineral reported by Palache is the same as that described in the preceding section. The brief description fits perfectly except for the negative chemical evidence.

Issued December 24, 1909.

EXPLANATION OF PLATE 37.

BENITOITE.

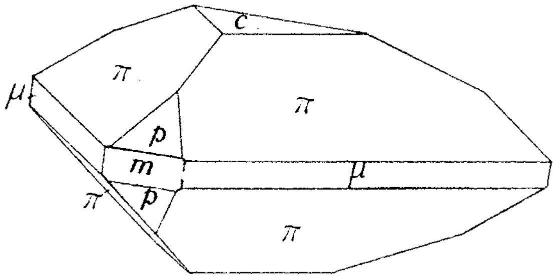
1. Very common habit: $c(0001)$, $p(10\bar{1}1)$, $\pi(0\bar{1}11)$, $m(10\bar{1}0)$, $\mu(0\bar{1}10)$.

2. Common habit with minute or no basal plane. The diminution of the basal plane is practically always accompanied by diminution of the positive pyramid.

3. A rather common habit, where $p(10\bar{1}1)$ intersects $c(0001)$ producing a hexagonal outline on the base, very rarely approaching an even development of positive and negative planes and giving a pseudo-hexagonal habit.

4. This figure without x is a type of a fairly common habit in which the $\pi \wedge \pi$ edges are truncated by $r(10\bar{1}2)$. The form x, of doubtful index, here taken as $(\overline{10}.1.9.10)$, occurs on but a few crystals and was observed complete only about one terminal of a lateral symmetry axis, though here represented complete for the three axes.

5. Diagrammatic representation of etch figures. The planes of the upper half of a crystal are supposed rotated about their upper horizontal edges until they all lie in the plane of $c(0001)$. Where differently shaped figures appear on the same form they represent the more common types and variations, or the effects produced by distinct development of internal planes. The broken lines represent the traces of the lateral planes of symmetry.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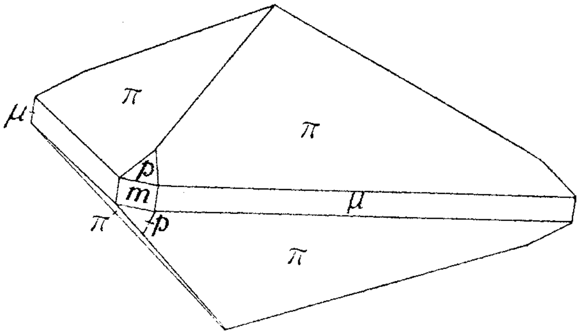
π
μ
p
m
μ
π
p
π

1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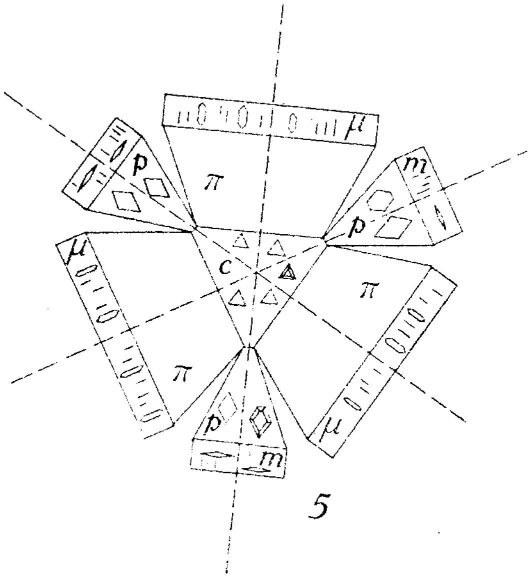
μ
π
p
π

2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c
μ
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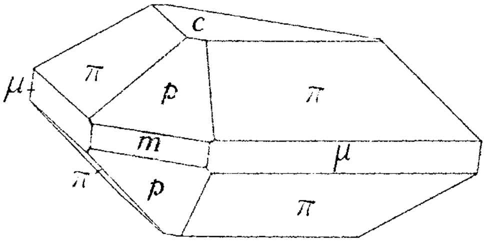
μ
p
m

5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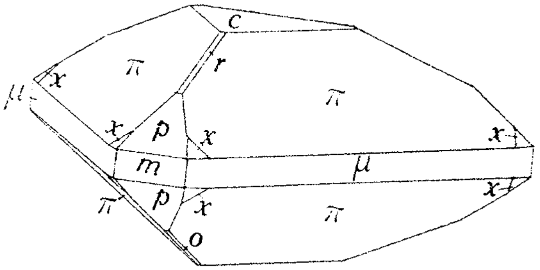
π
p
π
m
μ
π
p
π

3


c
μ
x
π
r
π
x
p
x
x
m
μ
π
p
x
x
π
o

4

EXPLANATION OF PLATE 38.

BENITOITE.

Planes shown: $c(0001)$, $a(11\bar{2}0)$, $m(10\bar{1}0)$, $\mu(01\bar{1}0)$, $p(10\bar{1}1)$, $\pi(01\bar{1}1)$, $d(22\bar{4}1)$.

1. Habit characterized by great development of the negative prism μ and found on a number of crystals.

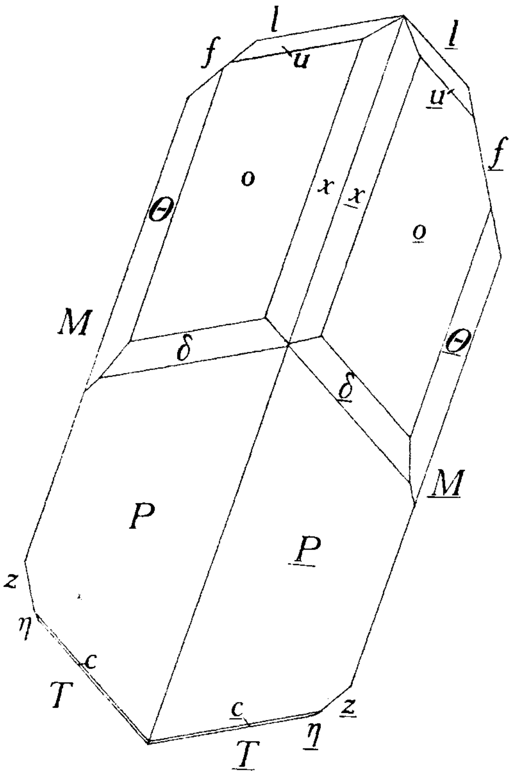
2. Habit characterized by great development of the positive prism m. It is in general not uncommon for m to be broader parallel to the vertical axis than μ.

3. Habit characterized by second order forms d and a found with but slight variation in 10 crystals in a lot of 500 examined. The oscillatory striations between c and p are often found instead of $r(10\bar{1}2)$ and appeared in front upper sectant of crystal from which the drawing was made.

4. Detail of part of a crystal showing a coarse development of the oscillatory growth zone between c and p. Of two crystals on which this coarse development was found, one had the second order hexagonal prism a (as figured) without d, and the other d without a.

ALBITE.

5, 5a. Albite in simple albite twin from druse. $P(001)$, $M(010)$, $l(110)$, $T(1\bar{1}0)$, $\eta(1\bar{2}0)$, $f(130)$, $z(1\bar{3}0)$, $x(\bar{1}01)$, $c(1\bar{1}1)$, $o(\bar{1}\bar{1}1)$, $\delta(\bar{1}\bar{1}2)$, $\Theta(\overline{31}1)$, $u(\overline{22}1)$.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u
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Θ
M
δ
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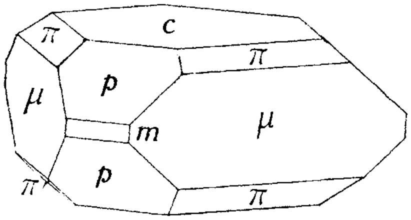
M
P
P
z
η
c
T
c
T
z
η

5a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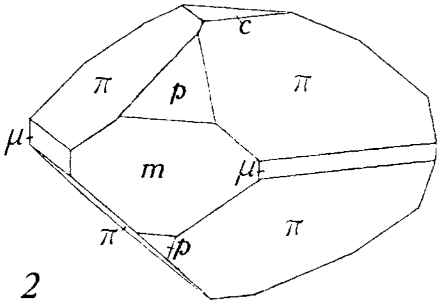
p
π
π

1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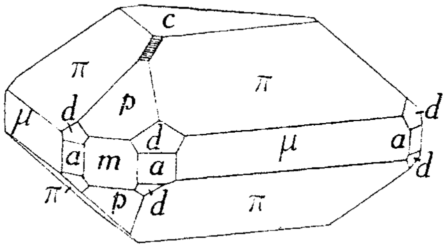
π
p
π

2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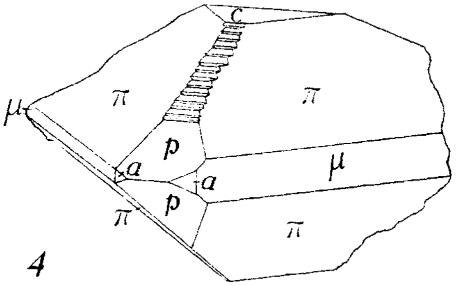
p
d
π

3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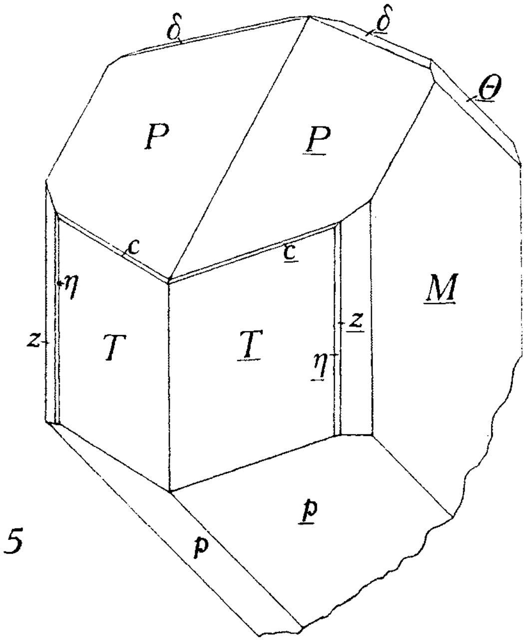
π

4


δ
δ
Θ
P
P
c
c
M
η
z
T
T
z
η
p
p

5

EXPLANATION OF PLATE 39.

NEPTUNITE.

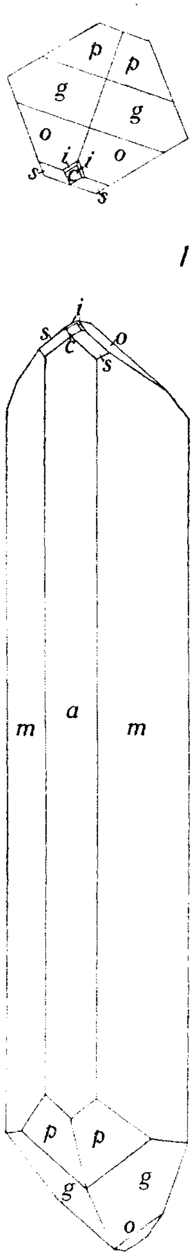
Forms shown: $c(001)$, $a(100)$, $m(110)$, $s(111)$, $o(\bar{1}11)$, $i(\bar{1}12)$, $g \doteq (\bar{2}11)$, $r(\bar{2}21)$, $p(\bar{3}11)$.

1. Common type. The form *g* is frequently slightly curved and is of variable width, and *p* is often the largest of the terminal forms. The back planes almost always cut much lower on the prisms than the front planes.

2. A not very common type with broad development of the unit pyramids, *s* and *o*. It shows a common appearance of *g* with curved edges and narrowing from center toward periphery. It is also very common for the basal plane *c* to have this outline, elongated obliquely to the symmetry plane, as is also shown in figures 3 and 4.

3. From a doubly terminated crystal with peculiar geometrically asymmetric development. It shows the two most common ways in which *r* appears, depending on the development of *g*.

4. Only one crystal of this type of development found. The front pyramid *s* cuts down lower on the prism than the back pyramid *p; i* and *g* are absent, and *r* and *p* occur as narrow strips bordering *o*.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c
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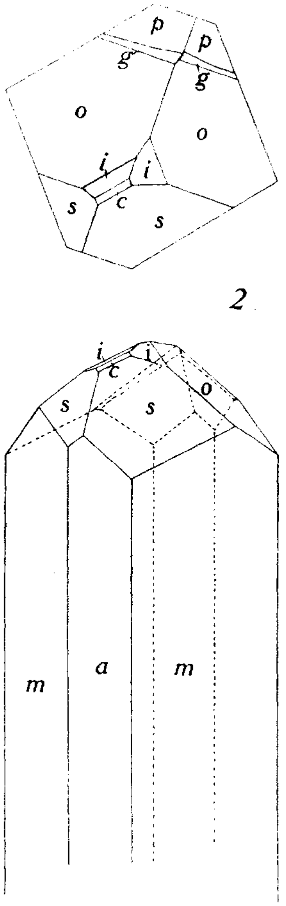
g
g
o

1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c
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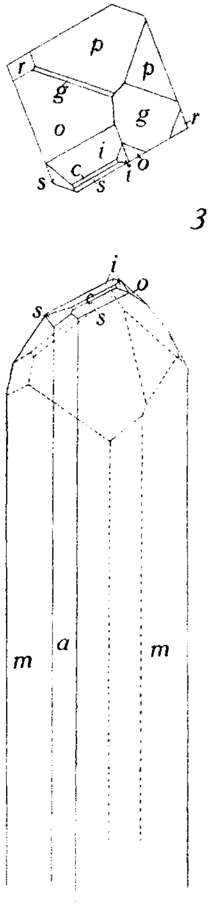
c
i
s
s
o
m
a
m

2


p
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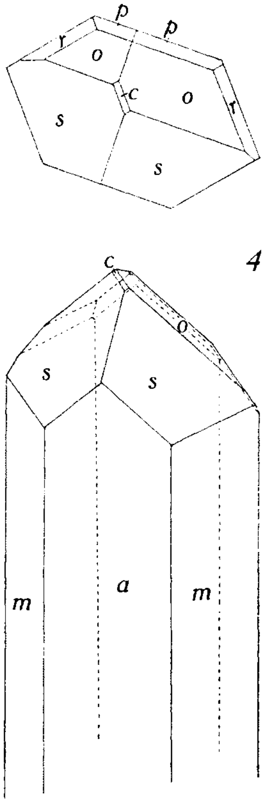
a
m

3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m
a
m

4