

## NEW AND KNOWN MINERALS FROM THE UTAH-COLORADO CARNOTITE REGION.

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By FRANK L. HESS.

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### VANOXITE, A NEW VANADIUM MINERAL.

With few exceptions, the carnotite deposits in the plateau region from Meeker, in northern Colorado, to Carrizo Mountain, on the line between New Mexico and Arizona, are in sandstone of McElmo (Lower Cretaceous or Upper Jurassic) age. Around the carnotite is usually an irregular envelope of dark vanadium-bearing sandstone, ranging from gray to black. The sandstone owes its color to vanadium minerals, but although many have searched for them no crystals of dark vanadium minerals visible to the unaided eye have yet been found. Like the carnotite, the other vanadium minerals so far found in the carnotite-bearing areas are secondary, and in many places they have traveled from a fraction of an inch to 6 feet or even farther through the sandstone from the nuclei where decaying plant remains precipitated both vanadium and uranium minerals in the accumulating sands. In some places the migrating solutions were intercepted by cracks, but even there they did not form easily visible crystals of the dark minerals, though here and there they deposited well-crystallized hewettite, meta-hewettite, volborthite, and calcio-volborthite. However, in a single specimen from the Red Jacket claim of the W. L. Cummings Chemical Co., in Gypsum Valley, San Miguel County, Colo. (latitude  $38^{\circ} 3' N.$ , longitude  $108^{\circ} 42' W.$ ), the walls of narrow cracks are covered with minute acicular crystals about 0.03 millimeter (0.0012 inch) long and one-fifth as thick, making a coating that looks like dark-brown velvet with a very short pile. This mineral I hope to describe at a later date.

In some places small masses of sandstone, in part concretionary, are tarry black; in others almost equally black sandstone forms peculiar thin curved layers 2 or 3 millimeters (one-eighth inch) or less thick, from which the light-colored sandstone cleaves cleanly with little regard for bedding.

The first specimen of the black vanadium-bearing sandstone seen at the United States Geological Survey was brought to the office in 1910 by Mr. R. H. McMillan, who had found it during an examina-

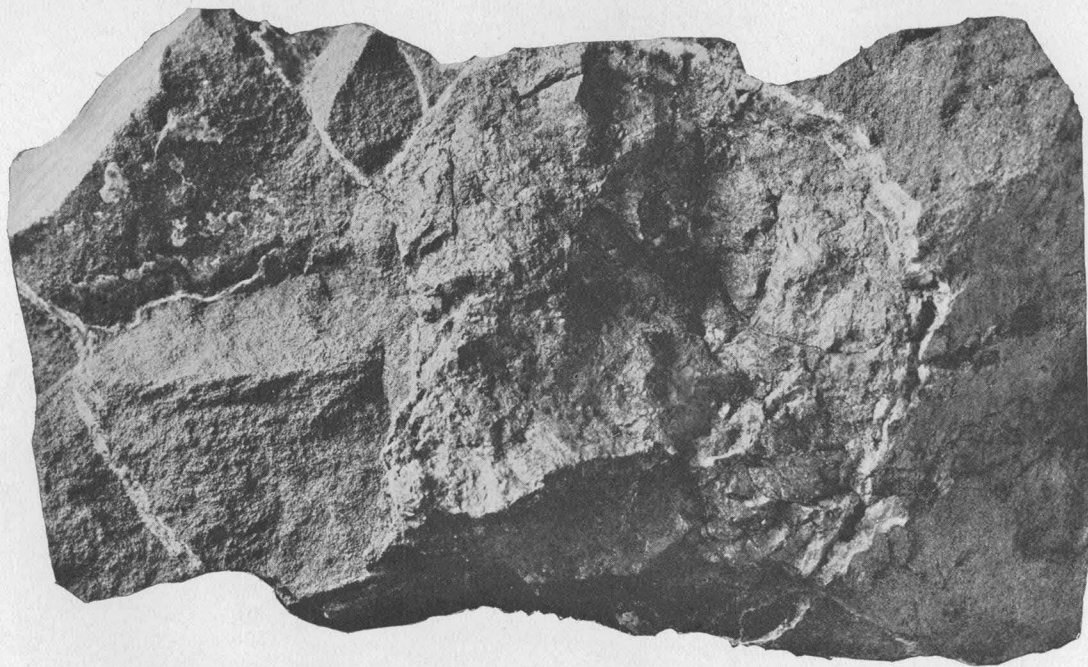
tion of the Jo Dandy claim, on the southwest wall of Paradox Valley, Montrose County, Colo. (sec. 21, T. 46 N., R. 17 W., latitude  $38^{\circ} 14'$  N., longitude  $108^{\circ} 46'$  W.). The material collected by Mr. McMillan was not suitable for analysis, for besides the sand grains, pyrite, carnotite, and gypsum could be recognized, and the specimen gave a radiograph even where no carnotite could be recognized. Mr. McMillan gave to the material the name "kentsmithite," and this name has become current among miners and prospectors of the region for any of the black or very dark vanadium-bearing sandstones.

Other specimens of the black vanadium-bearing sandstone from the Jo Dandy claim were furnished to the United States Geological Survey by Mr. A. O. Egbert, among which were the specimens on which the analyses quoted herein were made. Specimens from other claims were furnished by Messrs. Beattie & Beattie, Mr. O. Barlow Wilmarth, and others. Later still, specimens of dense black mineral almost free from sand, rich in vanadium but also rich in uranium, were furnished by Mr. Warren Bleecker and Mr. Karl Kithil, from Calamity Creek, Mesa County, Colo.; by Mr. H. K. Thurber, from Mr. A. O. Balsley's claims on Dry Wash, 16 miles southeast of Moab, Utah; and by Messrs. John I. Mullen and O. O. Gaw, from Dolores Camp, in sec. 19, T. 48 N., R. 18 W., Montrose County, Colo. In November, 1921, I visited the field, studied the occurrences of the black or dark vanadium minerals where exposures permitted, and collected specimens.

It seemed probable from field examinations that the several dark or black vanadium-bearing sandstones were colored by the same mineral, but microscopic and chemical work has shown that there are at least three minerals, besides the nearly sand-free black uraniferous mineral. In this paper only the black mineral first mentioned, from the Jo Dandy mine, is described.

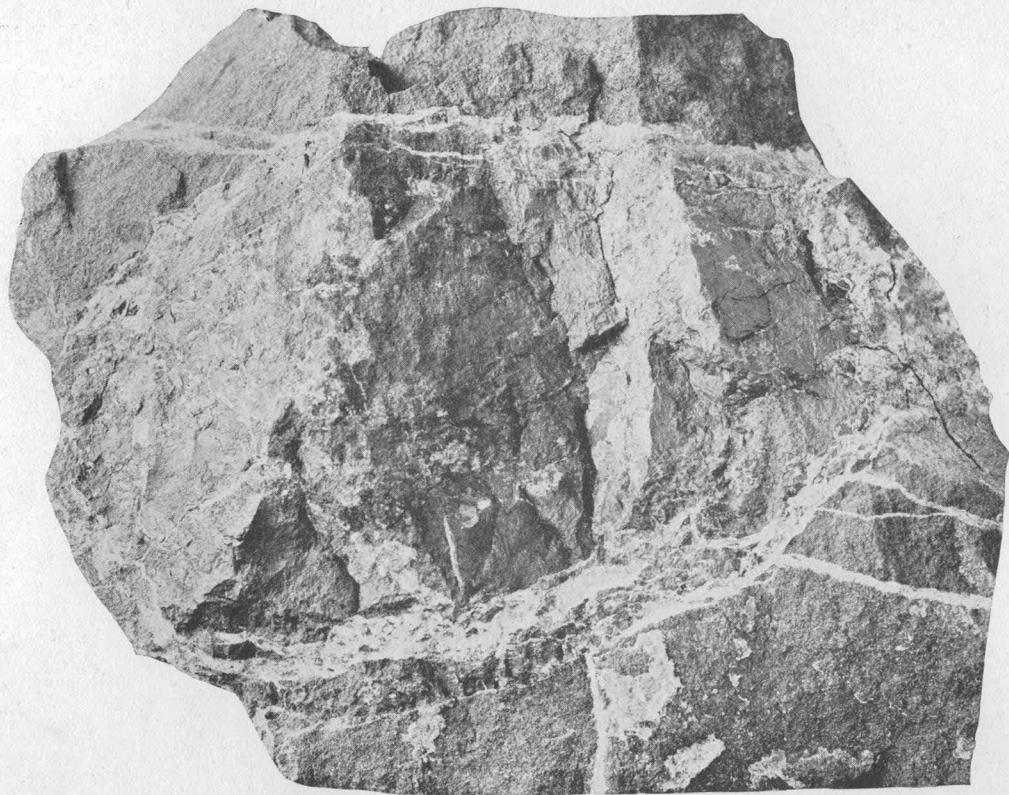
The Jo Dandy mine is high on the southwest side of Paradox Valley, in a sandstone of the McElmo formation, here dipping gently southward, away from the valley. The mine was worked in 1910 and 1911 for vanadium ore, which was shipped to England. Since then it has produced considerable carnotite ore.

When I visited the claim I was so fortunate as to be in the company of Mr. John I. Mullen, field superintendent of the Standard Chemical Co., to which the claim belongs. I was also peculiarly fortunate in the time of visit, because at that time the black vanadium-bearing sandstone was well exposed in the side of a drift in a somewhat eye-shaped section which followed the dip 7 or 8 feet and was between 2 and 3 feet thick. In the center was a dense black round spot 4 inches in diameter from which the mineral had evidently spread into the surrounding sandstone. Veinlets of gypsum cut the sandstone, and the black spot was both cut and outlined by them.



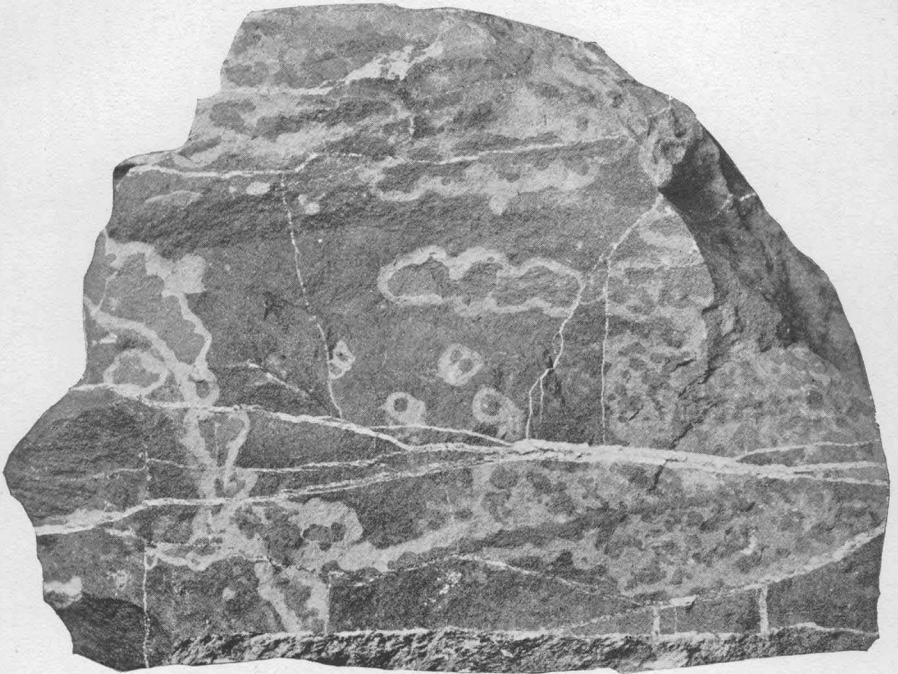
CROSS SECTION OF REPLACED WOOD IN SANDSTONE, JO DANDY MINE, PARADOX VALLEY, COLO.

The wood has been replaced by vanoxite, pyrite, and smaller quantities of other minerals. The white veins are gypsum, and gypsum outlines the replaced wood. The inclosing sandstone is impregnated with vanoxite and smaller quantities of other minerals. Three-fourths natural size.



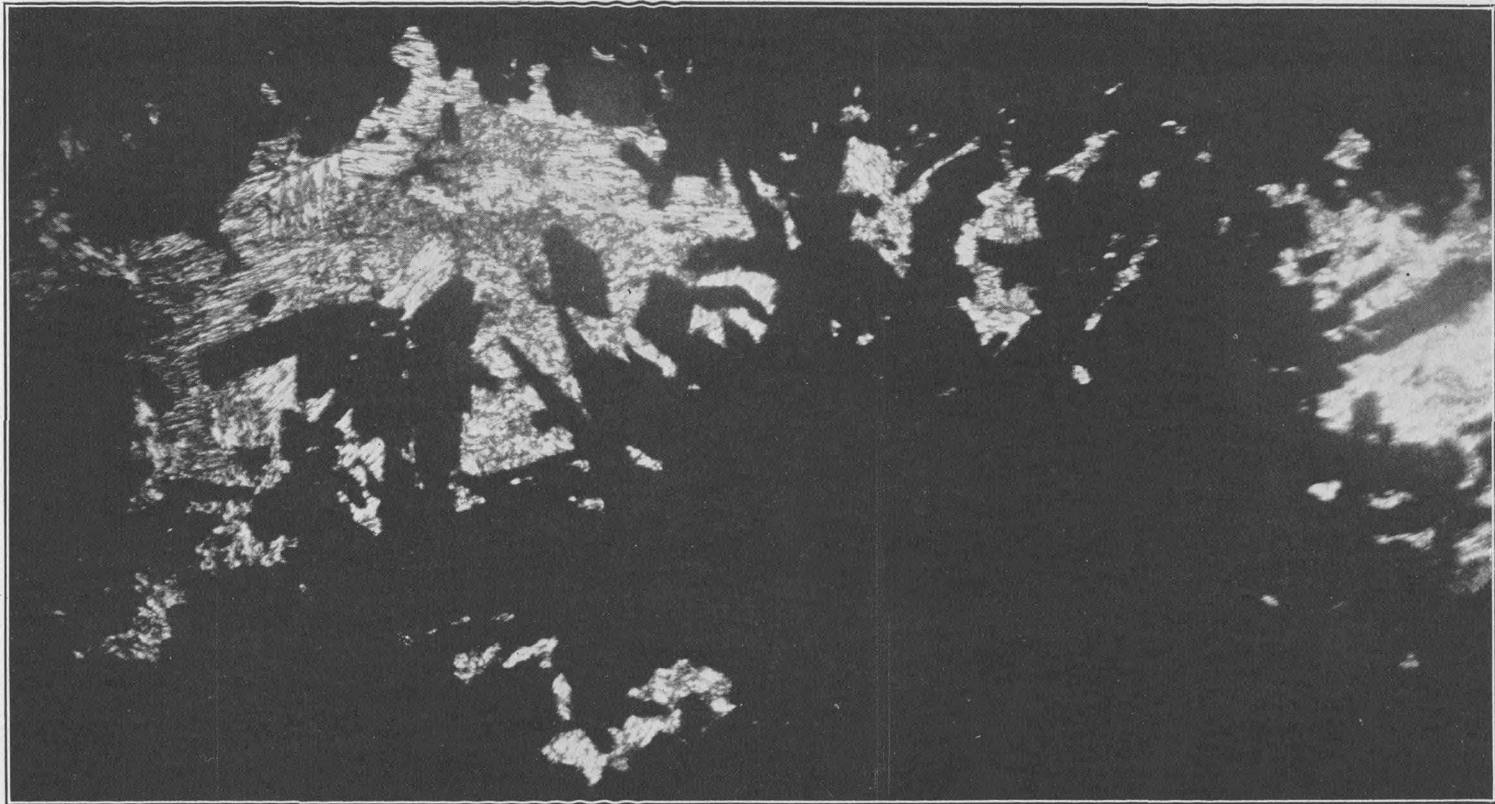
DIAGONAL SECTION OF REPLACED WOOD SHOWN IN PLATE IV.

Three-fourths natural size.



SANDSTONE IMPREGNATED WITH VANOXITE SHOWING PECULIAR BLOTCHING  
DUE TO SEGREGATION OF THE VANOXITE, JO DANDY MINE, PARADOX VALLEY,  
COLO.

One-third natural size.



VANOXITE CRYSTALS EXTENDING INTO A GYPSUM VEINLET, JO DANDY MINE, PARADOX VALLEY, COLO.

Photographed through crossed nicols. Enlarged 125 diameters.

Mr. Mullen had a piece of rock containing the spot worked out for me, and it proved to be a replacement of wood. (See Pls. IV and V.)

In the mine the sandstone surrounding the fossil wood was damp and gave the impression of being entirely black, but after it was dried and placed in the light a peculiar blotching became apparent. Queer irregular black spots of sandstone are bordered by light-colored sandstone 2 to 6 millimeters (one-eighth to one-fourth inch) thick. (See Pl. VI.) The vanadium mineral has segregated into the blotches, and the light-colored sandstone, now almost or quite free from vanadium, is largely cemented by gypsum and faintly stained by iron. Some faces along cracks are coated thinly with the dark vanadium mineral and are blue-black. A somewhat brownish-yellow stain from uranium minerals appears as some of the specimens dry. It resembles uvanite (hydrous uranium vanadate,  $2\text{UO}_3 \cdot 3\text{V}_2\text{O}_5 \cdot 15\text{H}_2\text{O}$ ) in color, but it is probably tyuyamunite, the lime carnotite. A mineral that is probably pintadoite (the green hydrous calcium vanadate,  $2\text{CaO} \cdot \text{V}_2\text{O}_5 \cdot 9\text{H}_2\text{O}$ ) colors the sides of one crack, and a considerable number of rocks on the dump were stained by it. At other places in the mine hewettite (the red hydrous calcium vanadate,  $\text{CaO} \cdot 3\text{V}_2\text{O}_5 \cdot 9\text{H}_2\text{O}$ ) is found, and in places the rock is spotted with dots 12 to 13 millimeters (one-half inch) in diameter of a dark vanadium mineral. Part of the dots have an aureole of carnotite. The mineral in the dots was naturally supposed to be the same as that described in this paper, but microscopic examination shows it to be entirely different. I hope to describe it in another paper. The mass replacing wood is opaque in thin section except where cut by veinlets of gypsum. It polishes easily and appears jet-black with spots of pyrite, but the microscope shows it to be generally impregnated with pyrite. Although no cellular structure could be made out, on heating it gives off odors familiar in distilling coal. It contains no sand, and the uranium, vanadium, and iron minerals are replacements of the wood and not mere fillings of a cavity left by its decay.

• Black crystals, the largest of which is about 0.25 millimeter (0.01 inch) long and about one-eighth as thick, extend into the gypsum veinlets. (See Pl. VII.) The thinnest parts of the crystals show no translucency. These are the largest crystals found. In the interstices of the sandstone similar crystals, which are also embedded in gypsum, reach a maximum length of about 0.04 millimeter (0.0016 inch). The thickness varies a good deal and ranges from possibly one twenty-fifth to one-fifth of the length. A few of the thinnest crystals show a brownish color. Owing to the extreme minuteness of the crystals it has been impossible to determine their optical properties. Some crystals have rhomboid sections. (See Pl. IX, B.)

In some of the sandstone the mineral has filled solidly the interstices between the sand grains, as shown in some places in Plate IX, B, although this is one of the most vuggy parts of the mass.

Analyses of two specimens of the best material sent by Mr. Egbert were made in the chemical laboratory of the United States Geological Survey by W. T. Schaller. One specimen (No. 1), besides the unknown mineral and quartz sand, contained gypsum, tyuyamunite, limonite, pyrite, and possibly other minerals. The other specimen (No. 2) was somewhat purer. The analyses of the two specimens and the calculated mineral contents are as follows:

*Analyses of black sandstone from Jo Dandy mine, Paradox Valley, Colo.*

[W. T. Schaller, analyst.]

No. 1.

Substance.	Per cent.	Tyuyamunite.	Gypsum.	Pyrite.	Remainder.	Recalculated to 100 per cent.	Molecular weight.	Molecular ratios.	
Vanadyl (V <sub>2</sub> O <sub>4</sub> )	11.93				11.93	53.1	166	0.320	2.2
Vanadium pentoxide (V <sub>2</sub> O <sub>5</sub> )	6.25	0.49			5.76	25.7	182	.141	} 1
Uranium trioxide (UO <sub>3</sub> )	1.55	1.55			.11	.5	142	.004	
Phosphorus pentoxide (P <sub>2</sub> O <sub>5</sub> )	.11								
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> )	.94			0.94					
Water (H <sub>2</sub> O)	[7.37]	.39	2.33		4.65	20.7	18	1.150	7.9
Lime (CaO)	3.78	.15	3.63						
Molybdenum trioxide (MoO <sub>3</sub> )	0.11								
Sulphur trioxide (SO <sub>3</sub> )	6.26		5.20	1.05					
Selenium (Se)	Trace.								
Silica (SiO <sub>2</sub> ):									
Insoluble	61.51								
Soluble	.19								
	100.00	2.58	11.16	1.99	22.45	100.0			

No. 2.

Substance.	Per cent.	Tyuyamunite.	Gypsum.	Limonite.	Remainder.	Recalculated to 100 per cent.	Molecular weight.	Molecular ratios.	
Vanadyl (V <sub>2</sub> O <sub>4</sub> )	22.56				22.56	50.9	166	0.307	1.9
Vanadium pentoxide (V <sub>2</sub> O <sub>5</sub> )	13.59	0.49			13.10	29.5	182	.162	} 1
Uranium trioxide (UO <sub>3</sub> )		1.55			.11	.2	142	.001	
Phosphorus pentoxide (P <sub>2</sub> O <sub>5</sub> )	2.58								
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> )				0.94					
Water (H <sub>2</sub> O):									
-110° C	3.13	.39	0.11	b.17					
+110° C	6.15				8.61	19.4	18	1.078	6.7
Lime (CaO)	.40	.15	.17		(.08)				
Sulphur trioxide (SO <sub>3</sub> )	.24		.24						
Selenium (Se)	Trace.								
Silica (SiO <sub>2</sub> )	51.35								
	100.00	2.58	0.52	1.11	44.38	100.00			

<sup>a</sup> The proportions of the three substances are treated as if the same as in analysis No. 1.

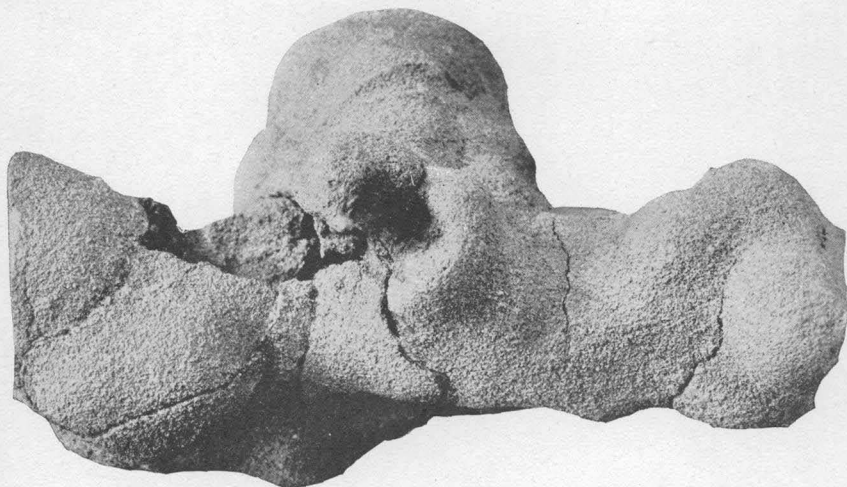
<sup>b</sup> Estimated as 15 per cent of the limonite.

The ratios for No. 1 give approximately the formula 2V<sub>2</sub>O<sub>4</sub>.V<sub>2</sub>O<sub>5</sub>.5H<sub>2</sub>O; for No. 2, 2V<sub>2</sub>O<sub>4</sub>.V<sub>2</sub>O<sub>5</sub>.7H<sub>2</sub>O. If the two sets of ratios are averaged they give 2:1, 1, and 7.5 respectively, or very close to 2V<sub>2</sub>O<sub>4</sub>.





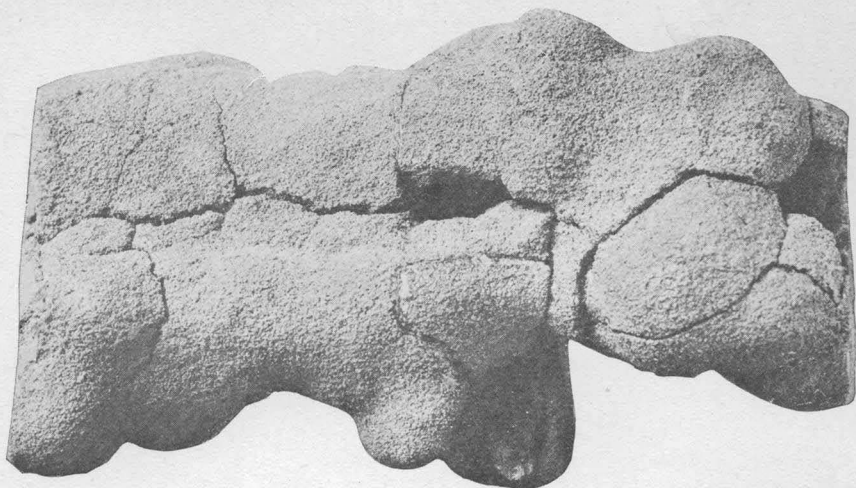
A.



B.

CONCRETION OF VANOXITE IN SANDSTONE, FROM BEATTIE & BEATTIE'S BILL BRYAN CLAIM, IN WILD STEER CANYON, ON THE SOUTH SIDE OF PARADOX VALLEY, COLO.

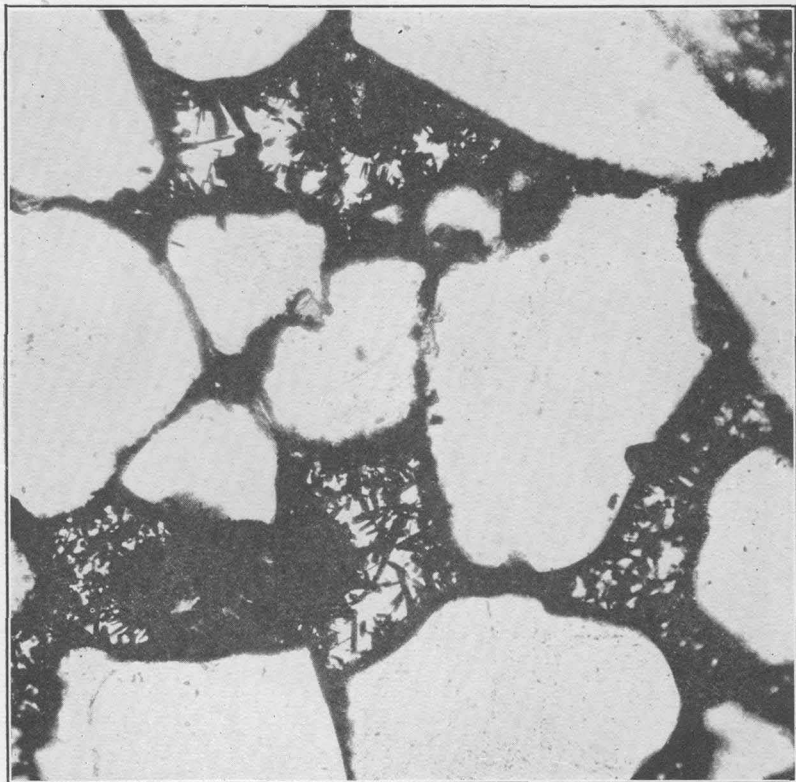
*A* and *B* are taken from opposite sides. The lighter spots in the prominent knob in *A* are carnotite with fossil plant remains. Similar material formed the core of the main part of the concretion. Natural size.



A.

UNDER SIDE OF THE CONCRETION OF VANOXITE SHOWN IN PLATE VIII.

The cracks shown in all three views (Pls. VIII and IX, A) are from the dehydration of the vanoxite.



B.

CRYSTALS OF VANOXITE IN INTERSTICES OF SANDSTONE, JO DANDY MINE,  
PARADOX VALLEY, COLO.

Enlarged 190 diameters.

$V_2O_5 \cdot 8H_2O$ . It is probable, as will come out in the discussion of this and other minerals, that the water content may be higher than is indicated by the formula.

I propose for this mineral the name vanoxite (van-ox'ite).

Vanoxite-bearing sandstone is also found in the Henry Clay claim of the Radium Co. of Colorado, at Long Park, on the northeast side of Paradox Valley, 5 miles north of the Jo Dandy claim. At this place some masses of sandstone are heavily impregnated with the mineral, so that thin sections show no trace of crystals, but only sand grains wholly embedded in the vanoxite, with a little pyrite. Where the mined rock was under cover so that the salt did not wash off during rains, the beautiful pascoite (an orange-colored soluble hydrous calcium vanadate,  $2CaO \cdot 3V_2O_5 \cdot 11H_2O$ ) was found on the surfaces.

Beattie & Beattie, of Naturita, Colo., sent to the United States Geological Survey a fine concretion of sandstone cemented by vanoxite from the Bill Bryan claim, in Wild Steer Canyon. (See Pls. VIII and IX, A.) A comparison of the views of this concretion with the forms shown in section in Plate VI indicates that they are very similar. In the Beattie & Beattie specimen two linear nuclei, along which the vanoxite formed, are crossed. The ends of the shorter nucleus are shown in Plate VIII. Here, as everywhere else in the carnotite deposits of the plateau region, there is fossil plant material, which is accompanied by some carnotite. When received at the Geological Survey this specimen was without crack. The shrinkage due to dehydration during the eight years that the specimen has been in the Survey is well shown in the views. Part of the specimen fell off and had to be glued back in place.

Other specimens, according to their richness and the degree to which vanoxite forms the cement for the sand grains, act similarly. When dried specimens are wetted they usually fall apart, apparently because the partly dehydrated vanoxite again takes up water and sets up new strains sufficient to break the rocks. The fine specimen shown in Plates VIII and IX, A, was almost destroyed by the wetting necessary to permit sawing off an end. Tiny shrinkage cracks may be seen between the sand grains in some thin sections. Such a specimen received from Mr. George Kunkle, from his claims 6 miles west of Gateway, Colo., is shown in Plate X, C.

The easy dehydration of the mineral, in which it resembles most of the other uranium and vanadium minerals of the region, makes it seem probable that the analyses must show very much less than the maximum quantity of water held. That the specimens were considerably dehydrated before analysis was begun was shown by shrinkage cracks, and grinding must have driven off more water, so the formula should probably be written  $2V_2O_4 \cdot V_2O_5 \cdot (8+)H_2O$ .

## RAUVITE, A NEW URANIUM-VANADIUM MINERAL.

When I first visited Temple Mountain, on the San Rafael Swell, in Emery County, 45 miles southwest of the town of Greenriver, Utah, in 1914, only a few short prospect tunnels had been driven into the uranium and vanadium bearing bed, which is here the Shinarump conglomerate<sup>1</sup> (Upper? Triassic). One of the tunnels on the west face of the mountain, looking out over the Swell, was in a sandy facies of the conglomerate, in which the sand is composed largely of asphaltite grains. Decomposition of the asphaltite had loosened the bonds and had made the sandstone very friable. The asphaltite had also given up more or less of its uranium and vanadium content. One of the products, a brown-yellow powdery mineral in small lumps 7 millimeters (a quarter of an inch) or less in diameter, was the new mineral uvanite ( $2\text{UO}_3 \cdot 3\text{V}_2\text{O}_5 \cdot 15\text{H}_2\text{O}$ )<sup>2</sup>. Other products were carnotite, hewettite, gypsum, hyalite, and meta-torbernite, the last two in very small quantity. Along a bedding plane near the top of the opening was also a purplish mineral, filling pores between the sand grains. In the richest specimens the mineral had formed comparatively pure masses, which were at most 12 to 13 millimeters (half an inch) thick and 6 to 8 centimeters (2 to 3 inches) broad. The masses had been made by accretion and in pushing the sand grains apart had minutely slickened parts of the mineral and had given it a varnished appearance. (See Pl. X, A, B.) Uvanite, carnotite, and hewettite form in the loose sand in much the same way. Under a lens some surfaces of the purplish mineral appear botryoidal and polished, but broken faces somewhat resemble gels like dried printer's-roller mixture or the "tallow clay" of the Joplin zinc region. The general purplish color is so nearly that of some hydrous iron oxide that it is difficult to distinguish between them, but the streak of the uranium mineral is lighter brown with a hint of yellow, as compared with the reddish brown of the iron oxide. Some of the broken faces have a distinctly bluish tint.

Under the microscope the mineral appears rather uncertainly crystalline. The index of refraction as determined by C. S. Ross is about 1.88, certainly between 1.87 and 1.90. It is just above that of the highest oils available at the time and can not be determined in melting media because it so easily loses water.

I was able to collect only a few ounces of fairly good material, and it is so inconspicuous that no one has since recognized it, in spite of extensive working of the deposits, though rarity rather than incon-

<sup>1</sup> For a description of these deposits see Hess, F. L., Uranium-bearing asphaltite sediments of Utah: Eng. and Min. Jour.-Press, vol. 114, pp. 272-276, 1922.

<sup>2</sup> Hess, F. L., and Schaller, W. T., Pintadoite and uvanite, two new vanadium minerals from Utah: Washington Acad. Sci. Jour., vol. 4, pp. 576-579, 1914.

spicuousness may have been the reason, for in the fall of 1921 I could find none except in very thin filmy coatings.

The material was analyzed by W. T. Schaller with the following result:

*Analysis of purplish mineral from Temple Mountain, Emery County, Utah.*

[W. T. Schaller, analyst.]

Uranium trioxide (UO <sub>3</sub> )	20.82
Vanadyl (V <sub>2</sub> O <sub>4</sub> )	2.05
Vanadium pentoxide (V <sub>2</sub> O <sub>5</sub> )	36.33
Lime (CaO)	2.00
Potash (K <sub>2</sub> O)	Trace.
Arsenic pentoxide (As <sub>2</sub> O <sub>5</sub> )	Trace.
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> )	2.39
Water (H <sub>2</sub> O)	13.38
Selenium (Se)	Trace.
Magnesia (MgO)	.12
Sulphur trioxide (SO <sub>3</sub> )	.13
Insoluble, mostly silica	24.06
	101.28

The iron (Fe<sub>2</sub>O<sub>3</sub>, 2.39) is probably present as limonite and as such would contain about 15 per cent of its combined weight in water (0.42), and these quantities may therefore be deducted as foreign matter. The magnesia, sulphur trioxide, and "insoluble" (quartz sand) are also regarded as impurities. Deducting these items and recalculating to a basis of approximately 100 per cent gives the following results:

*Recalculation of analysis of purplish mineral from Temple Mountain, Emery County, Utah.*

	Recalculated percentage.	Molecular weight.	Molecular ratios.	
Uranium trioxide (UO <sub>3</sub> )	28.1	286	0.095	2
Vanadyl (V <sub>2</sub> O <sub>4</sub> )	2.8	166	.017	} 6
Vanadium pentoxide (V <sub>2</sub> O <sub>5</sub> )	49.0	182	.270	
Lime (CaO)	2.7	56	.048	1
Water (H <sub>2</sub> O)	17.5	18	.972	20.2
	100.1			

This gives the formula CaO.2UO<sub>3</sub>.6V<sub>2</sub>O<sub>5</sub>.20H<sub>2</sub>O.

In this recalculation it is uncertain just what should be done with the V<sub>2</sub>O<sub>4</sub>. Conceivably it may act as a base with the UO<sub>3</sub>, but it seems more likely to be a reduced portion of the V<sub>2</sub>O<sub>5</sub>. The mineral was formed under oxidizing conditions that seem to indicate that V<sub>2</sub>O<sub>5</sub> would be the more natural state of the vanadium.

The mineral cracks badly on standing (see Pl. X, B), evidently owing to dehydration, so that the water should probably be even

higher than indicated by the formula given, on account of losses due to standing long in a dry atmosphere and to grinding.

I propose for this mineral the name *rauvite* (*raw'vite*), from the chemical symbols Ra, U, and V.

I also found the mineral on Flat Top, 2 miles southwest of Temple Mountain, but there its light streak is olive-colored and its heavy streak is almost black, with an olive tint.

#### META-TORBERNITE FROM TEMPLE MOUNTAIN, UTAH.

Among the minerals that I collected at Temple Mountain during my first visit was one that had a bright-green color and that here and there formed a thin coating on the faces of cracks in the bleached sandstone in the "flopover," a huge block that had broken loose from the south side of Temple Mountain and toppled over. Under a good hand lens tiny square-cornered plates could be distinguished in the mineral. On my later visit I found similar material at several other points.

The material from the "flopover" was analyzed by W. T. Schaller with the following result:

*Analysis of meta-torbernite from Temple Mountain, Emery County, Utah.*

[W. T. Schaller, analyst.]

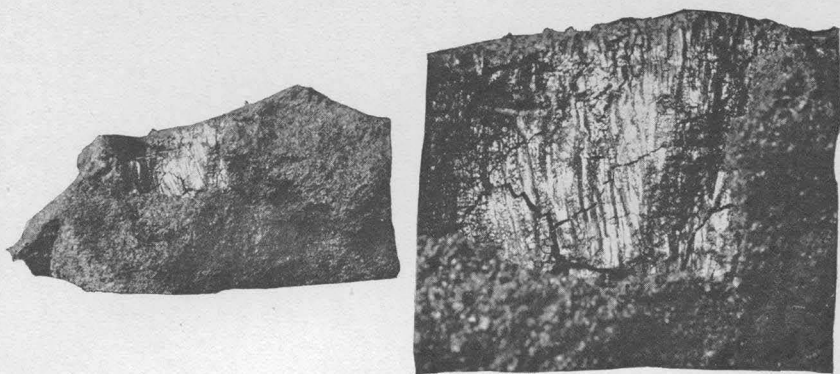
Substance.	Per cent.	Recalculated.	Molecular weight.	Molecular ratios.	
Uranium trioxide (UO <sub>3</sub> ).....	35.86	55.8	286	0.195	1.64
Cupric oxide (CuO).....	5.96	9.3	79.6	.117	
Lime (CaO).....	.05	.1	56	.002	1
Phosphoric pentoxide (P <sub>2</sub> O <sub>5</sub> ).....	<sup>a</sup> 11.16	17.4	142	.123	
Arsenic pentoxide (As <sub>2</sub> O <sub>5</sub> ).....	.13	.2	230	.001	1
Water (H <sub>2</sub> O).....	11.08	17.2	18	.956	
Selenium (Se).....	Trace.				8.03
Insoluble (SiO <sub>2</sub> ?).....	35.76				
	100	100			

<sup>a</sup> Determined by difference.

This gives only approximately the formula  $\text{CuO} \cdot 2\text{UO}_3 \cdot \text{P}_2\text{O}_5 \cdot 8\text{H}_2\text{O}$ , in which a little CaO is probably isomorphous with the CuO. The UO<sub>3</sub> is low, but this may be due to an error in analysis, and the determination of the P<sub>2</sub>O<sub>5</sub> by difference is of course unreliable. The analysis is of value mostly as determining the mineral. The quantity of water present corresponds with that contained in meta-torbernite. (See p. 75.)

#### ZIPPEITE FROM FRUITA, UTAH.

About 2 miles southeast of the little group of houses known as Fruta, in Wayne County, Utah, a fine eastward-draining canyon, the Grand Wash, has been cut down through the heavy creamy and pink Jurassic sandstone, the thinly bedded Chinle (Upper Triassic)

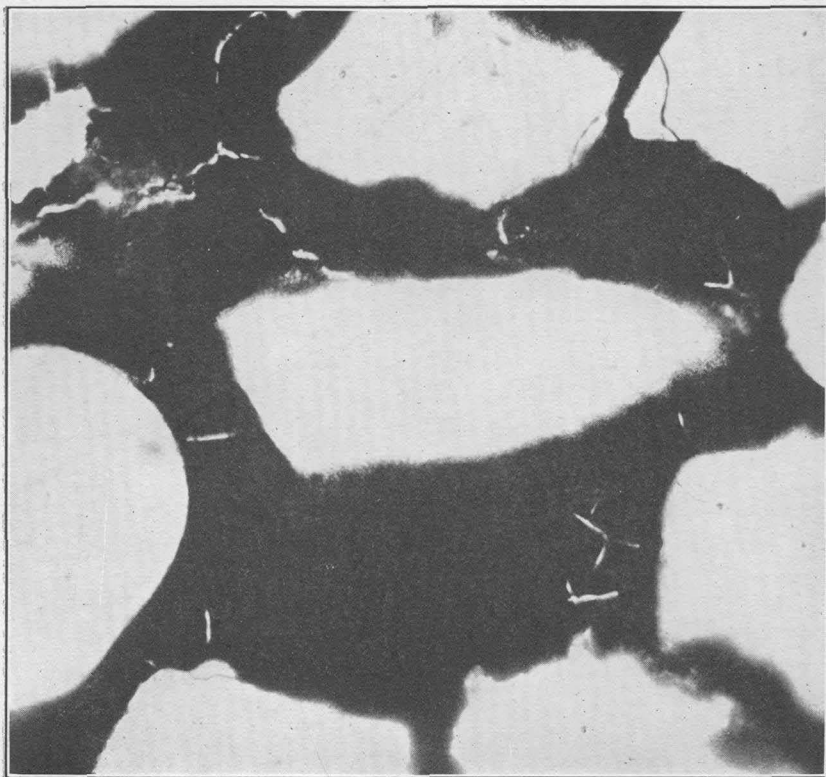


A.

B.

SEGREGATION OF RAUVITE IN SAND IN THE SHINARUMP CONGLOMERATE,  
TEMPLE MOUNTAIN, UTAH.

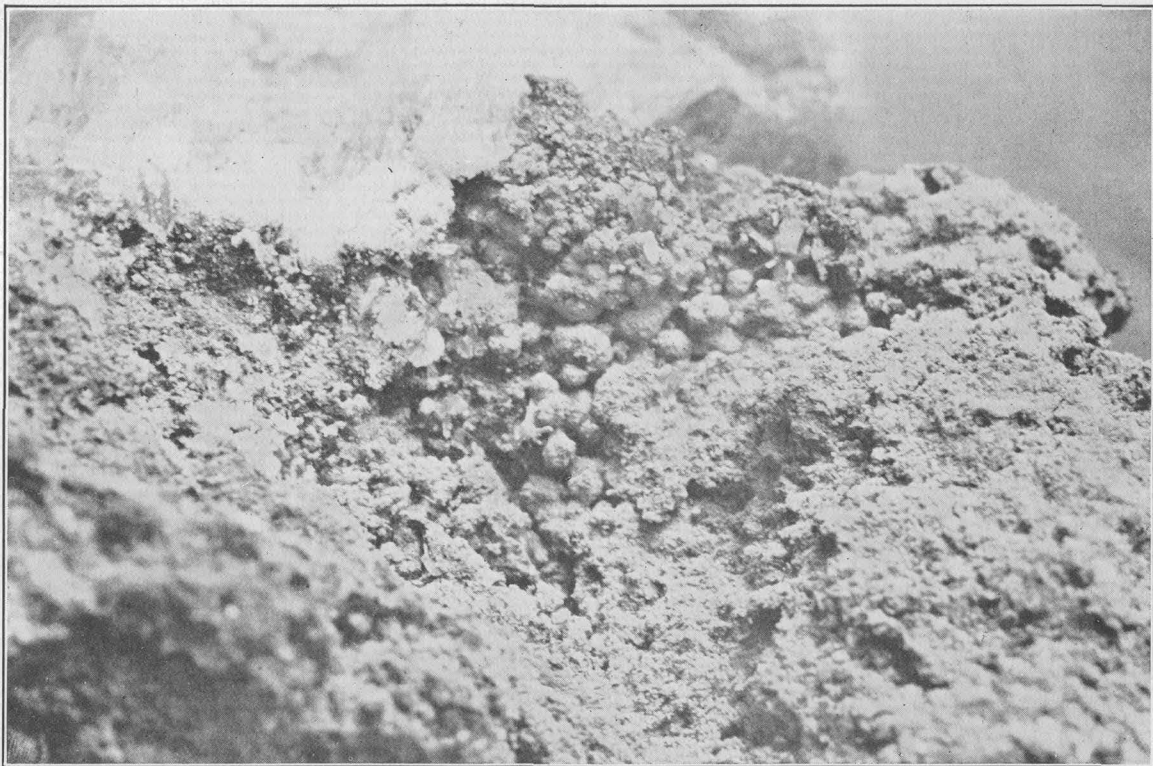
A, Natural size. B, Slickened part of the specimen shown in A, enlarged 4 diameters. Note the shrinkage cracks due to dehydration.



C.

SHRINKAGE CRACKS DUE TO DEHYDRATION OF VANOXITE BETWEEN  
SAND GRAINS IN A SECTION FROM THE KUNKLE CLAIMS, 6 MILES WEST  
OF GATEWAY, COLO.

Enlarged 250 diameters.



AGGREGATES OF ZIPPEITE WITH ACICULAR CRYSTALS OF GYPSUM, FROM GRAND WASH, 2 MILES SOUTHEAST OF FRUITA, WAYNE COUNTY, UTAH.

The specimen has been coated with ammonium chloride and small lumps have collected on the gypsum crystals. Enlarged 10 diameters.



red beds, and the Shinarump conglomerate, which is exposed near the bottom of the north side of the canyon.

Here, as at Temple Mountain, a patch of the Shinarump conglomerate carries some asphaltite, which was laid down as a sediment as a part of the "conglomerate." With the asphaltite is a bright-yellow uranium mineral, zippeite, accompanied by green copper minerals, the contrast in color making the uranium mineral more prominent.

The zippeite is a powder, but under the microscope it is seen to occur in tiny crystalline aggregates 0.13 millimeter (about one two-hundredth of an inch) in diameter. (See Pl. XI.) These aggregates are easily broken up into very much smaller particles. E. S. Larsen examined a specimen that B. S. Butler and I had collected in 1914 and gives the following data on it<sup>3</sup>:

Apricot-yellow powder. Very minute laths  $\perp X$ , with the angle of  $Z$  to elongation  $41^\circ$ ; on edge they give sensibly parallel extinction. Hence probably monoclinic, with  $\{010\}$  as the most prominent face and elongated along  $c$  and with  $X=b$ ,  $Z \wedge c=41$ . Optically—,  $2V$  large, dispersion not strong.  $\alpha=1.630 \pm 0.003$ ; nearly colorless.  $\beta=1.689 \pm 0.003$ ; pale yellow-orange.  $\gamma=1.739 \pm 0.003$ ; yellow-orange.

The reason Larsen found the mineral lath-shaped was probably that the mineral was very finely crushed. In specimens I examined it is only the very tiny fragments, apparently those obtained by breaking the aggregates very small, that show the lath shapes. Others are broader.

Fragments 0.07 millimeter (one three-hundredth of an inch) long may have one-half or less of the length made up of a copper mineral, and a tiny orbicular aggregate had for a nucleus a ball formed from a green copper mineral. This mineral seems to be crystallographically continuous with the zippeite.

A copper mineral separated from the uranium mineral contained phosphorus and much less arsenic. Immersed in oil having an index of 1.739 most of the grains show a lower index and part an index about that of the oil, so that the mineral is probably libethenite ( $4\text{CuO} \cdot \text{P}_2\text{O}_5 \cdot \text{H}_2\text{O}$ ) containing some molecules of olivenite ( $4\text{CuO} \cdot \text{As}_2\text{O}_5 \cdot \text{H}_2\text{O}$ ).

An analysis of the yellow mineral made by W. T. Schaller is given below, with Lindacker's analyses of zippeite from Joachimsthal, Bohemia (now called Jachymov, Czechoslovakia), the only other analyses of zippeite known.

<sup>3</sup> Larsen, E. S., The microscopic determination of the nonopaque minerals: U. S. Geol. Survey Bull. 679, p. 160, 1921.

*Analyses of zippeite from Jachymov, Czechoslovakia, and Fruita, Utah.*

Substance.	1	2	3
Uranium trioxide (UO <sub>3</sub> ).....	a 67.86	a 62.04	72.50
Sulphur trioxide (SO <sub>3</sub> ).....	13.06	17.36	11.11
Water (H <sub>2</sub> O).....	17.69	15.23	8.77
Lime (CaO).....	.61		.97
Phosphorus pentoxide (P <sub>2</sub> O <sub>5</sub> ).....			
Arsenic pentoxide (As <sub>2</sub> O <sub>5</sub> ).....			
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> ).....	.17		
Cupric oxide (CuO).....		5.21	.96
Insoluble (SiO <sub>2</sub> ).....			1.96
	99.39	99.84	100.00

<sup>a</sup> UO and U<sub>2</sub>O<sub>3</sub>.

<sup>b</sup> By difference.

1, 2. Analyses of zippeite from Jachymov, Czechoslovakia, by Lindacker, quoted by Dana, J. D., System of mineralogy, 6th ed., p. 978, 1909.

3. Zippeite from Grand Wash, Fruita, Utah. Analyzed by W. T. Schaller.

In analysis 1 the ferric oxide may be thrown out and the "lime" is probably to be considered gypsum (CaSO<sub>4</sub> + 2H<sub>2</sub>O), as it surely is in analysis 3. In No. 1 the water required for gypsum would be 0.4 and the sulphur trioxide 0.9. In No. 3 they would be H<sub>2</sub>O, 0.6; SO<sub>3</sub>, 1.49.

In No. 2 the CuO was apparently present as chalcantite (CuSO<sub>4</sub> · 5H<sub>2</sub>O), as SO<sub>3</sub> is the only acid radicle shown by the analysis. In No. 3 it is present as libethenite and olivenite. In No. 2 there must be deducted with the copper, SO<sub>3</sub>, 5.2, and H<sub>2</sub>O, 5.9; and in No. 3, H<sub>2</sub>O, 0.06, and P<sub>2</sub>O<sub>5</sub> + As<sub>2</sub>O<sub>5</sub>, 0.55.

Making these deductions and recalculating to 100 per cent gives the analyses as shown in the following table. It seems fair to suppose that the uranium is the only element present that all assuredly belongs to the mineral, and it is therefore used as a basis for calculation.

*Analyses of zippeite after deducting impurities and recalculating to 100 per cent.*

Substance.	Recalculated.	Molecular weight.	Molecular ratios.		Formula.
1. Uranium trioxide (UO <sub>3</sub> ).....	60.7	286	0.244	2	} 2UO <sub>3</sub> ·SO <sub>3</sub> ·8H <sub>2</sub> O.
Sulphur trioxide (SO <sub>3</sub> ).....	12.5	80	.156	1.3	
Water (H <sub>2</sub> O).....	17.8	18	.989	8.1	
	100.0				
2. Uranium trioxide (UO <sub>3</sub> ).....	74.3	286	.260	2	} 2UO <sub>3</sub> ·SO <sub>3</sub> ·5H <sub>2</sub> O.
Sulphur trioxide (SO <sub>3</sub> ).....	14.6	80	.183	1.4	
Water (H <sub>2</sub> O).....	11.1	18	.617	4.7	
	100.0				
3. Uranium trioxide (UO <sub>3</sub> ).....	80.3	286	.281	2	} 2UO <sub>3</sub> ·SO <sub>3</sub> ·3H <sub>2</sub> O.
Sulphur trioxide (SO <sub>3</sub> ).....	10.7	80	.134	0.9	
Water (H <sub>2</sub> O).....	9.0	18	.500	3.3	
	100.0				

The three analyses are in fair agreement except as to water, but analysis 3 is probably the best. It is probable, however, that the water content of zippeite is variable, depending, as in the uranite

group, on the temperature and dryness of the atmosphere to which the mineral has been exposed. The formula obtained from Lindacker's first analysis may therefore be most nearly correct—that is,  $2\text{UO}_3 \cdot \text{SO}_3 \cdot 8\text{H}_2\text{O}$ .

#### TYUYAMUNITE FROM THE HENRY MOUNTAINS, UTAH.

It had been pretty well established that the powdery yellow uranium mineral mined from the sandstones of McElmo (Lower Cretaceous?) age of the plateau region was the potash-bearing carnotite ( $\text{K}_2\text{O} \cdot 2\text{UO}_3 \cdot \text{V}_2\text{O}_5 \cdot x\text{H}_2\text{O}$ ), but while studying the carnotite deposits in Utah I found many places where thin cracks or cavities were filled with a waxy yellow mineral in tiny plates, either in radial aggregates or normal to the walls. From the fact that the mineral was crystalline I thought that it was probably the calcium carnotite, tyuyamunite ( $\text{CaO} \cdot 2\text{UO}_3 \cdot \text{V}_2\text{O}_5 \cdot x\text{H}_2\text{O}$ ), and I collected specimens for analysis. Only one analysis has been made, the results of which are given on page 74.

Before tyuyamunite from Russian Turkestan had been described by Nenadkevich, a crystalline yellow uranium mineral from Richardson, on the northwest side of the La Sal Mountains, Utah, had been analyzed by W. F. Hillebrand and shown to be the calcium-bearing carnotite, but before Doctor Hillebrand was ready to publish his results Nenadkevich's paper appeared.

The particular specimen that forms the subject of this note came from the Starlight claims of H. A. Hatch, on the northeast side of Mount Hillers, in the Henry Mountains, Garfield County, in southeastern Utah. The mineral occurs in minutely crystalline aggregates in a rusty fine-grained, rather soft sandstone and is closely connected with fossil wood and fragmentary fossil vegetation of other kinds. There is, as usual around the carnotite deposit, an envelope of sandstone carrying nonuraniferous vanadium minerals.

C. S. Ross obtained the following optical data on the material:

$2V = 48^\circ$ ;  $2E = 101^\circ$ ;  $\rho < \nu$  (moderate). Pleochroic, pale yellow to deep yellow. Orthorhombic, very thin flat plates. Y parallel to long edge of plates.  $\alpha = 1.72 \pm 0.01$ .  $\beta$  and  $\gamma$  could not be determined in liquids, and in melts of sulphur and selenium the mineral lost water, so that the determinations are of uncertain accuracy. As determined they are,  $\beta = 1.868 \pm 0.005$ ;  $\gamma = 1.953 \pm 0.005$ .

On type material from Tyuya Muyun Hill, Russian Turkestan, Larsen<sup>4</sup> gives the following data:

Optically —, X normal to the plates,  $2V$  moderate, birefringence very strong,  $\beta = 1.87 \pm 0.01$ .

<sup>4</sup>Larsen, E. S., The microscopic determination of the nonopaque minerals: U. S. Geol. Survey Bull. 679, p. 148, 1921.

## On material from Browns Park, Uintah County, Utah:

Y parallel to the long edge of the rhombs;  $2V = 36^\circ \pm 2^\circ$ ;  $2E = 70^\circ \pm 3^\circ$ ;  $\alpha = 1.670 \pm 0.01$ , nearly colorless;  $\beta = 1.870 \pm 0.005$ , canary-yellow;  $\gamma = 1.895 \pm 0.005$ , canary-yellow, slightly deeper than Y.

*Analysis of tyuyamunite from Henry Mountains, Utah.*

[W. T. Schaller, analyst.]

Substance.	Per cent.	Recalculated. <sup>a</sup>	Molecular weight.	Molecular ratios.	
Uranium trioxide (UO <sub>3</sub> ).....	52.22	57.7	286	0.202	2
Vanadium pentoxide (V <sub>2</sub> O <sub>5</sub> ).....	17.62	19.5	182	.107	1.06
Potash (K <sub>2</sub> O).....	.47	0.5	94	.005	1.09
Lime (CaO).....	5.36	5.9	56	.105	} 8.96
Water (H <sub>2</sub> O).....	14.79	16.3	18	.905	
Barium oxide (BaO).....	.26				
Ferric oxide (Fe <sub>2</sub> O <sub>3</sub> ).....	1.10				
Insoluble (SiO <sub>2</sub> ).....	8.51				
	100.33	99.9			

<sup>a</sup> After eliminating barium and iron [in the form of limonite containing 15 per cent of water (0.2)].

The ratios approximate closely the formula  $\text{CaO} \cdot 2\text{UO}_3 \cdot \text{V}_2\text{O}_5 \cdot 9\text{H}_2\text{O}$ , in which there is about 4.5 per cent of carnotite. Although the mineral taken for analysis appeared very pure, the presence of 8.51 per cent of insoluble matter and 1.10 per cent of  $\text{Fe}_2\text{O}_3$  shows that some gangue was admixed, and it is probable that the barium and a little of the vanadium and water came from the gangue. No carnotite in which barium is the base in place of potassium or calcium has yet been found, though there is no apparent reason why such a mineral might not be formed, and in the carnotite of which analyses are quoted on page 76, barium may be a constituent part of the mineral. It seems probable that a pure or nearly pure barium carnotite will sometime be discovered.

The original analysis of tyuyamunite, published by Nenadkevich,<sup>5</sup> was made on well-crystallized material from Tyuya Muyun Hill, in the Alai Mountains, Ferghana, Russian Turkestan, and was as follows:

*Analysis of tyuyamunite from Tyuya Muyun Hill, Ferghana, Russian Turkestan.*

[K. A. Nenadkevich, analyst.]

Substance.	Per cent.	Recalculated.	Molecular weight.	Molecular ratios.	
Uranium trioxide (UO <sub>3</sub> ).....	63.09	65.0	286	0.227	2.00
Vanadium pentoxide (V <sub>2</sub> O <sub>5</sub> ).....	21.90	21.6	182	.119	1.05
Lime (CaO) and strontia (SrO).....	5.99	6.2	56	.111	.98
Water (H <sub>2</sub> O).....	7.04	7.2	18	.400	3.52
Thallium (Tl).....	Trace.	Trace.			
	97.12	100.0			

<sup>5</sup> Nenadkevich, K. A., Tyuyamunite, a new species of mineral: Acad. imp. sci. St.-Petersbourg Bull. 6th ser., pp. 945-946, Nov. 1, 1912 (in Russian).

This gives, as will be observed, hardly 4 molecules of water, and the formula is approximately  $\text{CaO} \cdot 2\text{UO}_3 \cdot \text{V}_2\text{O}_5 \cdot 4\text{H}_2\text{O}$ .

In spite of the low water content Nenadkevich considers the mineral to be a member of the uranite group, and the remainder of the formula is a homologue of the general uranite formula.

The minerals of the uranite group have usually been considered to carry normally 8 molecules of water,<sup>6</sup> but Rinne,<sup>7</sup> Hallimond,<sup>8</sup> and others have found the water content of torbernite to be highly variable. Hallimond considers that torbernite normally carries 12 molecules of water, but he found that it was stable between very narrow limits and that on desiccation over concentrated sulphuric acid the water may be reduced to 8 molecules and at that point meta-torbernite I (see below) is formed. Meta-torbernite I is also found in nature.

Rinne observed that on mere heating at 60° to 75° C. (140° to 167° F.) torbernite lost 6.86 per cent of water, forming meta-torbernite and at 100° C. (212° F.) the mineral lost more than 11 per cent of water; both stages are accompanied by crystallographic changes. Hallimond called the two forms meta-torbernite I and meta-torbernite II. Rinne's results seem to indicate between 7 and 8 molecules of water in meta-torbernite I and about 5 molecules of water in meta-torbernite II, and he thought the two stages to be rather stable, but Hallimond's experiments seem to show progressive changes with rising temperature or lowering vapor pressure. Both think that there is no recovery of water.

The water content of tyuyamunite and carnotite is probably similarly affected, and the content when the mineral is first formed is probably very different from that of the mineral that has been long exposed to the desiccation characteristic of arid or semiarid regions, and, if near the surface, to the heat of the summer sun. "Butterballs," light porous nodules of the purest carnotite yet known, shrink and crack, probably through the loss of water of crystallization.

These facts undoubtedly account for the great difference in the water content of the Tyuya Muyun and Henry Mountains tyuyamunites.

That tyuyamunite and carnotite are probably mixed both isomorphously and mechanically is shown by the analysis of the material from the Henry Mountains and by the analyses of carnotite by W. F. Hillebrand,<sup>9</sup> published in 1905. These analyses were made

<sup>6</sup> See Dana, J. D., *System of mineralogy*, 6th ed., p. 856, 1909.

<sup>7</sup> Rinne, F., *Kupferuranit und seine Entwässerungsprodukte (Metakupferuranit)*: *Centralbl. Mineralogie*, pp. 618-626, Stuttgart, 1901.

<sup>8</sup> Hallimond, A. F., *The crystallography and dehydration of torbernite*: *Mineralog. Mag.*, vol. 17, pp. 326-339, 1916; *Meta-torbernite I and torbernite*: *Idem*, vol. 19, pp. 13-50, 1920.

<sup>9</sup> Hillebrand, W. F., and Ransome, F. L., *On carnotite and associated vanadiferous minerals in western Colorado*: *U. S. Geol. Survey Bull.* 262, p. 25, 1905.

with Doctor Hillebrand's consummate skill and care and to him meant that carnotite was a mixture of minerals. With the greater knowledge of the deposits since acquired, and particularly the knowledge of the accompanying vanadium and other minerals, the analysis can now be fairly well interpreted.

George P. Merrill examined Doctor Hillebrand's specimens and reported<sup>10</sup> that

The carnotite powder appears under the microscope in the form of exceedingly minute dustlike particles without crystal outlines and acting so faintly on polarized light as to at first seem almost amorphous. \* \* \* Working over a considerable amount of the powder I have found occasional clusters of this yellow mineral in the form of flattened radiating crystals with pyramidal terminations, which are without evident pleochroism, polarize only in dull colors, and give extinctions always parallel to the axis of elongation.

The radiating crystals were probably tyuyamunite. The analyses are as follows:

*Analyses of carnotite from Montrose County, Colo.*

[W. F. Hillebrand, analyst.]

	1			2		3
	a	b	c	a	b	
Insoluble.....	a 7. 10	b 8. 34	c 19. 00	d 10. 33	(e)	(f)
UO <sub>3</sub> .....	54. 89	52. 25	47. 42	54. 00	52. 28	20. 51
V <sub>2</sub> O <sub>5</sub> .....	18. 49	18. 35	15. 76	18. 05	17. 50	7. 20
P <sub>2</sub> O <sub>5</sub> .....	. 80	. 35	. 40	. 05	Trace.	None.
As <sub>2</sub> O <sub>3</sub> .....	Trace.	. 25	None.	None.	None.	None.
Al <sub>2</sub> O <sub>3</sub> .....	. 09	(?)	. 08	. 29	(?)	. 08?
Fe <sub>2</sub> O <sub>3</sub> .....	. 21	1. 77	. 72	. 42	3. 36	. 25
CaO.....	3. 34	2. 85	2. 57	1. 86	1. 85	1. 64
SiO <sub>2</sub> .....	. 02	(?)	(?)	Trace.	Trace.	(?)
BaO.....	. 90	. 72	. 65	2. 83	3. 21	. 29
MgO.....	. 22	. 20	. 24	. 14	. 17	. 07
K <sub>2</sub> O.....	6. 52	6. 73	6. 57	5. 46	5. 11	1. 51
Na <sub>2</sub> O.....	. 14	. 09	. 07	. 13	. 02?	. 01
Li <sub>2</sub> O.....	Trace.	(?)	(?)	Trace.	(?)	(?)
H <sub>2</sub> O at 105°.....	2. 43	2. 59	1. 85	3. 16	4. 52	1. 85
H <sub>2</sub> O at 350°.....	2. 11	3. 06	2. 79	2. 21	3. 49	g 1. 64
H <sub>2</sub> O above 350°.....	None.	None.	None.	None.	-----	h . 19
PbO.....	. 13	. 25	. 18	. 07	-----	. 09
CuO.....	. 15	. 20	. 22	Trace.	-----	Trace.
SO <sub>3</sub> .....	None.	. 12	. 18	None.	-----	None.
MnO <sub>2</sub> .....	. 18	. 23	. 18	. 05	-----	. 04
SiO <sub>2</sub> .....	. 15	. 06	. 13	. 20	-----	. 07
TiO <sub>2</sub> .....	. 03	. 10	(?)	(?)	-----	. 06?
CO <sub>2</sub> .....	. 56	. 33	None.	None.	-----	-----
	98. 46	98. 84	99. 01	99. 25	-----	-----

a Containing 0.54 H<sub>2</sub>O, 0.09 V<sub>2</sub>O<sub>5</sub>.

b The insoluble matter had the following composition: SiO<sub>2</sub>, 5.18; V<sub>2</sub>O<sub>5</sub>, 0.21; P<sub>2</sub>O<sub>5</sub>, 0.09; K<sub>2</sub>O, 0.26; Na<sub>2</sub>O, 0.04; H<sub>2</sub>O, 105°, 0.56, 350°, 0.32, + 350°, 0.48; Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, Cr<sub>2</sub>O<sub>3</sub>, etc., by difference, 1.20.

c The insoluble matter held in addition to 16.41 quartz and silicates (including 0.39 V<sub>2</sub>O<sub>5</sub> and a little UO<sub>3</sub>), H<sub>2</sub>O, 105°, 0.83; 300°, 0.73; + 300°, 1.03; total H<sub>2</sub>O, 2.59.

d Containing 0.16 V<sub>2</sub>O<sub>5</sub> and 1.90 H<sub>2</sub>O.

e The insoluble matter contained, besides quartz and silicates, 0.25 V<sub>2</sub>O<sub>5</sub>, 0.21 K<sub>2</sub>O, 0.05 Na<sub>2</sub>O.

f This analysis was made purposely on a relatively poor ore,

g At 300°.

h Above 300°.

1. Copper Prince claim, Roc Creek.
2. Yellow Boy claim, La Sal Creek.
3. Yellow Bird claim, La Sal Creek.

<sup>10</sup> Idem, p. 21.

In each analysis the "insoluble" gave some vanadium on further treatment, showing that other vanadium minerals than the easily soluble potash and lime carnotites were present. However, most of the other vanadium minerals associated with the carnotites are almost wholly soluble in dilute mineral acids, and the fact that the vanadium is too high in the analyses is to be explained by their presence.

The iron is probably all to be considered limonite and is to be combined with water sufficient to make 15 per cent of the mineral. The CO<sub>2</sub> is probably present in calcite, and the SO<sub>3</sub> in gypsum, so that both must be combined with lime. The P<sub>2</sub>O<sub>5</sub>, As<sub>2</sub>O<sub>5</sub>, Al<sub>2</sub>O<sub>3</sub>, SrO, BaO, MgO, Na<sub>2</sub>O, PbO, CuO, SiO<sub>2</sub>, and TiO<sub>2</sub> may be rejected as foreign, the lead being derived from the degradation of the uranium. The MoO<sub>3</sub>, persistent but in small quantity, may be isomorphous with the UO<sub>3</sub>, but it is more probably present as molybdate, though possibly as powellite.

This considered and recalculated to 100 per cent the analyses become:

*Hillebrand's analyses of carnotite recalculated to 100 per cent.*

	Analyses.						Molecular ratios.					
	1			2		3	1			2		3
	a	b	c	a	b		a	b	c	a	b	
UO <sub>3</sub> .....	62.9	61.4	61.7	63.7	62.1	59.7	2	2	2	2	2	2
MoO <sub>3</sub> .....	2	3	.2	.1	-----	1.1						
V <sub>2</sub> O <sub>5</sub> .....	21.2	21.5	20.5	21.3	20.8	21.0	1.05	1.1	1.05	1.05	1.06	1.1
CaO .....	3.0	2.7	3.2	2.2	2.2	4.8	1.2	1.2	1.4	.96	.97	1.3
K <sub>2</sub> O .....	7.5	7.9	8.6	6.4	6.1	4.4						
H <sub>2</sub> O .....	5.2	6.2	5.8	6.3	8.8	10.0	2.6	3.2	3.0	3.1	4.5	5.3

Although, except for the water content, the molecular ratios of all the analyses approximate the uranite type, in all the vanadium is a little too high, and in all but 2a and 2b the lime and potash content is too high. As has already been explained, other vanadium minerals were present in the material analyzed, and it is an exceptional sample from the plateau region that does not contain gypsum, calcite, or dolomite, one or all. Lime vanadates; the yellow pascoite; red hewettite, in some forms easily mistaken for a hydrous iron oxide; and the green pintadoite are widely spread, and all the deposits contain a vanadium mineral that resembles roscoelite, so that high results for vanadium are to be expected.

To give the uranite ratios, except water, only the following deductions from the original analyses are necessary:

	1a	1b	1c	2a	2b	3
V <sub>2</sub> O <sub>5</sub> .....	0.9	2.0	0.7	0.9	0.8	0.6
CaO .....	1.2	1.2	1.8	-----	-----	.2

Supposing these possibilities to be actualities, then we would have the following formulas:

	Per cent of tyuyamunite.
1a. $(Ca, K_2)0.2UO_3 \cdot V_2O_5 \cdot 2H_2O$ -----	18. 6
1b. $(Ca, K_2)0.2UO_3 \cdot V_2O_5 \cdot 3H_2O$ -----	20. 8
1c. $(Ca, K_2)0.2UO_3 \cdot V_2O_5 \cdot 3H_2O$ -----	14. 8
2a. $(Ca, K_2)0.2UO_3 \cdot V_2O_5 \cdot 3H_2O$ -----	36. 5
2b. $(Ca, K_2)0.2UO_3 \cdot V_2O_5 \cdot 5H_2O$ -----	38. 1
3. $(Ca, K_2)0.2UO_3 \cdot V_2O_5 \cdot 5H_2O$ -----	55. 0

The crystals observed by Doctor Merrill in examining the specimens were probably tyuyamunite. It is likely that they contained more or less isomorphous carnotite, and that the powder was carnotite. To the water content the remarks already made about tyuyamunite and torbernite apply. The water content should surely be much larger even if the minerals were not already considerably desiccated, for there was undoubtedly a loss in grinding the specimens.

From the considerations noted it seems to me likely that carnotites of the lime and potash varieties are isomorphous, but the normal water content is indeterminable from the analyses at hand.

The  $\frac{Pb}{U}$  ratios given by the analyses are as follows: 1a, 0.0026; 1b, 0.0053; 1c, 0.0043; 2a, 0.0013; 3, 0.0047; average 0.0036. The series is no more irregular than is to be expected from minerals as mobile as carnotite.

Accepting the formula

$$\frac{RaG(Pb)}{U} \cdot 7900 \cdot 10^6 = \text{age},$$

we find that an age of about 28,440,000 years is indicated by the lead present. This figure is probably much too small, owing to the quantity of lead lost by migrations of the carnotite as it has been dissolved by and reprecipitated from circulating waters. If the largest figure (0.0053) is taken, the age is indicated as about 42,000,000 years, and this appears to be more nearly correct, as it probably represents a mineral that has not lost so much of its lead.