Identification and Occurrence of Uranium and Vanadium Minerals From the Colorado Plateaus

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IDENTIFICATION AND OCCURRENCE OF URANIUM AND VANADIUM MINERALS FROM THE COLORADO PLATEAUS

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ABSTRACT

This report, designed to make available to field geologists and others information obtained in recent investigations by the Geological Survey on identification and occurrence of uranium minerals of the Colorado Plateaus, contains descriptions of the physical properties, X-ray data, and in some instances results of chemical and spectrographic analysis of 48 uranium and vanadium minerals. Also included is a list of locations of mines from which the minerals have been identified.

INTRODUCTION AND ACKNOWLEDGMENTS

The 48 uranium and vanadium minerals described in this report are those studied by the writers and their colleagues during recent mineralogic investigation of uranium ores from the Colorado Plateaus. This work is part of a program undertaken by the Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

Thanks are due many members of the Geological Survey who have worked on one or more phases of the study, including chemical, spectrographic, and X-ray examination, as well as collecting of samples. The names of these Survey members are given in the text where the contribution of each is noted. The writers are grateful to George Switzer of the U. S. National Museum and to Clifford Frondel of Harvard University who kindly lent type mineral specimens and discussed various problems.

PURPOSE

The purpose of this report is to make available to field geologists and others who do not have extensive laboratory facilities, information obtained in recent investigations by the Geological Survey on the identification and occurrence of the uranium and vanadium minerals of ores from the plateaus. Distinctive properties of each mineral are listed to encourage and facilitate identification by optical or chemical tests. A combination of data from X-ray powder patterns and spectrographic analyses is required to identify certain minerals, especially if the quantity of mineral is very small, but for many minerals these techniques are not necessary. The reader is also referred to other

compilations: Gruner and Gardiner's [1] "Tables of uranium and vanadium minerals" (1950) and "Mineral associations in the uranium deposits of the Colorado Plateau" (1952).

MINERAL DATA

The minerals include several new species and many that were rare and incompletely (or inaccurately) described before the recent intensive search for uranium. The data for each mineral include the best available formula, in general from "A glossary of uranium- and thorium-bearing minerals" (Frondel and Fleischer, 1952), and crystallographic and physical properties from Dana's "System of mineralogy," 7th edition, and from "Mineralogy of uranium and thorium minerals" (George, 1949). For minerals showing a considerable range of properties, selection has been made to emphasize those properties noted by the writers in specimens from the Colorado Plateaus.

CRYSTALLOGRAPHY

Crystallographic data are reduced to a minimum because such would be used rarely by the field geologist. An exception is crystal habit, such as the platy habit of the torbernite group and bladed or fibrous habit of uranophane. The habits of these commonly fine-grained minerals may be observed with a binocular microscope. Chiefly to establish the particular material that is referred to under each species, the *d*-spacing in Angstrom units is given for several strong lines of the X-ray diffraction powder pattern taken with CuKα radiation. The relative intensity of the lines is indicated by the abbreviations: VS very strong, S strong, M medium, and W weak. The X-ray photographs were taken by E. A. Cisney, and M. E. Thompson.

PHYSICAL AND OPTICAL PROPERTIES

Relatively few of the uranium and vanadium minerals are too fine grained, too high in refractive index, or too dark for determination of some optical properties. Certain minerals, notably the torbernite group and the carnotite group, dehydrate easily with resultant rise in refractive indices; identification of minerals in these groups by optical properties must be made with considerable care. Table 1 gives the optical properties of uranium minerals.

So many yellow and greenish-yellow uranium minerals, as well as a few yellow and greenish-yellow vanadium and copper minerals, occur on the plateaus that color is not a dependable means of identification unless combined with other properties. The color of fluorescence noted here is for minerals observed under ultraviolet light

[1] Gruner, J. W., and Gardiner, Lynn, 1950, Tables of uranium and vanadium minerals which are largely of secondary origin (duplicated).

(2537 A) and may differ considerably from the color or degree of fluorescence observed at 3650 A.

ANALYSIS

For the new and some of the doubtful species, chemical analyses made by A. M. Sherwood and R. G. Milkey are given. For other species spectrographic analyses used as an aid in identification are given and these are not necessarily of pure material. These are by C. L. Waring, H. W. Worthing, C. S. Annell, J. N. Stich, and K. E. Valentine. Semiquantitative spectrographic analyses (Waring and Annell, 1953) made on 10 mg of sample are given for constituents in the following percent ranges: more than 10, 1 to 10, 0.1 to 1, 0.01 to 0.1, and 0.001 to 0.01. Qualitative spectrographic analyses (Stich, 1953), made of 1 mg of sample, list the constituent elements as major (more than 10 percent), minor (about 1 to 10 percent), and trace (less than 1 percent).

OCCURRENCE

This study notes the primary or secondary nature of each mineral and whether it is found as impregnation, replacement, or coating on fractures and mine walls. The commonly associated minerals are listed. Only for a few rare minerals is the name of the person who collected the samples given. Most of the samples were collected by L. B. Riley, L. R. Stieff, T. W. Stern, and the writers; a smaller number by W. I. Finch, A. F. Trites and other Survey geologists, AEC geologists, and by mine operators.

IDENTIFICATION

Identification is based on the writers' experience. Until the writers had positively identified the mineral species of the Colorado Plateaus and become familiar with their properties, they relied heavily on X-ray powder patterns and spectrographic analyses. Minerals that are fine grained, in thin coatings, or admixed with other minerals, as are many from the plateaus, can be identified satisfactorily in the laboratory by use of a small amount of hand-picked or otherwise purified material. In this report emphasis is placed on simple physical or chemical tests to distinguish as many minerals as possible.

TEST FOR URANIUM

A satisfactory test for uranium is to make a bead test with a small loop of platinum wire and a flux composed of 45.5 percent by weight of Na_2CO_3, 45.5 percent by weight of K_2CO_3, and 9 percent by weight of NaF and observing with a long wavelength (3650 A) ultraviolet light the fluorescence caused by uranium (Grimaldi, May, and

Fletcher, 1952). The test is more easily made with a small platinum pan, such as the lid of a platinum crucible. The flux should be melted and the blank tested with the ultraviolet light before the mineral grains are added and the flux remelted for the final test. With a little practice one can distinguish between the bright fluorescence of a uranium mineral and the faint fluorescence of slightly uraniferous material such as uraniferous opal. If a positive test is obtained, the platinum wire or pan should be washed in hydrochloric acid before making another test.

The test described above may be modified by using a flux composed of 9 parts of household baking soda and 1 part of sodium fluoride (as sold by drug stores for ant poison) and ordinary iron wire. In this case the flux should be fused only a short time to avoid adding iron that causes quenching of the uranium fluorescence. Although a wavelength of 3650 A is best for accurate laboratory work, almost any battery-operated ultraviolet light suitable for prospecting may be used in this field test.

TEST FOR VANADIUM

To test for vanadium, dissolve a small part of the mineral or ore in aqua regia, evaporate to dryness, add as much water as original acid, and then add a few drops of hydrogen peroxide. If vanadium is present the solution will turn orange-red. Carnotite or tyuyamunite turns red-brown when a drop of concentrated hydrochloric acid is added, but this test is not always satisfactory for roscoelite ore.

TEST FOR VANADATES

The following suggestions for distinguishing between the many yellow and greenish-yellow, radioactive minerals of the Colorado Plateaus may help the inexperienced worker make the most effective use of a small amount of material. One should be able to limit the possibilities to a small group of related minerals or, in some cases, make a complete identification. With the aid of a binocular microscope and a bright light, hand-pick several grains that appear to be a single species of mineral. Note the habit, color, fluorescence, and any other distinctive properties of the mineral. Simple chemical tests made of single mineral grains on a glass slide on the stage of a binocular microscope will place the mineral in one of the groups noted below. Optical properties or other characteristics may then be used for more specific identification. When the identification is somewhat narrowed down, one should refer to the complete description of minerals in the tables.

Add a drop of concentrated HCl (from a small drop-bottle) to the mineral grain on the glass slide. If the mineral turns red-brown it is a vanadate—probably carnotite or tyuyamunite. This reaction is immediate and the red-brown color will disappear quickly as the

mineral dissolves. Place another grain in an immersion liquid of index 1.86.

1. If the mineral has two indices much higher than that of the liquid, it is probably carnotite.

2. If the mineral has indices nearly equal or lower than that of the liquid, it is probably tyuyamunite.

TEST FOR CARBONATES

If the mineral effervesces in dilute HCl, it is a carbonate. Watch the reaction under the binocular as the acid is added because the carbonates dissolve readily. Take care that no calcite impurity is present. The uranyl carbonates are all water-soluble and fluorescent (in varying degree) and have the lowest indices of refraction of any group of uranium minerals. To distinguish among the members of this group, begin by comparing the index of the unknown mineral with index liquid of 1.50.

1. If the highest index of the mineral is close to 1.50, the mineral may be bayleyite.

2. If the lowest index of the mineral is close to 1.50, the mineral may be either liebigite or rabbittite.

3. If the indices of the mineral are higher than 1.50, the mineral may be andersonite.

4. If one index of the mineral is above and one below 1.50, the mineral may be either swartzite or schroeckingerite.

TEST FOR SULFATES

Dissolve the mineral in dilute HCl, and place a drop of barium chloride solution on the glass plate beside the dissolved mineral. With the aid of the binocular, watch for a reaction as the barium chloride flows into the acid. If a white precipitate forms, the mineral is probably a sulfate. Take care to avoid gypsum impurity which will also give a sulfate test. Note that schroeckingerite is a carbonate sulfate and will react to both tests. The uranyl sulfates—johannite, uranopilite, and zippeite—may be distinguished by optical and other properties. Place a grain of the sulfate mineral in a liquid of index 1.63.

1. If the mineral has indices lower than 1.63, and is green and nonfluorescent, it is probably johannite.

2. If the mineral has indices close to 1.63, fluoresces brightly, and has low birefringence, it is probably uranopilite.

3. If the mineral has indices much higher than 1.63 and has high birefringence, it is probably zippeite (fluorescence variable).

TEST FOR SILICATES, OXIDES, PHOSPHATES, AND ARSENATES

If the mineral does not react positively to the vanadate, carbonate, or sulfate test, one can probably identify it by means of optical tests

as a member of the silicate, oxide, phosphate, or arsenate group. Optical tests of these minerals require less sample than further chemical tests, but they may not give a complete identification. Most of the minerals in these groups are soluble in HCl. Place a grain of the mineral in a liquid of index 1.67.

1. If the mineral has one index close to 1.67 and has acicular or prismatic habit, it may be one of the silicates: uranophane, beta-uranophane, or cuprosklodowskite.

2. If the mineral has indices well above 1.67, it may be one of the hydrated oxides: schoepite or becquerelite.

3. If the mineral has indices lower than 1.67 and occurs in square plates, it is probably a phosphate or arsenate. All of the phosphates and arsenates, except phosphuranylite and several rare lead phosphates not yet found on the Colorado Plateaus, have indices well below 1.67. Optical tests do not distinguish satisfactorily between the members of these groups because of the range of indices due to variable water content. Most of the members are yellow and fluorescent except metatorbernite and metazeunerite, which are green and commonly nonfluorescent. If a positive identification within the phosphate and arsenate groups is wanted, laboratory study by X-ray and spectrographic analysis is the most dependable means of identification.

LOCALITIES

Localities are listed by mine name and the mining district, as shown on a map by Shoemaker and Luedke.[2] Most mine names are those in use when samples were collected in the summer of 1952, but some are as recorded with samples collected in 1950, 1951, and 1953. To help the reader who is not familiar with the mining districts an alphabetical list of mine and mining district names is given in table 2; also the county and state in which each is situated. The number of localities is restricted to those from which specimens have been identified by the authors and to the type localities of minerals described from the Colorado Plateaus. In addition, a few minerals from the sandstone-type uranium deposits at Pumpkin Buttes, Wyo., and Fall River County, S. Dak., have been included.

MINERAL ASSOCIATIONS AND DISTRIBUTION OF TYPES OF ORE

Ore from the Colorado Plateaus may be classified on the basis of whether uranium is associated with vanadium. The nonvanadiferous ore contains traces of several metals and possibly as much as 1 percent of copper in some places. The two main types may be subdivided into highly oxidized or relatively unoxidized ore. Mineralogically the

[2] Shoemaker, E. M., and Luedke, R. G., 1952, Map of the uranium region of the Colorado Plateau: U. S. Geol. Survey Trace Elements Inv. Rept. 279.

types differ greatly because the affinity of vanadium for uranium tends to make carnotite or tyuyamunite the chief uranium mineral in oxidized vanadiferous ore, whereas many uranium minerals are formed in the oxidation of the nonvanadiferous ore.

OXIDIZED VANADIUM-URANIUM ORE (CARNOTITE)

For many years the chief ore mined on the Colorado Plateaus was oxidized vanadium-uranium ore from the western Colorado-eastern Utah area, now known as the Uravan mineral belt, and from Temple Mountain on the east side of the San Rafael swell in Utah. The most abundant uranium mineral was carnotite. The ore also contained a smaller amount of tyuyamunite and very little rauvite and uvanite. The most abundant vanadium minerals (aside from the uranyl vanadates) were vanadium hydromica and roscoelite or either, and corvusite, with local concentration of hewettite and metahewettite and small amounts of other secondary quinquivalent vanadium minerals: pascoite, hummerite, rossite, metarossite, steigerite, navajoite, fervanite, and the sodium analogue of hewettite. Many of the vanadate minerals fill fractures or coat joint surfaces and mine walls.

Many of these minerals have been found in mines recently developed in Monument Valley, Ariz. In the Shiprock district of Arizona and New Mexico, and along the north side of the Zuni uplift, N. Mex., tyuyamunite and metatyuyamunite are more abundant than carnotite. Several other uranium minerals found in small amounts in carnotite ore include schroeckingerite, meta-autunite, metazeunerite, uranophane, and novacekite. Locally, where both copper and vanadium are present, small quantities of volborthite and calciovolborthite occur as at Richardson Basin, Moab district, Utah, and in the Slick Rock district, Colo.

Placerville and Rifle, Colo., two areas that produced chiefly vanadium with relatively little uranium, have not been given detailed mineralogic study.

The vanadium-to-uranium ratio of the ores ranges from a high ratio of about 30:1 at Placerville and Rifle through lower values in the Uravan mineral belt, Colorado-Utah, the Shiprock district, Arizona-New Mexico, Monument Valley, Ariz., and the Grants district on the north side of the Zuni uplift, N. Mex., to a ratio of about 1:1 at Temple Mountain in the San Rafael district, Utah. Some differences in relative abundance of minerals in the several areas are due to the variation in V:U ratio. Other differences are due to local conditions, such as the high calcium content of the sediments in the Shiprock and Grants districts, which causes local predominance of tyuyamunite. In the Uravan belt the predominance of carnotite seems to be coincident with the area of the Pennsylvanian evaporite basin and may be related to the presence of potassium salts in the Paradox member of

the Hermosa formation. Presence of fossil bone may favor local development of autunite. Relative abundance of sodium in the Thompsons district accounts for schroeckingerite, andersonite, sodium vanadate, and a salt crust of thenardite. In the Grants district the fluorite associated with ore may be related to fluorite deposits in the center of the Zuni uplift.

UNOXIDIZED VANADIUM-URANIUM ORE

In the early days of uranium mining on the Colorado Plateaus, small concentrations of black minerals included in the carnotite ore were called corvusite-vanoxite ore and commonly thought to be composed of vanadium oxides.

Recently, as many new mines have been opened, much more black ore high in uranium, as well as in vanadium, has been found wherever ore bodies are protected from oxidation by a thick or impervious cover, as in the deeper ore bodies in the Long Park area of the Uravan district, or where ore has been exposed very recently by headward erosion of steep canyons, as in Lumsden Canyon, Gateway district, or La Sal Creek, Paradox district. Some mines such as Mi Vida mine, Monticello district, or Virgin mine, Uravan district, have chiefly black ore with very little secondary alteration, and others like Monument No. 2 mine in Monument Valley district, have scattered unoxidized remnants in ore that is chiefly oxidized.

Since 1950 mineralogic study has shown the presence of several important primary uranium and vanadium minerals. The black uranium minerals are pitchblende [3] (identified in 12 mines of uranium-vanadium ore) and a new uranium mineral (identified in 10 mines of uranium-vanadium ore). The new mineral was found in 1951 by L. R. Stieff and T. W. Stern (report in preparation). The low-valence vanadium minerals are montroseite and at least two other new vanadium oxides found by T. W. Stern (report in preparation). Both uranium and vanadium minerals are associated with pyrite, commonly with high-rank coalified wood, and traces of copper, lead, cobalt, nickel, molybdenum, and silver. Also present and probably representing a transition to the oxidized ore are melanovanadite, corvusite, and probably fernandinite.

The ore at Temple Mountain in the eastern part of the San Rafael district has been commonly referred to as asphaltite ore because of the presence of asphaltic and other carbonaceous material. However, higher-than-average carbon content does not prevent classifying this ore on the basis of mineral assemblage with the other uranium-vanadium ores. The relatively unoxidized portion of the ore contains pitchblende associated with a hard carbonaceous substance variously

[3] The term "pitchblende" is used as in Dana, 7th ed., v. 1, p. 613-614, for a massive variety of uraninite with specific gravity lower than 8.5 and thorium absent or less than 1 percent.

described as high-rank coal or polymerized petroleum residue (thucholite?); also present are pyrite and very small amounts of montroseite and galena.

OXIDIZED NONVANADIFEROUS URANIUM ORES

In contrast to the carnotite ore, the nonvanadiferous uranium ores are characterized by a wide variety of secondary uranium minerals that include hydrated oxides, carbonates, sulfates, phosphates, arsenates, and silicates. Most of these uranium minerals are yellow, orange, greenish yellow, or green, and microcrystalline or massive. They fill minute fractures in sandstone, conglomerate, or fossil wood, and coat joint surfaces and mine walls. In small ore pockets or even in small mines one of these minerals may be abundant, but among them no mineral is as predominant as carnotite is in the oxidized vanadium-uranium ore. In studies to date, the uranium sulfates seem the most abundant.

Copper, the chief associated metal in some of the nonvanadiferous ore, occurs in many secondary minerals, commonly as malachite, azurite, chalcanthite, antlerite, brochantite, and chrysocolla, and rarely as conichalcite, chalcoalumite, and volborthite. Other metals are present and differ in abundance from one mine to another: iron and manganese in limonite and wad, cobalt in bieberite (commonly dehydrated), sphaerocobaltite, erythrite, or cobaltoan pickeringite, molybdenum in ilsemannite or ferrimolybdite, and traces of lead, zinc, nickel, and silver.

Outcrops of these deposits or joint surfaces within a few inches of the cliff face commonly show bright-blue and green copper stain, bright-yellow uranium sulfates or carbonates, pink cobalt efflorescences dull-yellow jarosite, white alunite and, in a few places, fluorescent uraniferous opal and allophane. Clay lenses in the ore or nearby are bleached and altered to kaolinite, jarosite, alunite, or gibbsite.

UNOXIDIZED NONVANADIFEROUS ORE

Since 1949 relatively unoxidized nonvanadiferous uranium ore has been found at a number of places in the west-central part of the Monument uplift, now called the White Canyon mining district, and in scattered localities in the Green River, San Rafael, and Henry Mountains mining districts. The new black uranium mineral has been identified at 1 mine and pitchblende at 13 mines in nonvanadiferous ore (in addition to the 12 localities of pitchblende and 10 of the new mineral in vanadiferous ore). As in the case of the black vanadium-uranium ore, some mines have chiefly unoxidized ore and others have unoxidized remnants in ore that is fairly well oxidized.

The best development of relatively unoxidized nonvanadiferous ore is the pitchblende-copper sulfide deposit in which the Happy Jack

mine is located at White Canyon, Utah. The ore contains both sooty pitchblende and massive pitchblende that is so pure and of such high specific gravity (9.0) as to justify calling it uraninite. Some of the pitchblende replaces fossil wood and some, in tabular masses, does not show wood structure. It is closely associated with chalcopyrite, pyrite, bornite, chalcocite, sphalerite, and galena, and traces of cobalt, nickel, molybdenum, and silver. The abundance of secondary uranium sulfates as efflorescences on the mine walls shows the close relation between pitchblende and the sulfides.

Many mines have less copper associated with the pitchblende than there is at the Happy Jack mine. Although traces of molybdenum and cobalt are common in the uranium ore, no large amount of these metals has been found in any of the mines of the Colorado Plateaus. Many small copper deposits known for years as the Red Beds Copper deposits contain little or no uranium.

URANIUM MINERALS

The uranium minerals described in the following pages are those that the authors have studied from the Colorado Plateaus. One species, uvanite, exists only in the type specimen in the U. S. National Museum and no new localities have been found.

Classified according to chemical composition the described minerals are:

Oxides:

- Uraninite and pitchblende UO_2
- Becquerelite $2UO_3 \cdot 3H_2O$
- Fourmarierite $PbU_4O_{13} \cdot 7H_2O$
- Gummite, amorphous hydrated U oxide

Carbonates:

- Schroeckingerite $NaCa_3(UO_2)(CO_3)_3(SO_4)F \cdot 10H_2O$
- Bayleyite $Mg_2(UO_2)(CO_3)_3 \cdot 18H_2O$
- Andersonite $Na_2Ca(UO_2)(CO_3)_3 \cdot 6H_2O$
- Liebigite $Ca_2U(CO_3)_4 \cdot 10H_2O$ (?)
- Rabbittite $Ca_3Mg_3(UO_2)_2(CO_3)_6(OH)_4 \cdot 18H_2O$

Sulfates:

- Uranopilite $(UO_2)_6(SO_4)(OH)_{10} \cdot 12H_2O$
- Johannite $Cu(UO_2)_2(SO_4)_2(OH)_2 \cdot 6H_2O$
- Zippeite $(UO_2)_2(SO_4)(OH)_2 \cdot 4H_2O$

Phosphates:

- Autunite $Ca(UO_2)_2(PO_4)_2 \cdot 10\text{–}12H_2O$
- Meta-autunite I $Ca(UO_2)_2(PO_4)_2 \cdot 2\frac{1}{2}\text{–}6\frac{1}{2}H_2O$
- Bassetite $Fe(UO_2)_2(PO_4)_2 \cdot 8H_2O$
- Torbernite $Cu(UO_2)_2(PO_4)_2 \cdot 8\text{–}12H_2O$
- Metatorbernite $Cu(UO_2)_2(PO_4)_2 \cdot 8H_2O$
- Phosphuranylite $Ca(UO_2)_7(PO_4)_4(OH)_4 \cdot 10H_2O$ (?)

Arsenates:

- Metazeunerite $Cu(UO_2)_2(AsO_4)_2 \cdot 8H_2O$
- Novacekite $Mg(UO_2)_2(AsO_4)_2 \cdot 8\text{–}10H_2O$

Vanadates:
- Carnotite $K_2(UO_2)_2(VO_4)_2 \cdot 1\text{–}3H_2O$
- Metatyuyamunite $Ca(UO_2)_2(VO_4)_2 \cdot 5\text{–}7\ H_2O$
- Tyuyamunite $Ca(UO_2)_2(VO_4)_2 \cdot 7\text{–}10\frac{1}{2}\ H_2O$
- Rauvite $CaO \cdot 2UO_3 \cdot 5V_2O_5 \cdot 16H_2O$ (?) } closely related
- Uvanite $2UO_3 \cdot 3V_2O_5 \cdot 15H_2O$ (?) }

Silicates:
- Beta-uranophane $Ca(UO_2)_2Si_2O_7 \cdot 6H_2O$
- Uranophane $Ca(UO_2)_2Si_2O_7 \cdot 6H_2O$
- Cuprosklodowskite $Cu(UO_2)_2Si_2O_7 \cdot 6H_2O$

New mineral of uncertain formula:
- Black U-mineral having X-ray pattern like thorite.

Uranium-bearing materials are organic material, opal, allophane, limonite, and wad. Additional minerals from the Colorado Plateaus noted in Atomic Energy Commission reports are schoepite $UO_3 \cdot 2H_2O$, sabugalite $HAl(UO_2)_4(PO_4)_4 \cdot 16H_2O$, and sklodowskite $Mg(UO_2)_2Si_2O_7 \cdot 7H_2O$ (Gruner and Gardiner, 1952). Three new uranium carbonates, swartzite $CaMg(UO_2)(CO_3)_3 \cdot 12H_2O$, andersonite, and bayleyite were described from the Hillside mine, Yavapai County, Ariz., (Axelrod, Grimaldi, Milton and Murata, 1951). A second occurrence of bayleyite has been found in a copper-uranium deposit in White Canyon district, Utah (Stern and Weeks, 1952) and of andersonite in the Yellow Cat group, Thompsons district, Utah, in 1953. Soddyite $(UO_2)_5(SiO_3)_2(OH)_6 \cdot 3H_2O$, is known to occur also in Yavapai County, Ariz. (R. Berman, personal communication). Other minerals that may be found in the Colorado Plateaus deposits include uranocircite $Ba(UO_2)_2(PO_4)_2 \cdot 8H_2O$, uranospinite $Ca(UO_2)_2(AsO_4)_2 \cdot 8\text{–}12H_2O$, saléeite $Mg(UO_2)_2(PO_4)_2 \cdot 8\text{–}10H_2O$, and sengierite $Cu(UO_2)(VO_4)(OH) \cdot 4\text{–}5H_2O$ (?).

Several yellow uranium minerals from the Colorado Plateaus are still unidentified and some of these are probably new minerals. Work on these is in progress.

ANDERSONITE

$Na_2Ca(UO_2)(CO_3)_3 \cdot 6H_2O$

Crystal system: Hexagonal—rhombohedral.

Habit: Pseudocubic crystals, as thin granular coating.

Physical properties:

Color: Bright green.
Fluorescence: Bright green.
Luster:
Cleavage:
Hardness:
Specific gravity: 2.8
Strongest lines of X-ray powder pattern: S 13.0, S 7.97, S 5.68, S 5.22.

Optical properties:

	n	DICHROISM	
O	1. 520	Colorless	Uniaxial positive
E	1. 540	Pale yellow	

Analysis: Of synthetic material (Axelrod, Grimaldi, Milton and Murata, 1951). Analyst, M. Eiland:

Na_2O	CaO	UO_3	CO_2	H_2O	Total
9. 61	8. 80	44. 27	20. 61	16. 50	99. 79

Occurrence and associated minerals: Water-soluble secondary mineral occurring as efflorescence on mine wall with schroeckingerite, gypsum, bayleyite, and swartzite at Hillside mine (type locality). Also efflorescence on mine wall at Skinny No. 1 mine.

Identification: Soluble in water. Effervesces in HCl. Optically distinct.

Localities:

Type locality at Hillside mine, Yavapai County, Ariz.

Skinny No. 1 mine, Thompsons district.

AUTUNITE and META-AUTUNITE I

$Ca(UO_2)_2(PO_4)_2 \cdot 10\text{–}12H_2O$

(Meta–autunite I has $2\frac{1}{2}\text{–}6\frac{1}{2}H_2O$)

Crystal system: Tetragonal; ditetragonal–dipyramidal $4/m\ 2/m\ 2/m$.

Habit: Thin tabular {001}. As foliated or scaly aggregates.

Physical properties:

Color: Ranges from lemon yellow to pale green. Streak yellowish.

Fluorescence: Strong yellow-green. Meta-autunite less strong.

Luster: Vitreous, pearly on {001}.

Cleavage: {001} perfect, {100} indistinct. Not brittle.

Hardness: 2—2½.

Specific gravity: 3.1—3.2, varying with the water content.

Strongest lines of X-ray powder pattern: VS 8.3, S 3.59, W 1.60 (Meta-autunite I).

Optical properties:

ORIENTATION	*n*	PLEOCHROISM	
$X=c$	1.553–?	Colorless to pale yellow.	Anomalously biaxial negative due to loosely held water in both autunite and meta-autunite I, $2V$ 10–30° $r>v$ strong
Y	1.575–1.59	Yellow to dark yellow.	
Z	1.577–1.61	Yellow to dark yellow	

Meta-autunite from Thom claim is biaxial negative, $2V$ small to medium, nY and nZ equal to 1.603 ± 0.003.

Analysis: Qualitative spectrographic analysis of material from Thom claim:

Major	*U P*
Minor	Ca Si Fe
Trace	Al Co Na As Ni Mg Pb

Occurrence and associated minerals: Coating fracture surfaces of weathered brown sandstone.

Identification:

On drying or slight heating autunite passes reversibly to meta-autunite I.

A combination of habit, optical properties, and spectroscopic analysis.

Optical properties are quite variable. Use with caution.

X-ray powder pattern. Analysis for presence of Ca and lack of Ba necessary to distinguish from uranocircite.

Locality: Thom claim, Thompson district.

BASSETTITE

$$Fe(UO_2)_2(PO_4)_2 \cdot 8H_2O$$

Crystal system: Monoclinic, pseudo-orthorhombic.

Habit: Scaly, flattened on {010}.

Physical properties:

Color: Yellow.

Fluorescence: Yellow, weak, variable.

Luster: Pearly.

Cleavage: {010} perfect. {100} and {001} distinct.

Hardness:

Specific gravity: 3.10.

Strongest lines of X-ray powder pattern: S 9.4, M 3.48, M 2.19.

Optical properties:

ORIENTATION	n (Na)	PLEOCHROISM	
$X=b$	≈ 1.56	Pale yellow	Biaxial negative
Y	1.574	Deep yellow	$2V \approx 52°$
$Z \wedge c = 40°$	1.580	Deep yellow	

Analysis: Qualitative spectrographic analysis:

Major	U
Minor	P Na Fe
Trace	Al K Ba Si Ca Cu

Occurrence and associated minerals: Secondary coating on mine wall, near the portal.

Identification: X-ray powder pattern or spectrographic analysis.

Locality: Denise No. 1 mine, Green River district.

BAYLEYITE

$$Mg_2(UO_2)(CO_3)_3 \cdot 18H_2O$$

Crystal form: Monoclinic.

Habit: Minute prismatic crystals.

Physical properties:

Color: Sulfur yellow.

Fluorescence: Feeble.

Luster: Vitreous.

Cleavage:
Hardness: 2—2½.
Specific gravity: 2.05.
Strongest lines of X-ray powder pattern: S 7.6, S 13.0, M 3.82.

Optical properties:

ORIENTATION	*n*	PLEOCHROISM	
$X \wedge c$ 14°	1.455	Pinkish	Biaxial negative $2V=30°$
Y	1.490	Pale yellow	
$Z=b$	1.500	Pale yellow	

Analysis: Semiquantitative spectrographic analysis, in percent, of material from Hideout mine:

More than 10	U
1.0–10	Mg Ca (low)
0.1–1.0	Al
0.01–0.1	Si Sr

Occurrence and associated minerals: Found with schroeckingerite and gypsum as a coating on wall at Hideout mine. Forming at present where seepage occurs in outcrop on bank of dry stream bed at Pumpkin Buttes.

Identification:

Soluble in water. Effervesces in HCl.
Optically distinct. Be careful to distinguish from liebigite.
Indices unusually low for a uranium mineral.
Hideout material did not dehydrate in laboratory, as Arizona material did.

Localities:

Type locality at Hillside mine, Yavapai County, Ariz.
Hideout (Tiger) mine, White Canyon district.
Pumpkin Buttes area, Powder River basin, Wyo.

BECQUERELITE

$2UO_3 \cdot 3H_2O$

Crystal system: Orthorhombic; dipyramidal 2/*m* 2/*m* 2/*m*.
Habit: Tabular {001} and elongated [010]. Also massive.
Physical properties:

Color: Amber to brownish yellow. Streak yellow.
Fluorescence:
Luster: Adamantine, inclining to greasy.
Cleavage: {001} perfect, also {101}.
Hardness: 2-3.
Specific gravity: 5.2.
Strongest lines of X-ray powder patterns: S 7.5, M 3.53, M 3.19.

Optical properties:

ORIENTATION	*n*	PLEOCHROISM	
$X=c$	1.735	Colorless	Biaxial negative
$Y=b$	1.820	Light yellow	$2V=31°$
$Z=a$	1.830	Dark yellow	$r>v$ marked

Analysis: Qualitative spectrographic analysis of material from Posey mine:

Major	U
Minor	Si
Trace	Cu Fe Mg

Occurrence and associated minerals: Alteration product of pitchblende at Monument No. 2 mine and at Cato Sells mine. At Posey mine in high-grade pocket of yellow oxidized ore with cuprosklodowskite.

Identification:

X-ray powder pattern does not differ greatly from that of schoepite and other hydrated uranium oxides. Higher indices of refraction than schoepite.

Darker yellow color and lack of vanadium distinguish from tyuyamunite and carnotite.

Localities:

Posey mine, White Canyon district.
Cato Sells mine, Monument Valley district.
Monument No. 2 mine, Monument Valley district.
Lucky Strike No. 2 mine, San Rafael district.

CARNOTITE

$K_2(UO_2)_2(VO_4)_2 \cdot 1\text{–}3H_2O$

Crystal system: Monoclinic.

Habit: As a powder or as loosely coherent microcrystalline aggregates, some may be compact; disseminated; rarely as crusts of imperfectly platy crystals, flattened {001}.

Physical properties:

Color: Lemon yellow, greenish yellow; at Pumpkin Buttes, orange.
Fluorescence: None.
Luster: Dull or earthy; pearly or silky when coarsely crystalline.
Cleavage: {001} perfect.
Hardness: Soft.
Specific gravity: 4–5; 4.6 average of 4 measurements of crystalline carnotite.
Strongest lines of X-ray powder pattern: S 6.5, M 3.11, W 3.51

Optical properties:

ORIENTATION	*n*	PLEOCHROISM	
$X \approx c$	1.750	Nearly colorless	Biaxial negative, $2V$ 40°–50°
$Y \wedge a \approx 14°$	1.925–2.06	Canary yellow	Indices of refraction vary
$Z = b$	1.950–2.08	Canary yellow	with water content

Analysis: Semiquantitative spectrographic analysis, in percent, of material from near Cane Springs Pass, Moab district (USNM 95332):

More than 10	U V
1–10	K
0. 1–1	Al Ca Na Si
0. 01–0. 1	Ba Sr Fe

Occurrence and associated minerals: Chiefly disseminated in sandstone or locally as small pure masses, especially around petrified or carbonized tree trunks or other vegetal matter. Associated with tyuyamunite, metatyuyamunite, hewettite, rauvite, and corvusite. At Monument No. 2 mine, with pitchblende.

Identification: Carnotite has higher indices of refraction than any other yellow uranium mineral common on the Plateaus. Carnotite and tyuyamunite turn red-brown when a drop of concentrated HCl is added (vanadium test). Tyuyamunite fuses relatively easily; carnotite is infusible.

Localities: In most of the vanadium-uranium mines of the following districts on the Colorado Plateaus: Thompsons, Gateway, Uravan, Paradox, Bull Canyon, Gypsum Valley, Slick Rock, Moab, Monticello, Monument Valley, Grants, and the Temple Mountain part of the San Rafael district. Also at Pumpkin Buttes, Wyo., and at Coal Canyon, Red Canyon, and Craven Canyon, Fall River County, S. Dak.

CUPROSKLODOWSKITE

$$Cu(UO_2)_2Si_2O_7 \cdot 6H_2O$$

Crystal system: Orthorhombic.

Habit: Minute prismatic or acicular crystals. Usually grouped in radial clusters, also as thin films and botryoidal crusts.

Physical properties:

Color: Pale yellow-green; yellow in thin crystal blades.
Fluorescence:
Luster: Pearly to dull.
Cleavage: {100} and {010}.
Hardness: 3–4.
Specific gravity: 3.5±.
Strongest lines of X-ray powder pattern: VS 8.1, S 4.08, M 6.1.

Optical properties:

ORIENTATION	n	PLEOCHROISM	
X	1.654	Very pale yellowish green	Biaxial negative
Y	1.664–1.667	Very pale yellowish green	$2V$ small
$Z=c$	1.664–1.667	Pale greenish yellow	$r>v$ strong

Analysis: Qualitative spectrographic analysis of material from Posey mine:

Major	U Si
Minor	Cu
Trace	Pb Fe Na

Occurrence and associated minerals: As a fracture coating with brochantite. In a high-grade pocket as thin green veins in massive becquerelite.

Identification: Presence of Cu, acicular habit, and indices higher than those of johannite. Note uranophane has similar optical properties.

Localities: Posey mine, White Canyon district.

FOURMARIERITE

$PbU_4O_{13} \cdot 7H_2O$

Crystal system: Orthorhombic.
Habit: Tabular {001} and usually elongated [010].
Physical properties:

Color: Red to golden red; also brown.
Fluorescence:
Luster: Adamantine.
Cleavage: {001} perfect.
Hardness: 3–4.
Specific gravity: 6.0.
Strongest lines of X-ray powder pattern: S 3.38, S 3.04, S 1.89.

Optical properties:

ORIENTATION	n	PLEOCHROISM	
$X=c$	1.85	Colorless	Biaxial negative
$Y=b$	1.92	Pale yellow	$2V$ large
$Z=a$	1.94	Yellow	$r>v$ strong

Analysis: Qualitative spectrographic analysis of material from Lucky Strike No. 2 mine:

Major	U
Minor	Pb
Trace	Al Mg Si Fe

Occurrence and associated minerals: As an alteration product of pitchblende, with becquerelite and zippeite-like minerals at Lucky Strike; as red specks in pale-orange becquerelite and surrounding galena at Monument No. 2 mine.

Identification: Orange-red color, high indices of refraction, and negative test for vanadium.

Localities:
Lucky Strike No. 2 mine, San Rafael district (first collected by J. W. Gruner).
Monument No. 2 mine, Monument Valley district.

GUMMITE

Chiefly hydrated U oxide

A field term for amorphous or nearly amorphous yellow or orange alteration products of uraninite—used in somewhat the same sense as limonite and wad are used for iron and manganese oxides if specific minerals cannot be identified.

Many specimens formerly called gummite have been shown by modern laboratory methods to contain becquerelite, schoepite, uranophane, or some other uranium oxide, silicate, or carbonate.

Identified by color, high uranium content, and association with uraninite (or pitchblende).

JOHANNITE

$Cu(UO_2)_2(SO_4)_2(OH)_2 \cdot 6H_2O$

Crystal system: Triclinic; pinacoidal $\bar{1}$.

Habit: Prismatic; as coatings and small spheroidal aggregates of lath-like crystals.

Physical properties:

Color: Clear, light green. Streak paler.
Fluorescence: None.
Luster: Vitreous.
Cleavage: {100} good. Not brittle.
Hardness: 2–2½.
Specific gravity: 3.32.
Strongest lines of X-ray powder pattern: S 7.8, S 6.2, M 3.88.

Optical properties:

ORIENTATION	n	PLEOCHROISM	
X	1.577	Colorless	Biaxial positive
Y	1.597	Pale yellow	$2V \approx 90°$
Z	1.616	Greenish yellow	$r < v$ strong

Analysis: Qualitative spectrographic analysis of material from Happy Jack mine:

Major	U
Minor	Cu
Trace	Ca Al Mg Si

Occurrence and associated minerals: As wall or fracture coatings with uranopilite, zippeite-like minerals, brochantite, and chalcanthite. Coating pitchblende, chalcopyrite, and covellite.

Identification: Color, and tests for Cu and sulfate. Optical properties.

Localities:

Happy Jack mine, White Canyon district.
Oyler mine, Henry Mountains district.
Frey No. 4 mine, White Canyon district.

LIEBIGITE

$Ca_2U(CO_3)_4 \cdot 10H_2O$ [4]

Crystal system: Orthorhombic.

Habit: Crystals equant or short prismatic [001], usually indistinct with rounded edges. Commonly as granular or scaly aggregates and thin crusts; also botryoidal.

Physical properties:

Color: Light, vivid, greenish yellow.
Fluorescence: Light green, strong.
Luster: Vitreous, slightly pearly on the cleavage.
Cleavage:

[4] The valence state of U in this mineral is being determined.

Hardness: 2½–3.
Specific gravity: 2.41.
Strongest lines of X-ray powder pattern: S 8.7, S 6.8, S 5.4.

Optical properties:

ORIENTATION	n	PLEOCHROISM	
$X=a$	1. 497	Nearly colorless	Biaxial negative
Y	1. 502	Pale yellowish green	$2V$ 40°
Z	1. 539	Pale yellowish green	$r>v$ moderate

Analysis: Qualitative spectrographic analysis of material from Pumpkin Buttes:

Major	U Ca
Minor	--
Trace	Al Fe Mg Mn Si

Occurrence and associated minerals: Secondary coating at Pumpkin Buttes. Noted by D'Arcy George (1949) at Lusk, Wyo., perhaps as alteration product of uranophane.

Identification: Effervesces in HCl and soluble in water. Optical properties. (Be careful to distinguish from bayleyite.)

Localities:
Black Ape mine, Thompsons district.
Pumpkin Buttes, Wyo.
Lusk, Wyo.

NEW BLACK URANIUM MINERAL

Formula uncertain [5]

Crystal system: Tetragonal.
Habit: Massive; may show remnants of wood structure.
Physical properties:

Color: Black.
Fluorescence: None.
Luster: Adamantine.
Cleavage:
Hardness:
Specific gravity: More than 3.3 (Variable because of admixed material.)
Strongest lines of X-ray powder pattern: S 3.48, MS 4.62, M 2.64, M 1.80.

Optical properties: Opaque. Translucent in very thin fragments.

Analysis: No analysis of pure material is yet available; mineral occurs mixed with carbonaceous material and other black minerals.

Occurrence and associated minerals: Impregnating sandstone and replacing wood; with uraninite, and a low-valence (+3, +4) vanadium oxide, and pyrite. Found in mines with protective

[5] Analyses show as much as 61 percent U and varying amounts of Si, As, and V. The new mineral may be analogous to thorite ($ThSiO_4$), i. e., $USiO_4$, with OH substituting for Si, or it may be a hydrated oxide. (Stieff and Stern, personal communication, June 1953.)

cover or at the heads of steep canyons where erosion has recently exposed ore. (First found at La Sal No. 2 mine in August 1951 by T. W. Stern and L. R. Stieff, report in preparation).

Identification: X-ray powder pattern and lack of thorium. The X-ray powder pattern is very similar to that of thorite.

Localities:

	District		*District*
Arrowhead mine	Gateway	Grey Dawn mine	Paradox
Black Mama mine	do.	Wild Steer mine	Bull Canyon
Corvusite mine	do.	Little Muriel mine	Slick Rock
La Sal No. 2 mine	do.	Denise No. 1 mine	Green River
Matchless mine	do.	Mi Vida mine	Monticello
		Laguna area	Grants

NOVACEKITE

$$Mg(UO_2)_2(AsO_4)_2.8\text{–}10H_2O$$

Crystal system: Tetragonal (or pseudotetragonal).

Habit: Thin tabular {001}. As foliated or scaly aggregates.

Physical properties:

Color: Straw yellow.
Fluorescence: Pale yellow-green.
Luster: Pearly.
Cleavage: {001} perfect.
Hardness: 2½.
Specific gravity: 3.3.
Strongest lines of X-ray powder pattern: VS 10.2, S 3.56, M 5.1.

Optical properties:

ORIENTATION	*n*	
$X=c$		
Y	1. 620–1. 623	Biaxial negative
Z	1. 620–1. 623	$2V$ 0–15°

Analysis: Semiquantitative spectrographic analysis, in percent, of material from Laguna, Grants district:

More than 10	U Si
1–10	As Al Fe
0.1–1	Mg Ca
0.01–0.1	Ti Sr Ba

Occurrence and associated minerals: Coating on sandstone.

Identification:

Color, habit, fluorescence, and test for arsenate distinguish from all known uranium minerals except uranospinite [$Ca(UO_2)_2(AsO_4)_2.8\text{–}12H_2O$].

X-ray powder pattern similar to that of saléeite.

Localities:

Laguna, Grants district. This is the only known occurrence in North America, second in world (found by T. W. Stern, 1952).

PHOSPHURANYLITE

$Ca(UO_2)_7(PO_4)_4(OH)_4 \cdot 10H_2O$ (?)[6]

Crystal system: Tetragonal or pseudotetragonal

Habit: As earthy or scaly coatings or crusts, also as microscopic rectangular plates and laths.

Physical properties:

Color: Deep yellow to golden yellow.
Fluorescence: Variable.
Luster: Pearly.
Cleavage: {001} perfect but not easily observed.
Hardness: 2½.
Specific gravity:
Strongest lines of X-ray powder pattern: S 7.9, M 5.83, M 3.92, M 2.88.

Optical properties: variable.

ORIENTATION	*n*	PLEOCHROISM	
X or *E*	1. 660–1. 690	Colorless to pale yellow.	Usually biaxial negative. $2V$ usually 5–20° (as much as 35°) $r > v$ strong.
Y	1. 700–1. 718	Golden yellow.	
Z or *O*	1. 701–1. 718	Golden yellow	

Analysis: No analyses of pure material; mineral commonly admixed with clay.

Occurrence and associated minerals: Disseminated in sandstone or as coating on fracture.

Identification: X-ray powder pattern. The optical properties are variable and the mineral is usually too fine grained to exhibit a typical crystal form.

Localities:

North Point–Gonway claim, White Canyon district.
Posey mine, White Canyon district.
Cobalt No. 2 mine, Thompsons district.
Cactus Rat mine, Thompsons district.
Grey Dawn mine, Paradox district.
Mineral Ten claim, Green River district.

RABBITTITE[7]

$Ca_3Mg_3(UO_2)_2(CO_3)_6(OH)_4 \cdot 18H_2O$

Crystal system: Monoclinic.

Habit: Fibrous or finely acicular, in clusters of microscopic crystals; elongated [001].

Physical properties:

Color: Pale greenish yellow.
Fluorescence: Weak.
Luster: Silky.

[6] Personal communication, C. Frondel, 1953.

[7] Thompson, M. E., Weeks, A. D., and Sherwood, A. M., 1954 Rabbittite, a new uranyl carbonate from Utah: U. S. Geol. Survey Trace Elements Inv. Rept. 405.

Cleavage: {001}.
Hardness: Soft.
Specific gravity: Approximately 2.5.
Strongest lines of X-ray powder pattern: S 8.1, M 11.1, M 4.37.

Optical properties:

ORIENTATION	n	
X	1.502 ± 0.005	Biaxial positive (?) $2V$
$Y=b$	1.508 ± 0.005	large.
$Z \wedge c \approx 15°$	1.525 ± 0.003	

Analysis: Chemical analysis of material from Lucky Strike No. 2 mine, in percent. Analyst, A. M. Sherwood:

CaO	MgO	UO_3	CO_2	H_2O	Total
10.6	9.2	37.4	17.8	24.5	99.5

Occurrence and associated minerals: Efflorescent coating on mine wall near portal; with gypsum, sphaerocobaltite, bieberite, and uranium sulfates.

Identification: Habit, optical properties. Effervesces in HCl. Slowly soluble in water.

Locality:

Lucky Strike No. 2 mine, San Rafael district, Utah. Specimen collected by M. E. Thompson. Named for John C. Rabbitt, chief, Trace Elements Section, U. S. Geological Survey, 1947–53.

RAUVITE

$CaO \cdot 2UO_3 \cdot 5V_2O_5 \cdot 16H_2O$ (?)

Crystal system:

Habit: As dense slickensided masses, botryoidal crusts, filmy coatings commonly showing shrinkage cracks, and interstitial filling.

Physical properties:

Color: Commonly brownish red to purplish black; less commonly dirty orange-yellow. Streak yellow-brown.
Fluorescence: None.
Luster: Adamantine to waxy.
Cleavage: None.
Hardness: Ranges from waxy and sectile to brittle and glassy.
Specific gravity: 2.92 (for analyzed material, Monument No. 2 mine).
Strongest lines of X-ray powder pattern: VS 10.5, M (broad) 2.95, M 3.48, M 3.35.

Optical properties: Variable, from low birefringence with n about 1.89 to high birefringence, with indices approaching those of carnotite; poorly crystalline

$n=1.89-1.95$ Biaxial negative (?)

Analysis: Chemical analysis, in percent, of material from Monument No. 2 mine. Analyst, A. M. Sherwood:

UO_3	V_2O_5	V_2O_4	CaO	Al_2O_3	Acid insol.	Total H_2O	Total
31.49	48.28	1.44	2.76	0.70	0.61	15.49	100.77

Occurrence and associated minerals: Probably an alteration product of pitchblende and low-valence vanadium oxides; also possibly of tyuyamunite. Association and occurrence as for tyuyamunite; not so common as tyuyamunite.

Identification: X-ray powder pattern. Rauvite is very fine grained, and extremely variable in physical properties.

Localities:

Hummer mine, Bull Canyon district.
Corvusite mine, Gateway district.
Small Spot mine, Gateway district.
Road Hog 3A claim, Coal Canyon, Fall River County, S. Dak.
Monument No. 2 mine, Monument Valley district.
Temple Mountain, San Rafael district.
Arrowhead mine, Gateway district.
Cactus Rat mine, Thompsons district.

SCHROECKINGERITE

$$NaCa_3(UO_2)(CO_3)_3(SO_4)F\cdot 10H_2O$$

Crystal system: Orthorhombic [8]. Pseudohexagonal.

Habit: As clusters or globular aggregates of scales flattened {001}, some with a six-sided outline.

Physical properties:

Color: Greenish yellow.
Fluorescence: Strong, greenish yellow.
Luster: Weakly vitreous, sometimes pearly.
Cleavage: {001} perfect.
Hardness: 2½.
Specific gravity: 2.51.
Strongest lines of X-ray powder pattern: S 7.2, M 4.79, M 2.86.
Soluble in water, effervesces in HCl.

Optical properties:

ORIENTATION	n	PLEOCHROISM	
$X=c$	1.489	Very pale yellow	Biaxial negative
Y	1.542	Pale greenish yellow	$2V$ 0–25°
Z	1.542	Pale greenish yellow	

Analysis: Semiquantitative spectrographic analysis, in percent, of material from Red Desert, Wyo.:

More than 10	U Ca
0.1–1	F Na
0.01–0.1	Si Al Sr Zn Fe
0.001–0.01	K Ti Mg

Occurrence and associated minerals: In a near-surface deposit in clay at McCoy group, Thompsons district. As coating on mine wall, with bayleyite, at Hideout mine. As alteration product of pitchblende at Crabapple claim.

[8] C. Hurlbut, Personal communication, 1953.

Identification: If coarsely crystalline, six-sided plates and optical properties distinguish it from the other carbonates. Effervesces in HCl. Soluble in water. Positive sulfate test.

Localities:

McCoy group and Parco No. 25 mine in Yellow Cat group, Thompsons district.
Crabapple claim, Green River district.
Shinarump No. 3 mine, Green River district.
Hideout (Tiger) mine, White Canyon district.

TORBERNITE and METATORBERNITE

$Cu(UO_2)_2(PO_4)_2 \cdot 8\text{–}12H_2O$
Metatorbernite has $8H_2O$

(Metatorbernite probably more abundant in nature than torbernite)

Crystal system: Tetragonal; ditetragonal-dipyramidal *4/m 2/m 2/m*.
Habit: Tablets on {001}; often in rosettes or sheaflike aggregates of irregularly curved and composite crystals.
Physical properties:

Color: Pale green to dark green.
Fluorescence: Not commonly.
Luster: Vitreous; pearly on {001}.
Cleavage: {001} perfect. Rather brittle.
Hardness: 2½.
Specific gravity: Torbernite=3.2; metatorbernite=3.5—3.7.
Strongest lines of X-ray powder pattern of metatorbernite: VS 8.7, VS 3.68, M 4.93, M 3.49, M 3.35.

Optical properties:

Metatorbernite	Torbernite		
n	*n*	DICHROISM	
O 1.610–1.628 in white light	1. 592	Sky blue	Anomalous interference colors
E	1. 582	Green	
Uniaxial positive (?)	Uniaxial negative		

Analysis: Qualitative spectrographic analysis of material from Markey No. 3 mine:

Major	U
Minor	Cu Na Si P
Trace	Ca Mg As Fe

Occurrence and associated minerals: Crystalline aggregates on sandstone with metazeunerite, pyrite, chalcopyrite, chalcanthite, and alunite.
Identification: Color, crystal form, and absence of arsenic.
Localities:

Markey No. 3 mine, White Canyon district.
Grey Dawn mine, Paradox district.
Skyline mine, Monument Valley district.
Mineral Ten claim, Green River district.

TYUYAMUNITE and METATYUYAMUNITE

$Ca(UO_2)_2(VO_4)_2 \cdot 7\text{–}10\frac{1}{2}H_2O$

Crystal system: Orthorhombic.

Habit: As scales and laths flattened {001} and elongated [100]; as radial aggregates. Commonly massive, compact to cryptocrystalline; also pulverulent.

Physical properties:

Color: Yellow, greenish yellow (turns green on exposure to sunlight).
Fluorescence: None.
Luster: Of crystals adamantine; pearly on {001}; massive material waxy
Cleavage: {001} perfect, micaceous; {010} and {100} distinct.
Hardness: About 2.
Specific gravity: 3.62 (fully hydrated material).
Strongest lines of X-ray powder pattern:[9] S 9.9, M 4.93, M 3.29, M 3.16

Optical properties:

ORIENTATION	n	PLEOCHROISM	
$X=c$	1.57 calcd.	Nearly colorless	Biaxial negative
$Y=b$	1.805 ± 0.002	Pale canary yellow	$2V$ 42° $r<v$
$Z=a$	1.851 ± 0.002	Canary yellow	
			The indices increase on dehydration

Analysis: Chemical analysis, in percent, of material from Small Spot mine, Gateway district. Analyst, R. G. Milkey:

CaO	UO_3	V_2O_4	V_2O_5	H_2O	Total
6. 03	57. 08	0. 55	20. 31	16. 03	100. 00

Recalculated to 100 percent, after H_2O determination of fully hydrated sample.

Occurrence and associated minerals: Disseminated in sandstone. Coating joints and fractures, with metatyuyamunite, carnotite, rauvite, corvusite, and hewettite. At Mesa No. 1 mine, Shiprock district, with melanovanadite.

Identification: Tyuyamunite and carnotite can be distinguished from other yellow U minerals by the presence of vanadium: they will turn red-brown when a drop of concentrated HCl is touched to the mineral. X-ray powder pattern may be necessary to distinguish from carnotite and metatyuyamunite. When coarsely crystalline, may be distinguished optically. Fuses much more easily than carnotite.

Localities: Same as for carnotite. Abundant in Grants and Shiprock districts, with little carnotite.

Metatyuyamunite is a mineral with a formula like that of tyuyamunite, except for the number of water molecules, $Ca(UO_2)_2(VO_4)_2.5\text{–}7\ H_2O$. In general, its physical properties resemble very closely those

[9] Too vigorous grinding of tyuyamunite for a powder pattern destroys the structure.

of tyuyamunite. Its specific gravity is higher (3.81—3.93). Optically it is biaxial negative, but the indices of refraction are higher than tyuyamunite: $nX=1.67$ (calcd.), $nY=1.835$, $nZ=1.865$, $2V=44°$. The strongest lines of its X-ray powder pattern are S 8.4, M 4.21, M 3.24, M 3.04. These properties vary somewhat with minor changes in water content. Metatyuyamunite is found in the same districts as tyuyamunite, and is especially abundant near Haystack Mountain and Laguna, Grants district.

URANINITE (PITCHBLENDE)

Ideally UO_2 (commonly contains UO_3)

Crystal system: Isometric; hexoctahedral $4/m\ \bar{3}\ 2/m$ (?).
Habit: Massive. Commonly replaces cellular structure of wood.
Physical properties:

Color: Black.
Fluorescence: None.
Luster: Submetallic to pitchlike or greasy, and dull.
Cleavage: Fracture uneven to conchoidal. Brittle.
Hardness: 5–6.
Specific gravity: Uraninite 8–10. Colloform pitchblende less than 8.5.
Strongest lines of X-ray powder pattern: VS 3.14, S 1.65, S 1.93.

Optical properties: Usually opaque. Transparent in very thin splinters.

Analysis: Qualitative spectrographic analysis of pitchblende from Juniper claim:

Major	U
Minor	Si Ca
Trace	V Fe Na Mn

Spectrographic analysis of uraninite from Happy Jack shows not more than 1 percent of any element except uranium.

Occurrence and associated minerals: In unoxidized ore in mines located at the heads of steep canyons or under a protective cover. In vanadiferous ore uraninite is associated with a new black U mineral and low-valence vanadium oxides, montroseite, and others, and alters to rauvite, carnotite, and tyuyamunite, and rarely to becquerelite and uranophane. In nonvanadiferous ore, as at Happy Jack mine, uraninite is associated with sulfides of Fe, Cu, Pb, Zn, Co, and Ni and alters to becquerelite, fourmarierite, uranopilite, johannite, zippeite-like minerals, schroeckingerite and uranophane.

Identification: Black, high U content, very radioactive, commonly with yellow alteration products. X-ray powder pattern.

Localities:

MORRISON FORMATION

	District
Grey Dawn mine	Paradox
Juniper mine	Thompson
Corvusite mine	Gateway
Blue Jay mine	Moab

SHINARUMP CONGLOMERATE

Camp Bird No. 13 mine	San Rafael
Lucky Strike No. 2 mine	Do.
Marshbank Canyon mine	Do.
Pay Day mine	Do.
Rex No. 2 mine	Do.
Crabapple claim	Green River
Shinarump No. 1 mine	Do.
Oyler mine	Henry Mountains
Frey No. 4 mine	White Canyon
Happy Jack mine	Do.
Hideout mine	Do.
Markey No. 3 mine	Do.
Notch mine	Do.
White Canyon No. 1 mine	Do.
Cato Sells mine	Monument Valley
Monument No. 2 mine	Do.
Skyline mine	Do.

OTHER FORMATIONS

Haystack Mountain area	Grants
Placerville, Colo	Placerville
Huskon No. 2 claim	Little Colorado
Mi Vida mine	Monticello

URANOPHANE AND BETA-URANOPHANE

$Ca(UO_2)_2Si_2O_7 \cdot 6H_2O$

Crystal system: Orthorhombic.

Habit: Minute prismatic in radiated or stellate aggregates. Commonly massive and very finely fibrous.

Physical properties:

Color: Yellow, orange-yellow, streak paler.
Fluorescence: None.
Luster: Pearly to greasy.
Cleavage: {100}.

Hardness: 2–3.
Specific gravity: 3.8–3.9.
Strongest lines of X-ray powder pattern: S 7.9, S 3.95, M 4.82, M 2.98, M 2.92.

Optical properties:

ORIENTATION	n	PLEOCHROISM	
$X = a$	1.642–1.645	Colorless	Biaxial negative
$Y = b$	1.665–1.667	Pale canary yellow	$2V$ 32°
$Z = c$	1.667–1.670	Canary yellow	$r<v$ marked to extreme

Analysis: Partial chemical analysis in percent, by A. M. Sherwood; material from Lusk, Wyo.:

H_2O	SiO_2	CaO	UO_3	Total
13.02	12.66	8.53	65.24	99.45

Occurrence and associated minerals: Disseminated in sandstone at Pumpkin Buttes. At Grants coating limestone. At Cato Sells on pitchblende with becquerelite.

Identification: Absence of Cu distinguishes it from cuprosklodowskite; optical properties from other U minerals.

Localities:

Grants district; Cato Sells, Monument Valley district, Grey Dawn mine, Paradox district. Pumpkin Buttes and Lusk, Wyo.

Beta-uranophane is a dimorphous form of uranophane. It is monoclinic, and its habit is similar to that of uranophane. Optically it is biaxial negative; its indices of refraction are slightly higher (nX= 1.66—1.67, nY=1.67—1.70, nZ=1.68—1.71, $2V$=40°—70°); and its X-ray powder pattern is different. The strongest lines are VS 7.8, S 3.90, M 2.59. Beta-uranophane has not yet been identified from the Plateaus, by the writers but it may have been overlooked because it can be converted to uranophane by use of too much pressure in grinding.

URANOPILITE

$(UO_2)_6(SO_4)(OH)_{10}\cdot 12H_2O$

Crystal system: Probably monoclinic.

Habit: As velvety incrustations and globular or reniform masses composed of microscopic needles or laths elongated [001] and flattened {010}.

Physical properties:

Color: Bright yellow.
Fluorescence: Bright yellow-green.
Luster: Silky.
Cleavage: {010} perfect.
Hardness:
Specific gravity: 3.7–4.0.
Strongest lines of X-ray powder pattern: S 7.1, S 9.1, S 4.23.

Optical properties:

ORIENTATION	n	
X	1. 623	Biaxial negative
$Y \wedge c = 18°$	1. 625	$2V$ rather large (Na); 0° for some wavelengths
Z	1. 634	$r < v$ extreme; also $r > v$

Analysis: Qualitative spectrographic analysis of material from Happy Jack mine:

Major	U
Minor	—
Trace	Si Ca Co

Occurrence and associated minerals: Abundant in Happy Jack mine as wall coatings with johannite and zippeite-like minerals.

Identification: Test for sulfate and distinguish from zippeite and zippeite-like minerals by optical properties. From johannite by test for Cu.

Localities: Happy Jack mine, White Canyon district.

UVANITE [10]

$2UO_3 \cdot 3V_2O_5 \cdot 15H_2O$ (?)

Crystal system: Orthorhombic (?).

Habit: As minutely crystalline masses and coatings.

Physical properties:

Color: Brownish yellow.
Fluorescence: None.
Luster:
Cleavage:
Hardness:
Specific gravity:
Strongest lines of X-ray powder pattern: S 2.96, Mb 5.9, Mb 5.3, M 1.71 (b=broad).

Optical properties:

	n	PLEOCHROISM	
X	1. 817	Light brown	Biaxial positive
Y	1. 879	Dark brown	$2V = 52°$
Z	2. 057	Greenish yellow	

Analysis: Analyst, W. T. Schaller:

CaO	UO_3	V_2O_5	H_2O	Rem.	Total
1. 73	39. 60	37. 70	18. 28	1. 69	99. 00

Occurrence and associated minerals: Associated with carnotite, rauvite, hewettite, metatorbernite, hyalite, and gypsum in asphaltic sandstone at Temple Mountain, San Rafael district.

Identification: X-ray powder pattern (?). May be related to rauvite. Poorly defined mineral. Needs further work.

Locality: Temple Mountain, San Rafael district, Utah.

[10] Data from Dana system, 7th ed., v. 2, p. 1056, except X-ray powder pattern. No new localities found.

METAZEUNERITE

$Cu(UO_2)_2(AsO_4)_2 \cdot 8H_2O$

(Fully hydrated zeunerite probably rare in nature.)

Crystal system: Tetragonal; ditetragonal dipyramidal $4/m\ 2/m\ 2/m$.

Habit: Tabular {001} and resembling torbernite.

Physical properties:

Color: Grass green to emerald green.
Fluorescence: Yellow-green.
Luster: Vitreous, pearly on {001}.
Cleavage: {001} perfect. {100} distinct.
Hardness: 2–2½.
Specific gravity: 3.6.
Strongest lines of X-ray powder pattern: S 8.7, S 3.68, M 5.44, M 4.98.

Optical properties:

	n	DICHROISM	
O	1. 643—1. 651	Grass green	Uniaxial negative
E	1. 623—1. 635	Pale green	Indices vary with content of zeolitic water

Analysis: Qualitative spectrographic analysis of mineral from Markey No. 3 mine:

Major	U
Minor	Cu As Si
Trace	Co Fe Na Ca Pb

Occurrence and associated minerals: Coating joints and fracture surfaces.

Identification: Test for Cu and As, with green color, and habit as square plates.

Localities:

Markey No. 3 mine, White Canyon district.
Pay Day mine, San Rafael district.
Monument No. 2 mine, Monument Valley district.

ZIPPEITE-LIKE MINERALS

$(UO_2)_2(SO_4)(OH)_2 \cdot 4H_2O$

Crystal system: Orthorhombic. Some may be monoclinic.

Habit: Microscopic crystalline aggregates; rarely in blades or flakes.

Physical properties:

Color: Golden yellow to orange.

Fluorescence: Green. Some does not fluoresce.
Luster: Of aggregates dull to silky.
Cleavage: Probably {010} perfect.
Hardness: ≈2
Specific gravity: >3.2
Strongest lines of X-ray powder pattern:
S 7.14, M 3.56, M 3.47, M 3.12 (from Lucky Strike No. 2 mine); S 7.31, M 3.66, M 3.49, M 3.15 (from Oyler mine).

Optical properties:

ORIENTATION	*n* (Sample from Oyler mine)	*n* (Sample from Lucky Strike No. 2 mine)	PLEOCHROISM	
$X=b$	1.630		Pale yellow	Biaxial negative
Y	1.689	≈1.75	Yellow	$2V$ large (80°)
Z	1.739	≈1.86	Darker yellow	Indices vary widely. Some samples are apparently monoclinic, with $Z \wedge C \approx 40°$

Analysis: Chemical analysis, in percent, of material from Oyler mine. Analyst, A. M. Sherwood:

UO_3	SO_3	H_2O	CaO	Total
78.78	10.42	11.20	0.07	100.47

Occurrence and associated minerals: In mines as wall coatings, as joint and fracture coatings. Alone, or with johannite, uranopilite, or pitchblende.

Identification: A sulfate containing no Cu. May be distinguished optically from uranopilite. X-ray powder pattern varies.

Localities:
Happy Jack mine, White Canyon district.
Oyler mine, Henry Mountains district.
Lucky Strike No. 2 mine, San Rafael district.
Sodaroll claim, Green River district.

It is not known why the optical properties, X-ray powder pattern, and fluorescence vary. This description may include more than one mineral, polymorphous forms of the same mineral, or different hydration states of the same mineral.

TABLE 1.—*Optical properties of uranium minerals*

Uniaxial positive group

Indices and dichroism		*Name and composition*	*System and habit*	*Cleavage*	*Color*	*Remarks*
nE	nO					
1.540 Pale yellow	1.520 Colorless	Andersonite $Na_2Ca(UO_2)(CO_3)_3 \cdot 6H_2O$	Hex.—*R*. Minute pseudo-cubic crystals		Bright yellow-green. Fluoresces bright green	Effervesces with HCl
	1.610-1.628	Metatorbernite $Cu(UO_2)_2(PO_4)_2 \cdot 8H_2O$	Tet. Tablets on {001}	{001} perfect	Pale to dark green	

Uniaxial negative group

1.489	1.542	Schroeckingerite $NaCa_3(UO_2)(CO_3)_3(SO_4)F \cdot 10H_2O$	Pseudo-hex.	{0001} perfect	Greenish yellow. Fluoresces strong greenish yellow	Soluble in H_2O, effervesces in HCl
1.559 Colorless	1.574 Pale green-yellow	Saléeite $Mg(UO_2)_2(PO_4)_2 \cdot 8\text{–}10H_2O$	Tet. Tablets on {001}	{001} perfect {010}, {110} indistinct	Yellow to lemon yellow	
1.582 Green	1.592 Sky blue	Torbernite $Cu(UO_2)_2(PO_4)_2 \cdot 8\text{–}12H_2O$	Tet. Tablets on {001}	{001} perfect	Pale to dark green	
1.623–1.635 Pale green	1.643–1.651 Grass green	Metazeunerite $Cu(UO_2)_2(As O_4)_2 \cdot 8H_2O$	Tet. Tablets on {001}	{001} perfect {100} distinct	Grass green to emerald green	
1.66–1.69 Colorless to pale yellow	1.701–1.718 Golden yellow	Phosphuranylite $Ca(UO_2)_7(PO_4)_4(OH)_4 \cdot 10H_2O$ (?)	Tet. or pseudotet.	{001} perfect; not easily observed	Deep yellow to golden yellow	

Biaxial positive group

Indices and pleochroism			*Name and composition*	*2V, disp.*	*Optical orientation*	*System, habit*	*Cleavage*	*Color*
nX	nY	nZ						
1.497 Nearly colorless	1.502 Pale yellowish green	1.539 Pale yellowish green	Liebigite $Ca_2U(CO_3)_4 \cdot 10H_2O$	$2V = 40°$ $r > v$ moderate	$X = a$	Orth. Equant or short prismatic	{100}	Light greenish yellow
1.502	1.508	1.525	Rabbittite $Ca_3Mg_3(UO_2)_2(CO_3)_6(OH)_4 \cdot 18H_2O$	$2V$ large	$Y = b$ $Z \wedge c \approx 15°$	Mon. Acicular	{001}	Pale greenish yellow
1.577 Colorless	1.597 Pale yellow	1.616 Greenish yellow	Johannite $Cu(UO_2)_2(SO_4)_2(OH)_2 \cdot 6H_2O$	$2V \approx 90°$ $r < v$ strong		Tricl. Prismatic	{100} good	Clear, light green
1.623	1.625	1.634	Uranopilite $(UO_2)_6(SO_4)(OH)_{10} \cdot 12H_2O$	$2V$ large for Na; 0°-some wavelengths	$Y \wedge c = 18°$	Mon. ?	{010} perfect	Bright yellow. Fluoresces bright yellow green
1.817 Light brown	1.879 Dark brown	2.057 Greenish yellow	Uvanite $2UO_3 \cdot 3V_2O_5 \cdot 15H_2O$ (?)	$2V = 52°$		Orth. ?	Two pinacoidal	Brownish yellow

Biaxial negative group

1.455 Pinkish	1.490 Pale yellow	1.500 Pale yellow	Bayleyite $Mg_2(UO_2)(CO_3)_3 \cdot 18H_2O$	$2V = 30°$	$X \wedge c = 14°$ $Z = b$	Mon. Pris.		Sulfur yellow
1.465 Colorless	1.51 Yellow	1.540 Yellow	Swartzite $CaMg(UO_2)(CO_3)_3 \cdot 12H_2O$	$2V = 40°$ (calcd.)		Mon. Pris.		Green Fluoresces green

1.489	1.542	1.542	Schroeckingerite $NaCa_3(UO_2)(CO_3)_3(SO_4)F\cdot 10H_2O$	0–25°		Orth. Pseudo-hex.	{001} perfect	Yellow-green. Fluoresces strong yellow-green.
1.559	1.570	1.570	Saléeite $Mg(UO_2)_2(PO_4)_2\ 8–10H_2O$	$2V=61°$ $r>v$ strong		Tet. Square plates	{001} perfect {010} and {110} indistinct	Yellow to lemon yellow.
1.56± Pale yellow	1.574 Deep yellow	1.580 Deep yellow	Bassetite $Fe(UO_2)_2(PO_4)_2\cdot 8H_2O$	$2V\approx 52°$	$X=b$ $Z\wedge c=40°$	Mon. Pseudo-orth.	{010} perfect	Yellow
1.553 Pale yellow (Indices vary with water content)	1.575 Yellow	1.577 Yellow	Autunite $Ca(UO_2)_2(PO_4)_2\cdot 10–12H_2O$	$2V=10°–30°$ $r>v$ strong	$X=c$	Tet. Square plates	{001} perfect {100} indistinct	Lemon yellow to pale green. Fluoresces yellow-green strong.
	1.603 Yellow (Indices vary with water content)	1.603 Yellow	Meta-autunite I $Ca(UO_2)_2(PO_4)_2\cdot 2½–6½H_2O$	$2V$ small to medium	$X=c$	Tet.	{001} perfect	Same as autunite.
	1.620–1.623	1.620–1.623	Novacekite $Mg(UO_2)_2(AsO_4)_2\cdot 8–10H_2O$	$2V=0°–15°$	$X=c$	Tet. Square plates	{001} perfect	Straw yellow. Fluoresces pale yellow-green.
1.654 Very pale greenish yellow	1.664–1.667 Pale greenish yellow	1.664–1.667 Pale greenish yellow	Cuprosklodowskite $Cu(UO_2)_2Si_2O_7\cdot 6H_2O$	$2V$ small $r>v$ strong	$Z=c$	Orth. Prism.	{100} and {010}	Pale yellow-green; yellow in thin crystals.
1.642–1.645 Colorless	1.665–1.667 Pale yellow	1.667–1.670 Canary yellow	Uranophane $Ca(UO_2)_2Si_2O_7\cdot 6H_2O$	$2V=32°$ $r<v$ marked to extreme	$X=a$ $Y=b$ $Z=c$	Orth. Prism.	{100}	Yellow to orange-yellow.
1.650 Colorless	1.68 Pale greenish yellow	1.710 Greenish yellow	Soddyite $(UO_2)_5(SiO_3)_2(OH)_6\cdot 3H_2O$	$2V$ near 90° $r>v$ strong	$X=a$ $Y=b$ $Z=c$	Orth. Prism.	{010} and {100}	Yellow to greenish yellow.
1.66–1.67 Colorless	1.67–1.70 Lemon yellow	1.68–1.71 Lemon yellow	Beta-uranophane $Ca(UO_2)_2Si_2O_7\cdot 6H_2O$	$2V=40°–70°$ $r>v$ strong	$X=b$	Mon. Acicular	{010} and {100} perfect	Yellow to yellow-green.
1.630 Nearly colorless	1.689 Pale yellow to orange-yellow	1.739 Pale yellow to orange-yellow	Betazippeite $(UO_2)_2(SO_4)(OH)_2\cdot 4H_2O$	$2v$ large (80°)	$X=b$ $Z\wedge Nc=40°$	Mon. Prism.	{010} perfect	Orange-yellow.
1.690 Colorless	1.714 Lemon yellow	1.735 Lemon yellow	Schoepite $UO_3\cdot 2H_2O$	$2V=89°$ $r>v$	$X=c$ $Y=b$ $Z=a$	Orth. Tabular {001}	{001} perfect	Sulfur to citron yellow.
1.660–1.690 Colorless to pale yellow	1.700–1.718 Golden yellow	1.701–1.718 Golden yellow	Phosphuranylite $Ca(UO_2)_7(PO_4)_4(OH)_4\cdot 10H_2O$(?)	$2V=5°–20°$ (Max. 35°) $r>v$ strong	$X=c$	Tet. or pseudo tet.	{001} perfect	Deep yellow to golden yellow.
1.57 (Calcd.) Nearly colorless	1.805 Pale canary yellow	1.851 Canary yellow	Tyuyamunite $Ca(UO_2)_2(VO_4)_2\cdot nH_2O$ $n=7–10½$	$2V=42°$ $r<v$	$X=c$ $Y=b$ $Z=a$	Orth.	{001} perfect {010} {100} distinct	Yellow to greenish yellow.
1.735 Colorless	1.820 Light yellow	1.830 Dark yellow	Becquerelite $2UO_3\cdot 3H_2O$	$2V=31°$ $r>v$ marked	$X=c$ $Y=b$ $Z=a$	Orth. Tabular {001}	{001} perfect also {101}	Amber to brownish yellow.
1.67 (Calcd.)	1.835	1.865	Metatyuyamunite $Ca(UO_2)_2(VO_4)_2\cdot nH_2O$ $n=5–7$	$2V=44°$	$X=c$ $Y=b$ $Z=a$	Orth.	{001} perfect {010} {100} distinct	Yellow to greenish yellow.
	1.89–1.95		Rauvite $CaO\cdot 2UO_3\cdot 5V_2O_5\cdot 16H_2O$ (?)			Minutely crystalline		Yellow to brownish red.
1.85 Colorless	1.92 Pale yellow	1.94 Yellow	Fourmarierite $PbU_4O_{13}\cdot 7H_2O$	$2V$ large $r>v$ strong	$X=c$ $Y=b$ $Z=a$	Orth. Tabular {001}	{001} perfect	Red to golden red, brown.
1.750 Nearly colorless	1.925–2.06 Canary yellow	1.950–2.08 Canary yellow	Carnotite $K_2(UO_2)_2(VO_4)_2\cdot 1–3H_2O$	$2V=40°–50°$	$X\approx c$ $Y\wedge a\approx 14°$ $Z=b$	Mon.	{001} perfect	Lemon yellow to greenish yellow (orange).

VANADIUM MINERALS

The vanadium minerals described in the following pages (except the uranyl vanadates described under uranium minerals) include all those studied by the writers and thought to be valid species from the Colorado Plateaus.

Classified according to chemical composition the described minerals are:

Oxides:	Montroseite VO(OH) or (V,Fe)O(OH)
	Navajoite $V_2O_5 \cdot 3H_2O$
	New vanadium oxide probably V^{+3} and V^{+4}, hydrated
	New vanadium oxide $V_2O_3 \cdot V_2O_4 \cdot H_2O$
Vanadates:	Calciovolborthite $(Cu,Ca)_2(VO_4)(OH)$
	Volborthite $Cu_3(VO_4)_2 \cdot 3H_2O$ (?)
	Fervanite $Fe_4V_4O_{16} \cdot 5H_2O$
	Steigerite $Al_2(VO_4)_2 \cdot 6\frac{1}{2}H_2O$
	Rossite $CaV_2O_6 \cdot 4H_2O$
	Metarossite $CaV_2O_6 \cdot 2H_2O$
	Pascoite $Ca_2V_6O_{17} \cdot 11H_2O$
	Hummerite $K_2Mg_2V_{10}O_{28} \cdot 16H_2O$
	Melanovanadite $2CaO \cdot 2V_2O_4 \cdot 3V_2O_5 \cdot H_2O$ (?)
	Hewettite $CaV_6O_{16} \cdot 9H_2O$
	Metahewettite $CaV_6O_{16} \cdot 9H_2O$
	Sodium analogue of hewettite $Na_2V_6O_{16} \cdot 3H_2O$ (?)
	Corvusite $V_2O_4 \cdot 6V_2O_5 \cdot nH_2O$ (?) (similar to fernandinite $CaO \cdot V_2O_4 \cdot 5V_2O_5 \cdot 14H_2O$)
Silicates:	Roscoelite $(Al,V)_2(AlSi_3)(K,Na)O_{10}(OH,F)_2$
	Vanadium hydromica

Confusion exists about the names hewettite and metahewettite, originally described (Hillebrand, Merwin, and Wright, 1914) as having different optical properties and dehydration properties but the same chemical formula, $CaO \cdot 3V_2O_5 \cdot 9H_2O$. The type specimens in the U. S. National Museum, hewettite from Peru and metahewettite from southeast of Thompsons, Utah, have now dehydrated to $CaO \cdot 3V_2O_5 \cdot 3H_2O$ and give the same X-ray powder pattern. Recent investigation of vanadium ores from the Colorado Plateaus indicates at least two hydrates of calcium vanadate in nature, one with $9H_2O$ and one with $3H_2O$, but the writers have not found material with the optical properties given for metahewettite (Hillebrand, Merwin, and Wright, 1914). The natural vanadate with $9H_2O$ can be dehydrated readily in the laboratory with loss of $6H_2O$. During rehydration from the $3H_2O$ form to the $9H_2O$, an intermediate stage was observed, possibly with $6H_2O$ (this first observed by Barnes and Qurashi, personal communication, 1953). Although each of the hydrates has a distinct X-ray powder pattern, only the $3H_2O$ hydrate is abundantly found.

Two mineral species originally described from the Colorado Plateaus, vanoxite (Hess, 1925) and pintadoite (Hess and Schaller, 1914) are

omitted. The name vanoxite has been used for a variety of vanadium minerals. The composition of vanoxite had been calculated from a rock analysis of sandstone ore from the Jo Dandy mine, Colorado, after deducting quartz, gypsum, tyuyamunite, and limonite. The "type" specimen in the U. S. National Museum came from Wild Steer mine, Colorado, and was not analyzed. X-ray powder patterns of this "type" specimen are similar to those of corvusite and fernandinite. The black crystals observed in thin sections (Hess, 1925, p. 65) may have been montroseite. The description of pintadoite is so incomplete that no more of the mineral can be recognized. No X-ray pattern could be obtained from the National Museum sample of pintadoite which appears as a faint green stain on sandstone.

In 1950 when X-ray powder patterns were made to obtain standards of all the vanadium minerals, it was found that corvusite (USNM type specimen) and fernandinite (W. T. Schaller's type specimen) gave similar patterns. Further study showed a variation in properties and X-ray powder pattern among specimens of both species, and the investigation is still in progress. The chief difference between the minerals seems to be the presence of several percent of calcium in fernandinite and little or none in corvusite.

Another vanadium mineral that may be found although it has not yet been identified on the Plateaus is sincosite $CaV_2O_2(PO_4)_2 \cdot 5H_2O$, originally described from Peru and known to occur in the Phosphoria formation in Idaho (W. T. Schaller, personal communication, 1952).

CORVUSITE

$V_2O_4 \cdot 6V_2O_5 \cdot nH_2O$ (?)

(Resembles fernandinite $CaO \cdot V_2O_4 \cdot 5V_2O_5 \cdot 14H_2O$)

Crystal system:

Habit: Massive. Very finely crystalline. Slickensided surfaces appear fibrous. Finely columnar coatings on pebbles and sand grains.

Physical properties:

Color: Blue-black to greenish black. Greenish-black streak. Weathers brown.

Fluorescence: None.

Luster: Variable.

Cleavage: Fracture conchoidal.

Hardness: 2½–3.

Specific gravity: 2.82 (?).

Strongest lines of X-ray powder pattern: VS 12.1, M 3.47, W 1.83, VW 1.95.

Optical properties: Opaque except on thin edges, green when finely ground; biaxial, 2 indices above 1.90, high birefringence.

Analysis: Qualitative spectrographic analysis of X-ray spindle of type material:

Major	V
Minor	Fe
Low minor	Si Al

Occurrence and associated minerals: Impregnating sandstone and siltstone. Masses of relatively pure material are commonly slickensided. May be an alteration product of low-valence vanadium oxides. Associated with carnotite, tyuyamunite, rauvite, and hewettite. May alter to navajoite.

Identification: In hand specimen, black, commonly with blue-black iridescence, and greenish streak. When finely ground on glass slide, forms green waxy smear which easily distinguishes it from montroseite. X-ray powder pattern resembles that of fernandinite. (The corvusite-fernandinite minerals are being investigated, 1954.)

Localities: Abundant in mines in Thompsons, Gateway, Uravan, Paradox, Bull Canyon, and Slick Rock districts, in the Temple Mountain part of the San Rafael district, and at Monument No. 2 mine in Monument Valley district.

FERVANITE

$Fe_4V_4O_{16}\cdot 5H_2O$

Crystal system: Probably monoclinic.

Habit: Parallel fibrous aggregates.

Physical properties:

Color: Golden brown.

Fluorescence:

Luster: Brilliant.

Cleavage:

Hardness:

Specific gravity: 3.28 (measured on sample from Tiny mine).

Strongest lines of X-ray powder pattern: S 6.46, M 8.83, M 2.94.

Optical properties:

	n	
X	2.186 ± 0.005	Biaxial negative
Y	2.222 ± 0.005	$2V$ very small
Z	2.224 ± 0.005	

Analysis: Qualitative spectrographic analysis on sample from Tiny mine:

Major	Fe V
Minor	Si
Trace	Ba Mg Ca

Occurrence and associated minerals: Coatings and fracture fillings; with hewettite, metahewettite, steigerite, carnotite, and tyuyamunite.

Identification: Lighter brown color and higher indices of refraction than fibrous hewettite and navajoite.

Localities: Tiny mine, Gypsum Valley district; Hummer mine, Bull Canyon district; Fox mine in Dolores group, Uravan district; and Polar Mesa, Gateway district. Location of first occurrence in Gypsum Valley not described specifically by Hess and Henderson (1931).

HEWETTITE

$CaV_6O_{16}\cdot 9H_2O$

Crystal system: Monoclinic.[11]

Habit: As nodular aggregates and coatings of fibers or microscopic needles; elongated [010].

Physical properties:

Color: Deep red; less vivid on exposure in dry atmosphere.
Fluorescence: None.
Luster: Silky, adamantine.
Cleavage:
Hardness: Soft.
Specific gravity: 2.55.
Strongest lines of X-ray powder pattern: Fully hydrated VS 11.12, M 5.59, M 3.11, M 3.69; dehydrated ($3H_2O$) VS 8.2, M 3.06, M 2.29, M 2.20.

Optical properties:

ORIENTATION	n [12]	PLEOCHROISM	
X	1. 77	Light orange-yellow	Biaxial negative. Indices probably vary according to water content.
Y	2. 18	Light orange-yellow	
$Z=b$	2. 35–2. 4	Dark red	

Analysis: Chemical analysis of material from Hummer mine, Jo Dandy group. Analyst, A. M. Sherwood:

SiO_2	Al_2O_3	CaO	MgO	V_2O_4	V_2O_5	SO_3	HO_2	Total
0. 46	0. 13	6. 38	1. 61	8. 07	73. 15	0. 01	10. 12	99. 93

Occurrence and associated minerals: As coatings and fracture fillings; alteration product of less oxidized vanadium minerals: montroseite, corvusite. Associated with vanadium clay, rauvite, steigerite, fervanite, navajoite, carnotite, tyuyamunite, and others.

Identification: Color except from metahewettite and sodium analogue of hewettite. The nature of the difference between hewettite and metahewettite is not fully understood. Hewettite readily loses water unless sealed in a moist atmosphere and changes to a lower hydrate with $3H_2O$. The structures of these minerals are being investigated by W. H. Barnes, National Research Council, Canada.

[11] Barnes, W. H., and Qurashi, M. M., 1952, p. 414.
[12] Hillebrand, Merwin, and Wright, 1914, on fully hydrated hewettite.

Localities: Jo Dandy group, Bull Canyon district; Opera Box mine, Bull Canyon district; Matchless mine, Gateway district; Monument No. 2 mine, Monument Valley district; Grey Dawn mine, Paradox district; Fox mine, Uravan district; and Tiny mine, Gypsum Valley district.

METAHEWETTITE

$CaV_6O_{16}.9H_2O$ (?)

Crystal system: Monoclinic.[13]

Habit: As pulverulent masses composed of microscopic tablets or laths, and as parallel or radially fibrous to bladed aggregates or coatings; elongated [010].

Physical properties:

Color: Deep red; less vivid on exposure in dry atmosphere.
Fluorescence: None.
Luster: Dull to somewhat silky.
Cleavage:
Hardness: Soft.
Specific gravity: 2.51–2.94, varies with water content.
Strongest lines of X-ray powder pattern: S 8.1, M 3.08, W 1.80.

Optical properties:

ORIENTATION	n(Li) [14]	PLEOCHROISM	
X	1. 70	Light orange-yellow	Biaxial negative.
Y	2. 10	Deep red	$2V$ 52° calcd.
$Z=b$	2. 23	Deeper red	Indices probably vary according to water content.

Analysis: Qualitative spectrographic analysis of type material:

Major	V
Minor	Si Ca Fe Al
Trace	K Mg Na Nb Ba Pb

Occurrence and associated minerals: In highly oxidized ore; same as for hewettite.

Identification: Color, except from hewettite, and sodium analogue of hewettite. U. S. Nat. Mus. type material gives same X-ray pattern as hewettite. (See hewettite and discussion on p. 46.)

Locality: Yellow Cat group, Thompsons district. Although reported from Cactus Rat group, Thompsons district, several specimens from there are known to be sodium rather than calcium vanadate

HUMMERITE [15]

$K_2Mg_2V_{10}O_{28}.16H_2O$

Crystal system: Triclinic.

Habit: Finely crystalline aggregates or massive. Crystals formed by evaporation of water solution are elongated parallel to [001] or tabular parallel to {100}.

[13] Barnes, W. H., and Qurashi, M. M., 1952, p. 411.

[14] Reported by Hillebrand, Merwin, and Wright (1914) on fully hydrated metahewettite but not found in recent study of "metahewettite."

[15] First collected by Stieff, Stern, and Girhard in 1949 from the Hummer workings of Jo Dandy group of mines and studied by Weeks, Cisney, and Sherwood (1950). Named from the first locality.

Physical properties:

Color: Bright orange; may develop greenish tint on exposure to sunlight. Streak yellow.
Fluorescence: None.
Luster: Subadamantine on fresh surface, dulls on exposure.
Cleavage: {010} and {001} distinct. Brittle.
Hardness: About 2.
Specific gravity: 2.55.
Strongest lines of X-ray powder pattern: VS 8.3, M 9.7, M 2.76, W 7.5.

Optical properties:

ORIENTATION	n	
X	1.771 ± 0.003	Biaxial negative
Y	1.812 ± 0.003	$2V$ 70°.
$Z \wedge c = 32°$	1.833 ± 0.003	Dispersion strong $r > v$

Analysis: Chemical analysis of recrystallized material from North Star mine:

V_2O_5	V_2O_4	MgO	K_2O	Total H_2O	Total
64.33	1.36	5.44	6.96	21.88	99.97

Occurrence and associated minerals: As vein fillings with columnar structure perpendicular to the vein wall (similar to occurrence of gypsum in seams). Also as granular crusts coating or cementing sandstone, in highly oxidized ore zone.
Associated with hewettite and vanadium clay.

Identification: X-ray powder pattern or spectrographic analysis necessary to distinguish from pascoite. Orange color and solubility in water distinguish from all others.

Localities: Jo Dandy group, Bull Canyon district; North Star mine, Uravan district; Mesa No. 1 mine, Shiprock district and Whitney mine. Uravan district.

MELANOVANADITE

$2CaO.2V_2O_4.3V_2O_5$ (probably contains H_2O[16])

Crystal system: Triclinic.[16]

Habit: Velvety, divergent bunches of crystals elongated [001]; the prism faces usually rounded or striated.

Physical properties:

Color: Black; streak dark reddish brown.
Fluorescence: None.
Luster: Almost submetallic.
Cleavage: {010} perfect. Brittle.
Hardness: 2½.
Specific gravity: Commonly less than 3.0.
Strongest lines of X-ray powder pattern: VS 8.5, S 4.21, M 2.99.

[16] Barnes, W. H., and Qurashi, M. M., 1952, p. 417.

Optical properties:

ORIENTATION	n	PLEOCHROISM	
X	1. 73	Light reddish brown	Biaxial negative.
$Y \wedge c$ 15°	1. 96	Deep reddish brown	$2V$ medium
Z	1. 98	Dark reddish brown	

Analysis: Qualitative spectrographic analysis of material from Mesa No. 1 mine, Ariz.:

Major	V
Minor	Ca Fe
Trace	Si Al Na Mg

Occurrence and associated minerals: At Mesa No. 1 mine, coarsely crystalline aggregates in clay with marcasite. At Mesa No. 5 mine, impregnating sandstone. At Juniper mine rosettes on fracture in sandstone. In oxidized ore associated with tyuyamunite, pascoite, hummerite, and rossite. The first occurrence of melanovanadite in the United States was at Mesa No. 1 mine found by A. Rosenzweig of Atomic Energy Commission in 1951.

Identification: Distinguished from montroseite and other low-valence vanadium minerals by pleochroism and by low specific gravity.

Localities: Mesa No. 1 mine, Shiprock district, Mesa No. 5 mine, Shiprock district, and Juniper mine, Thompsons district.

MONTROSEITE [17]

VO(OH) or (V,Fe)O(OH)

Crystal system: Orthorhombic, dipyramidal.

Habit: Microscopic bladed and prismatic crystals. Also in compact crystalline aggregates.

Physical properties:

Color: Black; streak black.
Fluorescence: None.
Luster: Submetallic.
Cleavage: Perfect parallel {100}. Brittle.
Hardness: Soft.
Specific gravity: 4.0 (meas.) 4.1 (calcd.)
Strongest lines of X-ray powder pattern: S 4.29, M 2.65, W 3.39.

Optical properties: Opaque (even on thin edges).

Analysis: Partial chemical analysis of 120 mg of material from Bitter Creek mine:

FeO	V_2O_3	V_2O_4	H_2O	Total
8. 8	10. 5	72. 3	5. 0	96. 6

[17] First collected by Stieff, Stern, and Girhard in 1949 from Bitter Creek mine. Described by Weeks, Cisney, and Sherwood (1953). Crystal structure study by H. T. Evans and S. Block (1953) showed the correct formula to be as given above. Named from Montrose County, Colo., where Bitter Creek mine is located.

Occurrence and associated minerals: Occurs in unoxidized, black, uranium-vanadium ore, impregnating sandstone or as relatively pure masses in sandstone, associated with pyrite, barite, pitchblende and a new black U mineral. In oxidized zone alters to corvusite and hewettite.

Identification: X-ray powder pattern. Distinguished from other low-valence V minerals by blacker color and from melanovanadite and corvusite by greater density, opacity, and blacker streak.

Localities: Bitter Creek mine, Whitney mine, and Virgin mine, Uravan district; Matchless mine, Gateway district; Juniper mine, Thompsons district; Rex No. 2 mine, Temple Mountain portion of San Rafael district, Mi Vida mine, Monticello district.

NAVAJOITE

$V_2O_5 \cdot 3H_2O$

Crystal system: Monoclinic (?).

Habit: Fibrous, silky, elongated [010].

Physical properties:

Color: Dark brown; brown streak.
Fluorescence: None.
Luster: Silky
Cleavage:
Hardness: Soft.
Specific gravity: 2.56 measured.
Strongest lines of X-ray powder pattern: VS 12.1, M 10.7, M 2.91.

Optical properties:

ORIENTATION		PLEOCHROISM	
X	1.905 ± 0.003	Yellowish brown	Biaxial negative
Y	≈ 2.02	Light yellowish brown	
$Z=b$	>2.02	Dark brown	

Analysis: Of sample from Arizona. Analyst: A. M. Sherwood.

V_2O_5	V_2O_4	Fe_2O_3	CaO	SiO_2	H_2O	Total
71.68	3.08	3.58	0.22	1.20	20.3	100.06

Occurrence and associated minerals: Fibrous coating in crescent shape above and below pebbles in conglomerate; cross fibers 1/16 to 1/8 inch long filling fractures in sandstone or siltstones; with rauvite, corvusite, steigerite, and hewettite.

Identification: Darker brown and higher indices of refraction than hewettite. X-ray powder pattern.

Locality: Monument No. 2 mine, Monument Valley district, Arizona. Mineral named for Navajo Indian Reservation on which the Monument No. 2 mine is located. First sample collected by A. Rosenzweig, Atomic Energy Commission, in 1951. Material for chemical analysis and X-ray study collected by A. D. Weeks 1951 and 1952. Described by Weeks, Thompson, and Sherwood (1954).

NEW VANADIUM OXIDE

(probably V^{+3} and V^{+4}, hydrated)

Crystal system:

Habit: Massive, fibrous, radial aggregates, in veinlets along grain of mineralized wood.

Physical properties:

Color: Nearly black with bronze tint; bronze in polished section.
Fluorescence: None.
Luster: Adamantine.
Cleavage: One perfect.
Hardness:
Specific gravity: 3.25±.
Strongest lines of X-ray powder pattern: S 4.72, S 2.47, M 3.83, M 3.17.

Optical properties: Opaque.

Analysis: No analysis of pure material is yet available.

Occurence and associated minerals: Occurs with new black U mineral and another new V oxide [18] at La Sal No. 2 mine and with clausthalite and pitchblende at Corvusite mine. First found by L. R. Stieff and T. W. Stern in August 1951 at La Sal No. 2 mine, report in preparation.

Identification: X-ray powder pattern, not as black or heavy as montroseite, heavier than melanovanadite.

Localities: La Sal No. 2 mine, Gateway district; Mi Vida mine, Monticello district; Corvusite mine, Gateway district

PASCOITE

$Ca_2V_6O_{17}\cdot 11H_2O$

Crystal system: Triclinic.

Habit: As granular crusts, rarely showing minute lathlike crystals with oblique terminations.

Physical properties:

Color: Dark red-orange to yellow-orange.
Fluorescence: None.
Luster: Vitreous to subadamantine.
Cleavage: {010} distinct. Fracture conchoidal.
Hardness: ≈2½.
Specific gravity: 2.46.
Strongest lines of X-ray powder pattern: VS 8.7, M 7.4, W 9.4, W 4.69.

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[18] Another new V mineral was found with this one at La Sal No. 2 mine. It is known only from the X-ray powder pattern and single crystal X-ray photographs taken from a few microscopic crystals. The intensities are consistent with an atomic arrangement that contains elements of the montroseite structure and the rutile-type structure of artificial VO_2. It is orthorhombic and its formula is probably $V_2O_3\cdot V_2O_4\cdot H_2O$ (personal communication, H. T. Evans, U. S. Geological Survey).

Optical properties:

	n	PLEOCHROISM	
X	1.775 ± 0.005	Light cadmium yellow	Biaxial negative
Y	1.815 ± 0.005	Cadmium yellow	Crossed dispersion strong
Z	1.825 ± 0.005	Orange	
$2V$	50°–56°		

Optic plane is $\perp \{010\}$

Analysis: Qualitative spectrographic analysis of mineral from Mesa No. 1 mine, Ariz.:

Major	V Ca
Minor	Fe
Trace	Na Al Mg Si

Occurrence and associated minerals: Coating mine walls and open fractures; in oxidized zone; coating montroseite, melanovanadite, and other vanadium minerals.

Identification: X-ray powder pattern or spectrographic analysis necessary to distinguish from hummerite. Orange color and solubility in water distinguish it from all others.

Localities: Mesa No. 1 mine, Shiprock district; Bitter Creek mine and Mill No. 1 mine, Uravan district; Corvusite mine, and La Sal No. 2 mine, Gateway district; Hawkeye mine, Slick Rock district; Black Ape mine, Thompsons district.

ROSCOELITE AND VANADIUM HYDROMICA[19]

$$(Al,V)_2(AlSi_3)(K,Na)O_{10}(OH,F)_2$$

Crystal system: Monoclinic.

Habit: Massive.

Physical properties:

Color: Green, gray, tan, brown.
Fluorescence: None.
Luster: Pearly.
Cleavage: Basal.
Hardness: Soft.
Specific gravity:
Strongest lines of X-ray powder pattern: S 10.0, S 3.34, M 4.50, M 2.59.

Optical properties:

Transparent if finely divided. Birefringent.

Analysis: Roscoelite from Placerville, Colo. (Fischer, Haff, and Rominger, 1947, p. 124). Analyst, V. North:

SiO_2	Al_2O_3	FeO	V_2O_3	MgO	CaO	K_2O	Na_2O	H_2O	Rem.	Total
44.81	18.42	1.58	20.41	0.83	0.20	8.28	0.07	4.40	0.75	99.73
									Less O=F	0.06
										99.67

[19] Hydromica contains less potassium and is more hydrated than roscoelite.

Occurrence and associated minerals: Impregnating sandstone and replacing clay pellets and stringers. Associated with corvusite, hewettite, carnotite, tyuyamunite, and other vanadium (+5) minerals in the oxidized zone.

Identification: Although the X-ray powder pattern distinguishes this pair from other vanadium minerals, commonly it does not distinguish between these two minerals. Also, some "vanadium clay ore" probably consists of hydromica with included vanadium oxides. (M. D. Foster, U. S. Geological Survey)

Localities: Districts: Gateway, Placerville, Thompsons, Uravan, Paradox, Bull Canyon, Gypsum Valley, and Slick Rock.

ROSSITE

$CaV_2O_6 \cdot 4H_2O$

Crystal system: Triclinic.

Habit: Glassy lumps surrounded by flaky alteration rims of metarossite; thin seams in sandstone or shale.

Physical properties:

Color: Yellow to pale yellow.
Fluorescence: None.
Luster: Vitreous to somewhat pearly.
Cleavage: {010} good. Brittle.
Hardness: 2–3.
Specific gravity: 2.45.
Strongest lines of X-ray powder pattern: S 7.3, S 6.66, S 3.87.

Optical properties:

ORIENTATION	n	
X	1.710	Biaxial negative (?)
$Y \wedge b \approx 45°$	1.770	$2V$ large
$Z \approx c$	1.840	Dispersion very strong
		Yellow in transmitted light

Analysis: No new analysis. (See Dana, 7th ed.)

Occurrence and associated minerals: Secondary coatings and veinlets, in oxidized zone, with metarossite. USNM samples of rossite described in 1927 have all dehydrated (1950) to metarossite.

Identification: Optical properties, color. Soluble in hot water. This dehydrates readily to metarossite.

Localities: Bull Pen Canyon, Slick Rock district; Mesa No. 1 mine, Shiprock district.

METAROSSITE

$CaV_2O_6 \cdot 2H_2O$

Crystal system:

Habit: Soft and friable, platy to flaky masses in veinlets.

Physical properties:

Color: Very light yellow, pale greenish yellow.
Fluorescence: None.

Luster: More pearly than rossite.
Cleavage:
Hardness: Soft.
Specific gravity:
Strongest lines of X-ray powder pattern: S 5.9, S 5.1, M 3.05.

Optical properties:

	n	
X	1.840	Biaxial positive
Y	>1.85	$2V$ large
Z	>1.85	Dispersion strong

Analysis: Qualitative spectrographic analysis of material from Buckhorn claim:

Major	V
Minor	Ca
Trace	Al Si Nb Fe Mg

Occurrence and associated minerals: Same as for rossite.
Identification: Color, optical properties. Soluble in hot water.

Localities: Buckhorn claim, Slick Rock district; Spring Creek, Brushy Basin, Monticello district.

SODIUM ANALOGUE OF HEWETTITE

$Na_2V_6O_{16}\cdot 3H_2O$ or $(Na, K)_2O\cdot 2\frac{1}{2}V_2O_5\cdot 3H_2O$

Crystal system: Monoclinic.
Habit: Bladed or acicular; botryoidal.
Physical properties:

Color: Deep red; brownish red on exposure.
Fluorescence: None.
Luster: Adamantine, dulls on exposure.
Cleavage:
Hardness:
Specific gravity:
Strongest lines of X-ray powder pattern: VS 7.97, S 3.13, S 2.27.

Optical properties:

ORIENTATION	n	PLEOCHROISM	
X	1.797 ± 0.003	Yellow	
Y	>2.0	Orange-yellow	Biaxial negative
$Z=b$	>2.0	Orange-red	$2V$ medium

Analysis: Chemical analysis of material from Cactus Rat incline. Analyst, A. M. Sherwood:

V_2O_4	V_2O_5	Na_2O	K_2O	CaO	Acid insol.	H_2O-	H_2O+	Total
1.56	77.17	9.17	1.35	0.12	0.31	1.83	7.86	99.37

Occurrence and associated minerals: Coating a fracture in the roof of the Cactus Rat incline, with steigerite.
Identification: By color, except from hewettite. By X-ray or spectroscopic analysis from hewettite.

Localities: The first sample was collected by Benjamin Webber from the Thompsons district, during World War II and loaned to the writers by L. B. Riley. The second sample was collected by J. Stone in July 1952, from Cactus Rat incline, Thompsons district. Described by Weeks, Thompson, and Sherwood, manuscript in preparation.

STEIGERITE

$Al_2(VO_4)_2 \cdot 6\frac{1}{2}H_2O$

Crystal system:

Habit: As canary-yellow pulverulent coatings that are variously composed of cryptocrystalline fibrous material resembling chalcedony, gumlike masses, and occasionally flat plates.

Physical properties:

Color: Canary yellow.
Fluorescence: None.
Luster: Waxy in compact aggregates.
Cleavage:
Hardness:
Specific gravity:
Strongest lines of X-ray powder pattern: S 10.5, S 12.4, W 5.6.

Optical properties:

Mean index 1.710 ± 0.005

Analysis: Qualitative spectrographic analysis of material from Cactus Rat incline:

Major	V
Minor	Al Ca
Trace	U Na Fe Si

Occurrence and associated minerals: In highly oxidized ore at Cactus Rat, coatings on highly weathered sandstone, with sodium analogue of hewettite.

Identification: Color and lack of radioactivity.

Locality: Original locality: north wall of Gypsum Valley, Gypsum Valley district. Cactus Rat incline, Thompsons district; Monument No. 2 mine, Monument Valley district; Fox mine, Uravan district.

VOLBORTHITE

$Cu_3(VO_4)_2 \cdot 3H_2O(?)$

Crystal system: Monoclinic (?).

Habit: As scaly, spongy, or fibrous crusts and as rosettelike aggregates; also reticulated. Some as scales with a triangular or hexagonal outline.

Physical properties:

Color: Dark olive green to green and yellowish green.
Fluorescence: None.

Luster: Vitreous to pearly on the cleavage.
Cleavage: One perfect.
Hardness: 3½.
Specific gravity: 3.5—3.8.
Strongest lines of X-ray powder pattern: S 7.2, M 2.88, M 2.56, M 2.39, M 1.51.

Optical properties:

	n	COLOR	
X	2. 01	Green to greenish yellow in	Biaxial positive red
Y	2. 05	transmitted light.	Biaxial negative violet
Z	2. 10		$2V$ 68° Li, 83° Na
			$r>v$ inclined

Analysis: Qualitative spectrographic analysis on material from Daggett County, Utah:

Major	Cu V Si
Minor	Ba Al
Trace	Ca Mg Nb Fe

Occurrence and associated minerals: Coating joint and fracture surfaces in sandstone, with gypsum.

Identification: The distinction between volborthite and calciovolborthite is not well established. Test for V and Cu, and negative U test.

Localities: Radium No. 5 mine, San Juan No. 3 mine, and Cougar mine, Slick Rock district.

CALCIOVOLBORTHITE

$(Cu,Ca)_2(VO_4)(OH)$

Crystal system: Orthorhombic (?).

Habit: As scaly aggregates; also fibrous to dense.

Physical properties:

Color: Yellow-green, olive green.
Fluorescence: None.
Luster: Vitreous to pearly on the cleavage.
Cleavage: One perfect.
Hardness: 3½.
Specific gravity:
Strongest lines of X-ray powder pattern: S 7.2, M 2.88, M 2.56, M 2.39, M 1.51.

Optical properties:

	n	PLEOCHROISM	
X	2. 00	Brown	Biaxial negative.
Y	2. 01	Brown	$2V$ large
Z	2. 02	Green	$r>v$ strong

Analysis:

Occurrence and associated minerals: Coating on sandstone, with tyuyamunite and conichalcite.

Identification: The distinction between calciovolborthite and volborthite is not well established.

Locality: Richardson Basin, Moab district.

TABLE 2.—*List of mine and mining district names showing county and State*

Mine or district	*County*	*State*
Arrowhead mine	Mesa	Colo.
Bitter Creek mine	Montrose	Colo.
Black Ape mine	Grand	Utah
Black Mama mine	Mesa	Colo.
Blue Jay mine	San Juan	Utah
Buckhorn claim	San Miguel	Colo.
Bull Canyon district	Montrose, San Miguel	Colo.
Bull Pen Canyon (area)	San Miguel	Colo.
Cactus Rat group	Grand	Utah
Camp Bird No. 13 mine	Emery	Utah
Cato Sells mine	Apache	Ariz.
Coal Canyon (area)	Fall River	S. Dak.
Cobalt No. 2 mine	Grand	Utah
Corvusite mine	Grand	Utah
Cougar mine	San Miguel	Colo.
Crabapple claim	San Juan	Utah
Craven Canyon (area)	Fall River	S. Dak.
Denise No. 1 mine	Emery	Utah
Fox mine	Montrose	Colo.
Frey No. 4 mine	San Juan	Utah
Gateway district	Mesa	Colo.
	Grand	Utah
Grants district	McKinley, Valencia	N. Mex.
Grey Dawn mine	San Juan	Utah
Gypsum Valley district	San Miguel	Colo.
Green River district	Grand, Emery, Wayne	Utah
Happy Jack mine	San Juan	Utah
Hawkeye mine	San Miguel	Colo.
Haystack Mountain area	McKinley	N. Mex.
Henry Mountains district	Garfield, Wayne	Utah
Hideout (Tiger) mine	San Juan	Utah
Hillside mine	Yavapai	Ariz.
Hummer mine	Montrose	Colo.
Huskon No. 2 claim	Coconino	Ariz.
Jo Dandy group	Montrose	Colo.
Juniper mine	Grand	Utah
Laguna area	Valencia	N. Mex.
La Sal No. 2 mine	Mesa	Colo.
Little Colorado district	Coconino, Navajo	Ariz.
Little Muriel mine	San Miguel	Colo.
Lucky Strike No. 2 mine	Emery	Utah
Lusk area	Niobrara	Wyo.
Markey No. 3 mine	San Juan	Utah
Marshbank Canyon mine	Emery	Utah
Matchless mine	Mesa	Colo.
McCoy group	Grand	Utah

Mine or district	*County*	*State*
Mesa No. 1 mine	Apache	Ariz.
Mesa No. 5 mine	Apache	Ariz.
Mill No. 1 mine	Montrose	Colo.
Mineral Ten mine	San Juan	Utah
Mi Vida mine	San Juan	Utah
Moab district	Grand, San Juan	Utah
Monticello district	San Juan	Utah
Monument No. 2 mine	Apache	Ariz.
Monument Valley district	Navajo, Apache	Ariz.
	San Juan	Utah
North Point-Gonway claim	San Juan	Utah
North Star mine	Montrose	Colo.
Notch mine	San Juan	Utah
Opera Box mine	Montrose	Colo.
Oyler mine	Wayne	Utah
Paradox district	Montrose	Colo.
	San Juan	Utah
Parco No. 25 mine	Grand	Utah
Pay Day mine	Emery	Utah
Placerville district	San Miguel	Colo.
Polar Mesa	Grand	Utah
Posey mine	San Juan	Utah
Pumpkin Buttes area	Campbell	Wyo.
Radium No. 5 mine	San Miguel	Colo.
Red Canyon (area)	Fall River	S. Dak.
Rex No. 2 mine	Emery	Utah
Richardson Basin	Grand	Utah
Road Hog No. 3A claim	Fall River	S. Dak.
San Juan No. 3 mine	San Miguel	Colo.
San Rafael district	Emery	Utah
Shinarump No. 1 mine	Grand	Utah
Shinarump No. 3 mine	Grand	Utah
Shiprock district	San Juan	N. Mex.
	Apache	Ariz.
	San Juan	Utah
Skinny No. 1 mine	Grand	Utah
Skyline mine	San Juan	Utah
Slick Rock district	San Miguel, Dolores	Colo.
Small Spot mine	Mesa	Colo.
Sodaroll claim	San Juan	Utah
Spring Creek in Brushy Basin	San Juan	Utah
Temple Mountain area	Emery	Utah
Thom claim	Grand	Utah
Thompsons district	Grand	Utah
Tiny mine	San Miguel	Colo.
Uravan district	Montrose	Colo.
Virgin mine	Montrose	Colo.
White Canyon district	San Juan	Utah
White Canyon No. 1 mine	San Juan	Utah
Whitney mine	Montrose	Colo.
Wild Steer mine	Montrose	Colo.
Yellow Cat group	Grand	Utah

LITERATURE CITED

Axelrod, J. M., Grimaldi, F. S., Milton, Charles, and Murata, K. J., 1951, The uranium minerals from the Hillside mine, Yavapai County, Ariz.: Am. Mineralogist, v. 36, p. 1–22.

Barnes, W. H., and Qurashi, M. M., 1952, Unit cell and space group data for certain vanadium minerals: Am. Mineralogist, v. 37, p. 407–422.

Evans, H. T., Jr., and Block, Stanley, 1953, The crystal structure of montroseite, a vanadium member of the diaspore group: Am. Mineralogist, v. 38, p. 1242–1250.

Fischer, R. P., Haff, J. C., Rominger, J. F., 1947, Vanadium deposits near Placerville, San Miguel County, Colo.: Colorado Sci. Soc. Proc., v. 15, p. 115–134.

Frondel, J. W., and Fleischer, Michael, 1952, A glossary of uranium- and thorium-bearing minerals: U. S. Geol. Survey Circ. 194.

Garrels, R. M., 1953, Some thermodynamic relations among the vanadium oxides and their relations to the oxidation state of the uranium ores of the Colorado Plateaus: Am. Mineralogist, v. 38, p. 1251–1265.

George, d'Arcy, 1949, Mineralogy of uranium and thorium minerals: RMO–563, Atomic Energy Comm., Tech. Inf. Service, Oak Ridge, Tenn.

Grimaldi, F. S., May, Irving, and Fletcher, M. H., 1952, U. S. Geological Survey fluorimetric methods of uranium analysis: U. S. Geol. Survey Circ. 199.

Gruner, J. W., and Gardiner, Lynn, 1952, Mineral associations in the uranium deposits of the Colorado Plateau and adjacent regions with special emphasis on those in the Shinarump formation, part 3 Annual Rept. July 1, 1951—June 30, 1952: RMO–566, Atomic Energy Comm., Tech. Inf. Service, Oak Ridge, Tenn.

Hess, F. L., 1925, New and known minerals from the Utah-Colorado carnotite region: U. S. Geol. Survey Bull. 750, p. 63–78.

Hess, F. L., and Henderson, E. P., 1931, Fervanite, a hydrous ferric vanadate: Am. Mineralogist, v. 16, p. 273–277.

Hess, F. L., and Schaller, W. T., 1914, Pintadoite and uvanite, two new vanadium minerals from Utah, a preliminary note: Washington Acad. Sci. Jour., v. 4, p. 576–579.

Hillebrand, W. F., Merwin, H. E., and Wright, F. E., 1914, Hewettite, metahewettite, and pascoite, hydrous calcium vanadates: Am. Phil. Soc. Proc., v. 53, p. 31–54.

Palache, Charles, Berman, Harry, and Frondel, Clifford, 1944, 1951, Dana's system of mineralogy, 7th ed., v. 1 and 2, New York, John Wiley and Sons, Inc.

Stern, T. W., and Weeks, A. D., 1952, Second occurrence of bayleyite in the United States: Am. Mineralogist, v. 37, p. 1058–1060.

Stich, J. N., 1953, Spectrographic identification of mineral grains: U. S. Geol. Survey Circ. 234.

Waring, C. L., and Annell, C. S., 1953, Semiquantitative spectrographic method for analysis of minerals, rocks, and ores: Anal. Chemistry, v. 25, p. 1174–1179.

Weeks, A. D., Cisney, E. A., and Sherwood, A. M., 1950, Hummerite and montroseite, two new vanadium minerals from Montrose County, Colo. [abs.]: Geol. Soc. America Bull., v. 61, p. 1513.

Weeks, A. D., Cisney, E. A., and Sherwood, A. M., 1953, Montroseite, a new vanadium oxide from the Colorado Plateaus: Am. Mineralogist, v. 38, p. 1235–1241.

Weeks, A. D., Thompson, M. E. and Sherwood, A. M., 1954, Navajoite, a new vanadium oxide from Arizona [abs.]: Science, v. 119, p. 326.

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