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URANIUM AND RADIUM

BY

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1. The Needs of Better Mining Education.
5. Tungsten, by H. C. Rubel.
7. Magnesite, by Frank L. Culin, Jr.
13. Bibliography of Literature Regarding Arizona Mining and Geology, compiled under the direction of Estelle Luttrell.
16. Resources of Santa Cruz County, by Allen T. Bird.
17. Celestite and Strontianite, by Frank L. Culin, Jr.
18. The Selling of Copper, by H. J. Stander.
27. Gems, by Frank L. Culin, Jr.
30. Selling Prospects, by Chas. F. Willis.
32. What To Do With The Other Eight Hours, by S. C. Dickinson.
34. Valuation of Prospects.
35. Drilling for Oil.
36. How to Organize for Safety.
37. Shafts and Tunnels.
38. Keeping Your Town Clean.
40. Barites, by M. A. Allen and G. M. Butler.
44. Asbestos, by M. A. Allen and G. M. Butler.
47. Petroleum, by G. M. Butler and M. A. Allen.
Uranium and Radium

Preface

The fact that base metals have been quoted at relatively low prices since the war has caused many Arizona prospectors to lose interest in them and to turn their attention to rare metals. Judging from the number of inquiries concerning uranium-radium minerals that reach the Arizona Bureau of Mines, it seems evident that they are being eagerly sought and that information concerning them is in demand. This booklet has been prepared to supply such data concerning uranium and radium as prospectors and miners may find useful, and is admittedly nothing but a compilation of the more important known facts concerning these metals and their ores.

A Brief History of Uranium and Radium

Uranium.

The yellow oxide of uranium was extracted from the mineral pitchblende in 1789 by Klaproth, and was named uranium after the newly discovered planet Uranus.

Several investigators believed they had isolated the metal from the oxide, but it was not until 1840 that Peligot accomplished this feat and proved that the so-called elements previously announced were in reality the different oxides.

Radium.¹

"Radio-activity was discovered by Becquerel, a French scientist, in 1896. During the course of his researches regarding the action of phosphorescent and fluorescent substances upon a photographic plate enclosed in a light-proof envelope, he discovered that the

¹Extracted with the permission of the Denver Fire Clay Company from their Bulletin No. 176, entitled "The Lind Interchangeable Electroscope," and from their booklet entitled "Hammer Radium Specialties."
salts of uranium had the peculiar property of fogging a plate of this kind even though these salts had not been first caused to fluoresce or phosphoresce by exposure to sunlight. As his experiments had dealt only with uranium salts which had been first caused to phosphoresce or fluoresce, the discovery of similar effects upon a photographic plate, but without a similar exciting cause, led him to believe that he had found a new property of matter. This property was then known as Becquerel Radiation, but since the discovery of radium it is called radio-activity.

"Not only is this activity manifested by its action on a photographic plate, but it may also be detected by the phosphorescence it produces in certain materials, the best known of which is phosphorescent zinc sulphide, and also by its property of discharging a charged electroscope through the ionization of the air in proximity to the electroscope.

"Schmidt and Curie working independently found that thorium was also radio-active. Madame Curie ascertained that there were minerals more radio-active than uranium and that if uranium were separated from these minerals it had the normal activity, thus leading to the conclusion that there was some element or substance in the residue that possessed a high degree of activity. A chemical investigation of pitchblende from Joachimsthal showed that still another radio-active substance was separated with the bismuth, to which she gave the name of polonium in honor of her native land, Poland. Continuing the work, Madame Curie and her associates found another element, which was separated with barium, which, when brought to a state of concentration, was several million times as active as uranium. This was radium. Debriene afterwards found a fifth radio-active substance, actinium; and in 1906, Poltwood isolated the metal ionium. Development in the knowledge of radio-activity has been rapid since that time.

"This new element (radium), so remarkably different from all other elements, has radically changed the trend of science regarding the constitution of matter. The dream of the old alchemists was for the Philosopher's Stone which would magically transmute the baser metals into gold. This change from one
element to another is constantly being carried on in the spontaneous disintegration of radium. Now, science is tying by means of these radium rays to make true the dream of the alchemist; and science will feel well repaid for its labors if it can change one element into another, no matter what that element may be, for it thereby may discover fundamental laws, not known before, governing the structure of the atom.”

The continuous discharge of emanations by radio-active substances gradually weakens them, but the process takes place so slowly that a compound containing radium will have lost but half of its strength after 1800 years.

URANIUM AND RADIUM MINERALS

All uranium minerals contain minute quantities of radium, and radium is not known to occur in any mineral that does not contain uranium. In fact, the ratio of radium to uranium in any mineral has been found to be fixed at about one part of the former to three million parts of the latter.

Although a large number of uranium minerals have been identified, only five of them, carnotite, uraninite or pitchblende, autuninite, torbernite, and samarskite, have been used to any extent on a commercial scale as sources of uranium and radium, and only the first two species mentioned are or have been important sources of these elements.

CARNOTITE

Composition: A hydrated vanadate of uranium and potassium of doubtful formula. The pure mineral carries from 20 to 54 percent \( \text{U}_3\text{O}_8 \), 7 to 18 percent \( \text{V}_2\text{O}_5 \), 5 to 6.5 percent \( \text{K}_2\text{O} \), 0.3 to 2.8 percent \( \text{BaO} \), 1.6 to 3.3 percent lime, and traces of lead, aluminum, iron, arsenic, and phosphorus.¹

Color of Powder: Canary-yellow, usually paler than the color of the unpowdered mineral.

Hardness: Easily scratched and cut with the finger nail.

Fracture: Rarely occurs in large enough masses to test the frac-
ture, but such masses when found break like fine, dry earth.

Specific Gravity: 4.1, or about fifty percent heavier than quartz.

Occurrence: Carnotite is usually found as a yellow powder encrusting or filling the interstices between grains or cracks in sandstone. It may also encrust or fill cavities in silicified wood included in the sandstone. Occasionally loosely coherent earthy masses an inch or two thick are found. Sometimes associated with roscoeelite, a dull green vanadium mica. Microscopic examination proves that the mineral is crystalline and has a scaly form.

Blowpipe and Chemical Tests: Fuses easily to a dull-lustered, black mass containing small black pellets. Yields water when heated in a small glass tube closed at one end. Dissolves in hot dilute sulphuric acid, and yields a yellowish or orange solution that turns brown when hydrogen peroxide is added to it. Yields a yellow solution when dissolved in hydrochloric, and a green solution when dissolved in nitric acid. The mineral is radio-active, and this property can be tested with an electroscope or a radioscope.

Variety: Tyuyamunite. Similar to carnotite from which it cannot be distinguished at sight, but the potash is largely or entirely replaced by lime.

Additional: Carnotite is very apt to be confused with oxides of iron, molybdenum, lead, etc. While its associates and manner of occurrence will often indicate the probability that a yellow, earthy mineral is carnotite, it is always best to substantiate a tentative determination made in this way by resorting to blowpipe, chemical, or radio-active tests. Carnotite deposits are worked primarily for the radium and uranium that they contain, but some vanadium is recovered as a by-product. Although not as rich as uraninite, carnotite is by far the most important source of radium. Most of the carnotite ore now treated, however, contains but one part of radium to between 200,000,000 and 250,000,000 parts of the
Uranium and Radium

ore; in other words, the ore contains between four and five ten-millionths of one percent of radium. So little radium is there in carnotite ore that about eight carloads of average ore yield but one gram of radium—about half a thimbleful. To extract this small amount of radium requires the use of about ten carloads of acids, other chemicals, and coal.¹

URANINITE

Compositions Essentially a uranate of uranyl, or two different oxides of uranium, but it always contains some lead and calcium, usually thorium or zirconium, often the metals of the lanthanum and yttrium groups, the gases nitrogen, helium, and argon up to a percent of two, and small amounts of other elements, including radium. Some iron is always present, but it and water may be impurities. Uraninite rarely carries as much as eighty percent of uranium, but even the richest specimens contain only about two and a half hundred-thousandths of one percent of radium.

Luster: Usually dull-metallic; sometimes greasy or pitch-like to dull.

Colors Usually black; sometimes brown; rarely grayish or greenish.

Color of Powder: Commonly dark olive-green; occasionally black, dark brown, or dark gray.

Hardness: Ordinarily a trifle too hard to be scratched with a knife blade, although some unusual varieties are comparatively soft.

Fracture: Usually smoothly curved like glass or flint; uneven on some varieties. Shows no tendency to cleave or split in any definite direction.

Specific Gravity: Crystals may have a specific gravity of as high as 9.7, or nearly twenty-five percent heavier than iron, but the dull-metallic variety may have a specific gravity as low as 6.5, and this figure may be as low as 4.8 for dull, soft, very impure material.

¹Marvellite. The Cold Light Mfg. Co., New York City, p. 44.
Occurrence: Usually occurs in compact, massive form; sometimes it shows a botryoidal (like a bunch of grapes) or a kidney-like surface; occasionally granular; very rarely in octahedral or cubical crystals.

Blowpipe and Chemical Tests: Infusible or only slightly rounded on thin edges. When finely powdered and fused with borax on a platinum wire in an oxidizing flame the borax bead is yellow; in a reducing flame the bead is green. More or less easily soluble in nitric and sulphuric acids, various varieties differing considerably in solubility. Ammonia added to the nitric acid solution yields a sulphur-yellow precipitate. An electroscope or radioscope shows the mineral to be strongly radio-active.

Varieties: Cleveite. Occurs in modified cubic crystals, and contains about ten percent of the rare earths of the yttrium group and smaller amounts of thorium, argon, and helium. The specific gravity is about 7.5.

Nivenite. Occurs massive or indistinctly crystallized and contains about ten percent of the rare earths of the yttrium group with a smaller amount of thorium. The specific gravity is about 8.0, and it is the most soluble variety of uraninite, being slowly, but completely, decomposed by warm, dilute sulphuric acid.

Pitchblende. Occurs massive and apparently non-crystalline. Contains little or no thorium or rare earths. Yields test for water when powdered and heated in a glass tube closed at one end. The specific gravity is relatively low as compared with the crystalline mineral.

Additional: The hardness, high specific gravity, lack of cleavage or a tendency to split smoothly in any definite direction, and the common olive-green color of the powder are features that should usually suffice to identify uraninite. The mineral is usually associated with metallic sulphides, especially pyrite.

Uraninite is the richest ore of both uranium and radium, but is so rare that it is far less important than carnotite as a source of these elements.
AUTUNITE (Lime Uranite)

Composition: A hydrous uranium-calcium phosphate \(2\text{UO}_3\cdot\text{CaO}\cdot\text{P}_2\text{O}_5\cdot8\text{H}_2\text{O}\). A mineral of this formula will contain 62.7 percent of \(\text{UO}_3\) (or 53.2 percent of uranium) and one and three quarters hundred thousandths of one percent of radium.

Luster: Usually pearly—similar to that shown by translucent (not transparent) mica.

Color: Light yellow; sometimes lemon-yellow.

Color of Powder: Yellowish-white.

Hardness: The scales are usually too small to test them satisfactorily for hardness, but the mineral is very soft; it can usually be scratched with the finger nails.

Fracture: Splits or cleaves easily and smoothly into thin flakes like mica. The cleavage flakes are brittle.

Specific Gravity: Approximately 3.1, or seventeen percent heavier than quartz.

Occurrence: Occurs in small, nearly square, platy or scaly crystals, and in micaceous masses.

Blowpipe and Chemical Tests: Yields water when heated in a small glass tube closed at one end. Fuses easily to a black mass. Is soluble in nitric acid, and the addition of ammonium molybdate to the solution throws down a yellow precipitate. When finely powdered and fused with borax on a platinum wire in an oxidizing flame the borax bead is yellow; in a reducing flame the bead is green.

Miscellaneous: The general appearance of the mineral is so distinctive that there is little probability of confusing it with anything else. While it contains a fairly high percentage of uranium, it is too rare to constitute an important source of this element or of radium.

TORBERNITE (Copper Uranite)

Composition: A hydrous uranium-copper phosphate \(2\text{UO}_3\cdot\text{CuO}\cdot\text{P}_2\text{O}_5\cdot8\text{H}_2\text{O}\) or \(2\text{UO}_3\cdot\text{CuO}\cdot\text{P}_2\text{O}_5\cdot12\text{H}_2\text{O}\). A mineral with the formula first given will contain 61.2 percent of \(\text{UO}_3\).
(or 51.9 percent of uranium), and one with the latter formula will contain 56.6 percent \( \text{UO}_2 \) (or 47.9 percent of uranium). In either case the mineral will contain a trifle less than one and three quarter hundred thousandths of one percent of radium.

**Luster:** Usually pearly—similar to, that shown by translucent (not transparent) white mica.

**Color:** Usually relatively light shades of green, such as apple green; sometimes grass-green.

**Color of Powder:** Light green—a paler tint than that of the un(powdered mineral.

**Hardness:** The scales are usually too small to test them satisfactorily for hardness, but the mineral is very soft; it can usually be scratched with the finger nails.

**Fracture:** Splits or cleaves easily and smoothly into thin flakes like mica. The cleavage flakes are brittle.

**Specific Gravity:** About 3.5 or thirty-one percent heavier than quartz.

**Occurrence:** Occurs usually in thin (sometimes thick), tabular crystals which are commonly square or nearly so; sometimes in micaceous masses. Very rarely the crystals are pyramidal.

**Blowpipe and Chemical Tests:** Yields water when heated in a small glass tube closed at one end. Fuses easily to a black mass and yields a green flame (copper test). Is soluble in nitric acid, and the addition of ammonium molybdate to the solution throws down a yellow precipitate. When finely powdered and fused with borax on a platinum wire in an oxidizing flame the borax bead is yellow; in a reducing flame the bead is green to black. An electroscope or radio-scope shows the mineral to be radio-active.

**Additional:** The general appearance of the mineral is so distinctive that there is little probability of confusing it with anything else. Torbernite is probably less abundant than autunite with which it is often associated.
SAMARSKITE

Composition: A niobate and tantalate (columbate) of uranium, iron, members of the yttrium and cerium groups, etc. The formula is uncertain. Usually contains about ten or twelve percent uranium oxide (UO$_2$), six to fifteen percent yttrium group oxides (Y$_2$O$_3$ etc.), two to six percent cerium group oxides (Ce$_2$O$_3$ etc), and fifty-six percent niobium and tantalum (columbian) pentoxides (Nb$_2$O$_5$ and Ta$_2$O$_5$). Calcium, magnesium, manganese, tungsten, tin, titanium, etc., may also be present in small quantities. Specimens from one locality have been found to contain about eight percent of lead oxide (PbO). This variety has been called plumboniobate. Samarskite contains about three millionths of one percent of radium.

Luster: Glassy (like that of obsidian or black lava glass) to resinous.

Color: Usually jet black; sometimes dark brownish black.

Color of Powder: Dark reddish brown.

Hardness: Can occasionally be scratched with a knife if great pressure is applied. It is usually a trifle too hard to be thus affected. May be scratched with quartz.

Fracture: Smoothly curved, like broken glass or flint.

Specific Gravity: 5.6 to 5.8, or over twice as heavy as quartz or glass.

Occurrence: Occurs usually in disseminated grains, veinlets, or masses of irregular shape.

Additional: The general appearance, the specific gravity, the hardness, and the lack of a tendency to split in a definite direction will usually suffice to distinguish samarskite from minerals with which it might be confused. It has probably been mined in only one locality (Sankarn Mine, India) as a source of uranium and radium.
TESTS FOR URANIUM AND RADIUM

URANIUM.

Chemical: A chemical test that gives satisfactory results with many radium minerals should be conducted as follows:

Pulverize the ore very fine, and roast for about half an hour at a bright red heat in an open muffle or in the air. When cold add as much (by bulk) of carbonate of soda and as much of nitre as there is of the substance being tested, mix the three substances thoroughly, and fuse well in a crucible. Place the cold fused mass in a porcelain dish, and add twice its bulk of concentrated nitric acid and one-quarter as much water. If uranium is present, a yellow powder will form after standing about an hour. If this yellow powder is caught on a filter paper, dried, and heated on a piece of sheet iron, it will assume a scarlet color.

Other tests for uranium are given in the foregoing descriptions of minerals containing this element.

RADIUM.

Chemical: No chemical tests for radium as it occurs in nature are known, but, as has already been said, every natural substance containing uranium also carries radium.

Photographic Plate Test: Some of the rays or emanations from radium-bearing substances have the property of affecting a photographic dry plate in exactly the same way as does light, although minerals contain so little radium that a relatively long period of exposure is necessary. Moreover, the radium emanations have the property of passing, unimpeded, through opaque paper or cardboard, but cannot pass through metals. The facts just outlined are utilized in making the well known photographic dry plate test for radium, which may be conducted as follows:

Enter a room into which no light can penetrate and in which there is no source of light except a "ruby lantern" such as is used by photographers, open a box of small, high speed, photographic dry plates (the size is immaterial), extract one plate therefrom, and wrap it thoroughly in the black, opaque paper in which it was packed (quantities of this paper may be obtained from any photo-
grapher). Place the wrapped plate in the bottom of a light-tight box, laying the plate in such a way that the dull or coated side is on top. Place a silver coin in the middle of the plate on top of the black paper. Make a little tripod out of metal wire by twisting it together with a pair of pincers, and place this tripod over the coin, the legs resting on the black paper outside of the coin. Place the sample of mineral to be tested on top of the tripod, and bend the legs of the latter until the bottom of the mineral is about one inch above the coin. Place the cover on the box and set away for 24 hours, after which develop and fix the plate in the usual way, or have these operations done by a photographer. If the ore tested contains a commercially valuable percentage of radium, a shadowgraph of the coin will appear on the dry plate. It takes the form of a relatively light-tinted circle of the size of the coin, surrounded by a darker background. The bottoms of the legs of the tripod may also appear as light-colored spots on the dark background.

The lowest commercial grade of carnotite ore will produce a very faint image of the coin when the test is conducted as described and for the period mentioned, while the highest grade carnotite ore will yield a much more decided shadowgraph. Pitchblende produces even more satisfactory results. The contrast between the shadow of the coin and the surrounding background is somewhat more pronounced the longer the exposure to a radio-bearing mineral, but a 24-hour exposure is sufficient to produce satisfactory results. Experiments made by the Arizona Bureau of Mines show that carnotite ore containing too little of the mineral to be commercially valuable did not produce a perceptible shadowgraph after an exposure of as much as ten days.

In tests conducted by the Bureau, Seed's 26 Dry Plates were used. If slower plates are utilized, longer exposures may be necessary.

If a sensitive paper print is taken from a plate showing a shadowgraph such as has been described, the colors of the shadow and the background will, of course, be reversed.

*Radioscope Tests:* The Radioscope is a very useful little in-
instrument devised for ascertaining the presence of radium in any substance. The instrument distributed by the Denver Fire Clay Company of Denver, Colorado, is illustrated by Fig. 1. It consists of a glass jar three inches high to which is fitted a metal cap with a magnifying lens on top and a screen of phosphorescent zinc sulphide below the lens. The action of this instrument is based upon the fact that when a radium emination strikes phosphorescent zinc sulphide, a tiny spark or flash of light is produced. Since radio-active substances are throwing off these emanations all the time, a continuous succession of tiny flashes of light may be observed on the screen mentioned when examined through the lens on top of the instrument. To use the instrument a few ounces of the finely crushed mineral is placed in the jar, and water is added until the jar is about one-half filled with the mixture. The jar is then corked and shaken vigorously for one minute. The cork is then removed, and the screw cap containing the lens and the zinc sulphide screen is quickly put in place upon top of
the jar. If the brilliant flashes of light mentioned can then be seen through the lens, it is known that the substance tested is radio-active.

The following precautions must be rigidly observed in using this instrument:

1. Conduct the experiment in an absolutely dark room.
2. Keep the instrument in the dark for at least half an hour before making the test.
3. Do not allow a single drop of the water or supposed radio-active material to get up into the cap of the instrument.
4. Do not attempt to make a test until the eyes have become properly accustomed to the darkness. It is usually necessary for the operator to remain in absolute darkness for about twenty minutes before satisfactory results can be secured.

Tests made with the Radioscope show that it is an extremely sensitive instrument; and that good results may be secured from low grade carnotite ore that yields no shadowgraph with the photographic dry plate test after an exposure of ten days.

The price of the instrument as described, with a small quantity of high grade carnotite for experimental work, is $10.00.

Electroscope Test: The Electroscope consists essentially of a jar containing a strip of very thin flexible metal foil bent sharply in the middle, and suspended on a suitable support. If the instrument has not been used for some time the two suspended halves of the metal foil may be in contact or nearly so; but, if they are charged in any convenient way with static electricity, they fly apart and assume the position of an inverted V with inwardly curved sides. As the electrical charge is gradually dissipated, the two halves of the foil approach each other once more, and the rate at which they approach may be noted by the use of a watch and a scale placed behind the foil. If radio-active material is placed in the jar below the foil, and the two halves of the foil are caused to separate by charging them with static electricity, the rate at which they approach each other will be found to be greater than it was when no radio-active material was in the instrument. The higher the grade of the ore, the more rapidly will
the two halves of the foil come together; so by observing suitable precautions, and by comparing the rate of discharge of the foil with that produced by ore of known grade, the grade of the ore tested may be ascertained.

Many forms of Electroscope are on the market, but the "Lind Interchangeable Electroscope" as designed and used by the United States Bureau of Mines, and sold by the Denver Fire Clay Company, Denver, Colorado, has been found to give especially satisfactory results. A complete laboratory outfit for use on solids, gases, and liquids costs $224.75.

GEOLOGICAL OCCURRENCES AND ORIGIN OF URANIUM AND RADIUM ORES

Carnotite: Practically all of the important Rocky Mountain occurrences of carnotite are in sandstone which often contains petrified wood, and, occasionally bones or other fossils. Some roscoelite, gypsum, copper carbonates, and rare vanadium minerals may be associated with the carnotite. This mineral may be concentrated along cracks or bedding planes, may occur in pockets in nearly pure form, or it may impregnate the sandstone. It is sometimes associated with layers or kidneys of black or brown material that runs well in vanadium, and this dark colored ore will often turn yellow when exposed to the air or heated on top of a stove. The material shipped from the Paradox Valley, Colorado, contains on an average from two to three percent of uranium oxide (U₃O₈), and from three to four percent of vanadic oxide (V₂O₅), but the latter is regarded as a by-product, since the ore is chiefly valuable for the radium contained therein. Leith¹ discusses the origin of the Colorado and Utah deposits as follows:

"The ore minerals are supposed to have been derived from a thick series of clays and impure sandstones a few hundred feet above, containing uranium and vanadium minerals widely disseminated and to have been carried downward by surface waters containing sulphates. The ore bodies vary from very small pock-

Uranium and Radium

15 to deposits yielding a thousand tons or so, and are found irregularly throughout certain particular beds without any special relation to present topography or faults. The association of many of the deposits with fossil wood and other carbonaceous material suggests that organic matter was an agent in their precipitation, but the exact nature of the process is not clear. In a few places in Utah the beds dip at steep angles, and the carnotite appears in spots along the outcrops, and generally disappears as the outcrops are followed into the hillsides; this suggests that the carnotite may be locally redissolved and carried to the surface by capillary action, forming rich efflorescences. Because of the nature of the deposits, no large amount of ore is developed in advance of actual mining, but estimates based on past experience indicate the great potentialities of this region for future production.”

Most of the carnotite that has been found in Arizona occurs as an impregnation in sandstone, but so far as is known much of the material so far discovered is of relatively low grade.

At Olary, South Australia, carnotite has been found in the cracks and other cavities in an impure ilmenite (oxide of iron and titanium), and at Mount Pisgah, Pennsylvania, it occurs in a quartz conglomerate. The pebbles are in some places cemented with calcite (carbonate of lime) which has been replaced to some extent with the carnotite.

W. H. Emmons states that: 1 “Uranium and vanadium are readily dissolved in sulphate waters and both are regarded as mobile metals. Both metals are precipitated from soluble salts by organic matter. The carnotite deposits of Colorado are believed to be concentrations from cold ground waters that dissolved the metals from the associated rocks.”

According to the U. S. G. S. Press Bulletin of Oct., 1919, “Radium minerals are generally found in connection with granitic masses—that is, in places where granite forms at least part of the rock of the country. When the original minerals of radium break down through weathering other minerals are formed from them, such as autunite, torbernite, carnotite, and tyuyamunite.

Carnotite and tyuyamunite are the most abundant radium and uranium minerals and furnish the bulk of the world's radium and uranium.

**Uranite:** Richard B. Moore in a resume of the more important deposits of pitchblende of the world states: "In the cobalt-bismuth mines of Schneeberg, are found bismutite and various minerals of nickel, silver, and arsenic. There is also some pitchblende, uranochalcite, uranospinite, galenite, zinc blende, etc.

"Pitchblende has also been found in Cornwall, England, in the tin region. As at Joachimsthal and Johanngeorgenstadt, the mineral is found associated with nickel-cobalt veins, although only part of the veins are highly argentiferous. Even though these veins are closely connected with the tin veins, they apparently are not of the same age as the latter, but belong to the same general period of mineralization.

"Pitchblende has been found in the following localities in the United States: Feldspar quarry, at Middletown, Conn., in large octahedrons; in Hall's quarry, at Glastonbury, Branchville, Conn.; in a pegmatite vein and usually embedded in albite; at Marietta, S. C.; in the Baringer Hill district, Llano County, Texas; in the Brinton Mountain district, Black Hills, S. Dak.; in Mitchell County, N. C.; and in Gilpin County, Colorado. The latter district is the only one of commercial importance.

"All of the Gilpin County mines, with one exception, are found on or near Quartz Hill, a few miles from Central City. There are five that have produced pitchblende in quantity: the Kirk, Wood, German, Belcher, and Calhoun. The Kirk, Belcher, and German mines are close together on Quartz Hill, the Wood and the Calhoun being in the valley below.

"These mines, until recently, have been worked mainly for gold. In this district, gneiss and crystalline schist predominate, with intrusive andesitic dikes and occasionally acid granitic dikes. The rock containing the pitchblende, galema, sphalerite, etc., is a fine-grained aplitic granite which probably once contained an"
appreciable amount of biotite. The ore deposits are of two general types, one containing pitchblende with pyrite, sphalerite, and galena, and sometimes marcasite; the other type contains pyrite, chalcopyrite, sphalerite, and galena, with some gold and silver. Generally speaking, the two types are not associated, so that the miner has a choice of mining either for pitchblende or for gold.

"The Kirk Mine has probably been the most important producer of the five mentioned although reliable data on the output of pitchblende from this mine, up to a few years ago, has been difficult to obtain. During the last 12 years, about 20 tons of ore, with an average content of 35 percent $\text{U}_3\text{O}_8$, and over 100 tons with a content of 3 to 4 percent $\text{U}_3\text{O}_8$, have been mined. The mine has been shut down for some time. More recent operations of the German and Belcher mines produced 120 tons of low-grade ore, averaging about 1 percent $\text{U}_3\text{O}_8$, and 6 tons of high grade. Smaller quantities of ore have been produced at various times from these mines and from the Wood and the Calhoun.

"The pitchblende deposit at St. Joachimsthal, Austria, is in mica schist interbedded with lime schist and crystalline limestone. Toward the east and northeast the formation is gneiss. The gneiss was intruded by quartz porphyry subsequent to the deposition of the vein material. In the mica schist are fissures filled with volcanic material which cut the mineralized zone at various points and depths. The veins are usually 6 inches to 2 feet wide, in rare cases widening out to 3 feet. The mode of mineralization varies greatly, the ores occurring in both stringers and pockets.

"The veins show that deposition occurred in three periods: cobalt and nickel were deposited first, then uranium, and lastly silver. Dolomite spar is always present, and generally has a white or yellowish-white color, but changes to a brownish-red hue where pitchblende begins to appear, and is dirty gray where it is actually in contact with the ore. Deep blue fluorspar is always present.

"The mines at Joachimsthal have been worked since 1517. In 1545 the production of silver ores declined considerably, but since
then the deposits have been mined for bismuth and cobalt. During the last 25 years the mines have been worked for uranium. "In the vicinity of Annaburg, on the Saxony side of the Erzgebirge, the silver-cobalt veins resemble those at Joachimsthal. At Johanngeorgenstadt, the veins contain tin and silver-cobalt ores. Where dolomite spar is found, the silver-cobalt ores contain pitchblende, as at Annaberg. In the Gottessegen Mine the pitchblende occurs in the spar in pieces 2 to 3 in. in diameter. These mines are worked principally for bismuth ocher, but also for cobalt and nickel."

*Autunite and Torbernite:* These minerals usually occur associated with uraninite and other uranium minerals, with silver, lead, tin, tungsten, or copper ores, usually in veins in granite or schist; or in pegmatites.

*Samarskite:* This mineral is usually found in pegmatites.

**ARIZONA URANIUM AND RADION DEPOSITS**

Carnotite deposits, occurring on the Navajo Indian Reservation, have occasionally been reported to the Arizona Bureau of Mines. Since the Act of Congress throwing open some of the Indian reservations for the location and mining of deposits of metalliferous minerals, these deposits have been located, and samples therefrom submitted to the Bureau. From the samples and oral communications received, it is concluded that the carnotite occurrences in the northern part of the state are similar to those in Colorado.

W. H. Staver, a mining engineer residing at Idaho Springs, Colorado, has furnished the data from which was compiled the following description of deposits in the northeastern part of the State.

The deposits are located northeast and west of the Carrizo Mountains on the Navajo Indian Reservation in the extreme northeastern corner of Arizona. The ore is said to lie in layers that vary in thickness from thin seams up to beds four feet thick, and is found at two or more horizons in the McElmo formation, but it seems to be more plentiful in the lower part of the formation. The ore, sometimes fossiliferous, is said to be scattered very
plentifully over hundreds of acres, most of the masses being large enough to have commercial value. It is claimed that the overburden is less than twenty feet thick east of the mountains.

Less pure-yellow carnotite is visible than in the Colorado deposits, much of the ore being quite black. It is stated that the average of material exposed in outcrops will contain only one-half of one percent of $U_3O_8$, but smaller quantities of ore containing as much as five percent of this substance have been found. The ore appears to be unusually rich in $V_2O_5$, surface material averaging at least four percent, and there are a number of good masses that run as high as ten percent in this oxide.

Less than 500 feet of open-air bench work and 100 feet of underground work has been done, but it is estimated that 5000 tons of commercially valuable ore are probably available with slight additional development. It is believed that a much larger tonnage will eventually be exposed.

The property of the Carrizo Uranium Company is connected with Shiprock, New Mexico, by a good automobile road, the distance between the two points being 40 miles. There is said to be plenty of water available for all probable needs, and good timber may be obtained from the Carrizo Mountains.

A report received from Flagstaff, dated August 1, 1922, conveys the information that Ben S. Wilson, a prospector of Casa Grande, and Frank L. Hess, of the U. S. G. S., have recently examined the carnotite deposits discovered by John Wetherill, of Kayenta, as well as other deposits in the vicinity. It is said that evidences were found which lead to the belief that a considerable production of carnotite containing at least one and one-half percent of uranium oxide can be secured from the district, and that the Wetherill deposit has been acquired by Mr. Wilson and his associates who expect to operate it in the near future.

It is further stated that people from Colorado were investigating the carnotite deposits around Kayenta at the time that Messrs. Wilson and Hess were there.

B. G. Mellgren of Tombstone, recently told one of the writers that he knew of the location of two deposits of carnotite in that
vicinity, and exhibited specimens of the ore, but it was found impossible to secure any data relative to these occurrences of the mineral.

Pitchblende has been reported as occurring at the Happy Jack Mine, Wrightstown District, Santa Cruz County.\(^1\)

Gregory\(^2\) states that “In Monument Valley a uranium-vanadium mineral, probably carnotite, was found among the pebbles of the shinarump conglomerate and in association with petrified wood of the Chinle formation.

**PRODUCTION**

Most of the world’s production of uranium and radium comes from carnotite mined in Colorado and Utah. The U. S. G. S.\(^3\) gives the uranium production of the United State for 1920 as 35,076 tons of ore carrying 143.5 tons of uranium. This production was larger than that of any previous year. Other producing localities are Bohemia, South Saxony, and Cornwall, but the amount imported is very small.

According to Moore\(^4\) the production of radium in the United States in 1919 was about 15 grams. In 1921, however, the production had reached 35 grams, the largest in the history of the industry.

**USES**

*Uranium:* Uranium may almost be considered a by-product, since radium and vanadium are the elements most sought when uranium ores are mined and reduced. Most of the uranium produced is used in the manufacture of high-speed steel into which it is introduced in the form of ferro-uranium, an alloy of iron and uranium.

The properties of uranium steel are believed to be practically

\(^1\)U. S. G. S. Bulletin No. 624, Useful Minerals of the United States, compiled by Schrader, Stone, and Sanford.
\(^2\)U. S. G. S. Professional Paper 93, Geology of the Navajo Country, by Herbert E. Gregory.
\(^4\)R. B. Moore, Uranium and Radium Mining, Engineering and Mining Journal, January 17, 1920, and January 22, 1922.
identical with those of vanadium steel, but some high-speed steel manufacturers regard the former with disfavor, perhaps because of the metallurgical difficulties encountered when attempts to introduce uranium into steel were first made.

Uranium is also employed in the manufacture of aluminum-uranium and nickel-uranium alloys for which there is a limited demand. It may be interesting to note that fluorspar is used as a flux in the manufacture of all uranium alloys.

Certain salts of uranium are utilized to a limited extent in chemistry and medicine.

Uranium is extensively employed in the ceramic arts, and, prior to the discovery of the radio-active properties of uranium minerals, pitchblende was mined almost solely as a source of uranium for use in pottery, glazes, and iridescent glass. Uranium compounds impart brilliant, fireproof yellow, orange, or black tints to pottery, and color glass yellow. When uranium is used in the proper proportions, glass containing this element has a beautiful iridescent appearance.

Radium: Considerable progress has recently been made in the use of radium for therapeutic purposes, especially for the treatment of cancer; and there is a fairly large and growing demand for the substance from hospitals and experimental laboratories. By mixing comparatively low grade radio-active material with phosphorescent zinc sulphide, a paint that will glow in the dark may be made. The use of this material on watch and clock dials, electric switch buttons, keyholes, etc., has grown enormously in the last ten years, as is shown by the fact that only about 8,500 watches and clocks with luminous dials were produced in the United States during 1913, while in 1919 the output of the same articles reached 2,200,000.

MINING AND TREATMENT

The carnotite ore of Utah and Colorado occurs in sandstone, and the ore bodies are flat, lenticular, irregular, and vary greatly in size and extent. The ore is usually found outcropping in the

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1Engineering and Mining Journal, April 10, 1920.
walls of the canyons which were cut into the sandstone beds. Prospecting, as is also regular mining, is usually carried on by means of open cuts or tunnel work. Tunnel methods of mining are used even when the depth of the overburden is as little as five feet. Prospecting is also being done successfully by churn and diamond drilling.

In discussing the mining of carnotite, Colorado School of Mines Circular entitled "A World Storehouse of Rare Metals" says:

"In the early development of the carnotite ore bodies the method used was to drive a gravity tunnel into the formation by hand drilling, and this method is still used in some places. Where, however, the drill has outlined definite mineralized zones, inclined tunnels are driven so calculated as to come under the ore body. Ore can then be mined from the roof at a low cost for extraction. In places where the ore is soft, great care must be exercised so as not to lose the "fines" in which the high grade ore is usually found. For this purpose a tarpaulin is spread on the floor of the drift. In the Rock Creek valley, where the ore is soft and high grade, pans are placed against the vein or under the roof and the ore is scooped into them. All in all, so much waste rock must be handled to secure a small amount of shipping ore, so much care must be exercised in getting out the pay ore, and the mineralized zones are so erratic that supervision of carnotite mining operations requires constant attention and a high order of ability."

Both wet and dry concentration have been employed on carnotite ores. Wet concentration consists in the main of fine grinding agitation and decantation, the finer carnotite mineral being decanted off and the coarser sand particles being left behind. Dry concentration involves pulverization, and separation of the fine carnotite mineral from the coarser sand particles by fans. Both the wet and dry processes depend upon the softness of the carnotite mineral which tends to slime and pulverize easier than the sandstone rock with which it is associated. For a complete and exhaustive discussion of the mining and treatment of carnotite ores, the reader is referred to United States Bureau of Mines
Pitchblende occurs in veins. The methods of mining are, therefore, similar to those used in mining other vein deposits.

In Cornwall, England, a small instrument called an alphascope is used to determine the presence of small quantities of pitchblende in ore opened by development work. The radio-active pitchblende is known to be present in the ground being tested when a continuous scintillation appears in the alphascope. This effect is produced by the influence of the radio-active mineral on zinc sulphide in the alphascope. The instrument resembles a short hand telescope several inches in length and about an inch in diameter.

The high specific gravity of pitchblende enables it to be recovered from the rock gangue by ordinary methods of concentration, its concentration presenting no serious difficulties.

Both the uranium and the radium are extracted from the respective ores or concentrates by leaching followed by large-scale chemical treatment. For detailed descriptions of the methods followed in the extraction of radium and uranium from carnitite ores the reader is referred to U. S. Bureau of Mines Bulletin No. 104, Extraction of Radium, Uranium, and Vanadium from Carnitite, by Messrs. Parsons, Moore, Lind, and Schaefer.

PURCHASERS OF URANIUM AND RADIUM ORE

Primos Chemical Company, Primos, Delaware County, Pa.
Vernon Metal and Produce Company, 25 Beaver St., New York City.
Charles Hardy and Ruperti, 115 Broad St., New York City.
Radium Company of Colorado, Denver, Colorado.
Tungsten Products Co., Boulder, Colorado.
Radium Ore Sampling Co., Montrose, Colorado.
EXPLANATION OF THE METHOD USED IN QUOTING THE PRICE OF URANIUM

Uranium quotations are always based on the amount of $\text{U}_3\text{O}_8$ contained in ore and concentrates. If a certain ore or concentrate contains five percent of $\text{U}_3\text{O}_8$, it will contain 100 pounds of this substance per ton of two thousand pounds. If, then, the current price of uranium ore or concentrate is $3.50 per pound of $\text{U}_3\text{O}_8$ contained therein, the product mentioned will be worth $350 per ton.

TO CONVERT PERCENTAGES OF URANIUM TO PERCENTAGES OF URANIUM OXIDE AND VICE VERSA

As previously stated the price of uranium ore is based on the percentage of $\text{U}_3\text{O}_8$ (uranium oxide) that it contains. If the percentage of uranium is known and it is desired to determine the percentage of $\text{U}_3\text{O}_8$ present, multiply the percentage of uranium by 1.179. To determine the percentage of uranium when the percentage of $\text{U}_3\text{O}_8$ is known, multiply this figure by 0.848. For example, an ore containing 52.2 percent of uranium will carry $1.179 \times 52.2 = 61.544$ percent of $\text{U}_3\text{O}_8$; and one carrying 60.0 percent of $\text{U}_3\text{O}_8$ will contain $0.848 \times 60 = 50.88$ percent of uranium.

DEMAND AND MARKET

Uranium ores are of commercial value chiefly as sources of radium. They are sold, however, on the basis of the amount of uranium oxide ($\text{U}_3\text{O}_8$) and vanadium oxide ($\text{V}_2\text{O}_5$) contained therein.

The demand for radium fell off somewhat after the war, but is sufficiently great to cause an over-production of uranium for which there is at present only a limited demand. Indeed, some firms that treat uranium ores for the radium contained therein do not even attempt to recover the uranium present. This is particularly so in the case of carnotite ores. The use of ferro-uranium in the alloy steel industry has made little headway, although ferro-uranium may be easily manufactured.
Carnotite ore containing a minimum of two percent $U_3O_8$ was quoted in 1918 at $2.75 to $3.00 per pound of $U_3O_8$ contained therein. The market price as given by the Engineering and Mining Journal-Press, on July 8, 1922, is $3.50 per pound of $U_3O_8$ present, provided the ore carries two to two-and-a-half percent of $U_3O_8$. Higher grade ores are worth proportionately more per pound of uranium oxide contained therein.

Ore containing two percent of $U_3O_8$ is marketable, and is classed as "shipping ore"; "good ore" contains five to ten percent of oxide, and "high grade ore" runs better than ten percent of $U_3O_8$. Ore containing less than two percent of uranium oxide is called "mill ore."

According to Moore¹ there is very little carnotite ore sold on any basis, since most of the ore mined is produced by a few large companies that treat their own ore. The small miner has been largely eliminated.

In 1921 the price of radium was approximately $89,000 per gram, but the sale price really varied widely.

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MAP OF ARIZONA

Although the Bureau is now emphasizing geological investigations, and expects to complete a reconnaissance map of Arizona during the winter of 1922-23, it now has no geological map of the State available for distribution, and knows of no satisfactory geological map in print.

The Bureau has issued, however, an accurate base map of the State on a scale of approximately eight miles to the inch. This map measures about four by four-and-a-half feet; shows the location of all towns, railroads, streams, mountains, valleys, surveyed lands, and many other features; and is sold in two sheets, un-mounted, together with a complete index, for thirty-five cents, postage prepaid. The same map mounted on cloth with rollers at the top and bottom, together with the index, may be purchased for $2.50, postage prepaid. The appropriate remittance must accompany all orders for maps.

SERVICE OFFERED BY THE BUREAU

The Arizona Bureau of Mines will classify free of charge all rocks and minerals submitted to it, provided that this can be done without making elaborate chemical tests. Assaying and analytical work is done at rates fixed by law, which may be secured on application.

The Bureau is always glad to answer to the best of its ability inquiries on mining, metallurgical, and geological subjects; and takes pride in the fact that its replies are always as complete and authoritative as it is possible to make them.

The Arizona Bureau of Mines bulletins are now published semi-quarterly, and the Bureau will be glad to send all bulletins free of charge as issued to anyone requesting them.

All communications should be addressed and remittances made payable to “The Arizona Bureau of Mines, University Station, Tucson, Arizona.”