



Vanadium

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University of Arizona Bulletin

VANADIUM

BY

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2. The Arizona State Bureau of Mines.
3. A Directory of Arizona Minerals.
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106. A Geological Reconnaissance of the Tucson and Amole Mountains, by Olaf P. Jenkins and Eldred D. Wilson.
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Ralph R. Mott

University of Arizona Bulletin

MINERAL TECHNOLOGY SERIES No. 26

SEPTEMBER 1, 1921

Vanadium

PREFACE

The Arizona Bureau of Mines has received so many requests for information about vanadium and Arizona deposits of ores of this metal that the stock of Bulletin No. 18, Vanadium, has been exhausted. In preparing this revision of the bulletin issued in 1916, that work has been completely rewritten and, so far as possible, brought up to date. The bulletin herewith offered is admittedly nothing but a compilation of facts already published, and no attempt has been made to make it an exhaustive treatise on the subject of vanadium. It is believed, however, that the data ordinarily sought by prospectors are herein presented, and it is hoped that the dissemination of this information will stimulate vanadium mining in Arizona.

DISCOVERY OF VANADIUM

Del Rio, in 1801, discovered vanadium in ore from Mexico, and named it "erythronium"; but later when his conclusions were attacked by others he became doubtful of his own work, and decided that erythronium was merely impure chromium.

Sefstrom, in 1830, ~~while examining a piece of peculiarly soft iron smelted from the Taberg iron ores,~~ suspected the presence of a new element, and believed that the slag from the smelting of these ores should contain it. From this slag he succeeded in isolating the new element which was named from Vanadis, a surname of the Scandinavian goddess Freya.¹

VANADIUM MINERALS

The principal vanadium minerals mined as ores of this metal are patronite, roscoelite, vanadinite, and carnotite. These species are described herewith in the order mentioned.

¹ Le Vanadium by P. Nicolardot.

PATRONITE

Composition: A sulphide of vanadium and other bases. The formula is uncertain, but it contains from about nineteen to twenty-five percent of vanadium.

Luster: Metallic to dull. The material showing metallic luster usually tarnishes and dulls on exposure.

Color: Bright lead-gray to greenish-black.

Hardness: May be scratched with extreme difficulty or not at all with the finger nail, but is easily scratched and whittled with a knife.

Fracture: Uneven.

Specific Gravity: 2.65-2.71, or almost exactly that of quartz.

Occurrence: Occurs in non-crystalline masses associated with asphalt-like and coke-like material.

Blowpipe and Chemical Tests: Infusible when placed on charcoal or held in forceps. When heated in a small glass tube closed at one end drops of sulphur (orange when hot and light yellow when cold) accumulate above the material tested, and sulphureted hydrogen gas with the odor of bad eggs is evolved. Dissolves in hot dilute sulphuric acid, and yields a yellowish solution that turns brown when hydrogen peroxide is added to it.

Varieties or Related Species: Coal and asphalt from a number of localities are known to contain vanadium, possibly in the form of patronite; and ashes from these substances may run well in the metal. The solid, brittle, non-fusible bitumen known as grahamite is especially apt to carry vanadium.

Additional: Two-thirds of the world's consumption of vanadium comes from the patronite deposits of Peru.

ROSCOELITE

Composition: The formula of this vanadium mica is doubtful, but Genth calculated it to be $H_8K(Mg,Fe)(Al,V)_4(SiO_3)_{12}$. It also usually contains small quantities of manganese, lime, and soda. It is, mainly, a hydrous silicate of vanadium and

aluminum that contains between twenty-eight and twenty-nine percent vanadic oxide (V_2O_5) when pure.

Luster: Dull to pearly or grayish.

Color: Dark Green, greenish brown, or dark brown; usually greenish.

Hardness: The grains are usually too small to test them satisfactorily for hardness, but the mineral is very soft.

Fracture: Like all micas, it splits or cleaves easily and smoothly into thin plates.

Specific Gravity: About 2.9, or a trifle heavier than quartz.

Occurrence: Found in very small scales or star- or fan-shaped groups of micaceous aggregates. Sometimes the grains are so small that the ore resembles a shale, but the mineral usually impregnates a sandstone which in some localities contains petrified wood and a little carnotite.

Blowpipe and Chemical Tests: Fuses easily to a black glass. Saturated borax beads are yellow after heating in an oxidizing flame, and light green after heating in a reducing flame. Dissolves in hot dilute sulphuric acid, and yields a yellowish solution that turns brown when hydrogen peroxide is added to it.

Miscellaneous: Roscoelite might be confused with chlorite micas, but the latter almost never occur in sandstone, fuse with difficulty, and do not give the other blowpipe and chemical tests yielded by Roscoelite. Roscoelite is second in importance to patronite as an ore of vanadium.

VANADINITE

Composition: Probably $Pb_4V_3O_{12} \cdot PbCl$ (chloro-vanadate of lead). The pure mineral contains nineteen and three-tenths percent of vanadic oxide (V_2O_5), and seventy-three and one-tenth percent of lead. Very small quantities of phosphorus, and variable, but sometimes considerable, amounts of arsenic may replace the vanadium. Zinc, lime, iron, and copper are occasionally present in proportions up to about one or two percent.

Luster: The crystals often have an adamantine luster; that is, they appear to be coated with an exceedingly thin, transparent layer of some silvery metal. The luster of fractured surfaces may be adamantine or resinous.

Color: Red (often inclining toward orange), reddish brown, brown, gray, black, brownish yellow, or yellow. The tints are listed in the order of decreasing commonness.

Color of Powder: Light yellow to white.

Hardness: Too hard to be scratched with the finger nail, but easily scratched or even whittled with a knife.

Fracture: Usually uneven. Shows no tendency to cleave or split smoothly in any direction.

Specific Gravity: The average is a little less than seven, or nearly three times as heavy as an equal volume of quartz.

Occurrence: Usually occurs in small, very sharply formed, six-sided prisms with flat terminations. Occasionally some of the edges and corners of these small crystals bear additional faces, but complex crystals are relatively rare.

Sometimes the prismatic crystals are more or less hollow, or a large crystal may be made up of numerous smaller ones in parallel positions, the whole group tapering by a series of steps to a slender point at one end. In some localities the mineral occurs only in aggregates of small globular masses which are usually dark brown, grey, or black in color.

In the Cataract Canyon, Coconino County, deposit vanadinite is sometimes found deposited as a compact layer about a thirty-second of an inch thick on quartz crystals two or three inches in diameter. Such layers break easily from the quartz crystals, and on the surfaces originally in contact with the quartz have the appearance of a highly polished metal. Specimens of this kind are known as "vanadium mirrors," but they tarnish and lose their luster after being out of the ground for several months.

While the globular form may occur imbedded in the gangue, it is more apt to be found as an incrustation on the walls of cavities. The crystals likewise occur in groups as

such an incrustation, but isolated crystals are usually found scattered over the surfaces of fissures and vugs.

The well crystallized form of the mineral is usually associated with square, tabular, red, orange, or yellow crystals of wulfenite (molybdate of lead).

Blowpipe and Chemical Tests: Fuses easily on charcoal to a black, lustrous mass. Dissolves in hot nitric acid, and yields a yellow solution. If silver chloride is added to this solution, silver nitrate (which turns purplish when exposed to the sun) will be precipitated. Dissolves in hot dilute sulphuric acid, and yields a yellowish solution that turns brown when hydrogen peroxide is added to it. If a fragment is placed in cold concentrated nitric acid and allowed to stand for from one-half an hour to several hours, it may become red (if not already of this color) and a light yellow vanadic oxide in the form of powder will appear on the surface. If allowed to stand in the acid for two or three hours, the fragment will disintegrate, and considerable of the yellow vanadic oxide will be formed. After standing two or three days the acid becomes light green in color, and, if the test is made in a white porcelain vessel, a red and reddish brown ring will form above the evaporating liquid.

Variety: ENDLICHITE. Contains about equal proportions of vanadium and arsenic. Usually light yellow in color.

Miscellaneous: Vanadinite might be confused with crocoite (chromate of lead), mimetite (chloro-arsenate of lead), and wulfenite (molybdate of lead); but the first mentioned mineral yields an orange-colored powder, the second is never red in color, and fuses on charcoal to a globule of metallic lead, while the third is usually found in tabular, square crystals with beveled edges.

CARNOTITE

Composition: A hydrated vanadate of uranium and potassium of doubtful formula. Crook suggests¹ that the formula may

¹Thos. Crook, *Economic Mineralogy*, Longmans, Green & Co., p. 256.

be $2\text{U}_2\text{O}_3 \cdot \text{K}_2\text{O} \cdot \text{V}_2\text{O}_5 \cdot 3\text{H}_2\text{O}$. This compound would contain about twenty percent of vanadic oxide. Lime and barium sometimes replace the potash to some extent. Like all uranium compounds, carnotite contains an excessively minute proportion of radium.

Luster: Usually dull; sometimes slightly resinous.

Color: Bright canary-yellow.

Color of Powder: Canary-yellow.

Hardness: Easily scratched and cut with a finger nail.

Fracture: Rarely occurs in large enough masses to test the fracture, but such masses when found break like a piece of 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 the grains or the cracks in a 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 roscoelite. 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. Yields water when heated in a small glass tube closed at one end. Dissolves in hot dilute sulphuric acid, and yields a yellowish solution that turns brown when hydrogen peroxide is added to it. The mineral is radio-active, and this property can be tested with an electroscope.

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 deposits are worked primarily for the radium that they contain, but some vanadium is obtained therefrom as a by-product.

GEOLOGICAL OCCURRENCES AND ORIGIN OF VANADIUM ORES

According to Emmons,¹ several water-soluble compounds of vanadium are known to occur in nature, and the metal could have been transported in the form of any of them.

Vanadium was at one time considered a rare element, but it has been found to be very widely distributed. In spite of this fact, deposits of vanadium sufficiently rich to be of commercial value are not common.

The metal has been found in several European iron ores, in the Permian beds of Germany and Russia, and in the copper deposits of Russia and Cheshire, England. The last mentioned occurrence was at one time of commercial value. The bauxite deposits of France also contain vanadium.

According to Hillebrand, vanadium is characteristic of the titaniferous minerals of the Adirondacks, and he concludes from his studies of the distribution of vanadium that in its occurrence it favors the moderately basic eruptive rocks; but, in view of the wide distribution and varied mode of occurrence of the metal in nature, it seems probable that deposits of it may have been derived from both igneous and sedimentary rocks, or from animal and vegetable remains.

PATRONITE. Patronite is known to occur in commercially important amounts only in the Minasragra district in Peru. There, according to Hewett,² the mineral is found in red shales that have been cut at the point where the ore body occurs by a quartz porphyry dike. At least four distinctly different dike systems exist in the vicinity. The principal deposit has a lenticular form, and its maximum width and length are 28 and 350 feet. It occupies a fault that has displaced the quartz porphyry. It consists principally of (1) a lustrous black hydrocarbon called quisquite, (2) a dull, porous, coke-like mass that is nearly pure carbon, and (3) patronite. It appears that after the quisquite and coke-like material were solidified in the fault fissure, further movement sheared

¹ W. H. Emmons, *Enrichment of Ore Deposits*, United States Geological Survey Bulletin No. 625.

² D. Foster Hewett, *Vanadium Deposits of Peru*, *Trans. A. I. M. E.*, vol. XL., pp. 274-299.

and crushed them and the enclosing shales, and that then the patronite filled and solidified in the cavities thus formed or previously existing in the carbonaceous mass. Veinlets of quisquite and patronite have also invaded the country rock, and the latter has in some places, especially along the hanging wall, been impregnated to saturation with patronite. At the surface the patronite has been altered to red and yellow oxides of vanadium and a green iron vanadate which almost entirely replace or fill cracks and fissures in the shale. Nickeliferous pyrite and other impurities exist in the main lode which contains about ten percent of vanadic oxide, while the roasted ore averages between thirty-five and forty percent of this oxide. An impregnated, hard, blue-black shale on the foot wall carries thirteen percent vanadic oxide.

ROSOCOELITE. According to Moore and Kithil,¹ "probably the largest deposits of vanadium that have yet been discovered in the United States are in southwestern Colorado between and close to Placerville and Newmire in San Miguel County." The country rock is there composed of Jurassic and Triassic sediments, and the vanadium deposits occur in the La Plata formation along an unconformity that separates a sandstone bed in the lower part of the formation into two parts.

"The vanadium-bearing rock is a light to dull green, fine-grained sandstone. Sometimes the color is quite dark. Occasionally splotches of carnotite are found in the cracks and fissures, but the uranium content is too small to be worth saving. As a rule the richest ore follows the apparent unconformity between the two sandstones. In places a shallow layer, dark in color and from one-half to one inch thick, lies close to the unconformity, and is said to be rich in vanadium. This layer partly, at least, accounts for the origin of the vanadium in the sandstone above and below.

"A large proportion of the ore carries less than one percent V_2O_5 . The ore mined at Bear Creek has an average content of 1.25 percent V_2O_5 . Some of it contains as much as two percent V_2O_5 , or even a little more. The thin layer, already referred to, at places carries more than eight percent V_2O_5 . These low-grade

¹ E. B. Moore and K. L. Kithil, Preliminary Report on Uranium, Radium, and Vanadium, United States Bureau of Mines Bulletin No. 70, pp. 51-52.

roscoelite deposits can be mined at a profit because they are large and easily worked."

Seven miles southeast of Eagle, Eagle County, Colorado, is another deposit of roscoelite that the same authorities describe as follows:

"The ore is a dark greenish sandstone similar in appearance to the darker types of roscoelite found at Newmire, Colorado. It assays 25 to 1,000 ounces of silver to the ton. Much of the ore that is high in vanadium is low in silver, although this is not invariably true. The vanadium ore contains coarsely crystalline layers. The high-grade silver ore is more compact, usually darker, and has blue-black dots and splotches, due probably to silver bromide."

Leith¹ describes the Colorado and Utah deposits as follows:

"The deposits of Colorado and Utah are large lens-shaped bodies containing roscoelite (a vanadium-bearing mica) in fissures and brecciated zones and replacing the cementing materials of flat-lying sandstones. Locally the sandstones contain as much as twenty percent of the roscoelite. The deposits contain small amounts of fossil wood which may have been an agent in the precipitation of the vanadium. There is considerable doubt as to their origin, but it is generally supposed that they represent concentrations by surface waters of minute quantities of material originally scattered through the surrounding sediments; it has also been suggested that certain igneous dikes in this region may have had some connection with the mineralization."

As mentioned elsewhere in this bulletin, some of the richer roscoelite veins have the appearance of shale.

VANADINITE. Vanadinite is usually found, especially in the Southwest, in the oxidized portions of lead deposits, and is regarded as a secondary mineral formed by the oxidation of galena. At Cutter, New Mexico, it is associated with galena, copper carbonates, barite, fluorite, etc., but in Arizona it is commonly associated with wulfenite.

Prior to the discovery of the Peruvian deposits of vanadium

¹ C. K. Leith, *The Economic Aspects of Geology*, Henry Holt and Company, New York, p. 199.

most of the world's production of this mineral came from Spain where vanadinite occurs in the oxidized zone of lead veins, and the ore contains four to five percent of vanadic oxide as mined. This ore was hand picked and concentrated in a rather primitive fashion to a twelve percent product.

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 (U_3O_8), and from three to four percent of vanadic oxide (V_2O_5), 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 carnotite 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 pockets to deposits yielding a thousand tons or so, and are found irregularly throughout certain particular beds without any special relation to present topography or to 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

¹ Op. cit.

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 great potentialities of this region for future production."

ARIZONA VANADIUM DEPOSITS

The deposit of the U. S. Vanadium Company near Kelvin, Arizona, is vanadinite occurring principally along a shear zone in granite. The ore is usually confined to a number of comparatively narrow seams which, however, occasionally widen and coalesce into an ore body of considerable size. The vanadinite ore is associated with some wulfenite, and is claimed to run from three to five percent V_2O_5 .

A mile or two below the Indian village of Supai in Cataract Canyon, a tributary of the Grand Canyon, is located a vanadium deposit that was incorporated by its owner as the Northern Arizona Mining and Electric Power Company. The deposit occurs along joint planes in and as replacements of Redwall limestone. The vanadium ore is in the form of dark brown to nearly black globular aggregates lining fissures or vugs or imbedded in the gangue. It is associated with other oxidized lead ores, and occasionally a little zinc is present. The deposit appears to be entirely free from molybdenum. Large, well-formed quartz crystals are present in some parts of the deposit, and they are frequently coated with fine "vanadium mirrors." The ore has been developed in a number of openings on both sides of the canyon, but the principal workings are on the Bridal Veil claim, and there considerable work is being done for the purpose of ascertaining how much ore is available.

The only mine that has actually produced vanadium concentrates in the state of Arizona is the C. & B. Vanadium Mine¹ which is controlled by Wilson and Stone of Christmas, Arizona. The property, originally located as a gold-silver prospect, comprises six

¹ Information concerning the C. & B. Vanadium Mine was supplied by M. M. Carpenter, Tucson, Arizona.

claims in the Dripping Springs Mining district adjoining the Dripping Springs Copper Company's property, ten miles northwest from Christmas which is the nearest shipping point.

The geology of the region is described by Ransome in U. S. G. S. Professional Paper No. 115. A north-south fault zone crosses the property. This fault zone is in turn cut by numerous cross breaks. The deposit occurs on a limestone-d diabase contact, along the cross breaks and minor faults. The country rocks are limestone, diabase, diorite, and andesite.

The ore body at present opened up by 1,000 feet of shallow shafts and tunnels is twenty-five feet wide and fifty feet long. No development work other than that necessary to mine the ore has been done up to the present time. Five hundred tons of ore milled is believed to have averaged one to three percent of V_2O_5 . About fifty tons of concentrates were secured. Although most of the vanadium found here exists as vanadinite, there is some descloizite (hydrous vanadate of lead and zinc) present in the ore.

Valette and Company of Casa Grande are seeking a market for concentrates running about ten percent V_2O_5 , but have not completed the deal that will give them the control of the property from which these concentrates come, and prefer to withhold information concerning its location until the transaction is completed. For this reason data concerning this deposit could not be obtained.

Carnotite deposits have occasionally been reported to the Arizona Bureau of Mines as occurring on the Navajo Indian Reservation. 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.

B. C. Mellegren, of Tombstone, recently told one of the writers that he knew of the location of two deposits of carnotite in the vicinity, and exhibited specimens of the ore, but it was found

impossible to secure any data relative to these occurrences of the mineral.

VANADIUM OCCURRENCES

Vanadium has been reported as occurring in the following localities in Arizona.

Cochise County. Near Charleston, Fairbanks, Willcox and Light; Shattuck Arizona Copper Company; and Mowry Mine, Patagonia.

Coconino County: Cataract Canyon, 45 miles northwest of Grand Canyon station.

Gila County. The Patterson group of claims, the Lost Gulch, Lockwood, Clark & Stewart claims; New State Mine, Old Dominion Mine, Radium Mines Company, Continental Mine, C. & B. Vanadium Mine, and near the town of Young.

Maricopa County. The Vulture Mine, Farley's Collateral Mine, Phoenix Mine, Dragoon Mine, and near Wickenburg.

Mohave County. Missouri Mohave Mine, also near Hackberry, Gold Basin, and Signal.

Pinal County. Mammoth Mine, Oracle; Broken Hill Mines, Ray; Riggins Group, Ray; Black Prince Mine, Orizalia Mine, and near Florence, Kelvin, and Feldman.

Pima County. Grand Central Mines, Old Yuma Mine, Shamrock claim, near Casa Grande, and the Orizola claim south of Casa Grande.

Yavapai County. Silver Bell and Big Bug Mines, North Star claim, Humboldt Consolidated Mines Company, Crown King Mine, Grove Mine in the Humbug District, and near Jerome.

Yuma County. Hamburg, Princess, and Clara claims, and Red Cloud Mine.

VANADIUM CLAIM OWNERS OF ARIZONA

The following is a list of reported vanadium claim owners listed by the Bureau and revised to date:

Bachman-Merritt Metals Co., Nogales, Arizona.
R. T. Barton, Prescott, Arizona.

- Ed. W. Blair, Bisbee, Arizona.
Calvin Bywater, Dripping Springs, Arizona.
John E. Chapman, Box 1222, Phoenix, Arizona.
C. & B. Vanadium Mine, Christmas, Arizona.
Carl W. Chilson, Payson, Arizona.
Cole and Goodwin, Douglas, Arizona.
Murray C. Day, Duquesne, Arizona.
Dragon Mining and Development Company, Wickenburg,
Arizona.
Elmer and Warren, Prescott, Arizona.
Finnegan and Spiekermann, Wenden, Arizona.
O. D. M. Gaddis and W. C. Bishop, Kingman, Arizona.
Wm. L. Hargrove, Box 103, Prescott, Arizona.
T. C. and C. A. Hefner, Tombstone, Arizona.
Geo. N. Hicks, 219 Chamber of Commerce Bldg., Omaha, Neb.
L. P. Hillmer, Patagonia, Arizona.
J. C. Holmes, Patagonia, Arizona.
R. M. Howell, Box 302, Nogales, Arizona.
Kaaba Mining and Milling Co., C. H. Wagner, Round Valley
Mail Box, Kingman, Arizona.
C. W. McGraw, Kelvin, Arizona.
John Mulligan, Kingman, Arizona.
The Northern Arizona Mining and Electric Power Company,
Supai, Coconino County, Arizona.
W. M. Ownes, Sayers, Arizona.
Phoenix Gold Mining Company, Cave Creek, Arizona.
R. Robertson, Kirkland, Arizona.
Shattuck Arizona Copper Company, Bisbee, Arizona.
M. W. Stanton, 401 Caples Bldg., El Paso, Texas.
S. O. Stewart, Winkelman, Arizona.
E. C. Suman, Box 553, Prescott, Arizona.
U. S. Vanadium Dev. Co., Dr. Payne Palmer, Phoenix, Arizona.
Warrens and Helmer, Kirkland, Arizona.
S. M. Wills, Canille, Arizona.
Ben S. Wilson, Casa Grande, Arizona.
Wilson & Stone, Christmas, Arizona.
W. T. Yeckley, Willcox, Arizona.

PRODUCTION

The demand for vanadium depends upon the production of vanadium-alloy steels. According to statistics quoted herein two-thirds of the world's supply of vanadium is obtained from the Minasruga deposit of patronite in Peru, which is owned by the Vanadium Company of America. Most of the remaining third comes from the roscoelite and carnotite deposits of Colorado and Utah. A small amount of vanadium is obtained from the vanadium minerals mined in the oxidized zones of lead veins in New Mexico, Nevada, Arizona, and Spain¹.

APPROXIMATE WORLD PRODUCTION OF VANADIUM, FROM
U. S. G. S. MIN. RES. 1918

Year	Peru (Ore)			United States (Ore and Concentrates)
	Quantity (Short Tons)	Percentage V ₂ O ₅	Vanadium Contained (Short Tons)	Vanadium Contained (Short Tons)
1914	14.5	45.00	4	452
1915	3,145	45.58	803	627
1916	3,448	40.00	772	460
1917	4,083	35.78	821	484
1918	2,183	19.10	234	276

According to the Engineering and Mining Journal of January 17, 1920, the production of vanadium fell off during 1919 with a resultant increase in price. The automobile industry uses most of the vanadium steel alloy manufactured, and the demand for the metal is largely dependant upon the condition of that industry. Vanadium is, however, being used to a greater extent in high speed tool steels than was the case a few years ago, and this fact has stimulated the demand for it.

ARIZONA PRODUCTION

An attempt was made to work the deposit of the U. S. Vanadium Company of Kelvin, Arizona, in 1918, but treatment difficulties were encountered and work was discontinued.

¹ Vanadium in 1918 by F. L. Hess. United States Geological Survey Mineral Resources, 1918, Part I.

During the latter part of 1919 and early in 1920 the C. & B. Vanadium Mine in the Dripping Springs District near Globe was worked. This property produced about 500 tons of ore that is said to have yielded forty-nine tons of vanadinite concentrates carrying 9.5 percent of V_2O_5 .

There is at present a possibility of the Old Mohawk Mine at Mammoth being worked for vanadinite left in the mine and in the mill tailings.

USES

For many years vanadium was considered a scientific curiosity and had no industrial application of importance.

Vanadium was first employed by Berzelius in the manufacture of a black ink which it was later found could be made indelible. For many years this was the only industrial application. In 1861 Saint-Claire-Deville proposed its use in the ceramic arts, and about the year 1870 vanadium commenced to play an important part in the industry. The facility with which vanadium oxidizes and is reduced makes it of great value where a carrier for oxygen is desired. Witz's studies resulted in its replacing copper sulphate as an oxidizer in aniline black dyeing. By the use of a very small amount of vanadium, a more solid black can be obtained than with copper sulphate.¹

The production of several new colors has been made possible by the use of vanadium salts in dyeing, ceramics, and glass making. Its salts are also used in photography.

Vanadium now, however, plays its most important role in the manufacture of special steels.

In 1896 Chambley carried out some experiments on steels containing vanadium, but for many reasons they were not complete or satisfactory. The results obtained, however, were sufficient to convince him that there was a large field for vanadium steel in the manufacture of armor piercing shells, bearings, and connecting rods.²

In 1900 Arnold in England made extensive tests on vanadium

¹ P. Nicolardot, *Le Vanadium*.

² Ditto.

iron and steel, and established conclusively the advantages to be gained by the addition of vanadium to steel.

Most authorities agree that the valuable qualities imparted to steel by vanadium are due to its action as a powerful scavenger which eliminates dissolved oxides and dissolves occluded gases. Vanadium increases the strength of steel, and at the same time renders it better able to withstand wear and erosion, by adding to its self-lubricating properties.

Vanadium also seems to prolong the life of steel that is subjected to frequent reversals of stress which produce so-called crystallization, and result in "fatigue" or sudden rupture.

It renders chromium steels as easily machinable as ordinary carbon steels.

Its value as a scavenger is disputed by some who claim that there are other elements equal or superior to vanadium in this respect, and contend that it produces a beneficial effect upon the constituents of the steel outside of any influence it may have as a scavenger.

Chrome-vanadium and high speed tool steels are the chief commercial vanadium steels now on the market, and the benefits that have been gained by the use of vanadium in these steels has led to its use in steel castings.

The quality of high speed tool steels is greatly enhanced by the presence of vanadium, and it is extensively used by English, German, and American high speed tool steel manufacturers. Vanadium steel machining tools possess the advantage of holding their hardness or temper and cutting edge longer and at a higher temperature than ordinary carbon steel tools. This property makes it possible to machine with vanadium steel tools at a very high rate of speed, and to take deep cuts into the metal.

A large percentage of the chrome-vanadium steel now made goes into automobile and machine parts such as crank shafts, connecting rods, piston rods, axles, crank pins, gears, springs, locomotive side frames, etc.

In the paraphernalia of war vanadium steel plays an important part in aeroplane motors, submarines, armor plates, armored motor

cars, and gun barrels. Light machine guns and aerial artillery are also constructed of vanadium steel.

It possesses marked superiority for battering tools such as pneumatic chisels, setts, calking tools, and rock drills because of its combination of hardness, toughness, and strength.¹

From 0.12 to 0.22 percent of vanadium is used in steel, the amount depending upon the purpose to which it is to be put. In high speed tool steel as high as 2.5 percent has been used. Considerably more vanadium is added to a steel melt than appears in the cold steel.

There is some use for vanadium in the preparation of vanadium chemicals.

MANUFACTURE OF VANADIUM ALLOYS

The unsatisfactory results secured and the failures encountered when vanadium steels were first investigated can probably be traced to the lack of knowledge of the best method of introducing the vanadium into the steel, and to the impurity of the vanadium alloy used.

Vanadium is now introduced into iron or steel in the form of ferro-vanadium, an alloy of iron and vanadium approximating the proportion of two parts of iron to one of vanadium. According to Gibbs² the presence of aluminum and silicon within certain limits improve ferro-vanadium, but according to Nicolardot³ ferro-vanadium should be as free as possible from carbon and aluminum.

Ferro-vanadium is made either in the electric furnace or by the aluminum reduction or thermit process. The carbon content of ferro-vanadium made in the electric furnace is greater than in the alloy produced by the aluminum reduction process. It is claimed that ferro-vanadium produced by the former method also contains vanadium carbide which should not be present in the alloy if uniformly satisfactory results are desired.

Since impurities vitally affect the quality of vanadium steel, it is important that the ores from which ferro-vanadium is manufactured be free from impurities.

¹ G. L. Norris, *Vanadium Steel*, *Iron Age*, July 19, 1917.

² Wm. Gibbs, *Vanadium Steel*, *Cassiers Mag.*, 1910, Vol. XXXVIII.

³ *Op. Cit.*

In America most of the high grade ferro-vanadium is made by the thermit process. In Europe the electric furnace and thermit processes are both used.

SPECIFICATIONS

Buyers demand a 100 percent analysis of the vanadium ores and concentrates that are offered for sale. The price obtained for any vanadium ore is governed by its purity. Copper, molybdenum, tungsten, chromium, sulphur, lead, zinc, arsenic, phosphorus, alumina, and silica constitute the undesirable impurities. It is with great difficulty that molybdenum, tungsten, and chromium are separated from vanadium. Ferro-vanadium used in the manufacture of steel should be free from the above mentioned impurities, hence the vanadium ore or concentrates from which the vanadium is obtained must contain very little of these elements.

Since most of the vanadium deposits of the state of Arizona carry wulfenite, it may be of interest to know that the writers were informed by one Eastern ore buyer that vanadinite concentrates or high grade ore would be marketable if wulfenite was not present to a greater extent than two to three percent.

Most buyers desire car load lots, and contract for steady delivery, but spot lots are marketable.

ORE TREATMENT

By calcination, asphalt and sulphur are eliminated from patronite, the sulphide of vanadium, and its associates. The resulting product contains about 50 percent of V_2O_5 . It is fused with soda to form sodium vanadate which is smelted in an electric furnace to ferro-vanadium carrying thirty-five to forty percent vanadium.

In the treatment of carnotite for radium, the low grade ore is first concentrated, then the vanadium is separated as oxide of vanadium or iron vanadate which is reduced in the electric furnace to ferro-vanadium. A complete description of the methods of mining and the treatment of carnotite ores by the National Radium Institute in Colorado is given in Bulletin 103 of the United States Bureau of Mines, by Kithil and Davis.

Roscoelite-bearing sandstone is roasted with salt and pyrite, lixiviated, filter pressed, and the solution treated with a ferric salt to precipitate the vanadium as ferric-vanadate which is smelted in the electric furnace to ferro-vanadium.

Vanadinite ores are selectively mined, sorted, and concentrated. Dry concentration was tried by the U. S. Vanadium Company at Kelvin, Arizona, but was not a success. The method of concentration practiced at the C. & B. Vanadium Mine was extremely simple. The plant consisted of a crusher, two 10-mesh trommel screens, and two Overstrom tables. The over-size from the trommels went to the dump, and all material that passed a 10-mesh screen was tabled. A concentrate was obtained that ran 9.5 percent V_2O_5 . Although this mill worked successfully, the tailing loss was very great. Treatment tests made at the University of Arizona show that this ore is amenable to flotation, and by this process the recovery is increased at least thirty percent.

The method of concentration of vanadinite ore followed at Cutter, New Mexico, described in the Mining and Scientific Press of September 9, 1916, should be of interest to possible producers in Arizona. This method was briefly as follows:

The lead vanadate ore at Cutter occurs in a gangue that is calcareous and contains quartz, barite, manganese oxide, galena, fluorite, iron minerals, and small amounts of arsenic, copper, and phosphorus. Some of the ore was sent from the mine directly to the oxide plant for treatment — it was too rich to be milled.

Since the specific gravities of barite, galena, and lead vanadate are 4.5, 7.4, and 6.8, respectively, it is difficult to separate the vanadium mineral from the barite and galena. The best saving made on one percent vanadium ore, when the ore was crushed in a crusher, rolls, and Elspass mill, and concentrated on Wilfley tables, vanners, and slime tables, was 69 percent. The assays of the mill products were as follows:

	Vanadium %
Wilfley concentrate.....	8 to 9
Secondary concentrates.....	4.5 to 5
Slime	0.7 to 1.85

When rolls were substituted for the Elspass mill and regrinding was done in a Hardinge mill, less slime was formed and the

extraction was increased to 80-86 percent. This high extraction was obtained when treating the ore in the order outlined below.

- (1). Crushing with rolls.
- (2). Screening.
- (3). Concentration.
- (4). Re-grinding the tailings and middlings from the Wilfley tables, the tailings from the corrugated Frue vanner, and the over-size from the impact screens of the re-grinding unit, in a Hardinge conical mill.
- (5). Screening.
- (6). Classification.
- (7). Concentration of the re-ground product, and
- (8). Concentration of slimes from both primary and secondary crushings.

PURCHASERS OF VANADIUM ORES AND CONCENTRATES

Vanadium Company of America, Vanadium Bldg., Pittsburgh, Pa.

Primos Chemical Company, Primos, Delaware County, Pa.

Vernon Metal and Produce Company, 25 Beaver St., New York City.

H. A. Watson and Company, Inc., 55 Liberty St., New York City.

York Ferro Alloys Company, York, Pa.

Foote Mineral Company, 107 N. 19th St., Philadelphia, Pa.

Electro Metallurgical Company, 42nd Street Bldg., New York City.

C. W. Leavitt and Company, 30 Church St., New York City.

Metal and Thermit Corporation, 120 Broadway, New York City.

Charles Hardy, Park Row Bldg., New York City.

EXPLANATION OF THE METHOD USED IN QUOTING PRICES OF VANADIUM

Vanadium quotations are always based on the amount of V_2O_5 contained in ore or concentrates. If a certain ore or concentrate contains twenty percent of V_2O_5 , it will contain four hundred pounds of this substance per ton of two thousand pounds. If, then, the current price of vanadium ores or concentrates is one dollar per pound of V_2O_5 contained therein, the product mentioned will be worth four hundred dollars per ton.

MARKET VALUE

The following price quotations for vanadium ores and concentrates were taken from the Engineering and Mining Journal:

July 30, 1921.	\$1 per pound of V_2O_5 , f. o. b. New York, guaranteed minimum of 18 percent V_2O_5 .
August 6, 1921.	No change.
July 2, 1921.	No change.

TO CONVERT PERCENTAGES OF VANADIUM TO PERCENTAGES OF VANADIC OXIDE AND VICE VERSA

The price of vanadium ore is based on the percentage of V_2O_5 (vanadic oxide) that it contains. If the percentage of vanadium is known, and it is desired to determine the percentage of V_2O_5 present, multiply the former figures by 1.778. To determine the percentage of vanadium, multiply the percentage of V_2O_5 by 0.562. For example, an ore containing 9.5 percent vanadium will carry $1.778 \times 9.5 = 16.891$ percent V_2O_5 ; and one carrying 15.5 percent of V_2O_5 will contain $0.562 \times 15.5 = 8.71$ percent of vanadium.

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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 1921-22, 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, unmounted, 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."