DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

TO ACCOMPANY MAP MR-16

VANADIUM IN THE UNITED STATES

(Exclusive of Alaska and Hawaii)

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Introduction

The productive and potential raw material sources of vanadium in the United States (exclusive of Alaska and Hawaii) are shown on the accompanying map. This map is at the scale of 50 miles to the inch. The text accompanying the map briefly describes the major geologic types of deposits of vanadium, and it lists the productive and potential sources by the name of the deposit or geographic area and by coordinates to the nearest minute of latitude and longitude. Each productive or potential source is listed by state and a number, and its location on the map is identified by the same number. The text and the map were compiled from published and unpublished information; at least one reference is given for each locality if reports on it have been published.

On the map the geologic types of deposits are indicated by the shape of symbols, and for most deposits the approximate amount of the total contained vanadium (production, if any, plus material in the ground) is indicated by the size of symbols. Most spot symbols represent a mine, group of mines, or an area of closely spaced mines that have produced ore yielding vanadium. Some spots, however, show mines that have produced ore containing vanadium but from which this metal has not been recovered, and some spots merely show unproductive deposits of potential interest for vanadium and perhaps other metals. Bedded deposits of productive or potential interest are shown by lines representing outcrops of vanadium-bearing beds, and the general areas of potential interest are outlined by broken lines.

In western Colorado, southeastern Utah, and northeastern Arizona--part of the region generally known as the Colorado Plateau--many hundreds of deposits have yielded ore from which both vanadium and uranium have been recovered. A few of the symbols shown represent individual deposits, but most of the symbols represent groups of many deposits. References to published reports and maps are listed specifically for some areas. Readers interested in the general geologic occurrence of these deposits are also referred to published reports by Fischer (1942), Fischer and Hilpert (1952), and various papers published in Page and others (1956), Garrels and Larsen (1959), and by the United Nations (1958). A map compiled by Finch (1955) and published on a simplified geologic base shows the locations of many individual vanadium and uranium deposits in the region.

Geochemical habits

Vanadium occurs in nature in the 3-, 4-, and 5-valent states. It is relatively insoluble in the 3-valent state, and probably also in the 4-valent state, but it is rather soluble in the 5-valent state, the highest state of oxidation.

Vanadium is relatively abundant as a "trace element" in igneous rocks. It averages about 90 parts per million and is slightly more abundant than copper or zinc and several times more abundant than lead (Green, 1959). It is more abundant in mafic igneous rocks than in silicic ones.

Vanadium does not form the essential part of any rock mineral in igneous rocks, but rather its ions replace those of iron and aluminum in dark-colored silicates and of iron in magnetite; it is especially abundant in magnetite in deposits of titaniferous magnetite. In the rock-forming silicates and magnetite, vanadium is fixed in the relatively insoluble lower oxidation states. Probably not much vanadium is available for hydrothermal transport, for very little is found in hydrothermal veins except for the gold-quartz veins and those containing titanium-bearing minerals (Fischer, 1959).

During normal weathering of igneous rocks, most of the vanadium that is released (mostly from the silicate minerals) goes into the clay minerals formed, probably in the 4-valent state (Rankama and Sahama, 1950, p. 599). It probably remains with these minerals as they are transported to places where they accumulate as sedimentary rocks, for argillaceous sediments are generally more vanadiferous than other types. The vanadium content of shales averages about the same as that of igneous rocks, whereas the average vanadium content of sandstones and limestones is considerably less. On the other hand, if igneous rocks or vanadiferous clay minerals are weathered under conditions of intensive oxidation, the vanadium is converted to the relatively soluble highly oxidized state and goes readily into surface- and ground-water solutions.

Vanadium can be precipitated from solution and locally concentrated in rocks under the following general conditions (Goldschmidt, 1954, p. 492):

1. In the presence of hydroxides of aluminum or ferric iron. This process could form or enrich the vanadium concentration in some bauxites and in some residual and sedimentary iron ores.

2. In the presence of cations of heavy metals, such as lead, zinc, and copper. This process could form the vanadate ores.

3. In a reducing environment, as in the presence

Introduction (cont'd.)

of carbonaceous material. If the vanadium-bearing solutions are moving through rocks, this process could form deposits such as those in sandstone on the Colorado Plateau. If, on the other hand, the solutions are surface waters, this process could form deposits in sediments like carbonaceous shales and phosphate rock that accumulate in waters depleted in oxygen. Furthermore, if the carbonaceous materials in these sediments are converted to liquid hydrocarbons, the vanadium can move as a dissolved constituent, which would explain the high vanadium content in the ash of some petroleum. And if this petroleum was distilled naturally to form an asphaltite, the contained vanadium could be residually concentrated in the asphaltite, forming a deposit geologically like the fabulous vanadium deposit at Minaragra, Peru.

Deposits and occurences

Titaniferous magnetites.--Vanadium occurs in appreciable amounts in most titaniferous magnetites, ranging from about 0.2 to more than 1 percent V_2O_5 and probably averaging between 0.4 and 0.6 percent (Singewald, 1913). Deposits of this type are associated with both gabbros and anorthosites, but the largest and most economically promising are those with anorthosite. Some bodies of titaniferous magnetite are merely local differentiates of the magma, and the concentrated masses of the metallic minerals merge with the nonmetallic minerals of the host rock and also contain disseminated crystals of the rock minerals. Other bodies have been injected into the host rock, presumably after remelting of the ore minerals in their place of original crystallization; such bodies have well-defined borders and many are nearly pure mixtures of ilmenite and magnetite. Titaniferous magnetite deposits vary greatly in size, but many of them contain millions of tons of titaniferous magnetite. In many deposits, however, the magnetite and ilmenite are so finely intergrown that they cannot be separated at a profit under present conditions.

Moderate- to large-sized deposits of titaniferous magnetite occur in Rhode Island, New York, North Carolina, Minnesota, Wyoming, and California, but only the deposit at Lake Sanford, N. Y., has been mined intensively, yielding an ilmenite and magnetite concentrate. The ore averages about 0.5 percent V_2O_5 and the magnetite concentrate about 0.7 percent V_2O_5, but no vanadium has been recovered from this material.

Nontitaniferous magnetites.--Some magmatic magnetite deposits that are so low in titanium as to be classified as nontitaniferous contain 0.1-0.3 percent V_2O_5. Most magnetites of this class are derivatives from syenitic magmas; some bodies have differentiated in place, others have characteristics that indicate pegmatitic or hydrothermal transport. The only deposits of this type known in the United States are in New Jersey; they have been mined on a moderate scale. The ore contains 0.1-0.2 percent V_2O_5, but no vanadium has been recovered from it. Very large deposits of this type occur elsewhere in the world.

Titanium-bearing veins.--Rutile and ilmenite concentrates from vein deposits in Arkansas and Virginia contain up to several tenths percent V_2O_5. No vanadium minerals have been recognized in these deposits, however, so presumably vanadium substitutes for titanium in the ore minerals. These deposits have been worked on a moderate scale, but no vanadium has been recovered from them.

Gold-quartz veins.--Roscoelite, the vanadium-bearing mica, is commonly reported as a gangue mineral in gold-quartz veins, especially those that contain gold-telluride minerals. Lovering and Goddard (1950, p. 234) report that a small shipment of roscoelite ore, apparently averaging more than 2 percent V_2O_5, was made in 1910 from Kekionga-Magnolia vein, Boulder County, Colo. (see map). Roscoelite is reported with several other gold-telluride-quartz veins in the Colorado Front Range (Lovering and Goddard, 1950), with gold-telluride minerals at Cripple Creek and in the La Plata Mountains, Colo., and in a few gold-quartz veins in California and Oregon. Only the Kekionga-Magnolia deposit is shown on the accompanying map, however, for no data are available on the vanadium grade of the other deposits; likely their vanadium content is generally too low to be of commercial interest.

Vanadates in base-metal deposits.--Vanadates of lead, zinc, and copper occur in the oxidized zones of many base-metal deposits in the southwestern United States, but probably most of the occurrences reported in published literature are merely of mineralogic interest. Only those deposits from which shipments of vanadate ore have been reported are shown on the accompanying map. Judging from the scanty data available, the average grade of the vanadate ore shipped is about 1 percent V_2O_5. The total vanadium recovered from these deposits is small.

Similar deposits are found in many parts of the world, and a few of these have been moderately productive. Typically the vanadate deposits occur in areas of arid climate and deep oxidation, and most though not all of the productive deposits are in carbonate country rock. The vanadate minerals occur in irregular patches in the oxidized zones. The primary sulfide minerals in these deposits contain no more that trace amounts of vanadium.

Vanadium-uranium deposits in sandstone.--Vanadium-uranium deposits in sandstone are numerous in western Colorado, eastern Utah, and northeastern Arizona. They have been the principal domestic source of vanadium. Developed reserves are moderately large, and probably many more deposits will be found by continued exploration.

Nearly all the productive vanadium deposits occur in continental sandstones of Mesozoic age. Most of these host rocks contain carbonized plant fossils. The ore ranges in grade from 1 to 2 percent V_2O_5 and 0.1 to 0.5 percent U_3O_8. Ore minerals below the zone of oxidation are low-valence oxides and silicates of vanadium and uranium. Accessory pyrite and marcasite are common but generally not abundant, and copper sulfides are present in places. Many secondary minerals form in the zones of oxidation. The ore minerals mainly fill sandstone pores; replacement of the host rock is relatively minor except for rich and spotty concentrations in plant fossils and sandstone. Introduced gangue minerals other than those that commonly cement sandstone are inconspicuous or absent.

Typically the deposits are lenticular or tabular and nearly parallel to bedding. Many of them are small, but some contain more than a million tons of ore. The influence of sedimentary structures, such as lenses, in localizing deposits has been recognized by many geologists; tectonic structures, on the other hand, have not obviously localized many deposits. Some deposits are near igneous intrusive bodies, and some are near hydrothermal veins, but these do not differ conspicuously from those that are remote from known centers of igneous or hydrothermal activity.

Similar deposits in northwestern New Mexico and in the Black Hills region of South Dakota and Wyoming have yielded uranium but no vanadium, for their vanadium content is generally less than 0.5 percent V_2O_5. Nevertheless, some of these deposits are large, and as they are being mined intensively and offer a potential byproduct source of vanadium, representative deposits in these areas are shown on the accompanying map.

Vanadium in asphaltite and petroleum.--Numerous references to vanadium in asphaltite and related substances are cited in literature. Quantities to about 40 percent vanadium in the ash are reported, but most of the descriptions of the occurences are too scant to permit appraisal. Only the asphaltite deposit near Page, Okla., from which a small yield of vanadium during World War I is reported, is shown on the map. The deposit at Minaragra, Peru, the world's most productive vanadium deposit, is an asphaltite.

Some crude oils contain vanadium, some as much as several percent in the ash. Small quantities of vanadium are recovered each year from the ash and soot from oil-fired boilers.

Vanadiferous phosphate.--Most marine phosphates contain very little vanadium, but those in southeastern Idaho and adjoining states contain as much as 0.3 percent V_2O_5. The phosphate rock is in one or more layers in phosphatic shale of the Phosphoria formation of Permian age and its stratigraphic equivalents. In addition to vanadium, the phosphate rock also contains fluorine and a little uranium and selenium. The minerals containing these elements have not been identified, but probably the elements were precipitated from sea water with the phosphate rock, for locally their content in a single bed is nearly constant. A small but significant byproduct of vanadium has been recovered during the acid treatment of phosphate rock to make fertilizer, and the recovery of vanadium from the ferrophosphorus byproduct of elemental phosphorus production is being planned. Reserves of minable phosphate rock are very large.

Vanadiferous shale and related material.--In addition to the vanadium-bearing phosphate rock in phosphatic shale of the Phosphoria formation, some of the shale beds in this stratigraphic unit in Idaho and Wyoming contain appreciable vanadium. Individual shale beds are thin, ranging only to several inches in thickness, but they are of wide extent and each has a nearly constant vanadium content. The greatest concentration is in a zone ranging from about 2 to 10 feet in thickness and about 35 to 50 feet below the top of the phosphatic shale member. Beds in the central few inches of this zone contain 1.5 to 2.5 percent V_2O_5, and the entire zone averages from 0.7 to 1.0 percent V_2O_5. These beds also contain a little molybdenum, nickel, and selenium. No vanadium has been recovered from these beds, but they constitute a very large potential resource.

A similar vanadiferous shale occurs in Tooele County, Utah, but its known extent is small.

In 1960 vanadiferous shales in central Nevada were being intensively explored. These shales are reported to contain as much as 1 percent V_2O_5, but they are not shown on the accompanying map, for their extent, average grade, and potential have not been announced.

The vanadiferous graphitic schist of Alabama may represent the metamorphosed equivalent of a vanadiferous shale. These deposits contain as much as a few tenths percent V_2O_5, and they represent a potential resource of small to moderate importance as a byproduct of the graphite.

Locality Index

Mine, group, or area, and reference	Lat. N.	Long. W.
ALABAMA		
1. Graphitic schist zone. Pallister and Thoenen, 1948.	32°45' 33°23'	86°28' 85°46'
ARIZONA		
1. Rattlesnake mine area. Stokes, 1951.	36°54'	109°17'
2. Eurida mine area. Stokes, 1951.	36°48'	109°17'
3. Syracuse mine area. Stokes, 1951.	36°45'	109°03'
4. Cove Mesa. Jones, 1954.	36°39'	109°16'
5. Lukachukai area. Dodd, 1956.	36°33'	109°15'
6. Monument 2 mine area. Witkind, 1956.	36°56'	109°53'
7. Mitchell Mesa. Witkind, 1956.	36°56'	110°07'
8. Monument 1 mine area. Witkind, 1956.	36°57'	110°14'
9. Oljeto Wash area.	36°59'	110°19'
10. Defiance (Apache) mine. Peterson, 1950.	33°32'	110°48'
11. C & B mine group (Bywater mine?). Ross, 1925.	33°07'	110°54'
12. St. Anthony (Mammoth) area. Creasey, 1950.	32°42'	110°41'
ARKANSAS		
1. Magnet Cove area. Fryklund and others, 1954.	34°28'	92°51'
2. Potash Sulphur Springs area. Fryklund and others, 1954.	34°29'	92°56'

Locality Index (cont'd.)

CALIFORNIA

1. Leiser Ray mine, Goffs area. Hewett, 1956.	35°02'	115°04'
2. Eldorado (New Eldorado) mine. Brown, 1923.	33°54'	115°56'
3. San Gabriel Mountains. Oakeshott, 1948.	34°25'	118°21'

COLORADO

1. Kekionga-Magnolia vein. Lovering and Goddard, 1950.	39°59'	105°24'
2. Caribou area. Lovering and Goddard, 1950.	39°59'	105°35'
3. Garo area. Wilmarth, 1959.	39°07'	105°55'
4. Iron Mountain area. Singewald, 1913.	38°21'	105°27'
5. Skull Creek area. Clinton and Carithers, 1956.	40°16'	108°42'
6. Meeker group.	40°08'	107°42'
7. Rifle Creek area. Fischer, 1961.	39°40'	107°41'
8. Beaver Mesa.	38°39'	109°02'
9. Tenderfoot Mesa. Cater, 1955a.	38°40'	108°54'
10. Calamity Mesa. Fischer and Hilpert, 1952; Cater, 1955b.	38°37'	108°52'
11. Outlaw Mesa. Fischer and Hilpert, 1952; Cater, 1955b.	38°36'	108°48'
12. Mesa Creek area. Cater, 1955b.	38°33'	108°46'
13. Dolores group area. McKay, 1955.	38°24'	108°46'
14. Martin Mesa. McKay, 1955.	38°24'	108°51'
15. Roc Creek area. Shoemaker, 1956.	38°27'	108°57'
16. Club Mesa. Fischer, 1942; Boardman and others, 1958.	38°22'	108°44'
17. Long Park area. Cater, 1955c; Cater and others, 1955.	38°18'	108°45'
18. Bitter Creek area. Cater and others, 1955; Heyl, 1957.	38°16'	108°41'
19. La Sal Creek area. Carter and Gualtieri, 1957.	38°20'	109°02'
20. Jo Dandy area. Cater, 1954; Cater, 1955d.	38°14'	108°45'
21. Wild Steer area. Cater, 1954.	38°15'	108°49'
22. Bull Canyon area. Cater, 1954.	38°11'	108°50'
23. Little Gyp area. Cater, 1955e.	38°11'	108°57'
24. Leopard Creek area. Fischer and others, 1947.	38°02'	108°03'
25. Bear and Fall Creek areas. Fischer and others, 1947.	37°59'	108°00'
26. Pitchfork mine area. Cater, 1955f.	38°01'	108°39'

COLORADO (cont'd.)

27. Long Ridge mines area. Cater, 1955f.	38°03'	108°43'
28. Radium Hill area. Cater, 1954, 1955g.	38°07'	108°50'
29. McIntyre Canyon area. Shawe and others, 1959.	38°05'	109°01'
30. Slick Rock area. Cater, 1955h; Shawe and others, 1959.	38°03'	108°56'
31. Summit Canyon area. Cater, 1955h, 1955i; Shawe and others, 1959.	37°58'	108°59'
32. Spud Patch area. Cater, 1955j; Shawe and others, 1959.	37°59'	108°52'
33. Dolores Canyon area. Cater, 1955j; Shawe and others, 1959.	37°55'	108°48'
34. Egnar area. Shawe and others, 1959.	37°55'	109°00'
35. Barlow group area. Bush, 1956.	37°44'	107°57'
36. Graysill group area. Bush, 1956.	37°43'	107°54'
37. Lightner Creek area. Bush, 1956.	37°21'	107°59'

IDAHO

1. Paris-Bloomington area. McKelvey and Strobell, 1955.	42°12'	111°20'

IDAHO, WYOMING, MONTANA, AND UTAH

Vanadium-bearing phosphate beds. McKelvey, 1949.	(see Map)

MINNESOTA

1. Duluth gabbro area. Grout, 1949-50.	47°48' 48°04'	91°40' 90°10'

MONTANA

1. Big Pryor Mountains. Hart, 1958.	45°05'	108°27'

NEW JERSEY

1. Dover district. Sims, 1958.	40°56'	74°33'
2. Oxford district. Bayley, 1910.	40°48'	75°00'
3. Van Syckles (Church) mine. Bayley, 1910.	40°39'	74°59'
4. Hager mine. Bayley, 1910.	40°36'	75°08'

NEW MEXICO

1. Eastside mine area. Stokes, 1951.	36°43'	109°01'
2. Hogback (Gallup) area. Hilpert and Moench, 1960.	35°36'	108°35'
3. Ambrosia Lake area. Hilpert and Moench, 1960.	35°25'	107°50'
4. Poison Canyon area. Hilpert and Moench, 1960.	35°21'	107°49'

NEW MEXICO (cont'd.)

5. Jackpile mine area. Hilpert and Moench, 1960.	35°08'	107°20'
6. North Magdalena area. Lasky, 1932.	34°08'	107°17'
7. Palamos Gap area. Hess, 1912.	33°03'	107°13'
8. Hall mine. Lindgren and others, 1910.	32°55'	107°31'
9. Lucky Bill mine. Larsh, 1913.	32°46'	108°07'

NEW YORK

1. Split Rock mine. Kemp, 1897-98.	44°15'	73°21'
2. Elizabethtown area. Kemp, 1897-98.	44°11'	73°33'
3. Lake Sanford area. Balsley, 1943.	44°03'	74°03'

NEVADA

1. Goodsprings area. Hewett, 1931.	35°49'	115°28'

NORTH CAROLINA

1. Sturgills belt. Nitze, 1892.	36°33'	81°27'
2. Tuscarora and Shaw belts. Bayley, 1923.	36°17' 36°02'	79°45' 80°07'
3. Roan Mountain belt. Pratt, 1919.	36°08'	82°10'

OKLAHOMA

1. Page. Ham, 1956.	34°43'	94°32'

RHODE ISLAND

1. Iron Mine Hill. Hohnson and Warren, 1908.	42°00'	71°28'

SOUTH DAKOTA

1. Lucky Bud mine area. Schnabel, 1957.	43°29'	103°58'
2. Coal Canyon area. Bell and Bales, 1955.	43°26'	103°52'
3. Hot Point group area. Bell and Bales, 1955.	43°25'	103°46'
4. Runge mine. Wilmarth and Gott, 1958.	43°23'	103°49'
5. Gould lease area. Braddock, 1955.	43°22'	103°43'
6. Damsite group area. Braddock, 1955.	43°18'	103°41'
7. Canyon Lode. Post, 1956.	43°19'	103°34'

UTAH

1. Tidwell Draw area. Clark and Million, 1956; Johnson, 1959.	38°58'	110°22'
2. Temple Mountain area. Johnson, 1957.	38°41'	110°42'
3. Yellow Cat area. Stokes, 1952.	38°50'	109°33'

UTAH (cont'd.)

4. Cactus Rat area. Stokes, 1952.	38°52'	109°27'
5. Squaw Park area. Stokes, 1952.	38°51'	109°21'
6. Polar Mesa.	38°41'	109°08'
7. Beaver Mesa.	38°37'	109°05'
8. Cane Springs area.	38°25'	109°27'
9. Rattlesnake mine area.	38°18'	109°20'
10. La Sal Creek area. Carter and *Gualtieri*, 1957.	38°20'	109°05'
11. Mid-Lisbon Valley area. Isachsen and Evensen, 1956.	38°12'	109°15'
12. South Lisbon Valley area. Puffett and Weir, 1959.	38°07'	109°07'
13. Dry Valley area.	38°07'	109°13'
14. East Canyon area.	38°03'	109°13'
15. Happy Jack mine area.	38°00'	109°22'
16. Montezuma Canyon area.	37°41'	109°14'
17. Monument Canyon area.	37°39'	109°08'
18. Cottonwood Canyon area.	37°35'	109°36'
19. Butler Wash area.	37°31'	109°37'
20. Trachyte Creek area. Johnson, 1959.	38°01'	110°38'
21. Whirlwind mine area.	37°15'	110°27'
22. Mitton mine area.	37°01'	110°15'
23. Silver Reef area. Proctor, 1953.	37°15'	113°22'
24. Mercur Dome mine. King and Wilson, 1949.	40°19'	112°13'

VIRGINIA

1. Roseland District. Watson and Tabor, 1913.	37°44'	78°58'

WYOMING

1. Little Mountain area. Hart, 1958.	48°58'	108°10'
2. Hulett Creek area. Robinson and Goode, 1957.	44°47'	104°53'
3. Blowout mine area. Sharp and White, 1957.	43°54'	105°50'
4. Moe No. 14 mine area. Sharp and White, 1957.	43°52'	106°03'
5. Brown mine area. Sharp and White, 1957.	43°42'	105°59'
6. Pat group area. Sharp and Gibbons, 1957.	43°13'	105°37'
7. Box No. 4 mine area. Sharp and Gibbons, 1957.	43°02'	105°27'
8. Iron Mountain area. Pinnel and Marsh, 1954.	41°36'	105°19'
9. McDougal Pass area.	42°50'	110°48'
10. Swift Creek area.	42°46'	110°51'

Locality Index (cont'd.)

WYOMING (cont'd.)

11.	Afton area.	42°41'	110°52'
12.	Labarge Creek area.	42°35'	110°44'
13.	Sublette Ridge area.	42°15'	111°01'
14.	Tump Range area.	42°07'	110°48'

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