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ATLAS OF METAL AND NONMENTAL MINERAL PROVINCES CONTERMINOUS U. S.

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KLEMIC AND TOOKER—VANADIUM

Planimetric Base from National Atlas 1:7 500 000, 1970

PRELIMINARY MAP OF VANADIUM PROVINCES IN THE CONTERMINOUS UNITED STATES

BY

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Background information relating to this map and others in the Atlas of Metal and Nonmetal Provinces in the Conterminous United States is published as U.S. Geological Survey Circular 792 (Tooker, 1979), available free of charge from the U.S. Geological Survey, Branch of Distribution, 1200 Eads St., Arlington, VA 22202.

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards and nomenclature.

INTRODUCTION

This map provides background information on the geologic occurrence and distribution of vanadium source materials in the conterminous United States and its use and significance as a critical mineral commodity. Vanadium generally occurs only in trace amounts in most natural materials (Turekian and Wedepohl, 1961) but has been concentrated above its average in crustal rocks in several types of mineral deposits that are widely distributed in provinces in the United States. Even so, only a few types of deposits contain sufficient quantities of vanadium for its economic recovery, mainly as a byproduct of iron, uranium, phosphorus, lead, and petroleum production. The purpose of this map is to show the location and magnitude of current domestic production, and possibly the location and a preliminary evaluation of undeveloped potential sources of vanadium in the conterminous United States.

Vanadium is a metallic element that is used mainly as an alloying material in steel and also in titanium base alloys and in chemical compounds; it can be replaced by substitute materials (Taylor and Broderick, 1976). Major sources are vanadiferous slags from the smelting of vanadiferous titaniferous iron ores; ferrophosphorus used in the production of metallic phosphorus, and leach liquids from the processing of base-metal ores are lesser byproduct sources. Some vanadium is obtained as a primary ore. Substitutes for vanadium as an alloying material include columbium, manganese, molybdenum, titanium, and tungsten, depending upon their relative costs and suitability for producing alloys of desired specifications. All of these are also considered to be critical metals. Because most vanadium is used in alloys, little of it is recycled, but some is recovered from scrap steel, and a small amount of catalytic vanadium is reprocessed (Broderick, 1977).

Apparent consumption of vanadium in the United States in 1978 was about 6,542 metric tons and was about 22 percent of estimated world production (U.S. Bur. Mines, 1979). Imports of raw and processed materials for consumption in 1978 were about 3,220 metric tons of contained vanadium, equivalent to 49 percent of apparent consumption. South Africa and Chile supply more than 80 percent of United States vanadium imports, the USSR supplies about 9 percent, and other countries about 8 percent.

The probable demand for vanadium in the United States in year 2,000 has been forecast at 29,900 metric tons (Broderick, 1977), and cumulative demand through that year to be 426,000 metric tons. Thus substantial amounts of new domestic minable minerals will need to be developed if the United States is to supply even as much as 50 percent of this forecast.

The geologic environments in which vanadium may be concentrated are numerous and variable. This metal is an abundant trace element that occurs mainly in silicate rock. It forms no important rock-forming minerals, but generally replaces iron and possibly aluminum in iron and ferromagnesian minerals, and is commonly associated with titanium and phosphorus. Vanadium is most abundant in crustal mafic igneous bodies as irregular disseminated bodies or injected plugs or dikes. The metal is less abundant in intermediate to silicic igneous rocks, which contain vanadium in (nontitaniferous) magnetite and phosphate minerals that occur in disseminations, in massive or pegmatite bodies, or localized in contact metamorphosed or hydrothermal replacement bodies in adjacent host rock. Hydrothermal veins, either containing titanium oxide minerals or gold and quartz, may also contain small amounts of vanadium.

The map was compiled from published reports (Fischer, 1962, 1975a, b; Fischer and Feitler, 1968; U.S. Geol. Survey, 1976) and records of U.S. Geological Survey vanadium resource specialists, including some data assembled by R. P. Fischer for the Computerized Resource Information Bank (CRIB) of the U.S. Geological Survey. We are indebted to J. A. Calkins and R. J. Basckle for assistance in the use of CRIB data and R. A. Gulbrandsen for sources of information on vanadium in phosphate deposits in Idaho. Where appropriate, the province boundaries are based on the distribution of associated host rocks and geologic structures shown on the geologic map of the United States (King and Beikman, 1974). Some of the technical terms and geologic concepts used in this map, which is a part of the atlas of metal and nonmetal province maps, are defined or discussed in a companion background report by Tooker (1979).

DISTINGUISHING MAP FEATURES

The vanadium province map summarizes current information about the location, size, and areal distribution of deposits and occurrences of resource materials for this metal, and, where possible, does so in the context of the geologic environments in which they were found. A province, as defined here, is a contiguous region containing sparsely populated or clustered groups of deposit and occurrence localities anomalously enriched above its crustal abundance (>100-150 ppm (parts per million)) in vanadium-bearing minerals, which generally were concentrated in distinctive geologic environment. In some cases geologic types of deposits may overlap within a province. No distinction as to economic or subeconomic character is implied in this broad definition, but large size deposits show the main current as well as past production sites within provinces. Where possible, province boundaries are drawn along enclosing geologic units, on the basis the geologic map of the conterminous United States (King and Beikman, 1974). Some provinces may consist of a number of detached outlying areas. In the absence of prominent mappable features, boundaries have been drawn arbitrarily around groups of localities that seem to share a common geologic origin. A number of solitary and isolated occurrences are present that do not seem to fall into a regional geologic pattern at present and may represent only a dispersed local concentration. The dispersion may be regarded as having some local resource potential or may be an unrecognized clue to a more extensive undiscovered resource. The province map is intended to direct attention to geologically favorable sites for concentration of vanadium, particularly during the systematic resource assessment of federally owned lands.

Vanadium deposits and occurrences have been classified on the map for purposes of comparison in the atlas of metal and nonmetal provinces (Tooker, 1979) into large and small sizes. A large vanadium deposit is defined (Fischer, 1962) as containing combined production and (or) remaining minable minerals in excess of 10,000 pounds (4,536 kilograms or 4.5 metric tons) of vanadium. Such a deposit would have been valued in 1978 at about $44 million but could by itself supply only a small fraction of one year's industry demand.

For most commodities large deposits have been subdivided into types A and B (Tooker, 1979). Type A were those active deposits that had substantial production in 1975, on the basis of U.S. Geological Survey information and an international survey of major mines (Mining Mag., 1976). Because no large vanadium mines were shown to be active by these sources, no type A vanadium deposits are shown on the map. A number of type B shown are either large (inactive) former producers temporarily out of production because of economic conditions, mined-out deposits that may or may not contain additional undiscovered resource extensions, or currently minor producers of byproduct vanadium at present, which we consider may contain additional minable vanadium materials.

Small deposits and occurrences, whose production of vanadium in minable minerals and (or) potentially minable materials is less than 10,000 pounds, are classified as type C. Many, if not most, of the type C localities represent subeconomic or unevaluated resource possibilities.

Economic deposits of vanadium are formed by geologic processes that either concentrate the element to amounts above the average for the host-rock type or alter the form in which the vanadium occurs to a form that is readily extractable. The location of a number of favorable vanadiferous geologic units resulting from such processes are shown on the map. The principal domestic source of vanadium has been from stratiform deposits in Mesozoic continental sandstone that commonly contains carbonized plant debris. Marine phosphate rock and phosphatic shale in Paleozoic carbonate sequences may also contain stratabound vanadium as a coproduct with phosphorus (Gulbrandsen, 1966). Vanadium-bearing graphitic schist may be a metamorphosed shale. Vanadium is recovered from the ash of some asphaltite, petroleum, and coal deposits. Weathering and erosion processes provide an added mechanism for concentrating vanadium. During the weathering of igneous rocks in humid climate elements, vanadium is released and fixed in sedimentary clay mud and in carbonaceous shale and in some cases is precipitated with residual bauxite. Vanadate minerals occur in areas of arid climates where deep oxidation of lead, zinc, and copper deposits occur in carbonate rocks, the vanadium presumably concentrated by ground water. Finally, vanadium also occurs in some black sand placer deposits. More detailed discussions of the types of geologic occurrences are provided by Fischer (1973, 1975a, b) and Desborough (1977).

Deposits may have economic value for vanadium only because manmade and geologic processes increase the grade or convert the vanadium into a readily extractable form. For example, geologic processes act to form concentrations of vanadiferous titaniferous magnetite in iron and titanium ore bodies, which may have 10 to 100 times as much vanadium as is average for crustal rocks. In the processing of such ores into separate iron-rich and titanium-rich fractions, the vanadium, which tends to be associated with the iron mineral magnetite, is concentrated additionally by manmade processes. When the magnetite is smelted for iron, the vanadium is further concentrated in the slag from the ore and is more readily extractable than it was in the crude ore. Geologic processes also concentrate vanadium in asphaltic minerals or bitumens formed as residual materials by the loss of volatiles from petroleum and other carbon-rich material of organic origin. Manmade processes concentrate vanadium in the ash residues from the combustion of petroleum or coal.

VANADIUM PROVINCES

Twenty-six vanadium provinces on the map show the areas in the conterminous United States that contain known and, in some cases, untested resource possibilities. The geologic character of these anomalous vanadium province concentrations and a preliminary estimate of the resource potential of provinces are listed in table 1. Except for a few scattered localities, most of them occur in rocks comprising old continent crust, and most of the depsits and occurrences lie in the eastern part of the Cordilleran belt. The Appalachian belt and Precambrian Shield regions contain fewer vanadium localities. Eight type B deposits occurring in province 1 were formed in a type VII geologic environment. Four remaining type B deposits in provinces 4, 6, 24, and 25 were localized in type I environment, generally in rocks of Precambrian age.

Vanadium provinces in the conterminous United States may be classed into three main categories:

1. Areas in which vanadium is known to occur in economically significant amounts, based upon current, past, or planned production.
2. Areas having deposits considered to be of potential economic significance for vanadium.
3. Areas having deposits or occurrences in which the presence of vanadium in minor amounts has been noted and which are therefore considered to be geologically favorable for exploration for vanadium deposits.

Category 1.--The area near Hot Springs, Ark. (province 2), where vanadium was concentrated in a mineralized zone in metamorphosed sedimentary rocks and an adjacent syenitic intrusion, is the only United States vanadium province in which the metal is recovered as the primary product of mining. Vanadium is also recovered as a byproduct of phosphorus from province 3, which includes part of the phosphorus province of Idaho and Wyoming (province 3). Vanadium is recovered as a coproduct from the uranium-vanadium ores of the Colorado Plateau (province 1) and is likely to be recovered from similar deposits in South Dakota (province 4).

Category 2.--Vanadiferous titaniferous magnetite deposits, which contain large quantities of ores similar to those processed for iron and coproduct titanium and vanadium in other countries, are also potential sources of vanadium in the United States. Such deposits are in northeastern New York (province 24), in northeastern Minnesota (province 18), in northern Wisconsin (province 18a), and in southeastern Wyoming (province 4). Similar, but small deposits, in central Colorado (province 12) and southern California (province 6) may also be included as representatives of this category.

Category 3.--Provinces containing base-metal deposits that in turn contain minor quantities of vanadium are located in southerwestn New Mexico (province 13), in central and southeastern Arizona (province 11), and in an area including parts of southern Nevada, northwestern Arizona, and southern California (province 7). Areas in southwestern Virginia (province 22), western North Carolina (province 21), and in northern New Jersey (province 23) contain groups of small vanadium-bearing iron deposits, and a zone of graphitic vanadiferous gneiss in eastern Alabama (province 19) may be considered as a minor vanadium provinces. Other widely dispersed minor occurrences of vanadium are in various types of mineral deposits in the western United States, the Appalachian region, the New England States, and in eastern Oklahoma. These regions may have potential for the occurrence of unidentified resources whose existence can only be considered as being hypothetical or speculative at present.

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Table 1.--*Location, types of deposits, resource potential estimates and status of resource knowledge of vanadium provinces*

No.	Province: State	Province: Area	Geologic types of deposits[1]	Preliminary estimates of resource potential[2]: High	Medium	Low	Status of geologic resource information: Adequate	Insufficient
1	Utah, Arizona, New Mexico and Colorado	Uravan belt and Colorado Plateau	VII	X	--	--	X	--
2	Arkansas	Magnet ove	II	--	--	X	--	X
3	Idaho, Montana, Wyoming, Utah and Nevada	Phosphoria Formation (Permian)	VI, IX, X	X	--	--	X	--
4	Wyoming	Iron Mountain (anorthosite)	I	--	X	--	--	X
5	Wyoming and South Dakota	Black Hills	VII	--	--	X	--	X
6	California	San Gabriel Mountains (anorthosite)	I, III, VI	--	--	X	--	X
7	California, Nevada, and Arizona	Mojave-Colorado River	I, VI	--	--	X	--	X
8	Nevada	Central phosphate belt	IX	--	--	X	--	X
9	Idaho	Idaho batholith	X	--	--	X	--	X
10	Utah	Mississippian shales localities	VI, IX	--	X	--	X	--
11	Arizona	Southern	VI	--	--	X	--	X
12	Colorado	Front Range mineral belt	I, III, VI	--	--	X	--	X
13	New Mexico	Rio Grande Rift	VI	--	--	X	--	X
14	Wyoming	Northeast	VII	--	--	X	--	X
15	South Dakota	Tertiary lignite (coop)	VIII	--	--	X	--	X
16	Oklahoma	Wichita Mountains	I		unknown		--	X
17	Do.	Asphalites	VIII	--	--	X	--	X
18	Minnesota	Duluth gabbro	I	--	X	--	--	X
19	Alabama	Graphitic schist belt	IV	--	--	X	--	X
20	North Carolina	Piedmont	I	--	--	X	--	X
21	Do.	Appalachian Mountains	I	--	--	X	--	X
22	Virginia	Western	I	--	--	X	--	X
23	Pennsylvania and New Jersey	Magnetite deposits	I, VI	--	--	X	--	X
24	New York	Adirondack Mountains	I	--	X	--	--	X
25	Rhode Island	Iron Mine hill	I	--	X	--	--	X
26	Pennsylvania	Eastern	VII		unknown		--	X

[1] Index to types of vanadium deposits

Vanadium deposits of magmatic origin

- I. Associated with stratiform titaniferous magnetite in mafic (gabbro and anorthosite) rocks.
- II. Associated with disseminations or massive nontitaniferous magnetite in mafic to intermediate (syenite) rocks.
- III. Associated with vanadium-bearing hydrothermal vein-forming solutions as: (a) intergrowths with ilmenite in uranium-bearing veins; (b) vanadium mica in gold-quartz veins; or (c) included in titanium minerals of titanium-bearing veins.

Vanadium deposits in metamorphic or altered rocks

- IV. Associated with graphite in schist (metamorphosed shale).
- V. Associated with argillic alteration zone as a byproduct of magnetite and ilmenite in contact zone of alkalic igneous complex.

Epigenetic vanadium deposits

- VI. Vanadate (Pb, Zn, Cu) crusts and fillings formed by ground water in oxidized zones of base-metal vein and replacement deposits in carbonate or silicic igneous rocks.
- VII. Silicate and oxides disseminated in pores of stream-laid sandstone by ground water, commonly a byproduct of uranium and copper.
- VIII. Dispersed in coal, crude oil, and oxidized residues in natural asphalites.
- IX. Associated with marine sedimentary phosphate rock (phosphatic shale), a byof phosphorus.
- X. Black sand placers.

[2] A high estimate indicates the presence or expectation of more than one large (type A or B) deposits; a low estimate is based on the presence of type C deposits and (or) occurrences alone.