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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

CLASSIFICATION AND DISTRIBUTION OF URANIUM-BEARING VEINS IN THE UNITED STATES*

By

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June 1956

Trace Elements Investigations Report 486

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*This report concerns work done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

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FOREWORD

This paper is part of an introductory chapter to a comprehensive report entitled, "Geology of uranium-bearing vein deposits in the United States," in preparation by George W. Walker, Frank W. Osterwald, and others. The comprehensive report will include detailed information on tectonic and structural setting, kinds of host rocks, wall-rock alteration, mineralogy, physical characteristics, processes of deposition, and concepts of origin of uraniferous veins; but because it will not be completed until sometime in the future, some chapters of the report are being transmitted as they are finished. Therefore, this paper is designed to (1) establish the tentative scope of the comprehensive report, (2) define for use in the comprehensive report several geologic terms that are used differently by different geologists, (3) establish a tentative classification of uranium-bearing veins, and (4) summarize available data on the geographic and geologic distribution of uranium-bearing veins. Review of available foreign and domestic literature concerning vein deposits has not been completed; in addition, detailed data are lacking regarding several facets of the geology related to uraniferous veins. As a result many of the thoughts presented herein are tentative, particularly as regards the classification of uranium-bearing veins and their geologic distribution.

The authors are aware that some of the material presented in this paper is at variance with previously published views of other workers. The authors concur with DeGolyer (1950, p. 1608-1609) who said that:

"...we should re-examine those problems for which we believe we have found satisfactory solutions in order to determine whether some other solution may not be feasible and whether or not our solution is unique. Particularly it is urged that we divest ourselves of prejudice and reconsider problems which are not solved but are regarded as practically solved by what Chamberlin called the 'ruling theory.'... If we achieve no more than the simple classification into the categories of 'proved' or 'unproved' of the theories upon which our art and science are based, we will have taken a long step forward of very material value."...

"Many of our judgements of the value of individual prospects are based upon assumptions that certain theories are true. The theories may or may not be true and the assumptions are thus true or false. The history of the art of prospecting is strewn with the wrecks of what were once 'ruling theories,' many of which were accepted because they seemed to be so reasonable...."

Many of the ideas concerning classification, definition, and distribution of uranium-bearing veins presented in this paper are purely descriptive and are carefully separated from what we believe to be tentative or unproved concepts of genesis. By this means we hope to establish the fundamental geology that controls the distribution of uranium-bearing veins in order better to evaluate environments in which the deposits do or might occur.

The compilation of data and the preparation of this report were done by members of the Research and Resource Group, U. S. Geological Survey, on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. The report is based on both published and unpublished information collected principally by personnel of the U. S. Geological Survey, the U. S. Atomic Energy Commission or its predecessor organization, The Manhattan Engineer District, by staff members of other Federal or State agencies and by geologists in private industry. Information concerning foreign uranium-bearing vein deposits has been extracted almost exclusively from published reports; references to these and other data are included at appropriate places.

CLASSIFICATION AND DISTRIBUTION OF URANIUM-BEARING VEINS IN THE UNITED STATES

By George W. Walker and Frank W. Osterwald

INTRODUCTION

In the preparation of this report many problems have been encountered, most of which are caused by the different usage of geologic terms by different geologists. As a result several geologic terms have been defined to aid in establishing the scope of the report, and to determine which deposits should be included as uranium-bearing vein deposits. Some geologic data concerning foreign vein deposits have been included, in part, for purposes of comparison with deposits in the United States, but principally to establish a broader geologic base on which to classify uraniferous veins and better to evaluate the diverse geologic characteristics of the deposits and of their structural and petrologic environments. In this report vein deposits are classified into eight mineralogic types.

Any classification of uranium-bearing vein deposits is dependent basically upon segregating uraniferous "vein deposits" from other types of uranium deposits. In order to classify uranium-bearing veins and to establish their geographic and geologic distribution a logical and useful, although arbitrary, definition of a vein is required. The lack of agreement among geologists about the distinguishing characteristics of a vein precludes unanimous endorsement of any classification of uranium-bearing veins whether based on processes of deposition, mineral assemblage or metal ratios, shape of deposits, structural setting, kinds of host rocks, or on origin. Many uranium deposits have diverse geologic characteristics because uranium is concentrated by a wide variety of processes in many different physical and chemical environments and because many deposits have been acted upon by several of these processes. Commonly the resulting uranium deposits, as pointed out by McKelvey (1955), ". . . grade into one another so subtly and completely that it is difficult to segregate them descriptively." A single deposit may show both structural and stratigraphic control; locally it may contain an assemblage of minerals that indicates deposition from thermal solutions whereas in other parts of the deposit the mineral assemblage indicates a deposition from non-thermal solutions; it may have several varieties of favorable or mineralized host rock; and the ore and gangue minerals may show evidence of both replacement and open-space filling. These and other data indicate diverse origins for uranium deposits. Furthermore, for many deposits positive criteria are lacking as to mode of origin and to the processes that concentrated and deposited the metals. Consequently, any definition of a vein based on mode of origin is inherently burdened with the vagaries of unproved, and commonly unwarranted speculation. To the authors a genetic definition is untenable and they prefer Lindgren's (1933, p. 155-156) definition of a vein.

DEFINITIONS

Vein

Lindgren (1933), in describing the spatial relations of veins, defined a vein as follows:

> "Veins are tabular or sheet like masses of minerals occupying or following a fracture or a set of fractures in the enclosing rock; they have been formed later than the country rock and fractures, either by filling of the open spaces or by partial or complete replacement of the adjoining rock, or most commonly by both of these processes combined."

For several reasons, Lindgren's definition of a vein, with minor modifications, was selected for use in this report. Dominant among these reasons are: (1) The definition is relatively simple, is subject to little, if any, misinterpretation, and essentially is based on well-established, observable geologic features; (2) it commonly assigns shape and general structural setting to a vein deposit or a part of a deposit and outlines the overall geometric distribution of the introduced minerals; and (3) it excludes most if not all factors related to mode of origin, crystallization temperatures of ore and gangue minerals, nature of ore solutions and whether only certain mineral assemblages are characteristic of uranium-bearing veins. The exclusion from the definition of any concept of temperature is justified, particularly for uranium deposits, by the lack of definite data on temperature during crystallization and by geologic evidence indicating or suggesting a wide range of crystallization temperature even within a single deposit from relatively high temperatures to temperatures approaching that of near-surface ground water.

The definition has some limitations principally related to the nature of the fractures or the sets of fractures and to the resultant shape of a deposit. Consequently, some supplemental information is necessary to establish more clearly the characteristics of a vein. Fractures or sets of fractures, as used in the definition, encompass most induced openings in rocks. The induced openings may be the result of compressive, tensile, or torsional stresses related to folding, faulting, and intrusion of igneous masses; they also may be related to volcanic pipes, collapse breccias and solution caves or to near-surface, post-sedimentation slumping and release of stress. The tabular nature of veins, therefore, may be apparent only in detail in parts of a deposit or it may encompass an entire major ore body. Furthermore, in some deposits, ore minerals are concentrated in lenses, pods, irregular masses, or in shoots along tabular structures. In addition, a few concentrations of ore minerals, principally those characterized by extensive alteration and replacement of the wall rocks, show an apparent lack of tabular shape. However, because the great majority of uranium-bearing veins are tabular either on a large or small scale, this qualifying term has been retained in the definition with the realization that it is not all inclusive.

Only those deposits in which the induced openings dominated in localizing the introduced minerals are herein defined as veins. Locally, replacement of wall rock constituents is prevalent but, in general, it is confined to relatively thin zones adjacent to the induced openings. The definition includes those deposits or concentrations of uranium minerals that are localized in epigenetic fractures or cavities irrespective of the valence state of the uranium or the character of any associated metallic or nonmetallic minerals. Many other uranium deposits localized dominantly by favorable wall rocks or by original cavities and structures in these rocks may show vein affinities where induced cavities have been partly instrumental in localizing the introduced minerals. Some of these deposits, as for example several in the Todilto limestone of Jurassic age, San Mateo Valley area, Grants district, New Mexico, several small deposits in Wingate sandstone at Temple Mountain, Utah, a few deposits in the Kayenta formation and Wingate sandstone in Richardson Basin, Utah, and others in Mesozoic and Paleozoic rocks of the Colorado Plateau, are characterized by epigenetic structures that have contributed to the localization of the deposit.

Deposit

The term "deposit" is used herein to denote any abnormal concentration of uranium minerals; it has no connotation of size or potential for commercial exploitation of the uranium concentrations. As used in this definition, an abnormal concentration of uranium minerals is restricted, in general, to localities where uranium is concentrated over that occurring in the enclosing wall rocks at a ratio of approximately 2 or more to 1.

CLASSIFICATION OF URANIUM-BEARING VEIN DEPOSITS

Many different classifications of ore deposits have been proposed (Bateman, 1950, p. 355-365); some are based on empirical data and others are based on theoretical deductions. Mode of origin, temperature and pressure relationships, processes involved in deposition, mineral content, geometry, position of constituent minerals, and structural setting have been used to establish arbitrary classes of ore deposits. Many of these classifications are vulnerable from several critical aspects particularly because of the lack of definite data on temperature and pressure at time of deposition, and on the chemical composition, physical state, and origin of the ore solutions. Perhaps the most valid classification of ore deposits should be one based on the tectonic and petrologic environment of deposits, but here again critical data are lacking. As a result a descriptive and arbitrary classification based on mineral content of the deposits was selected for use in this report. The classification is based largely on the mineralogic characteristics of deposits in the United States and to a lesser extent on the characteristics of deposits in other parts of the world. Data regarding foreign deposits are used in part, for purposes of comparison, and partly to establish better the validity of the classification; their use has resulted in establishing one class — davidite-bearing veins — that are not known to occur in the United States.

Uranium-bearing vein deposits, as defined herein, are tentatively subdivided on the basis of mineralogy into 8 classes, most of which are overlapping and only a few of which have proved to be important commercial sources of uranium in the United States. These types are: (1) Fluorite-bearing veins; (2) veins in which uranium is subordinate to base-metal sulfide minerals including deposits containing sulfides and sulfarsenides of cobalt and nickel; (3) veins in which uranium minerals are "dominant," but which may contain minor amounts of other introduced metallic minerals; (4) magnetite or other iron oxide-bearing veins; this excludes deposits in gossan derived from supergene alteration of base-metal sulfide deposits but does include those uraniferous deposits characterized dominantly by magnetite, hematite, or limonite; (5) veins dominated by thorium or rare earths minerals; (6) brannerite-bearing quartz or siliceous veins; (7) davidite-bearing veins; and (8) veins containing uraniferous hydrocarbons.

Fluorite-bearing veins

Uranium deposits in this class are characterized by common or abundant fluorite gangue associated with uraninite or pitchblende and their alteration products, including several hexavalent-uranium minerals _/, principally uranyl phosphates, silicates, carbonates, and locally vanadates (Wilmarth and others, 1952); in addition to fluorite, the most common gangue is either quartz or cryptocrystalline silica minerals, and some deposits, most of which are foreign, contain some barite and calcite. Some of the deposits also contain small to moderate amounts of lead, zinc, copper, iron, or molybdenum sulfides; these are not necessarily listed in order of abundance. Several of the deposits are fissure veins, commonly with ore-grade uranium concentrations in shoot-like structures, some are stockworks and breccia zones accompanying faults, and others are breccia "pipes." In the fissure veins, coarse crystals of fluorite, banded vein filling, vugs, and drusy textures are common.

Most of the deposits are probably the result of deposition from low- to moderate-temperature hydrothermal solutions; some of the minerals in the upper parts of the deposit may have been deposited directly by solfataric action or by non-thermal ground waters.

The deposits in the Marysvale district, Utah (Gruner and others, 1951; Taylor and others, 1951; Kerr and others, 1952; Walker and Osterwald, 1956), in this class, have been the most important sources of uranium from veins in the United States. Some of the deposits, as for example those in the

_/ The term hexavalent-uranium minerals is used in this report to denote uranyl compounds.

Thomas Range (Staatz and Osterwald, in preparation) and the Staats mine (Wilmarth and others, 1952), Utah, in the Jamestown district, Colorado (Phair and Shimamoto, 1952), and several in New Mexico, have been prospected and developed principally for fluorite but have yielded only small amounts of uranium ore. Grade of ore in Marysvale deposits, and similar deposits elsewhere, is typically a few tenths of a percent uranium and locally, for very small tonnages of ore, may be as much as 0.5 percent. Most of the uranium is either in separate pitchblende masses, thin seams, or sooty powder or in secondary, hexavalent-uranium minerals near the ground surface. Most of the deposits exploited principally for fluorite contain only a few hundredths of a percent of uranium that occurs as finely divided pitchblende particles disseminated in the fluorite, or possibly substituting for calcium in the calcium fluoride molecule, or locally, near the surface, as sparse crystals of hexavalent-uranium minerals (Staatz and Osterwald, in preparation). At least in the Thomas Range the uranium content varies independently of the fluorite content within individual deposits (Staatz and Osterwald, in preparation) and a similar relationship may exist elsewhere.

Foreign deposits in this class include several near Wölsendorf, Germany (Kohl and Haller, 1934; Everhart and Wright, 1953), Marienbad, Czechoslovakia, possibly some of the uraniferous veins of the Central Massif, France (Geffroy and Lenoble, 1953), and the Rexpar mine, British Columbia, Canada (Leaming, 1953).

Base-metal sulfide veins

Deposits in this class are characterized dominantly by sulfides or sulfarsenides of base metals commonly with different amounts of precious metals either in a carbonate or siliceous gangue. The deposits generally are fissure fillings, although locally replacement of wall rocks is prevalent.

Although most classifications of uranium-bearing veins (Bastin, 1939; Everhart and Wright, 1953; McKelvey, 1955; Klepper and Wyant, in preparation) have indicated a relatively "clear cut" and "logical" distinction between "simple" base-metal sulfide veins and those vein deposits characterized by sulfides and sulfarsenides of cobalt and nickel, in this report they are considered variants of a single class entitled, "Base-metal sulfide veins." A classification somewhat similar to this was used by Geffroy and Sarcia (1954) for European vein deposits.

The base-metal sulfide veins and veins characterized by sulfides and sulfarsenides of cobalt and nickel are grouped together because (1) structural setting and textural characteristics of vein filling are similar, (2) virtually all are considered to be the result of mesothermal to lower epithermal deposition, (3) taken as a group the similarity of cation and anion content of the sulfide-bearing veins as a whole is more impressive, to the authors, than the dissimilarities, (4) available data indicate an almost continuous gradation in the content of cobalt, nickel, silver, and probably uranium from "simple" base-metal sulfide veins to those previously classed as "nickel - cobalt - native silver - pitchblende veins" (Bastin, 1939), and (5) although a spatial relation between pitchblende and sulfides of cobalt, nickel, and silver is obvious in some deposits, locally this only denotes a favorable structural setting for deposition and not a genetic tie between the metals. The dissimilarities in cation content and their relative abundance may depend largely on their relative availability and only to a minor extent on the processes involved in their deposition.

Domestic deposits

Many domestic uranium-bearing vein deposits contain both tetravalent- and hexavalent-uranium minerals associated with, but generally in amounts subordinate to, sulfides of copper, lead, zinc, and iron. Commonly the gangue is quartz or chalcedony though locally lesser amounts of calcite, siderite, ankerite, rhodochrosite, or barite may occur. Several of the deposits in this class are gold- and silver-bearing; some contain molybdenum minerals and some are characterized by hematite, either in the veins or as stain on the adjacent wall rocks. A few deposits contain minor amounts of bismuth and some contain sulfides or sulfarsenides of cobalt and nickel. Uraniferous gossans containing hexavalent-uranium minerals produced by supergene alteration are known at several of the deposits that originally contained mostly pyrite, sphalerite, and galena and with minor amounts of silver, copper, gold, probably uraninite or pitchblende and trace amounts of vanadium. Examples are some of the properties in the Wallapai district, Arizona and the Yellow Pine (Goodsprings) district, Nevada. Adsorbed uranium (Lovering, 1955), associated with hydrated iron oxides and lead, zinc and copper of carbonates and sulfates, is present in some of the gossans.

Most of the deposits are fissure veins or vein systems with uranium minerals commonly confined to shoots; locally pitchblende stringers or lenses and pods are erratically distributed along the fissure veins. In some of the uraniferous lead-zinc deposits of the western United States the ore filled open fissures and replaced carbonate wall rock. In these deposits most of the uranium is disseminated in the lead-zinc ore, although locally sparse, small, irregular masses of hard or sooty pitchblende may be erratically distributed in the ore.

Because the uranium in the base-metal sulfide deposits is locally concentrated and elsewhere is erratically distributed the grade of the ore ranges between wide limits. Small parts of veins, or of ore shoots, may contain several percent uranium, although the average of mined ores is typically a few tenths of a percent. In most deposits the tonnage of ore-grade material is small and may be only a few tons, but several properties in the United States contain several thousand tons of uranium ore.

Examples of uraniferous veins in this class are the Carrol, Cherokee, Copper King, and Wood-Calhoun mines, Colorado, the Comet and Gray Eagle mines, Montana, several deposits in the Yellow Pine (Goodsprings) district, Nevada, and the Wallapai district, Arizona, the Silver Cliff mine, Wyoming, and pitchblende deposits at Huron River, Michigan, and the Rustler group, Idaho. Other examples that contain abnormal amounts of either cobalt or nickel or both, in addition to sulfides of lead, zinc, and copper, are the Caribou mine, Colorado, the Blackhawk mine, New Mexico, and perhaps several deposits in the Coeur d'Alene district, Idaho.

Foreign deposits

Foreign vein deposits in this class, not only have been the dominant source of uranium from vein-type deposits, but also to 1955, probably had yielded more uranium than all other sources combined; a few have yielded large amounts of silver and lesser amounts of other metals. This class includes the Shinkolobwe mine in the Belgian Congo (Thoreau and Terdonck, 1933; Kerr and Merritt, written communication, 1943; Everhart and Wright, 1953), which is the richest and largest known epigenetic deposit of uranium; deposits in the Joachimsthal and Johanngeorgenstadt districts, Czechoslovakia, and the deposits at Great Bear Lake, Northwest Territories, Canada (Kidd and Haycock, 1935); smaller deposits are known in the Cornwall district, England (Everhart and Wright, 1953), near Freiberg, Saxony, the Carrizal Alto district, Chile (Everhart and Wright, 1953), Vilcabamba district, Peru (George, 1949), Rum Jungle district, Northern Territory, Australia (Fisher and Sullivan, 1954), and elsewhere.

Most of these deposits are mesothermal fissure veins and vein stockworks; crystalline uraninite or more commonly massive or colloform pitchblende is present as veins and veinlets, ranging from a small fraction of an inch to several feet in thickness, and pods and irregular masses up to several tons in weight. Pitchblende grains also are disseminated in sheared and unsheared wall rock; some of the disseminations are spatially related to the massive veins and pods and some are not. Iron in the form of pyrite, magnetite, or hematite is ubiquitous and commonly abundant in most deposits. Other metallic constituents, some of which locally have been principal or coproducts of mining, are copper, lead, zinc, molybdenum, cobalt, nickel, silver, bismuth, and gold; most are sulfides, arsenides, sulfarsenides, or locally sulfantimonides, although the native elements silver, bismuth, and some copper and gold have been identified. Calcite or dolomite gangue is most commonly associated with pitchblende or uraninite in these veins but other carbonate minerals, quartz, chalcedony (or jasper), barite, and chlorite are locally important vein constituents. A few deposits contain virtually no gangue minerals.

Near-surface supergene alteration has produced a host of hydrated uranyl oxides, sulfates, phosphates, arsenates, and silicates, most of which also contain copper, calcium, magnesium, barium, lead, or other cations. Ianthinite, the only known "supergene" uranium mineral that contains tetravalent uranium (George, 1949), has been identified in several of these deposits, but may have formed by low-temperature hydrothermal alteration (Kohl and Haller, 1934).

Veins in which uranium minerals are "dominant"

Deposits in this class may contain tetravalent- or hexavalent-uranium minerals, with or without small amounts of hydrated iron oxides or sulfide minerals of which pyrite and marcasite are most common. The uranium mineral may be associated with quartz, cryptocrystalline silica or hyalite opal gangue or there may be virtually no gangue minerals. Deposits in which uranium minerals are "dominant" commonly contain hexavalent-uranium minerals, principally autunite (or meta-autunite), torbernite (or metatorbernite), and uranophane; locally uranyl arsenates or vanadates, such as metazeunerite, novacekite, carnotite, or tyuyamunite are the dominant uranium minerals. In other deposits pitchblende is dominant, occurring either in a hard form in veinlets or irregular masses or in finely divided powdery form coating fractures and disseminated in altered wall rock.

Many deposits are characterized by hexavalent-uranium minerals coating fractures and shears and may be the result of (1) solution of the uranium from the wall rocks by ground water and deposition wherever a change of chemical environment decreased the solubility of the uranium, (2) evaporation of uranium-bearing ground waters under suitable climatic conditions to form calichelike concentrations, or (3) oxidation, essentially in place, of tetravalent-uranium minerals originally introduced by hydrothermal solutions. Several of these deposits have been explored only to shallow depths and may be the near-surface expression of uranium-bearing veins of some other class.

Several deposits in this class, for example the Los Ochos mine in Colorado, and the Midnight mine in Washington, have comparatively large reserves of ore averaging a few tenths of a percent uranium. Most of the deposits in this class, however, are small and contain only a few tens or hundreds of tons of mineralized rock assaying slightly less than 0.1 percent uranium.

The W. Wilson and Free Enterprise mines, Montana, and the Schwartzwalder mine, Colorado, are included in this class, though they locally contain minor to moderate amounts of base-metal sulfide minerals, suggesting that they are transitional between veins in which uranium minerals are "dominant" and base-metal sulfide veins.

Siliceous veins in Portugal, which contain pitchblende and several hexavalent-uranium minerals, show affinities for veins "dominated" by uranium minerals, although some ores are rich in galena, hematite, and fluorite (George, 1949). Other foreign deposits, probably of this class, include those at Tyuya Muyun, Ferghana, USSR (Pavlenko, 1933; Shimkin, 1949), deposits in the Cuneo-Lurisia district, Italy (Nininger, 1954), and a deposit at Bukhova, Bulgaria (Bain, 1950).

Magnetite or other iron oxide-bearing veins

Several deposits, including the Prince mine, New Mexico (Walker and Osterwald, 1956), pitchblende deposits near Critchell, Colorado, deposits near Peekskill, New York (Walthier, 1955), Oxford, New Jersey, and possibly uraninite or pitchblende deposits in oxidized iron ore of the Iron River iron-formation member (of Michigamme slate) in northern Michigan, contain abundant magnetite or hematite or both, but commonly only minor amounts of base-metal sulfide minerals. Gangue minerals commonly are lacking, but minor amounts of recrystallized or altered minerals of the wall rocks occur in some deposits.

Locally, the uranium in these deposits is contemporaneous with and genetically related to the iron oxide minerals, whereas in other deposits the uranium minerals were deposited in or near fractures or fissures that cut concentrations of magnetite or hematite.

The deposits probably have diverse origins but, in general, are related to (1) pyrometasomatic replacement of wall rocks by iron-rich minerals, (2) possible redistribution of "syngenetic" uranium during metamorphism of ferruginous sedimentary rocks, or (3) deposition directly from thermal solutions in favorable, iron-rich environment, similar to the origin postulated for deposits near Schmiedeberg (Germany) by Berg (1936) and Meister (1926).

Tetravalent uranium is present in pitchblende stringers, veinlets or small pods; in some deposits the uranium is in minute, unidentified particles disseminated through the magnetite, possibly substituting for Zn, Cu, Cd, or other ions in the spinel (magnetite) lattice. Near-surface oxidation and alteration of some of these deposits formed abundant hydrated iron oxides and locally hexavalent-uranium minerals which commonly coat fractures or fill pore spaces.

Most of the deposits are small and contain only a few hundreds or, locally, thousands of tons of mineralized rock commonly averaging a few hundredths of a percent uranium. A few deposits, principally those characterized by veins or veinlets of pitchblende, may average a few tenths of a percent uranium; but, in general, they contain only a few tons of material of this grade.

Uranium-bearing veins dominated by thorium or rare earths minerals

Although most concentrations of thorium and rare earths minerals contain only a few thousandths of a percent uranium, several in the United States contain a few hundredths and, locally, tenths of a percent uranium. In some, the uranium is combined, probably in solid solution, with thorium and rare earths of the cerium group in a variety of high-temperature, relatively refractory minerals including thorianite, monazite, and allanite. Geometrically, deposits of this type can be classed as veins, because the introduced minerals commonly occur in fissures. These deposits are probably of high-temperature, hydrothermal origin in which most of the minerals were emplaced under near-pegmatitic conditions. In other deposits of this class, the uranium is in some unidentified form possibly either absorbed or adsorbed by hematite which is a common constituent of the thorium- and rare earths-bearing veins. The uranium in some deposits of this type possibly was deposited contemporaneously with the hematite and other introduced minerals, but in others it may have been deposited much later in a favorable, iron-rich environment either by hydrothermal solutions or by circulating ground water.

Examples of deposits in this class are known in the Powderhorn district, Colorado (Malan, Roger, oral communication, 1955), San Bernardino County, California (Walker, Lovering and Stephens, 1956), Johnson County, Tennessee, Lemhi County, Idaho, and several other widely distributed localities in the western United States. The tonnage of uranium-bearing rock at all of the properties is probably small; and, as far as known, none have yielded commercial ores of thorium, rare earths, or uranium; however, a few do contain several hundreds of tons of vein material with a thoria content of several percent.

Brannerite-bearing quartz or siliceous veins

Brannerite, an oxide of titanium, uranium, and calcium with minor yttrium, thorium, and iron was identified in quartz veins in Chaffee County, Colorado (Adams, 1953), and Mono County, California (Pabst, 1954). Common to veins in both areas are minor amounts of muscovite, pyrite, chalcopyrite, and molybdenite; the Colorado deposits contain, in addition, beryl and very small amounts of molybdite, rutile, and fluorite, whereas the California veins contain several silicate minerals and minor magnetite, calcite, and bismuthinite. According to Adams, the veins in Colorado are transitional between pegmatites and hydrothermal veins and Pabst believes the California deposits are, "...mesothermal quartz veins related genetically to nearby pegmatite and aplite...."

The brannerite occurs only as a trace constituent in both areas, commonly as sparse euhedral crystals. Nevertheless, commercial deposits may be found in the United States, because potentially exploitable deposits with somewhat similar mineralogy have been reported in the Middle Vosges, France (Geffroy and Lenobel, 1953), and Bou Azzer, French Morocco (Jouravsky, 1952a, 1952b, p. 226-230). Brannerite associated with molybdenite, chalcopyrite, and small crystals of uraninite, occurs in high-temperature veins in the Vosges (Branche, Chevet, Guillemin, 1951), and in the French Moroccan deposits brannerite occurs in quartz veins associated with molybdenite, chalcopyrite, and native gold. At Bou Azzer, nickel-cobalt-gold veins that cut the brannerite-bearing veins contain no known uranium.

A uranium deposit at Crockers Well, South Australia, may also be a representative of this class. According to King (1954), absite — a new mineral species resembling brannerite and consisting essentially of uranium and titanium, with some thorium and rare earths — is associated with biotite, rutile, apatite, and blue quartz in brecciated Archean rocks.

Davidite-bearing veins

Davidite, an iron-titanium oxide with rare earths, uranium, thorium, and other cations substituting for iron or titanium, has been found in high-temperature hydrothermal veins at Radium Hill, near Olary, South Australia, and in the Tete district of Mozambique; no comparable deposits are known in the United States. The deposits at Radium Hill and Mozambique have yielded commercial uranium ore.

According to Parkin and Glasson (1954), the davidite at Radium Hill "... occurs in intimate intergrowth with rutile, ilmenite, hematite, and some magnetite ..." associated with biotite and quartz in a series of veins cutting Precambrian metasedimentary rocks that were intruded by both mafic and acid rock types. The veins are probably late-stage replacements in shears and fracture zones and apparently are transitional between hydrothermal veins and pegmatites. Near-surface oxidation of the davidite produced fracture coatings consisting of carnotite, metatorbernite, and other hexavalent-uranium minerals containing vanadium (Sprigg, p. 44, 1954). The deposits apparently are in part similar to base-metal sulfide veins for they contain cobalt, nickel, copper, gold, silver, lead, and zinc (Sprigg, p. 22, 1954) in addition to uranium.

At Mavuzi in the Tete district of Mozambique, a black, opaque mineral considered to be a variety of davidite by Bannister and Horn (1950), occurs in sheared, scapolitized, and carbonatized pre-Karroo (Precambrian) norites and anorthosites (Davidson and Bennett, 1950). Most of the davidite, associated with rutile, sphene, magnetite, ilmenite, apatite, and molybdenite, not necessarily in order of abundance, is found in rock facies rich in scapolite and calcite or dolomite. The deposits also contain minor pyrite, pyrrhotite, chalcopyrite, hematite, and large amounts of vein quartz.

Veins containing uranium-bearing hydrocarbons

Different uranium-bearing hydrocarbons, many of which have been called thucholite, are known from many localities in the United States and elsewhere, but only a few can be classed as vein deposits. In a few deposits, principally foreign ones, the uranium-bearing hydrocarbon is the most abundant of the introduced materials and for this reason a separate class has been established. Most of these veins, either foreign or domestic, are similar to base-metal sulfide deposits, principally because much of the uraniferous hydrocarbon is closely associated with pitchblende, sulfides of iron, copper, lead, and zinc, and locally with minerals containing silver, cobalt, nickel, and molybdenum; gangue minerals, including calcite, quartz, barite, and chlorite, also are common.

The uranium in these deposits is contained in pitchblende, hexavalent-uranium minerals, and possibly as organo-uranium complexes; some of the pitchblende is in minute particles disseminated in the hydrocarbon. The uranium content of the hydrocarbons is different in different places; locally, selected specimens contain several percent uranium (Davidson and Bowie, 1951; Wilmarth and Vickers, written communication, 1952), but the quantity of material of this grade is apparently small.

Best known among domestic deposits of this class are those near Placerville, San Miguel County, Colorado, in which uranium-bearing hydrocarbons are associated with base-metal sulfide minerals and locally some pitchblende, molybdite, erythrite, and annabergite in a gangue of calcite, barite, and quartz (Wilmarth and Vickers, written communication, 1952). The deposits occur in faults cutting sedimentary rocks, principally sandstone and conglomerate, of the Dolores and Cutler formations and, according to Wilmarth and Vickers (written communication, 1952), Kerr and others (1951, p. 25), and Gruner and Gardiner (written communication, 1950), are probably hydrothermal in origin.

Small amounts of uranium-bearing hydrocarbons are widespread in mesothermal veins in the Lake Athabasca area, Saskatchewan, Canada (Robinson, 1955, p. 69; Lang, 1952, p. 80, 91, 93, 96); uraniferous bitumen, apparently in veins, also has been reported associated with chalcopyrite in the Laxey lead-zinc mine on the Isle of Man, Great Britain (Davidson and Bowie, 1951, p. 2), at the Moonta bornite mine near Adelaide, South Australia (Davidson and Bowie, 1951, p. 2), in Russia (Orlov, 1932), and elsewhere.

GEOGRAPHIC DISTRIBUTION

The number of domestic vein deposits in which uranium minerals have been identified and from which samples have shown a uranium content of 0.01 percent or more can be numbered in the hundreds and perhaps total as many as 500 different localities. More than 95 percent of these are in, or to the west of, the Cordilleran Foreland. _/ Most are notably concentrated in the Front Range mineral belt of Colorado, the Boulder batholith area, Montana, and the Marysvale district, Utah; fewer deposits are known in the Blackhawk

_/ The Cordilleran Foreland is the area east of the Cordilleran deformed belt (King, 1951, p. 58-62; Horberg, Nelson, and Church, 1949, p. 192-194).

and White Signal districts of southwest New Mexico, the Thomas Range and the Beaver area, Utah, Kern River area, California, the Yellow Pine (Goodsprings) district, Nevada, the Wallapai district, Arizona, the Cochetopa district, Colorado, northeastern Washington and northern Michigan. Other uranium-bearing veins are known in widely distributed localities in the western United States in South Dakota, Montana, Wyoming, Colorado, Texas, New Mexico, Arizona, Utah, Idaho, Nevada, California, and Washington. A few widely distributed uranium-bearing veins also are known in the eastern United States in New York, New Jersey, eastern Tennessee, North Carolina, and Georgia.

The distribution of known uranium-bearing veins is, in part, attributable to geologic conditions and, in part, to the intensity of prospecting in areas where deposits have already been found. Furthermore some areas, particularly in the western United States, are more easily prospected because (1) bedrock is extensively exposed with relatively little soil and vegetation cover, (2) near-surface efflorescences of hexavalent-uranium minerals are common which have led, locally, to the discovery of primary uranium ores beneath the outcrop, and (3) land laws are, in general, more favorable as related to the right of location and exploitation of mineral deposits.

The geographic distribution of uranium-bearing veins in the United States is shown on Plate 1 and the mineralogic classes of the deposits also are shown by symbols. Furthermore, the deposits have been segregated into three groups based on available production data. The three groups are: (1) Those vein deposits that have yielded more than 100 tons of commercial uranium ore; some of these, including the Midnight mine (Washington), the Buddy (or Sunnyside), Potts, Freedom, Prospector, and Bullion Monarch mines at Marysvale (Utah), the Silver Cliff mine (Wyoming), W. Wilson mine (Montana), and the Schwartzwalder and Los Ochos mines (Colorado), have yielded several hundreds or thousands of tons of ore; (2) those that have yielded less than 100 tons of ore, but from which some production of uranium is reported; and (3) deposits that as far as known, have yielded no uranium ore; although several of the deposits in this group are potential sources of uranium, available ore has not been shipped because the property is inaccessible, the ore is not readily amenable to standard metallurgical processes, the cost of mining is excessive, or for several other reasons.

GEOLOGIC SETTING AND DISTRIBUTION OF URANIUM-BEARING VEINS

The distribution of uranium-bearing veins in the United States is governed, in part, by many geologic features, both large and small, that are related directly or indirectly to tectonic and petrologic processes. Concentration and deposition of uranium are also related to different evolutionary stages in the tectonic cycle. The diverse physical characteristics of the veins and their environments, the absence of any obvious source for many deposits, and their diverse mineralogy suggest that the uranium in some of these deposits originates from dispersed sources in rocks of the crust, and in others through redistribution of pre-existing concentrations of uranium minerals. Further, the distribution of known uranium-bearing veins is complicated by those geologic and climatic processes that tend to destroy or modify near-surface deposits of uranium minerals.

Some concepts of origin related to geologic distribution

A summary of the data regarding the distribution of uranium in the earth's crust and the relative abundance of uranium in the different kinds of rock that make up the crust, by Klepper and Wyant (written communication, 1955), indicates that uranium is an ubiquitous but minor constituent of all kinds of rocks. These data indicate that among products of magmatic differentiation uranium is most abundant in silicic and silicic-alkalic intrusive and extrusive rocks and, that among sedimentary rocks, uranium is most abundant in marine phosphorite and black marine sapropelic shale. Several workers also have postulated that some ill-defined parts of the earth's crust are relatively enriched in uranium (Klepper and Wyant, 1956), and that these uranium-rich provinces have persisted for long periods of geologic time. A review of attempted correlations of uranium deposits and occurrences either with rocks containing relatively large amounts of uranium or with postulated uranium provinces reveals that, within the United States, (1) some uranium occurrences are spatially related to rocks with abnormal amounts of uranium, as for example, in the Front Range mineral belt (Phair, 1952), (2) in many places no such spatial relation can be established, perhaps largely because of lack of data, (3) nowhere has a definite genetic relation been proven between deposits and rocks with abnormal amounts of uranium, and (4) uranium provinces are either extremely large and geologically complex or they are very abundant, as shown by the wide distribution of vein deposits (pl. 1). The concept of uranium provinces may be valid for some parts of the earth's crust; on the other hand it may be valid only in the sense that some parts of the earth's crust contain more rocks characteristically enriched in uranium or that those rocks crop out over larger areas than other rocks with less uranium.

Although positive criteria are lacking as to the origin, within the crust, of the uranium now found in abnormal concentrations of uranium minerals, and to the methods of uranium mobilization, transportation, and deposition, several hypotheses have been proposed. Foremost among these are (1) that the uranium has been derived from residual fluids resulting from magmatic differentiation and represents a component of the magma and, (2) it has been derived from a dispersed source in rocks of the crust and mobilized and redistributed where equilibrium conditions are disrupted by structural deformation, dynamic or thermal metamorphism, or intrusion of igneous masses. Both of these modes of origin may be important locally, but our lack of data precludes determination of the dominant origin for uraniferous vein deposits. Nevertheless, the wide distribution of uranium-bearing veins in the United States, the diverse geologic characteristics of these deposits and of their structural and petrologic environments seem more compatible either with (1) several different modes of origin or (2) with disruption of equilibrium conditions as a result of orogenic activity (including vulcanism, intrusion, and structural deformation).

Relation to host rocks

Uraniferous veins have been discovered in rocks of igneous, metamorphic, and sedimentary origin that show extreme differences in chemical and mineralogic composition. On a world-wide basis, concentrations of uranium minerals in veins are known in silicic rocks, as for example at Shinkolobwe, Wolsendorf, Urgeirica, Great Bear Lake, Lake Athabasca, and Carrizal Alto; in rocks apparently of intermediate composition at Great Bear Lake, Joachimsthal, Johanngeorgenstadt, and Cornwall; and in mafic rocks at Lake Athabasca, Montreal River district (Ontario), and the Tete district. At Shinkolobwe some ore is found in dolomite although most occurs in quartzite. Within some districts and even within a single deposit uranium has been deposited in both silicic and subsilicic rocks. Deposits in the Lake Athabasca area are found in quartzite, granite, diabase, metabasalt, graphite schist, amphibolite, and in several other rock types. Similarly, uranium-bearing veins in the United States occur in rocks of diverse origins and chemical and mineralogical character, although a majority of deposits are either within or near bodies of felsic intrusive or extrusive rocks (Everhart, 1956); other kinds of host rocks include many varieties of schist and gneiss, metasedimentary and metavolcanic rocks, carbonaceous sedimentary rocks, arenaceous sedimentary rocks, carbonate rocks, and intermediate to mafic igneous rocks.

Adjacent to most uraniferous veins these rocks have been altered in different ways but, in and near some deposits, no alteration effects are evident. The alteration effect, where present, is characterized by silicified, sericitized, argillized, chloritized, pyritized, or hematized wall rocks or by a combination of these alterations. Some of the alterations may be the result of action by the hydrothermal solutions that introduced the uranium, but others probably resulted from weathering and oxidation of base-metal sulfide minerals and other vein constituents.

The age of the host rocks is different in different deposits within the United States; large numbers of deposits are known in Precambrian rocks and in rocks of Late Cretaceous or Tertiary age and a smaller number in rocks of Paleozoic or early Mesozoic age. Most of the veins within these rocks are either Late Cretaceous or Tertiary in age, as indicated by both geologic interpretation and by radioactivity age determinations. A few deposits in the eastern United States may be Paleozoic in age, and Kerr and Kulp (1952) have determined a Precambrian age for pitchblende in the Sunshine mine, Idaho; some of the caliche-like deposits (see page 20), characteristic of arid or semi-arid regions in the western United States probably are forming at the present time through deposition from ground water evaporating at or near the surface.

No one mineralogic class of vein deposit, as described herein, is restricted to any particular kind of host rock. Thus it would appear that the chemical and mineralogic character of rocks is, in general, less important as a control on the localization and deposition of uranium, than the permeable structures which permit migration of uranium-bearing solutions, and the relationship, in time and space, of these structures to the geologic processes that created them, that is to their tectonic environment.

Tectonic setting

In order to fit uraniferous veins into the proper tectonic framework, it is necessary to discuss them on the basis of: (1) controls of individual deposits, (2) controls for districts, and (3) position of uranium-bearing veins within the broad tectonic evolution of large regions. The material which follows is organized on this three-fold basis.

Controls of individual deposits

The structures in which individual domestic uranium-bearing vein deposits are found can be divided roughly into five general types. Though this division implies a classification of structural environments in which uranium-bearing veins are found, presently available data do not permit correlation of these structural types with the mineralogical classes previously established. It is probable that deposits of several mineralogic classes occur in each of the structural types. These types are, (1) linked, or cymoidal veins between parallel faults or fracture zones, so-called wrench faults (Harrison, 1955, p. 313-314), (2) persistent parallel or en echelon fractures, or associated minor fractures, (3) minor faults and rock contacts near margins of intrusions, (4) normal and reverse faults, fractured zones and intrusions of the types commonly observed in the Basin and Range province, and (5) internal fractures of unspecified type in intrusive rocks.

Examples of the linked or cymoidal veins between large faults or fracture zones are found in the Front Range, Colorado, the Marysvale district, Utah, and the Los Ochos area, Colorado. Geological evidence suggests that all these deposits are Laramide or younger in age and that the last movements along the veins have principally horizontal components. In the Central City area of the Front Range and in the Marysvale district the veins are characterized by pronounced shoot structures localized along the veins.

Deposits in persistent parallel or en echelon fractures or associated minor fractures include those in the Boulder batholith, Montana (Roberts and Gude, 1953; Becraft, 1953) and the deposits along the eastern margin of the Front Range, Colorado (including the Schwartzwalder, and Morrison or Pallaoro deposits). Probable examples of deposits in this type of environment include the Silver Cliff mine, Wyoming (Wilmarth and Johnson, 1954), the Copper King mine, Colorado, the deposits of the Hazel group, Wyoming (T. L. Finnell, 1955, oral communication), and in the Esterbrook district, Wyoming. The geologic age of many of these deposits is not known, but most seem to be Laramide or younger and some, including the Boulder batholith deposits and those of the Hazel group are probably post-Oligocene in age. The deposits in the Esterbrook district may be of Precambrian age.

Examples of deposits along minor faults and contacts near the margins of intrusions include the Midnight mine, Washington, the Early Day claims, Nevada, and the Prince mine, New Mexico (Walker and Osterwald, 1956). These deposits are closely related in space to bodies of intrusive rock, but only at the Prince mine has a genetic relationship been demonstrated between uranium and pyrometasomatism. The small faults and rock contacts are merely favorable structures in which uranium-bearing and other minerals were deposited. Most of the deposits questionably are of post-Cretaceous age.

Many deposits in Nevada, Utah, Arizona, New Mexico, and Texas contain small amounts of uranium, associated with normal and reverse faults, intrusions and areas of volcanic rock characteristic of the Basin and Range province. Examples of this type of deposit include (1) those in the Thomas

Range district, Utah, (2) some in the Yellow Pine (Goodsprings) district, Nevada, (3) the Staats fluorspar mine, Utah, and (4) the Moonlight mine, Nevada. The geologic age of many of these deposits is not known; some are probably early Tertiary and others may be as young as Miocene or Pliocene in age (Staatz and Osterwald, in preparation).

A few deposits occur along fractures of unspecified type in the interior of intrusives. The most important of these deposits consist of concentrations of uranium minerals with lesser amounts of other minerals in Kern Canyon and vicinity, California and near Mt. Spokane, Washington. Most of these deposits are in rocks thought to be of late Mesozoic age.

Controls of districts

Some areas, containing metalliferous veins including some areas containing uraniferous veins, have characteristic types of geologic structure. A partial correlation between uranium districts in the Cordilleran Foreland with characteristic structural environments was pointed out by Osterwald (1956). Because the data are incomplete, a correlation between mineralogical types of uraniferous veins and their associated geologic structures, such as the one by Newhouse (1942) relating the type of metal deposits in mining districts with the type of faults or folds within the districts, cannot be made at the present time. However, some domestic uranium-bearing vein districts do have characteristic structural environments; these are (1) Colorado Front Range (parallel northwest-trending fractures), (2) Boulder batholith (parallel northeast- to east-northeast trending faults and fault zones), (3) central Wyoming (northwest-trending folds and faults, and (4) Midnight mine, Washington, and Early Day claims, Nevada (fractured contacts of intrusive bodies).

Areas of numerous normal and reverse faults with or without intrusions or areas of volcanic rocks are common district controls for uranium-bearing veins in the Basin and Range province.

Relation of uranium-bearing veins to regional tectonic evolution

Metal deposits related to the Variscan folding, which according to Schneiderhöhn (1952, p. 60-62) was one of the most important times of metal introduction over most of the earth, are found at many places in central Europe, in Cornwall, England, in French Morocco, and in Portugal and Spain; many of these deposits contain uranium. In North America only the Appalachian Mountains and the Ouachita Mountains were folded during the Variscan orogeny; these two ranges contain relatively few known uranium-bearing vein deposits. Furthermore, the known uranium-bearing veins in the western United States are geologically more similar to the post-Variscan "regenerated" deposits in Yugoslavia (Ristic, 1956) than they are to the veins in central Europe. This similarity may imply a genetic difference between the veins of central Europe and those of the western United States.

Geffroy and Sarcia (1954, p. 152-154) have considered the distribution of various types of uraniferous veins within the Hercynian (Variscan) areas of Europe. They find that uraniferous sulfide veins containing nickel, cobalt, bismuth, and silver are alined at the margin of the European Hercynian area. This would include deposits in (1) Sudeten, in Czechoslovakia, (2) the Erzgebirge, and Mansfeld, in Germany, and (3) Cornwall, England.

Fluorite-bearing uraniferous veins are alined along an east-west direction south of the sulfide-bearing deposits. The fluorite-bearing deposits include Wolsendorf, and probably Durrmaul, Germany, and Grury and the Ecarpiere, France. Deposits containing principally uranium-bearing minerals are localized along the axial zone of the Variscan area but seem to be somewhat younger than the sulfide-bearing veins along the margin with nickel, cobalt, bismuth, and silver. The deposits with principally uranium-bearing minerals include Lachaux, and Limousin, in France, the Black Forest in Germany, and the deposits in Portugal.

The concept that uranium-bearing veins are distributed locally around the margins of old shield areas or massifs (Bain, G. W., 1950, p. 282; Geffroy and Sarcia, 1954, p. 149) at least when applied specifically to deposits in western North America and in the Canadian Shield may require some revision. Some uraniferous veins are distributed around the margins of the Colorado Plateau and within the marginal parts of the Cordilleran Foreland; nevertheless, we do not have sufficient information to believe that there are not other uraniferous vein deposits beneath the gently dipping sedimentary rocks which cover much of this area. Similarly, the uraniferous veins of the Canadian Shield, though they are near the margins of the outcrop area of Precambrian rocks, may not be actually at the margin of the shield; the Canadian Shield may extend beneath the sedimentary cover for considerable distances to the south and southwest, and might include the areas of the Cordilleran Foreland and the Colorado Plateau.

Some concepts of geologic distribution within selected regions of the United States

The geologic distribution of known, as well as undiscovered, uranium-bearing veins in the United States can be related to, (1) tectonic activity, including structural, metamorphic, and igneous processes, that tend to mobilize and redistribute uranium, (2) the geologic age of the tectonic activity, (3) the development, at a suitable time during the tectonic cycle, of favorable host environments in which the mobilized uranium can be localized and deposited, and (4) those geologic, hydrologic, and climatic processes that collectively or individually tend to destroy or modify concentrations of uranium minerals. Comparative studies of these four geologic factors in various regions may lead to a better understanding of the geologic and geographic distribution of uranium-bearing veins in the United States. For this reason, some brief comparative comments about a few selected regions are presented.

The abundance of uranium-bearing veins in and to the west of the Cordilleran Foreland is a result of (1) the concentration of uranium minerals during comparatively recent time in structures as a result of Late Cretaceous and Tertiary deformation and igneous activity, (2) the presence of uraniferous veins at or near the surface through subsequent uplift and erosion, and (3) the persistence of these veins because of the arid to semiarid climatic conditions characteristic of the region. The Cordilleran Foreland is an area of pre-orogenic folding and faulting that has not been strongly deformed since Precambrian time. For this reason it contains uranium-bearing veins of somewhat different geologic habit from those of Precambrian age in the Canadian Shield, or those of Paleozoic age in central Europe.

East of the Cordilleran Foreland only a few widely distributed uranium-bearing veins are known, although others undoubtedly will be found as the search for uranium continues. In general, the uranium-bearing vein deposits in the eastern regions are thought to be older than those to the west and are related to crustal disturbances of Precambrian, Paleozoic, and Late Triassic age. Some of the concentrations of uranium formed during Precambrian or early Paleozoic orogenies probably were redistributed through changes in equilibrium conditions related to the Appalachian Revolution or the Palisades disturbance; some probably were destroyed by erosion or are under thick sections of sediments. Furthermore, much of the region has been subjected to relatively deep chemical weathering and leaching as a result of moist climatic conditions during Tertiary and Recent times. Such weathering not only destroys or obscures surficial deposits of uranium minerals, but also prevents formation of caliche-like efflorescences of hexavalent-uranium minerals which, in the western United States, are a direct guide to uranium deposits beneath the outcrop.

The most important deformation in the Appalachian Region, however, corresponded roughly in time with the Hercynian (Variscan) of Europe (Schneiderhöhn, 1952, p. 62); the structure, metamorphic rocks, and synorogenic intrusions are similar to those of Europe. The authors consider it likely that undiscovered uraniferous veins are present in the Appalachian Region because of (1) the similarity of geologic setting and tectonic history, possibly including the similar geologic age of the tectonic activity, to uranium-bearing areas of Europe and (2) the presence of known uranium-bearing veins in the Region.

The area of the Ouachita-Wichita-Arbuckle Mountains system in Texas and Oklahoma has many structural and tectonic features that are similar to those of the western part of the Cordilleran Foreland. The Ouachita Mountains are in a folded and overthrust zone of geosynclinal sedimentary rocks that are similar in geology and age to Variscan (Hercynian) Mountains of Europe. The geologic similarity between the Ouachita Mountains and the Variscan areas of Europe suggests the possible occurrence of similar uranium-bearing vein deposits in the Ouachita Mountains. The geologic structure of the Wichita-Arbuckle systems is very similar to the structure of the ranges within the Cordilleran Foreland. The Wichita-Arbuckle area, with its associated basins, is a foreland area (King, P. B., 1951, p. 54-58) associated with the Ouachita system in the same way as the Cordilleran Foreland is associated with the ranges of the Cordilleran geanticline. The scattered occurrences of uranium minerals, and the widespread association of uranium with hydrocarbons within the Ouachita-Wichita-Arbuckle region suggest the uranium deposits may have had an origin very similar to the uranium deposits of the Cordilleran Foreland.

The lack of known uranium deposits in the coastal parts of California, Oregon, and Washington may be related to: (1) during the evolution of this major tectonic province, the mobilization and redistribution of uranium has not occurred in sufficient volume in relatively recent times to form deposits, (2) the mobilization and redistribution did not coincide with the development of favorable environments for deposition, or (3) removal of near-surface concentrations by leaching as a result of heavy rainfall. Furthermore, much of the region is not readily amenable to prospecting because of the thick soil and vegetation cover and the relative scarcity of outcrops.

Although only a few, widely distributed uranium deposits have been found in the Columbia Plateaus (Fenneman, 1931), owing largely to a thick and very extensive cover of middle to late Tertiary lavas, some deposits can be expected beneath the lavas and possibly even within the lavas where permeable structures have permitted flow of thermal or non-thermal waters. Furthermore, within the region, structural and petrologic environments exist, locally, that in areas contiguous to the Columbia Plateaus contain uranium-bearing veins; these environments include faults and fracture zones in acid volcanic and pyroclastic rocks (Lake and Harney Counties, Oregon) and in acid to intermediate plutonic rocks (Stevens and Spokane Counties, Washington).

SUMMARY

Uranium-bearing vein deposits have been arbitrarily segregated into eight intergrading mineralogic classes; no one of these mineralogic classes of vein deposits is restricted to any particular petrographic or structural environment; and each class may occur in several apparently very different environments. Tectonic, petrologic, hydrologic, and climatic processes are fundamentally responsible for the geologic distribution of uranium-bearing veins; however, the interplay of these processes produces such complex geologic results that no universally applicable generalizations can be made by

extrapolation from any one district or region to any other district or region. The diverse geologic characteristics of these deposits and of their structural and petrologic environments seem more compatible either with (1) several different modes of origin or (2) disruption of equilibrium conditions as a result of orogenic activity.

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