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Geology - Mineralogy
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Series A

UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

SELECTED PAPERS ON URANIUM DEPOSITS IN THE UNITED STATES*

By

E. P. Kaiser, R. U. King, V. R. Wilmarth,
F. Stugard, Jr., D. G. Wyant, G. B. Gott,
and others.

May 1952

Trace Elements Investigations Report 168

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

USGS - TEI Report 168

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SELECTED PAPERS ON URANIUM DEPOSITS IN THE UNITED STATES

FOREWORD

The six papers included in this report were prepared in an attempt to summarize briefly, and make available to the public, part of the information concerning uranium deposits that is in unpublished reports of work done by the U. S. Geological Survey under the auspices of the Manhattan Engineer District, and later, the U. S. Atomic Energy Commission. They were presented orally at the Rocky Mountain Section meetings of the Geological Society of America at Rapid City, South Dakota, on April 13, 1951, 1/ and consequently are of limited scope as regards details and documentation. It is believed, however, that the publication of these papers in their present form will assist persons currently engaged in the search for and study of uranium deposits. Much more detailed, scientific papers on most of these subjects are being prepared and will include a considerable quantity of data collected since April 1951.

DISTRIBUTION OF URANIUM DEPOSITS IN THE UNITED STATES

By

E. P. Kaiser and L. R. Page

ABSTRACT

Uranium deposits in the United States may be grouped as: (1) deposits with structural control, and (2) deposits with stratigraphic control. The deposits with structural control include veins, breccias, and pipes; disseminated deposits associated with fractures; pyrometasomatic deposits and pegmatites. The deposits with stratigraphic control include (1) phosphates, carbonaceous shales, and lignites; (2) limestones and dolomite; (3) deposits of the carnotite type; and (4) surficial or caliche deposits.

Most of the known uranium deposits are in the western United States. Arizona, Utah, and Colorado contain the largest number of deposits.

The deposits with structural control, except the uraniferous pegmatites, are commonly in or related to igneous rocks of post-Cretaceous age, and many of them are Tertiary volcanic rocks. Notably few deposits are genetically related to pre-Cambrian rocks and to Jurassic intrusives. The pegmatite deposits of

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1/ Abstracts of papers submitted to the meeting in Rapid City, S. Dak., April 13 - 14, 1951, Rocky Mountain Section of the Geological Society of America: Geol. Soc. Am. Bull., pt. 2, vol. 62, pp. 1535, 1537, 1538, 1542, 1543, and 1544, 1951.

the western United States are believed to be pre-Cambrian; those of the eastern United States are post-Devonian.

Carbonaceous shales, phosphates, and lignites are restricted, for the most part, to terranes of Paleozoic and Tertiary age. Most of the carnotite-type deposits are in sedimentary rocks of Mesozoic age, and the most productive deposits are in rocks of Jurassic age.

Study of the distribution of known deposits indicated that the principal favorable areas for further prospecting are those in or near Triassic and Jurassic sedimentary rocks and Tertiary igneous rocks.

The U. S. Geological Survey started an intensive study of uranium deposits in 1944. This program was carried out at first on behalf of the Manhattan Engineer District and later on behalf of the Atomic Energy Commission. We think that some of the geologic and mineralogic information gathered by the Survey during the past few years is of general geologic interest and should be called to the attention of geologists at this time. Also, recent changes in the price schedules suggest that the finding and exploitation of uranium deposits will become increasingly important.

This paper and the five following papers will attempt to compile some of the information on uranium deposits that has been accumulated during the past few years by the U. S. Geological Survey.

Much unpublished information has been accumulated over a period of years by many members of the Geological Survey. Particular acknowledgment should be made of the early work by C. E. Prouty, J. O. Harder, S. E. Clabaugh, A. L. Slaughter, J. M. Nelson, C. W. Chesterman, and F. H. Main, formerly with the Survey, and of A. P. Butler, F. M. Stead, and D. G. Wyant, still with the Survey, because their work has served as the basis for many of the later studies undertaken by the Reconnaissance and other groups.

The uranium deposits of the United States are of two broad types - those with structural control and those with stratigraphic control. These two types of control are, of course, not mutually exclusive. The deposits with structural control can be further subdivided into the following groups: (1) veins, breccias, and pipes; (2) disseminated deposits; (3) pyrometasomatic deposits; and (4) pegmatites.

Deposits with stratigraphic control include: (1) phosphates, (2) black shales, (3) limestones and dolomites, (4) lignites, (5) deposits in sandstone, and (6) surficial or caliche deposits.

The distribution of localities where uraniferous deposits, except pegmatites, have been studied is shown on figure 1. Deposits of vein type, other structurally controlled deposits, and deposits with stratigraphic control have been indicated. The structurally controlled deposits are most abundant in Arizona, Utah, and Colorado.

Of the structurally controlled deposits, the vein-type deposits are most numerous, and have been found in most of the western states. They include fissure veins, shear zones and stringer zones, and silicified zones or reefs. All domestic production of pitchblende has come from deposits of the vein type. 2/ At Marysvale, Utah, the recently discovered deposits of the secondary minerals--uranophane, autunite, and torbernite--occur in the upper part of pitchblende-bearing vein structures.

True disseminated deposits of uranium minerals are not common; an example is the Red Bluff prospect in Arizona (Kaiser, 1951), where uranium is disseminated in pre-Cambrian quartzite. At many places secondary minerals occur on fracture surfaces in both igneous and sedimentary rocks, with no obvious major structural or stratigraphic control. These are generally of little interest, except as possible indicators of larger deposits.

Pyrometasomatic uranium deposits are known in the Goodsprings district, Nevada (Harder and Wyant, 1944, p. 36), where secondary uranium minerals are associated with oxidized lead, zinc, and copper minerals. At the Stalin's Present prospect, Pershing County, Nevada, a narrow band of lime-silicate rock in granite contains uraninite.

Pegmatites that contain uranium minerals are known from all pegmatite districts in the United States, but they rarely are more than mineralogical occurrences (Page, 1950).

The stratigraphically controlled deposits are widespread. The carnotite deposits in the Morrison formation of the Colorado Plateau have been our principal domestic source of uranium (Fischer, 1942; 1950). The uraniferous phosphates (McKelvey, 1949; McKelvey and Nelson, 1950), black shales, and lignites are of wide extent and in the aggregate contain a large amount of uranium, but the deposits are of very low grade.

2/ During 1951 pitchblende was produced from several deposits with stratigraphic control.

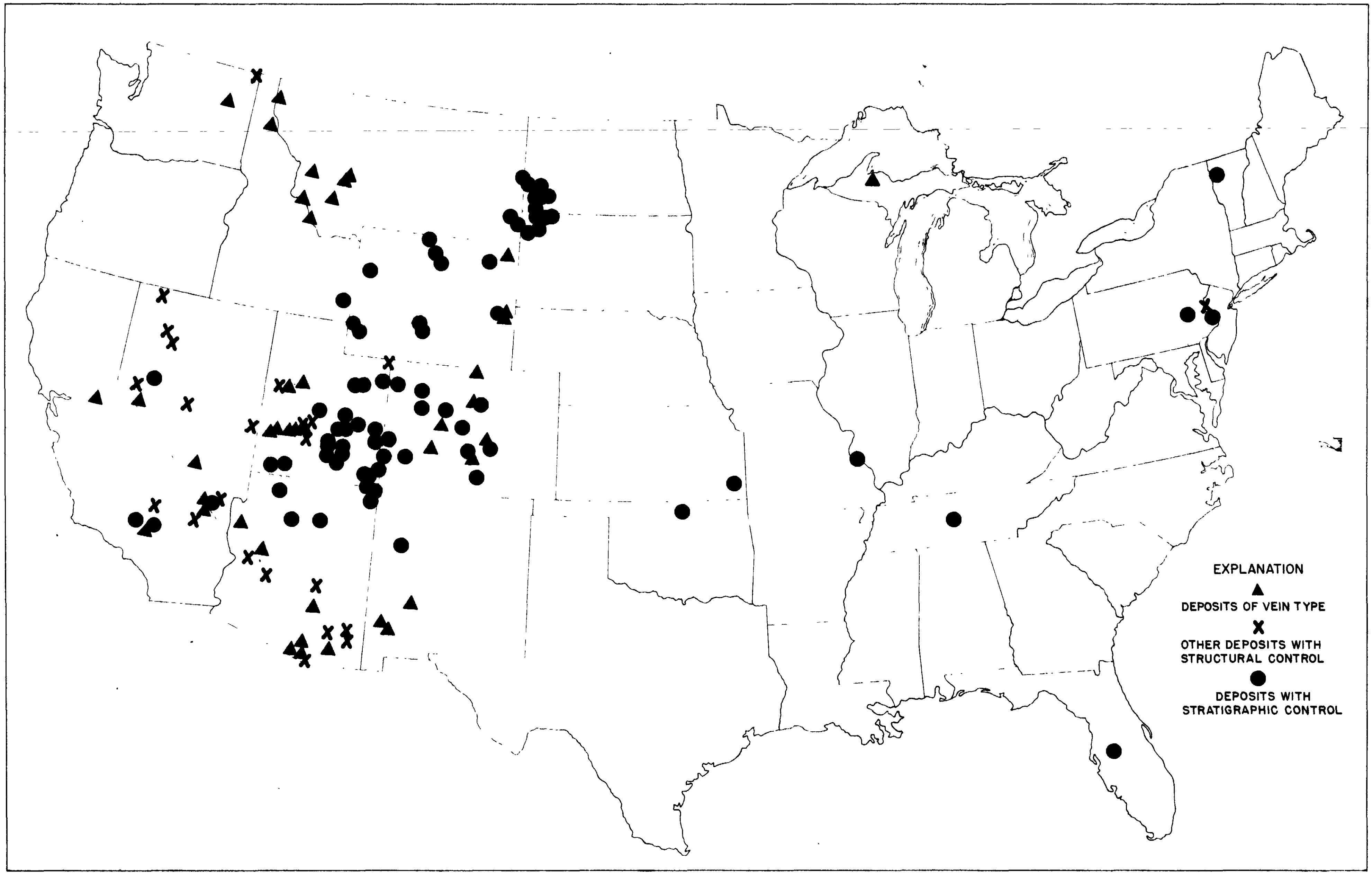

FIG. 1.-DISTRIBUTION OF URANIFEROUS DEPOSITS

Less common are the uraniferous limestones, dolomites, and caliche-type deposits.

The distribution of these types of deposits in relation to geologic age are shown in figures 2, 3, 4, and 5.

Figure 2 shows the structurally controlled deposits in the southwestern quarter of the United States, and the outcrops of pre-Cambrian rocks. Recent generalizations by Bain (1950) have stressed the significance of the relation of major uranium deposits to pre-Cambrian shield areas. It can be seen from figure 2 that there is little correlation between the distribution of uranium deposits and pre-Cambrian rocks in this area. Of course, this may explain why we have no deposits comparable to those at Great Bear Lake in Canada.

The relation of the uranium deposits in the same area to post-Triassic intrusives is shown in figure 3. There is no close correlation between the intrusives and deposits, but there is a relative scarcity of known deposits in and near the Sierra Nevada batholith. Details not shown on this figure that may be of significance are (1) the presence of Tertiary intrusives in the Colorado Plateau area; (2) the occurrence of the Marysvale deposits in and near a small Tertiary stock; (3) the intimate relation of the Colorado Front Range deposits to small Laramide intrusives; and (4) the relationship between uranium veins and the rocks of the Boulder batholith of Montana.

The relation of uranium deposits to Tertiary volcanic rocks is indicated in figure 4. The outline of the Colorado Plateau, according to Fenneman (1931), has been added. Of particular interest is the grouping of uranium deposits in and near areas of Tertiary volcanics in Utah, Arizona, southern California, Nevada, and Colorado, and the relative scarcity of volcanic extrusive rocks in the Colorado Plateau area.

Figure 5 shows the distribution of terranes, as shown on the United States geologic map, that contain stratigraphically controlled deposits.

The uraniferous phosphate deposits of the Permian Phosphoria formation are believed to be syngenetic, and contain small amounts of uranium, as well as other metals. In Florida, phosphate deposits in the Bone Valley formation of Pliocene age are similar to those in the Phosphoria. Only a small part of the formation is uraniferous, as indicated by the dashed line on figure 5.

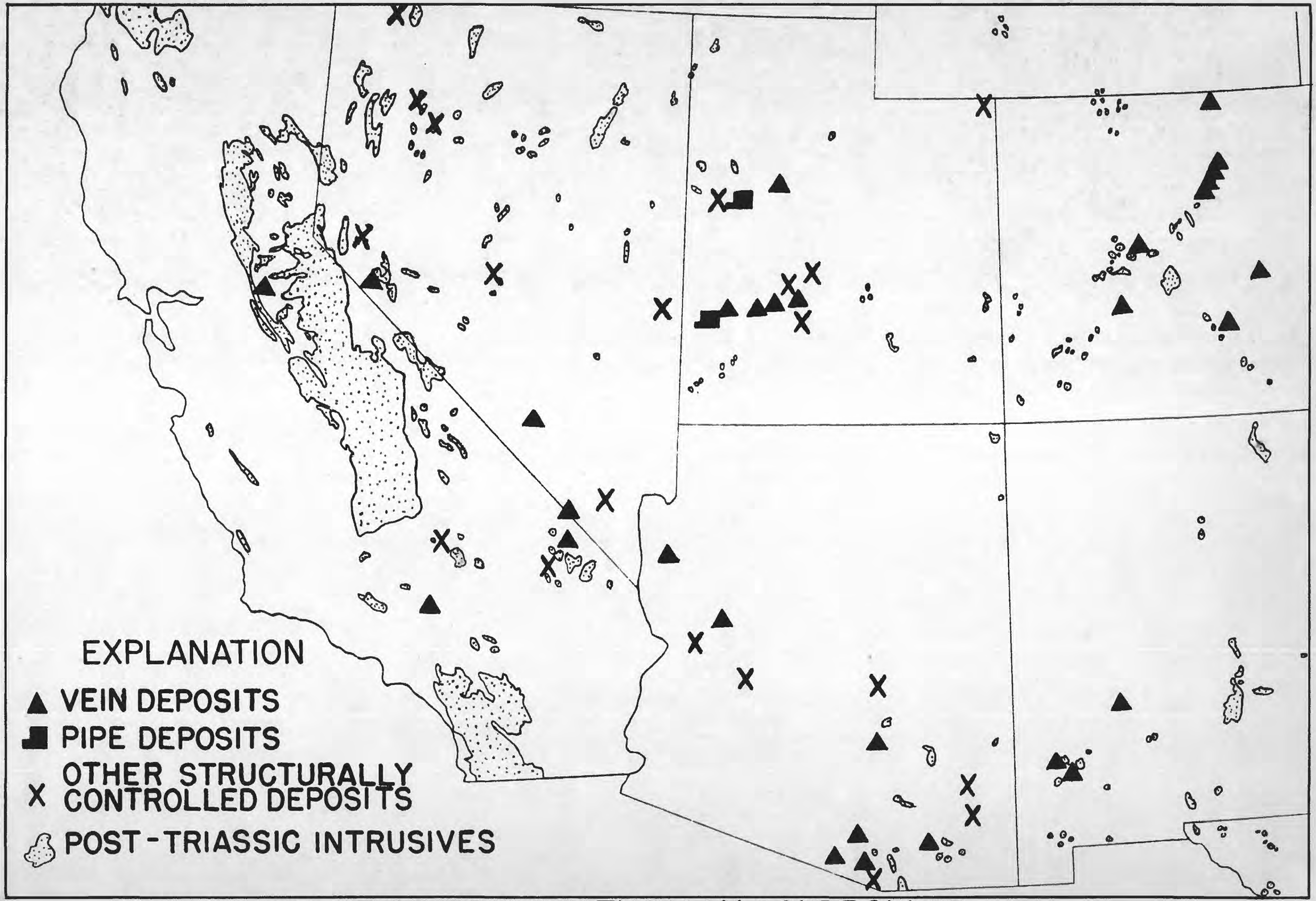

FIG. 3. —RELATION OF STRUCTURALLY CONTROLLED URANIUM DEPOSITS TO POST-TRIASSIC INTRUSIVES

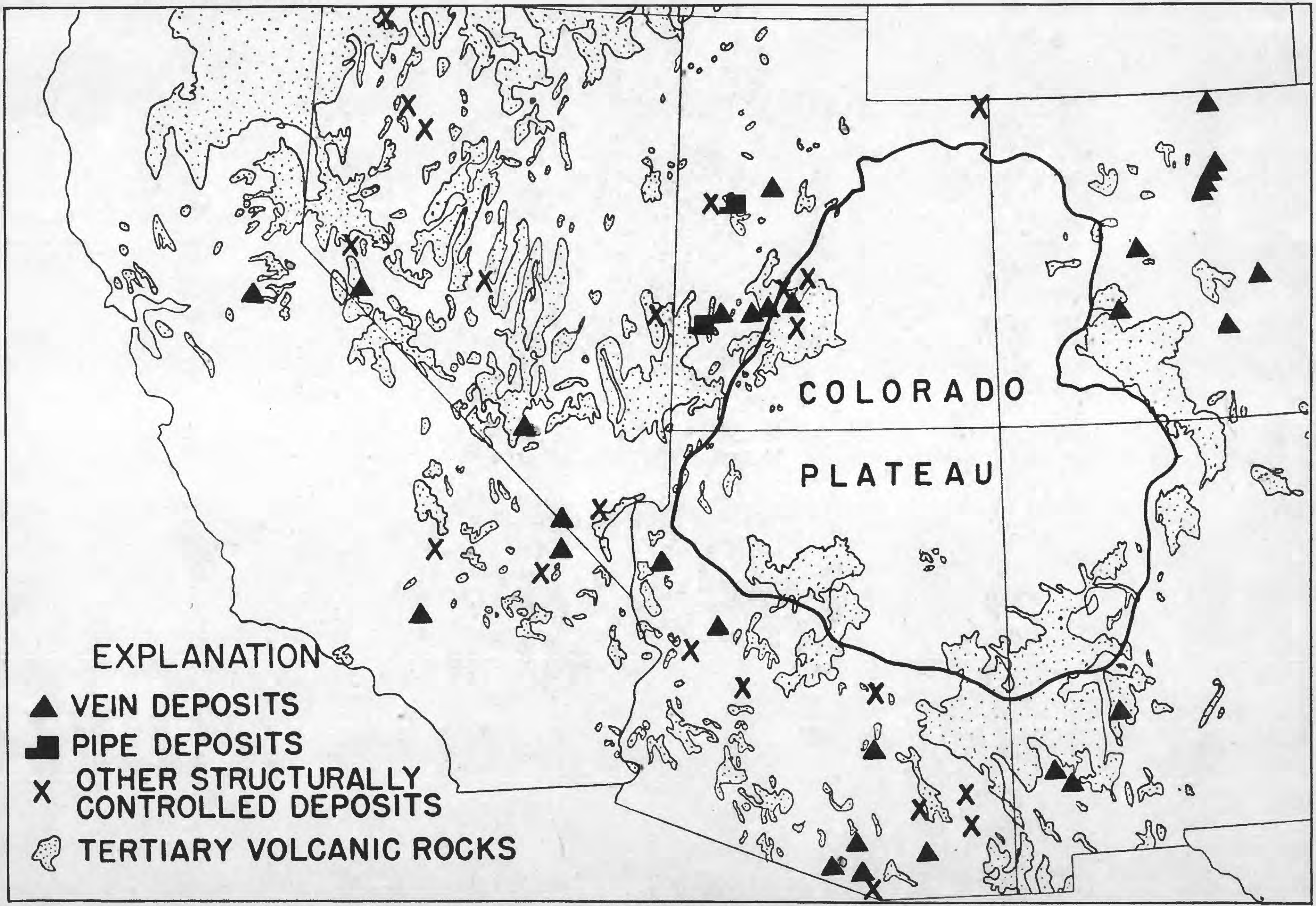

FIG. 4.—RELATION OF STRUCTURALLY CONTROLLED URANIUM DEPOSITS TO TERTIARY VOLCANIC ROCKS

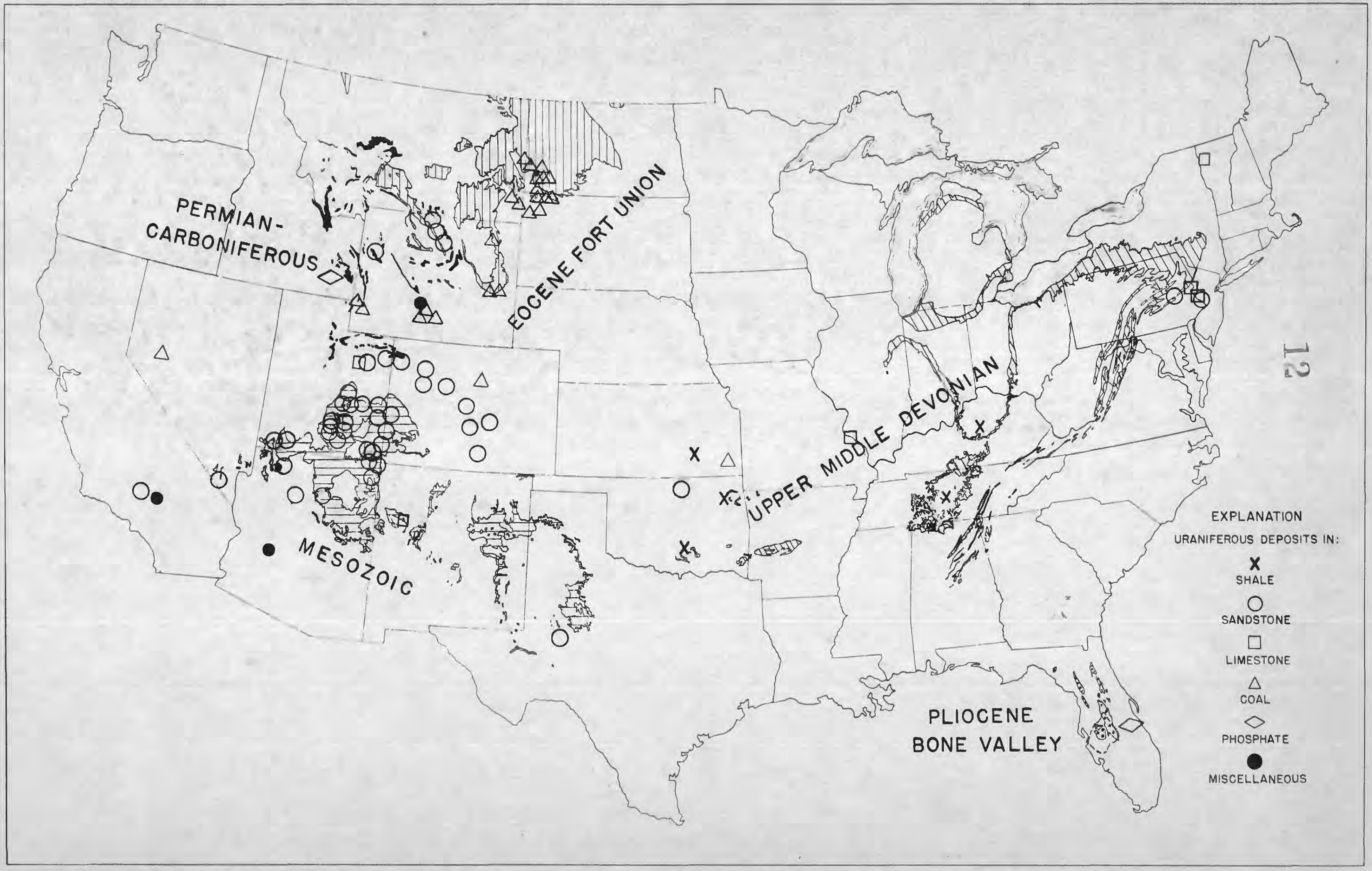

FIG. 5.-DISTRIBUTION OF URANIFEROUS DEPOSITS WITH STRATIGRAPHIC CONTROL

Uraniferous black shales are widely distributed in age. Samples of the pre-Cambrian Nonesuch shale in the Michigan peninsula contain as much as 0.004 percent uranium. No uraniferous shales of Cambrian age are known in the United States, although in Sweden shales of that age are reported to be a current source of uranium.

Black shales of upper Devonian and Mississippian age that commonly are uraniferous include the Chattanooga shale of Tennessee and Kentucky, and the New Albany shale of Indiana, the New Antrim shale of Michigan, and the Woodford shale in the Mid-continent region. Black shales of the Phosphoria formation of Permian age are uraniferous. In contrast, the black shales of the Permian basin of Texas and New Mexico are not notably uraniferous.

The most extensive uraniferous lignites are those of early Tertiary age in North Dakota, South Dakota, Wyoming, and Montana. Uraniferous lignite of Tertiary age is also found in Nevada. Uraniferous sub-bituminous coals of Cretaceous age are known in western Wyoming and some uraniferous bituminous coals of Paleozoic age occur in the mid-continent area.

The most productive uranium deposits in sandstone are in the Jurassic Morrison formation of the Colorado Plateau, but deposits are known in sandstones ranging in age from Paleozoic to Tertiary.

Uranium is present in the Paleozoic Milton dolomite of Vermont, and in Tertiary limestone in Utah, in the Mississippian Spergen limestone in Missouri, and in the Jurassic Todilto limestone at Grants, New Mexico.

In the Red Desert area of Wyoming, schroeckingerite (Larsen and Gonyer, 1937) occurs in sands and clays of early Tertiary age, in a thin zone above the water table and is thought to be a caliche-type deposit.

The following papers will describe in more detail several aspects of domestic uranium deposits.

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PITCHBLENDE DEPOSITS IN THE UNITED STATES

By

Robert U. King, Frank B. Moore,
and E. N. Hinrichs

ABSTRACT

Pitchblende is found in the United States in (1) veins and breccia zones, (2) pyrometasomatic deposits, (3) pegmatites, and (4) sedimentary rocks. On the basis of past production, the deposits in veins and breccia zones are of the greatest commercial significance.

Most of the vein deposits containing pitchblende are in the Front Range Mineral Belt of Colorado, but a few are in Arizona, Idaho, Montana, Nevada, and Utah. The pitchblende deposits in the Front Range Mineral Belt appear to be coextensive with alkali-rich Tertiary intrusive rocks, but a similar relation is not known elsewhere in the United States.

Pitchblende-bearing vein deposits can be classified on the basis of mineral association as (1) quartz-sulphide type, (2) quartz-sulphide-carbonate type, (3) quartz sulphide-carbonate-hematite type and (4) fluorite-quartz type.

Pitchblende is finely disseminated in deposits of the fluorite-quartz type. In mesothermal veins, pitchblende occurs as pods and stringers distributed erratically over relatively narrow vertical limits. In many deposits, pitchblende occurs both as hard botryoidal masses and as powdery films and coatings.

The metallic minerals commonly associated with pitchblende in vein deposits include galena, sphalerite, chalcopyrite, pyrite, silver minerals, and gold. In contrast to well-known deposits in Canada and Africa, cobalt or nickel minerals have been found in only a few of the domestic pitchblende-bearing veins. In a few places, veins containing secondary uranium minerals near the surface contain pitchblende at depth.

The relationship of pitchblende-bearing veins to types of wall-rock alteration has not been clearly established.

Pitchblende or uraninite occurs in many places in the United States; however, most of the domestic production has come from vein deposits in the Front Range Mineral Belt of Colorado.

Pitchblende was discovered in the United States at the Wood mine in the Central City district, Colorado, in 1871. Since that time pitchblende has been found in many deposits in this district. Other pitchblende deposits have recently been discovered in most of the other western states. Since 1944 an intensive search for uranium has been conducted by the U. S. Geological Survey on behalf of the Manhattan Engineer District and the Atomic Energy Commission.

Pitchblende is found in vein and breccia deposits, in deposits in sedimentary rocks, in pegmatites, and in other deposits not readily classified in these groups. In vein deposits pitchblende occurs as hard, botryoidal masses, as sooty films and coatings, and as microscopic granular disseminations. In sedimentary rocks it occurs as disseminations in sandstone and limestone. In pegmatites, uraninite is the most common uranium mineral but is of little economic importance.

Vein and breccia deposits of pitchblende are found in igneous rocks in Lincoln County, Washington; near Clancey, Jefferson County, Montana; at Marysvale, Piute County, Utah; in Pima County, Arizona; and in more than 20 deposits in the Front Range Mineral Belt of Colorado (fig. 6). Vein deposits in sedimentary or metamorphic rocks occur in the Coeur d'Alene district, Idaho; in Niobrara County, Wyoming; in Baraga County, Michigan, and in San Miguel County, Colorado. Pitchblende is disseminated in sedimentary rocks at Hack's Canyon, Arizona; White Canyon, Utah; and at Grants, New Mexico. In Pershing County, Nevada, pitchblende occurs with contact metamorphic minerals in a thin dark band in granite.

Vein deposits of pitchblende can be classified on the basis of mineral association as (1) quartz-sulfide type, (2) quartz-sulfide-carbonate type, (3) quartz-sulfide-carbonate-hematite type, and (4) fluorite-quartz-sulfide type.

Massive and sooty pitchblende occurs in veins of the quartz-sulfide type, such as the deposits at Quartz Hill in the Central City district, Colorado; at Prairie Divide, Larimer County, Colorado; at Ralston Creek, Jefferson County, Colorado; in Lincoln County, Washington; and near Clancey, Montana. Masses or pods of pitchblende, sparsely and erratically distributed in veins, are known to be as much as 8 inches thick by more than 10 feet in diameter. The pods contain from 70 to 80 percent U_3O_8.

Pyrite, galena, and sphalerite commonly are associated with pitchblende in these deposits, but galena and sphalerite are not always present. Chalcopyrite is present in some deposits, but generally is not abundant. Fine-grained, dense quartz is the common gangue mineral in places. In Lincoln County, Washington, molybdenite is present in addition to the other base metal sulfides. The Colorado quartz-sulfide deposits contain gold and minor silver and were valuable chiefly for the gold. The miners in the Central City district have learned by experience that an inverse relationship exists between the gold and the pitchblende content--where pitchblende was found the gold content was low.

Pitchblende vein deposits of the quartz-sulfide-carbonate type are typified by those in the Lawson

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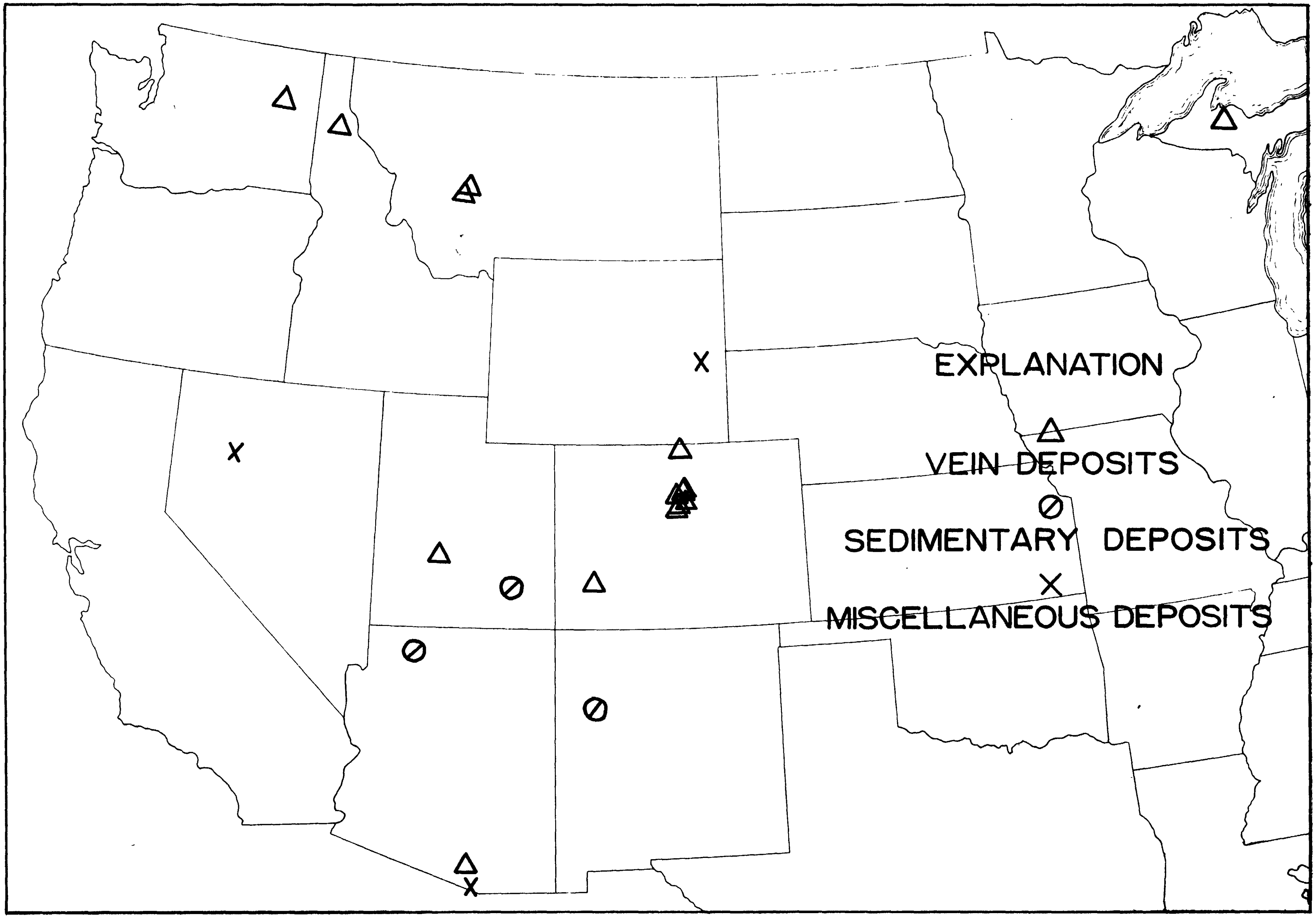

FIGURE 6.—PITCHBLENDE DEPOSITS IN THE UNITED STATES

district and in the Caribou mine, Colorado. These pitchblende ore bodies are generally smaller than those in the quartz-sulfide veins of the Front Range. Isolated pods contain as much as 70 percent uranium. The sulfide minerals include pyrite, galena, sphalerite, chalcopyrite, and tetrahedrite, although the chalcopyrite and tetrahedrite are subordinate. Silver is the most common precious metal. Quartz, dolomite, and calcite are the common gangue minerals, and at the Caribou mine carbonates locally comprise the entire vein filling.

Pitchblende in veins of the quartz-sulfide-carbonate-hematite type occurs in microscopic grains or aggregates disseminated in dense quartz-hematite or jasperoid and as fine-grained steaks at the edges of carbonate veinlets; for example, the deposits in the Coeur d'Alene district, Idaho. The metallic minerals include silver minerals, galena, sphalerite, gersdorffite, and chalcopyrite in a siderite-quartz gangue. At Caribou some thin veinlets of reddish hematite-stained quartz are present in the veins.

The fluorite-sulfide-quartz type of pitchblende veins are represented by deposits in the Jamestown district, Colorado, and the Marysvale district, Utah. At Jamestown uraninite occurs in microscopic grains disseminated in fluorite veins and also in brecciated quartz-monzonite that has a fluorite matrix. Pyrite, galena, sphalerite, and rarely chalcopyrite are sparsely disseminated through the deposits. At Marysvale pitchblende occurs as small hard nodules and as sooty streaks and masses with pyrite and fluorite.

The pitchblende-bearing veins in the United States cut rocks ranging in age from pre-Cambrian to Tertiary, but most of the known deposits are in pre-Cambrian granitic and metamorphic rocks. The pitchblende deposits at the Caribou mine, Colorado; Clancey, Montana; Pershing County, Nevada; and Marysvale, Utah, are in or near granite, monzonite, or quartz monzonite intrusives of late Cretaceous or Tertiary age.

With few exceptions, the pitchblende-bearing veins in Colorado are confined to the northeastern half of the Front Range Mineral Belt. This area is characterized by the occurrence of numerous bostonite dikes (fig. 7). These rocks are peculiar to this area, as far as we know, and are two to five times as radioactive as the enclosing pre-Cambrian granite-gneiss and schist and in places contain as much as 0.01 percent uranium. Some of the pitchblende-bearing veins cut these dikes.

Sericite and clay minerals seem to be the more common alteration products associated with pitchblende-bearing veins in the Front Range of Colorado. The wall rock of the pitchblende veins at

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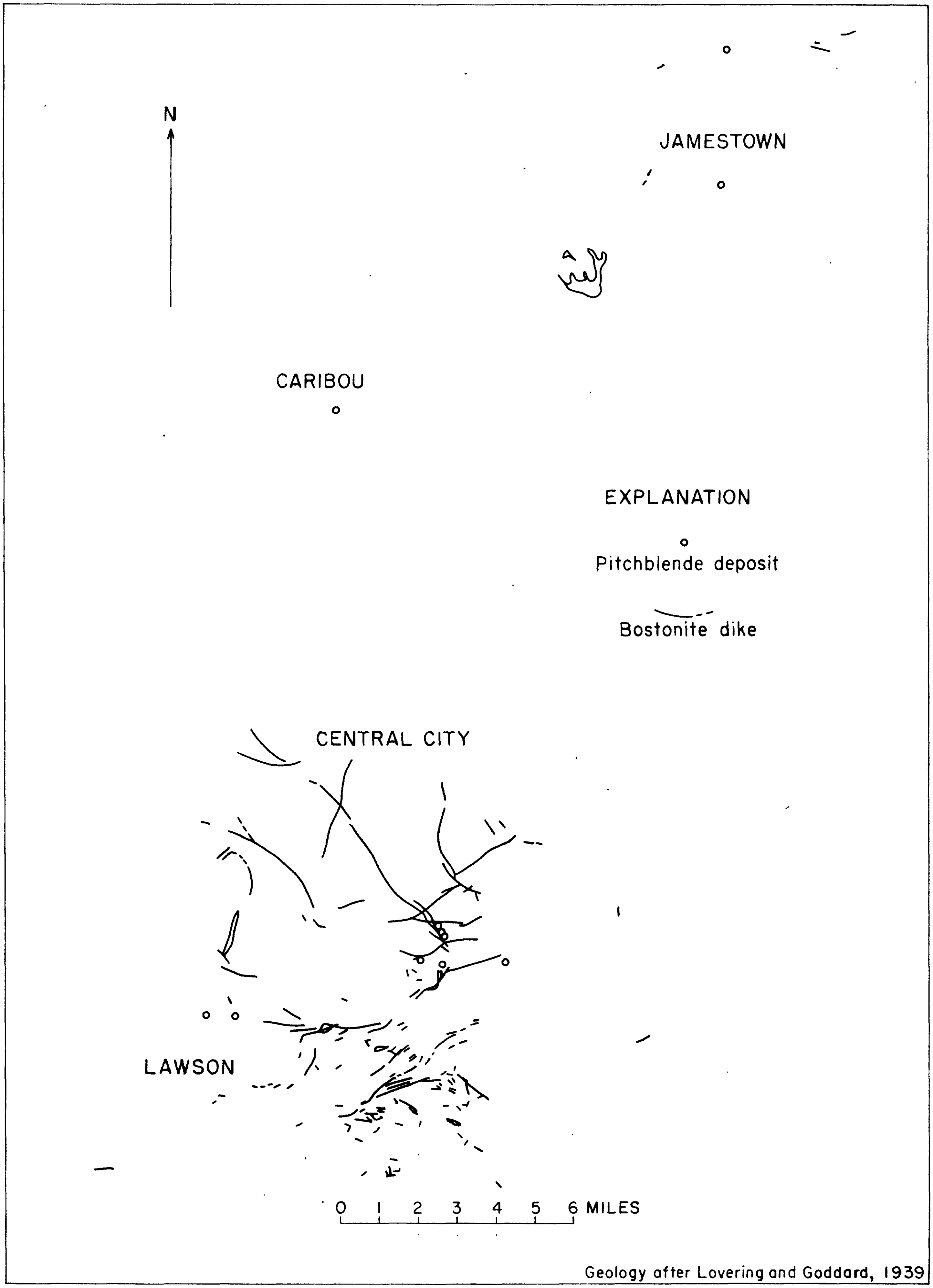

Geology after Lovering and Goddard, 1939

the Caribou mine has been intensely altered. Pyroxene has been converted to chlorite, feldspars to clay minerals, and feldspars and biotite to sericite. Calcite and siderite cut and replace feldspars; quartz replaces earlier minerals.

In the Colorado pitchblende deposits, secondary minerals have been noted in a few places. In the Lawson district torbernite and autunite occur near the surface and pitchblende occurs at depth in nearby veins, but primary and secondary minerals have not yet been found in the same veins. Johannite and zippeite are the only secondary minerals that have been found in the Central City district.

Torbernite has been identified at Jamestown in a pitchblende-bearing fluorite deposit. Oxidized pyrometasomatic lead-zinc-copper deposits at Goodsprings, Nevada, contain the secondary uranium silicate, kasolite, and the phosphate, dumontite, which may have developed from the weathering of pitchblende.

Pitchblende is associated with copper sulfides and secondary uranium minerals in sandstone in the basal part of the Shinarump formation at White Canyon, Utah. Pitchblende has also been identified from deposits in the Coconino sandstone at Hack's Canyon, Arizona, and in the Todilto limestone at Grants, New Mexico. At Grants uranophane, carnotite-tyuyamunite, fluorite, and calcite are also present.

The common metals associated with pitchblende in the United States are lead, zinc, copper, silver, and gold, though not all are present in the same deposit. Analyses of samples from the 1040-level in the Caribou vein, Colorado, indicate that pitchblende is most abundant in the parts of the vein richest in copper, lead, and silver, and is less abundant in those parts rich in zinc. This relationship has not been established in other deposits in the United States.

In contrast to foreign deposits, cobalt, nickel, and bismuth generally are not closely associated with pitchblende deposits in the United States. In the Coeur d'Alene district, Idaho, cobalt occurs near but not within the pitchblende-bearing veins. Small quantities of cobalt are present in the deposits of White Canyon, Utah, and at Caribou, Colorado.

Pitchblende veins have been considered by some writers as shallow deposits, but recent work indicates that they may have a greater vertical range than has hitherto been suspected. Figure 8 shows that pitchblende in the Front Range, Colorado, occurs over a vertical distance of at least 1,000 feet.

At Kirk mine in the Central City district of Colorado, pitchblende is known from the surface to a

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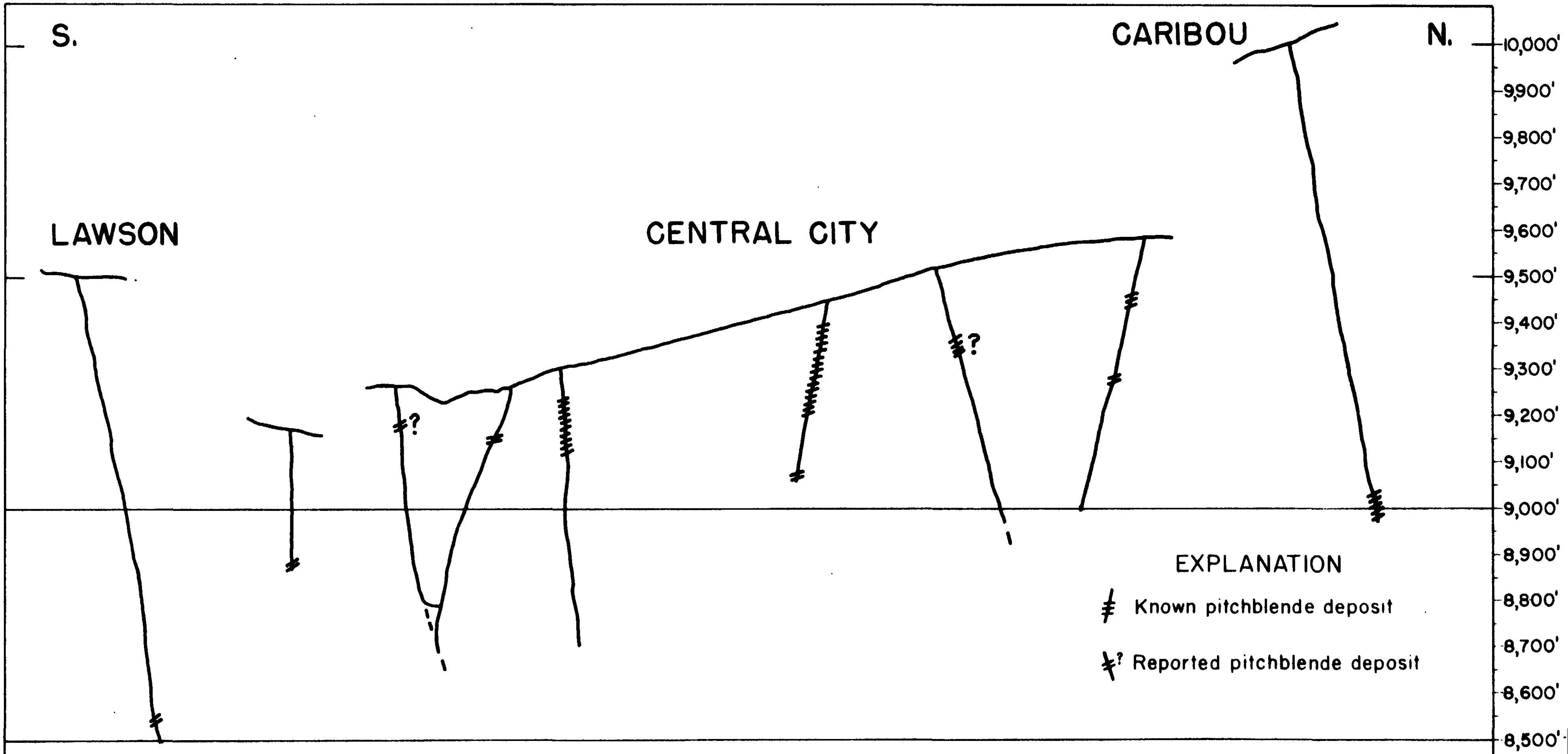

FIG. 8.-SECTIONS SHOWING DEPTH RELATIONS OF PITCHBLENDE DEPOSITS, COLORADO

maximum depth of 400 feet where there are indications that the pitchblende ore shoot may bottom. The pitchblende in the Caribou mine and in the mines of the Lawson district, Colorado, occurs at a depth of about 1,000 feet; at the Sunshine mine, Idaho, it occurs on the 3,100- and 3,700-foot levels. The vertical range in which the pitchblende occurs within these veins, however, appears to be rather short - on the order of 200 to 400 feet.

In summary, by far the greatest number of the pitchblende deposits found in the United States to date have been in the Front Range Mineral Belt of Colorado. Pitchblende is most common in deposits containing copper, lead, and silver although in foreign deposits, cobalt, nickel, and bismuth are considered favorable associations. Recently discovered deposits indicate that pitchblende may be found in veins over a greater vertical distance than has hitherto been suspected.

URANIUM IN FLUORITE DEPOSITS

By

V. R. Wilmarth, H. L. Bauer, Jr., M. H. Staatz,
and D. G. Wyant

ABSTRACT

The association of small quantities of fluorite with uranium minerals in veins has been reported for many localities. Recent studies in Colorado, Utah, Wyoming, and New Mexico indicate that uranium is a common constituent of many fluorite deposits.

Fluorite deposits known to contain uranium occur in breccia zones, veins, pipes, and bedded replacement deposits. These deposits can be grouped on the basis of essential minerals as (1) fluorite, (2) fluorite-quartz-sulphide, and (3) fluorite-sulphide deposits. The deposits contain pitchblende or other primary minerals, together with such secondary uranium minerals as schroeckingerite, torbernite, autunite, uranophane, carnotite, and sklodowskite.

In some deposits the uranium is in fine-grained primary minerals disseminated through the fluorite ore body; in others the uranium is in the fluorite itself in a form not yet identified. Secondary uranium minerals coat fracture surfaces, grain boundaries, and vugs in both the ore bodies and adjacent wall rocks.

Purple fluorite is commonly associated with radioactive deposits, but the many exceptions to this rule make this a criterion of limited value in prospecting for uraniferous fluorite deposits.

Uranium minerals are associated with fluorite in fluorite deposits and in polymetallic veins in the United States and other countries. The fluorite veins at Wölsendorf, Bavaria, are the only ones that have furnished appreciable quantities of uranium ore. Although no uranium has been produced as a by-product of fluorite mining in the United States, uranium has been found in 18 fluorite deposits (fig. 9) in the western states. Recent studies by the U. S. Geological Survey on the behalf of the Atomic Energy Commission have shown that some of these deposits may yield significant quantities of uranium.

The fluorite deposits known to contain radioactive minerals occur as veins, breccia zones, pipes, and tabular to irregular replacement bodies.

Most, if not all, of these deposits are related to Tertiary igneous activity. The deposits, however, are in pre-Cambrian granites, Middle Paleozoic to Tertiary sedimentary rocks, and Tertiary igneous rocks.

The uranium-bearing fluorite veins in all districts are similar in that they have irregularly

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FIGURE 9.—DISTRIBUTION OF RADIOACTIVE FLUORITE DEPOSITS IN THE WESTERN PART OF THE UNITED STATES

mineralized margins. The fluorite veins--such as those at the Thursday property (fig. 10)--range from 6 inches to 25 feet in width and from 5 to 1,000 feet in length. Within the vein filling, discontinuous and en echelon tabular shoots of fluorite are common in some deposits; in others, pockets, seams, and small rod-like bodies are abundant. The average fluorite content in these deposits is as much as 80 percent and the uranium content ranges from 0.003 to 0.45 percent.

Uraniferous fluorite breccia zones in the Jamestown district, Colorado, and in southwestern New Mexico, range from 5 to 50 feet in width and from 40 to 350 feet in length. The Burlington mine (fig. 11) in the Jamestown district, is typical of the fluorite that has been mined to depths of more than 600 feet. Fluorite forms the matrix of the breccia and, consequently, the fluorite content of these deposits varies widely. The fluorite and uranium content of the breccia zones studied to date is, in general, less than that in vein deposits.

Uraniferous fluorite pipes are known only in the Thomas Range, Utah, where they are important sources of fluorspar. Some of the pipes are circular; others--such as the Fluorine Queen shown on figure 12--are elliptical or irregular in plan, and all pipes plunge at steep angles. The circular pipes are as much as 15 feet in diameter and have a smooth sharply defined contact with the enclosing dolomite. The elliptical or irregular pipes, in plan view, range in size from 10 feet by 25 feet to 25 feet by 145 feet. The contacts are ragged and indefinite in outline as many small fluorite veinlets extend outward from the main body into the country rock. One of the fluorite pipes has been mined through a vertical distance of over 220 feet. The fluorspar that has been recovered contains from 65 to 95 percent CaF_2 and from 0.005 to 0.33 percent uranium.

Near Sundance, Wyoming, tabular or irregular replacement deposits along fractures and bedding planes in limestones vary in size from a few widely spaced crystals of fluorite to discontinuous masses 3 feet wide and 50 feet long. The Poison Lake Lode, Beaverhead County, Montana, is a series of small fissure fillings and replacement bodies that constitute a zone as much as 75 feet wide and 200 feet long. Both of these deposits are highly radioactive, but most of the radioactivity is caused by thorium.

Uraniferous fluorite deposits are similar in mineralogy, and can be grouped according to their essential mineral constituents as fluorite, fluorite-quartz-sulfide, or fluorite-sulfide deposits.

The uraniferous deposits (fig. 9) that are essentially composed of fluorite contain as much as

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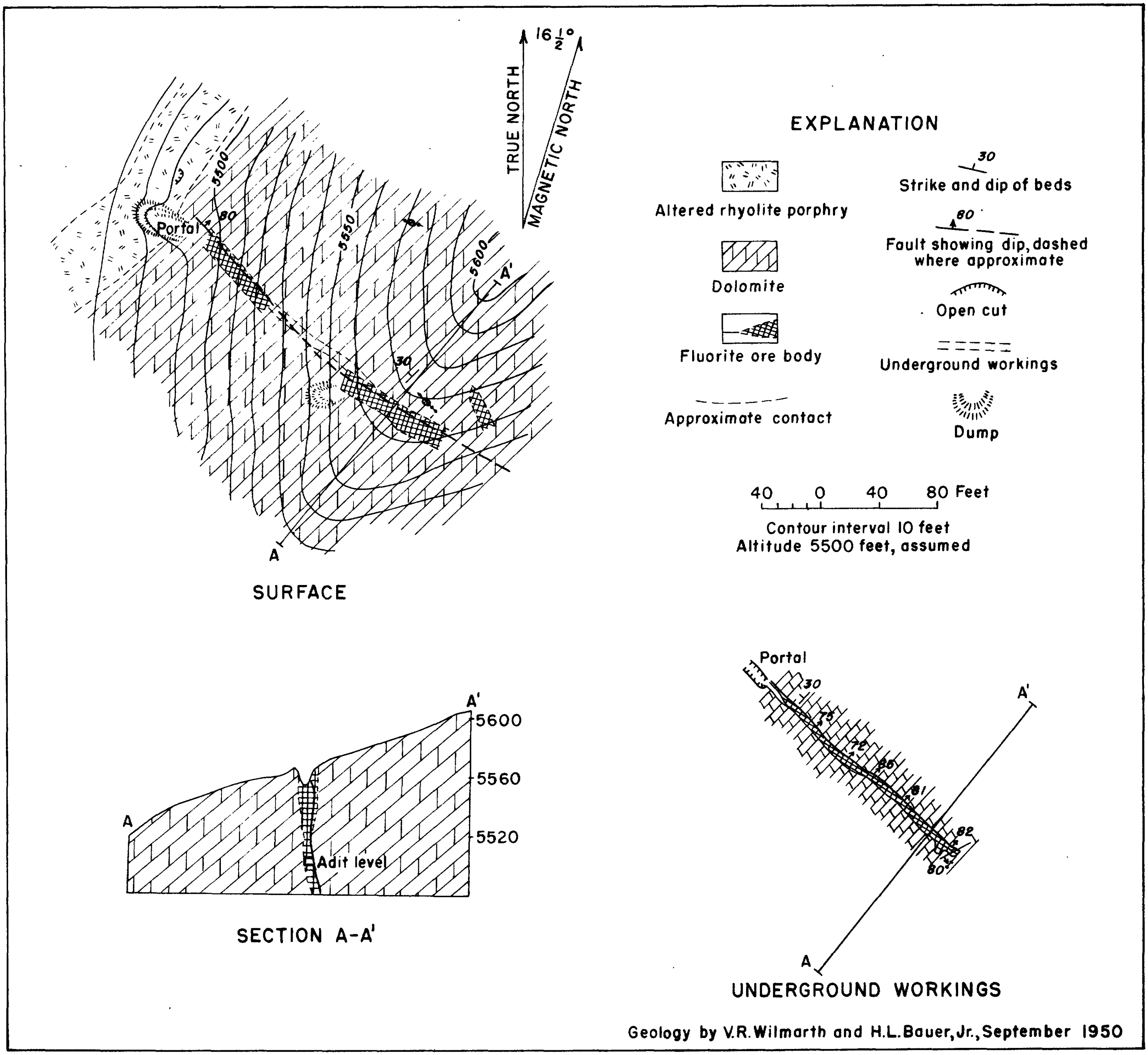
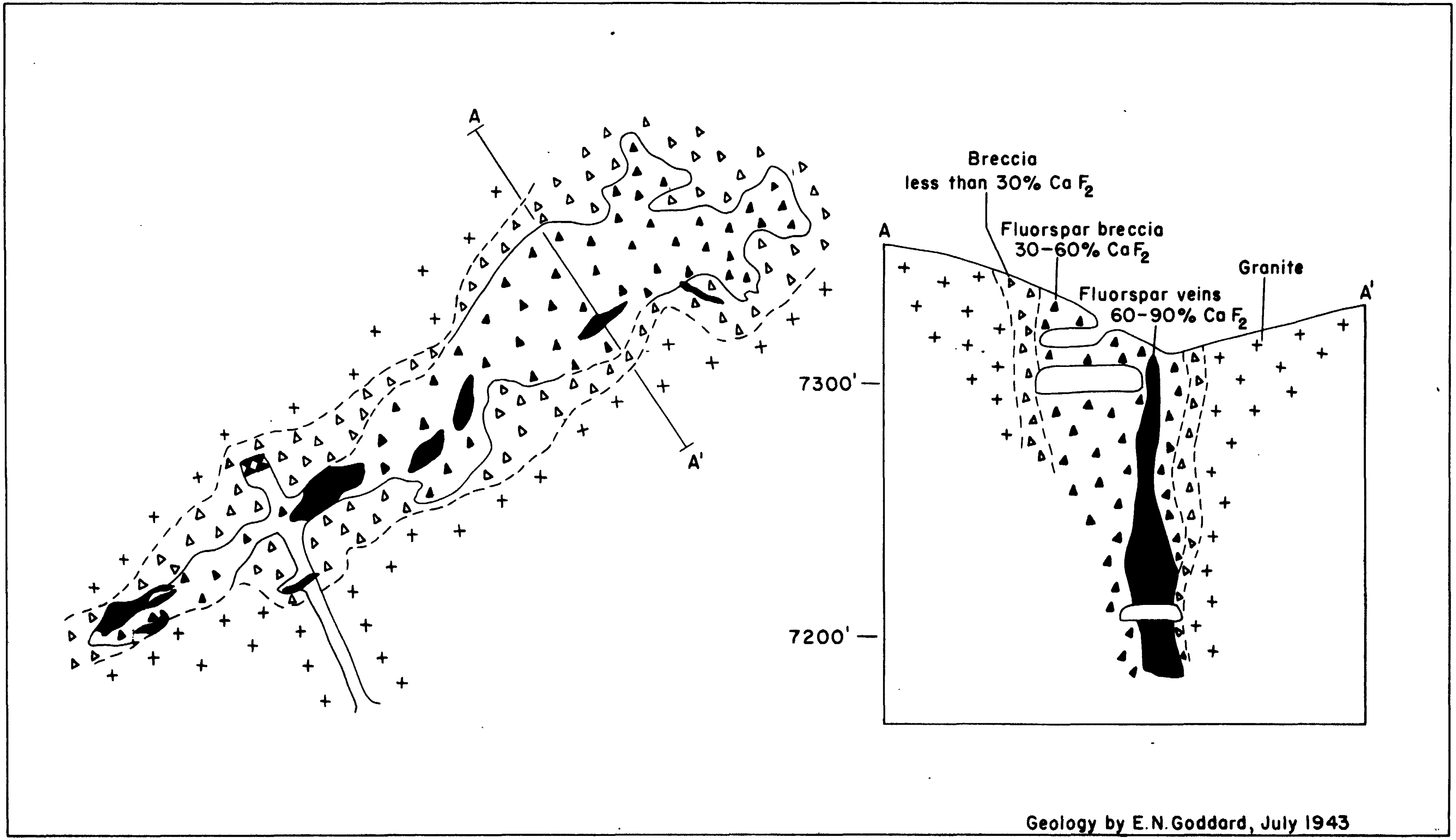


Geology by V.R.Wilmarth and H.L.Bauer,Jr., September 1950

FIGURE 10.-GEOLOGIC MAP AND SECTION, THURSDAY PROPERTY, JUAB COUNTY, UTAH



Geology by E.N. Goddard, July 1943

FIGURE 11.-GEOLOGIC MAP AND SECTION OF THE BURLINGTON MINE, JAMESTOWN, COLORADO

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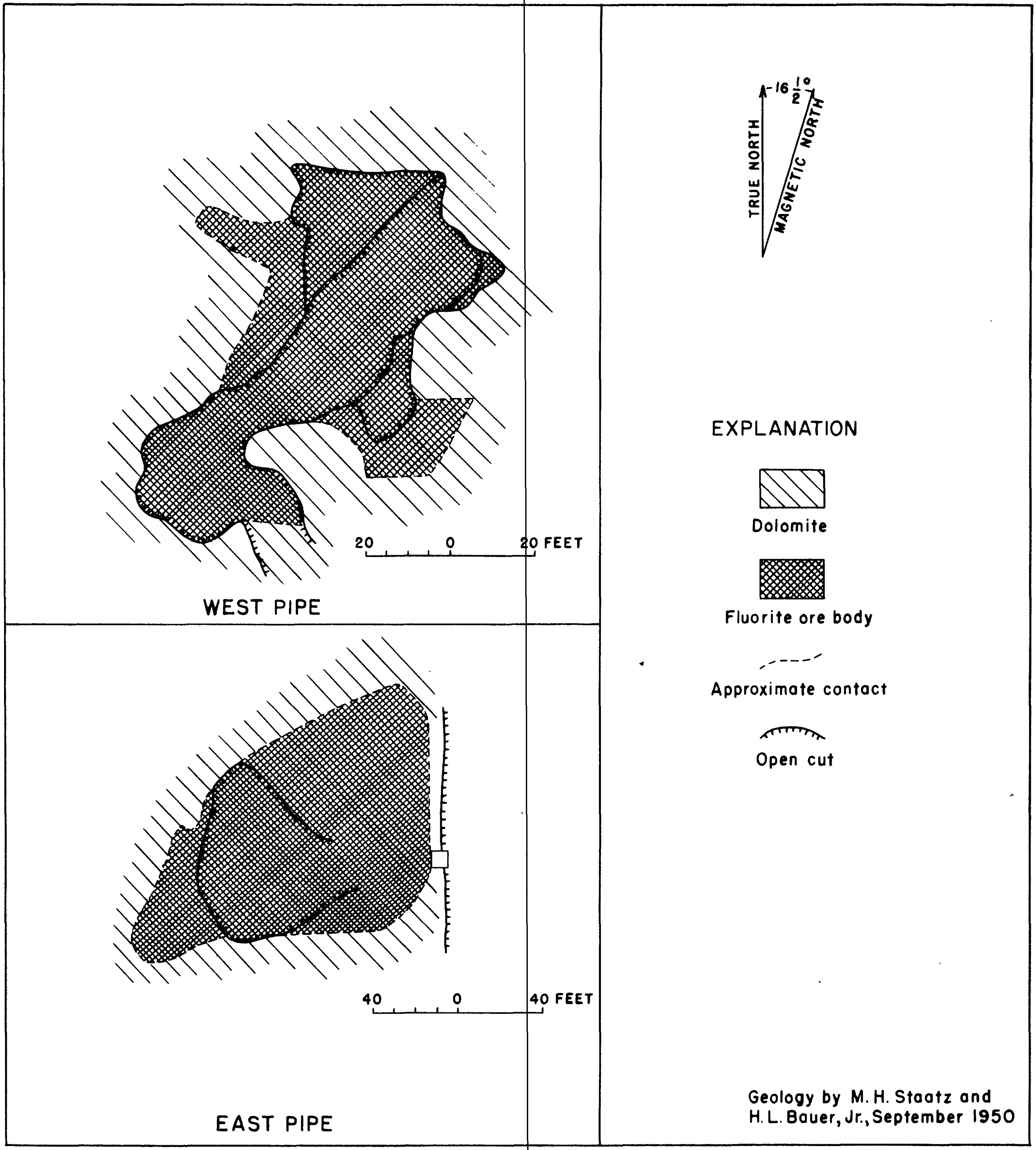

Geology by M. H. Staatz and
H. L. Bauer, Jr., September 1950

FIGURE 12.–GEOLOGIC MAPS OF THE FLUORINE QUEEN PROPERTY,
JUAB COUNTY, UTAH

0.33 percent uranium, but primary uranium minerals have not been identified. Either the uranium mineral is exceedingly fine-grained or the uranium may substitute for calcium in the calcium fluoride molecule. In some of the deposits small quantities of secondary uranium minerals coat fracture surfaces in both the ore body and adjacent wall rocks. Carnotite has been found in the Thomas Range deposits, Utah; autunite and uranophane at the Staats mine, Beaver County, Utah; uranophane at the Terry property, Sierra County, New Mexico; and autunite from the Hines property, Grant County, New Mexico. The fluorite ranges from a fine-grained, pulverulent, earthy variety in pipes to a coarsely crystalline variety common in breccia zones, veins, and irregular replacement deposits. Except for the white earthy, highly uraniferous fluorite of the Thomas Range deposits, all radioactive fluorite so far as known is dark purple to black. Common gangue minerals are clay minerals, barite, chert, carbonates, and wad.

Deposits containing fluorite, quartz, and metallic sulfides are found in fissure veins near the contact of acid igneous rocks or in the igneous rocks. Deposits of this type have been found in Utah, Colorado, Wyoming, and Montana. All but one of the deposits in Utah and Colorado contain secondary uranium minerals that coat fractures in the dark purple fluorite. In the Honeycomb Hills, Utah, the uranium minerals, sklodowskite, uranocircite, and soddyite coat crystal faces of pale green fluorite. Kasolite, a lead-uranium silicate, has been identified in the Saint Peters Dome area of Colorado; autunite at Indian Creek, Utah; uranophane in the eastern part of the Thomas Range, Utah; and autunite and other uranium minerals in the Marysvale district, Utah. No uranium minerals have been identified with the dark radioactive fluorite at the Poison Lake Lode, Montana, and the Sheeprock Mountains, Utah. Non-radioactive, pale green fluorite predominates in the more siliceous parts of these deposits. In all deposits the fluorite is erratically distributed as small irregular masses and narrow veinlets that are associated with massive and finely crystalline white quartz. The primary sulfide minerals--galena, sphalerite, chalcopyrite, and pyrite--commonly are in blebs, pockets, or narrow veinlets that cut quartz and fluorite. The accessory secondary minerals--azurite, malachite, limonite, opal, clay minerals, and hematite--are locally abundant.

Uraniferous deposits of fluorite and metallic sulfides without quartz occur as veins and breccia zones in pre-Cambrian to Tertiary igneous rocks in Colorado and Arizona. Pitchblende, uraninite, autunite, and torbernite are associated with finely crystalline to massive dark violet or black fluorite. Uraninite has been identified as discrete grains disseminated through the fluorite of the deposits in the

Jamestown district, Colorado. Torbernite occurs on fractures in fluorite and altered granodiorite in the Nations Treasure mine in this district. Pitchblende occurs in narrow veinlets in the fluorite veins on the Black Dike claims, Pima County, Arizona. Autunite is found along fractures in schist at the Sure Fire property, in the same county. No uranium minerals have been identified at the Red Hills deposits, Yuma County, Arizona, but abnormal radioactivity was noted in close association with lavender fluorite. In the fluorite-quartz-sulphide deposits a variety of sulfide minerals occur as small irregular masses, lenses, and fine-grained aggregates. The predominant sulfide minerals are galena, sphalerite, pyrite, chalcopyrite, but minor quantities of enargite and tennantite are present locally. Clay minerals, carbonates, quartz, and opal are common gangue minerals.

In summary, uraniferous fluorite is found in many geologic environments in the western states. Pitchblende or uraninite has been reported only from the fluorite-sulfide deposits at Jamestown, Colorado, and the Black Dike claims, Yuma, Arizona. In both localities dark-purple fluorite is associated with the uranium minerals. At 10 of the 18 known radioactive fluorite deposits, secondary uranium minerals are associated with dark-purple to black fluorite. At six of these localities, the form in which the uranium occurs is unknown. In general it would appear that dark-purple to black fluorite is a favorable indication of the presence of radioactivity, and wherever dark-colored fluorite is discovered radiometric studies and sampling for uranium should be undertaken.

SECONDARY URANIUM DEPOSITS IN THE UNITED STATES

By

Frederick Stugard, Jr., Donald G. Wyant, and Arthur J. Gude III

ABSTRACT

Reconstituted, or secondary, uranium minerals found in domestic deposits include oxides, phosphates, silicates, vanadates, arsenates, sulfates, and carbonates. Next to the vanadates, carnotite, and tyuyamunite, the most abundant are the phosphates autunite and torbernite and the silicate uranophane. Less common are deposits containing the oxides gummite and pitchblende; the phosphates dumontite and uranocircite; the silicates kasolite, sklodowskite, and soddyite; the arsenates zeunerite and uranospinite; the sulfates zippeite, uraconite, and johannite; and the carbonates rutherfordine and schroeckingerite. Other secondary minerals, in general, are only of mineralogic interest.

Most secondary uranium mineral deposits show no apparent relation to known primary uranium minerals. The deposits now being mined at Marysvale, Utah, however, are surface expressions of pitchblende-bearing deposits. Recent studies indicate that development of secondary minerals has in some places resulted in concentration and elsewhere in dispersion of uranium. Concentrations from ground water have formed extensive deposits of schroeckingerite in Sweetwater County, Wyoming.

Many uranium compounds appear to be highly soluble and mobile. Successful distinction between secondary deposits resulting from concentration and those resulting from dispersion of primary deposits has not generally been made to date. Some sooty pitchblende is secondary.

Investigations by the Geological Survey on behalf of the Atomic Energy Commission have brought together considerable information on the mineralogy, distribution, and occurrence of secondary uranium deposits in the United States. Nevertheless, comparatively little is known on these subjects. Use of genetic designations such as "hypogene" and "supergene" does not yet seem practicable. We have designated as secondary minerals those derived from previously deposited uranium minerals. Under this definition, many carnotite deposits of the Colorado Plateau are considered primary. Original vein fillings are also considered primary.

Secondary uranium minerals occur in small quantity in many metallic veins, pyrometasomatic deposits, altered zones of volcanic rocks, sedimentary rocks, and pegmatites. In rare instances, secondary uranium minerals are sufficiently abundant to be economic sources of uranium, but elsewhere one of their main values is as possible indicators of associated primary ore.

More than 60 uranium minerals commonly of secondary origin have been listed (George, 1949; Frondel and Fleischer, 1950). If varietal names and uranium-proxy minerals be included, the list grows to more than 300. Species previously recorded only from foreign localities are being discovered in almost every new deposit studied. Mineralogic work on this group is often difficult because of the intimate mixtures and variable water content that characterizes these assemblages, and because of similarities among species of physical, optical, and chemical properties. Definite field identification of individual minerals is commonly impossible, or must be changed after laboratory study.

Secondary deposits include uranium chemically combined as vanadates, phosphates, silicates, arsenates, sulfates, carbonates, and oxides. Almost every deposit includes several of these groups. Figure 13 shows some of the minerals that are known and their chemical grouping.

Most uranium--and formerly radium--production in the United States has come from carnotite (the hydrous potassium-uranium vanadate) deposits in sandstone. Tyuyamunite is the calcium analogue of carnotite. The most ubiquitous of all uranium minerals probably are the phosphates autunite and torbernite, and their meta- forms. Dumonite and uranocircite are less abundant phosphates. The most common uranium silicate is uranophane, which usually occurs as fracture coatings in igneous and sedimentary rocks. Less common silicates include kasolite, sklodowskite, and soddyite.

Uranium arsenates are known from very few localities in the United States. Zeunerite is known from Majuba Hill, Nevada, and the Clancey area, Montana. Uranospinite, the calcium-uranium arsenate, has been tentatively identified from the Honeycomb Hills of Utah.

Efflorescent uranium sulfates and carbonates occur in semi-arid environments. Zippeite characteristically occurs as coatings on mine walls, carbonized wood, and gypsum, as in the Oyler mine near Fruita, Utah. Uraconite is possibly only a lower hydrate of zippeite, and has been found on mine faces in Gilpin County, Colorado, and in the Hillside mine, Arizona. Johannite, a hydrous copper-uranium sulfate, is associated with a large suite of secondary minerals in the Happy Jack mine, San Juan County, Utah, and is also reported from Gilpin County, Colorado. Schroeckingerite, the fluoro-sulfate and carbonate, occurs both in sedimentary rocks, as at Wamsutter, Wyoming, and above vein structures, as at Marysvale, Utah, and the Hillside mine, Yavapai County, Arizona. Rutherfordine, a carbonate, is intimately mixed with pitchblende and uranophane in veins of cryptocrystalline silica near Clancey, Montana; much material previously called rutherfordine is now being re-identified as other uranium minerals with

GROUP	MINERAL	PROBABLE FORMULA	MEGASCOPIC APPEARANCE
VANADATES	CARNOTITE	$K_2O.2UO_3.V_2O_5.nH_2O$	Yellow. Powdery.
	TYUYAMUNITE	$CaO.2UO_3.V_2O_5.nH_2O$	Greenish yellow. Powdery
PHOSPHATES	AUTUNITE	$CaO.UO_3.P_2O_5.H_2O$	Lemon yellow to apple green. Fluoresces bright greenish yellow. Platey crystals.
	TORBERNITE	$CuO.2UO_3.P_2O_5.12H_2O$	Green platey crystals.
	DUMONTITE	$2P_bO.3UO_3.P_2O_5.5\ H_2O$	Yellow.
	URANOCIRCITE	$BaO.2UO_3.P_2O_5.12\ H_2O$	Yellow to yellow green. Vivid greenish yellow fluorescence.
SILICATES	URANOPHANE	$CaO.2UO_3.2SiO_2.6\ H_2O$	Straw yellow to orange yellow. Acicular crystals.
	KASOLITE	$P_bO.UO_3.SiO_2.H_2O$	Yellow, slightly brownish.
	SKLODOWSKITE	$MgO.2UO_3.2SiO_2.6\ H_2O$	Yellow.
	SODDYITE	$5UO_3.2SiO_2.6\ H_2O$	Greenish yellow.
ARSENATES	ZEUNERITE	$CuO.2UO_3.As_2O_5.12\ H_2O$	Green platey crystals.
	URANOSPINITE	$CaO.2UO_3.As_2O_5.12\ H_2O$	Yellow to green. Fluoresces bright greenish-yellow.
SULFATES	ZIPPEITE	$2UO_3.SO_3.nH_2O$	Yellow to orange. Fluoresces yellowish-green.
	URACONITE	$2UO_3.SO_3.nH_2O$	
	JOHANNITE	$CuO.2UO_3.2SO_3.7\ H_2O$	Yellow, green, or black.
	SCHROECKINGERITE	$Ca_3Na.UO_2.CO_3.SO_4.F.10\ H_2O$	Yellow to greenish yellow. Fluoresces bright yellowish green.
CARBONATES	"RUTHERFORDINE"	$Ca.CO_3$ plus uranium silicate mineral	Yellow.
OXIDES	"GUMMITE"	U^6,Pb, H_2O in variable proportions	Bright orange.
	BECQUERELITE	$2UO_3.3\ H_2O$	Amber.
	SOOTY PITCHBLENDE	UO_2 plus UO_3	Black unless colored by impurities such as fluorite.

FIGURE 13.—COMMON SECONDARY URANIUM MINERALS

carbonate impurities. Three new carbonate minerals have recently been described by Axelrod, et al. (1951), and new discoveries are to be expected. As is evident from figure 13, numerous minerals appear very much alike to the naked eye.

The three most common secondary oxides of uranium are "gummite", becquerelite, and sooty pitchblende. "Gummite" is a common alteration product of uraninites in pegmatites, and is easily recognized by its orange color; it does not have a valid formula. Some becquerelite and sooty pitchblende are redeposited forms of primary, hard pitchblende.

An understanding of the distribution of secondary minerals in uranium deposits is essential to evaluation of the economic possibilities for most mines and prospects. Fragmentary information indicates that during the weathering and alteration of primary uranium deposits, different secondary uranium minerals form in different zones. The minerals formed vary with the composition of the vein and country rock, and the solutions formed by weathering. Figure 14 shows the general zonation of secondary uranium minerals in weathered veins. The diagram is a composite of available data from numerous deposits in sedimentary and igneous rocks.

As shown in the right hand column, a vein containing primary uranium oxides, with the necessary accessory metals, would be altered under favorable conditions of weathering to yield a secondary deposit capped by a zone of efflorescent uranium sulfates and carbonates. This zone may be expected to grade downward into a zone containing uranium silicates, phosphates, arsenates, or vanadates; the assemblage that is developed depends upon the composition of the solutions causing the alteration. This assemblage grades downward into a zone of secondary uranium oxides, accompanied by relict primary uranium oxides. Below this is the zone of unaltered primary oxides.

The deposit of secondary minerals is shown in figure 14 as widening upwards, spreading laterally along fractures. This lateral migration may result in an over-all dispersion of the uranium from the vein. In places such as Marysvale, Utah, these deposits are sufficiently rich to form a minable ore body.

Marysvale is the best domestic area to date that has economic deposits in both primary and secondary minerals in the same altered vein structures. Investigations of operating mines in the district, currently in progress by the Atomic Energy Commission, are expected to yield much information on the relationships of primary to secondary minerals.

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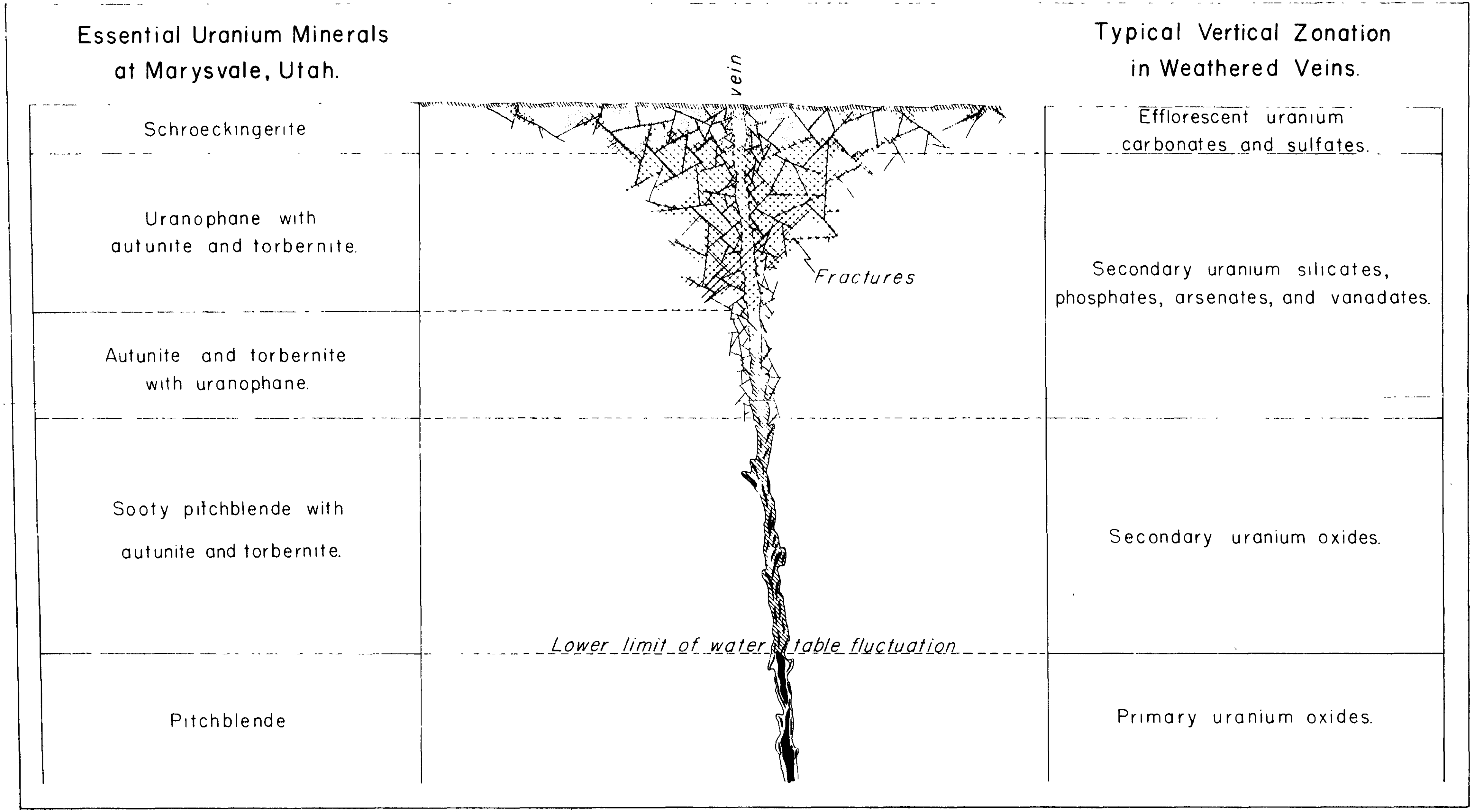

FIGURE 14.— DIAGRAMMATIC RELATIONSHIPS BETWEEN SECONDARY AND PRIMARY URANIUM MINERALS IN WEATHERED VEINS.

Weathering of veins containing pitchblende, quartz, fluorite, pyrite, and other sulfides at Marysvale has produced the typical zonation of uranium minerals, as shown in the left-hand column of figure 14. At the surface, schroeckingerite is associated with uranophane, autunite, and torbernite; this assemblage grades downward into a zone in which uranophane is the dominant mineral. Autunite and torbernite become relatively abundant in the lower parts of this zone, and grade into a zone containing sooty pitchblende and relict masses of primary pitchblende.

The diagram showing zonation of secondary minerals in veins may be considered a mnemonic device. If figure 14 be turned on its side so that the surface represents a vertical cliff face, it will represent essentially the sequence of minerals found in sedimentary deposits inward from a leached outcrop, as for example at the Happy Jack mine, San Juan County, Utah. The surface exposure of this ore body contains efflorescent salts such as johannite and chalcanthite. Uranophane and torbernite appear within a short distance and increase in abundance inwards toward a deposit containing pitchblende, pyrite, chalcopyrite, chalcocite, and gersdorffite.

In contrast to the example just given, some actual vein-type deposits do not appear in the field to look much like the idealized diagram. In the Marysvale area, at East Slope No. 2 deposit (fig. 15), secondary uranium minerals are associated with alunitic and clay alteration zones in a vein-like structure within hornfels. Autunite metatorbernite, schroeckingerite, and uranophane are distributed along the face of the open cut in two main zones, roughly symmetrical about a core of hematite-alunite-quartz-kaolinite rock. The uranium minerals coat fractures and joints in the altered hornfels. It is not known whether this deposit is transitional downwards into other depth zones of the typical vein structure.

Secondary uranium vanadates and arsenates occur in vein structures at several places. For example, tyuyamunite is found in fractured quartzite at the Yellow Canary claims, Daggett County, Utah, and carnotite in the fluorite deposits of the Thomas Range district, Utah. Zeunerite is associated with torbernite at Majuba Hill, Nevada, and Clancey, Montana. These localities, together with the others mentioned in this report, are shown in figure 16.

Many pegmatites contain "gummite", autunite, and other minerals as halos around primary uranium minerals. Pegmatite localities are not shown on figure 16.

Lignites in North and South Dakota, Montana, and Wyoming, contain a hydrous uranium oxide,

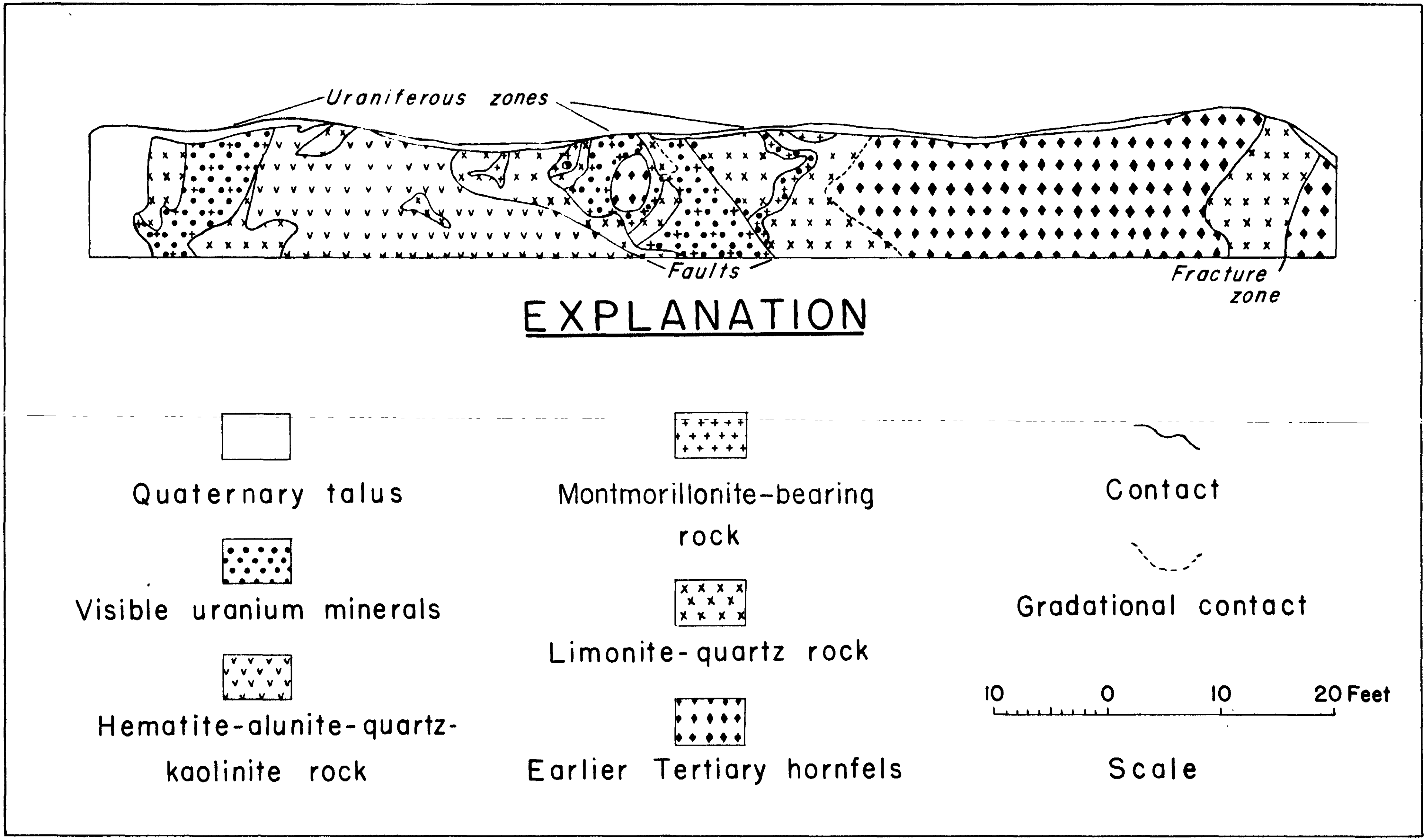

FIGURE 15.-SKETCH SECTION ALONG WEST FACE OF THE UPPER CUT, EAST SLOPE NO. 2 URANIUM PROSPECT, PIUTE COUNTY, UTAH

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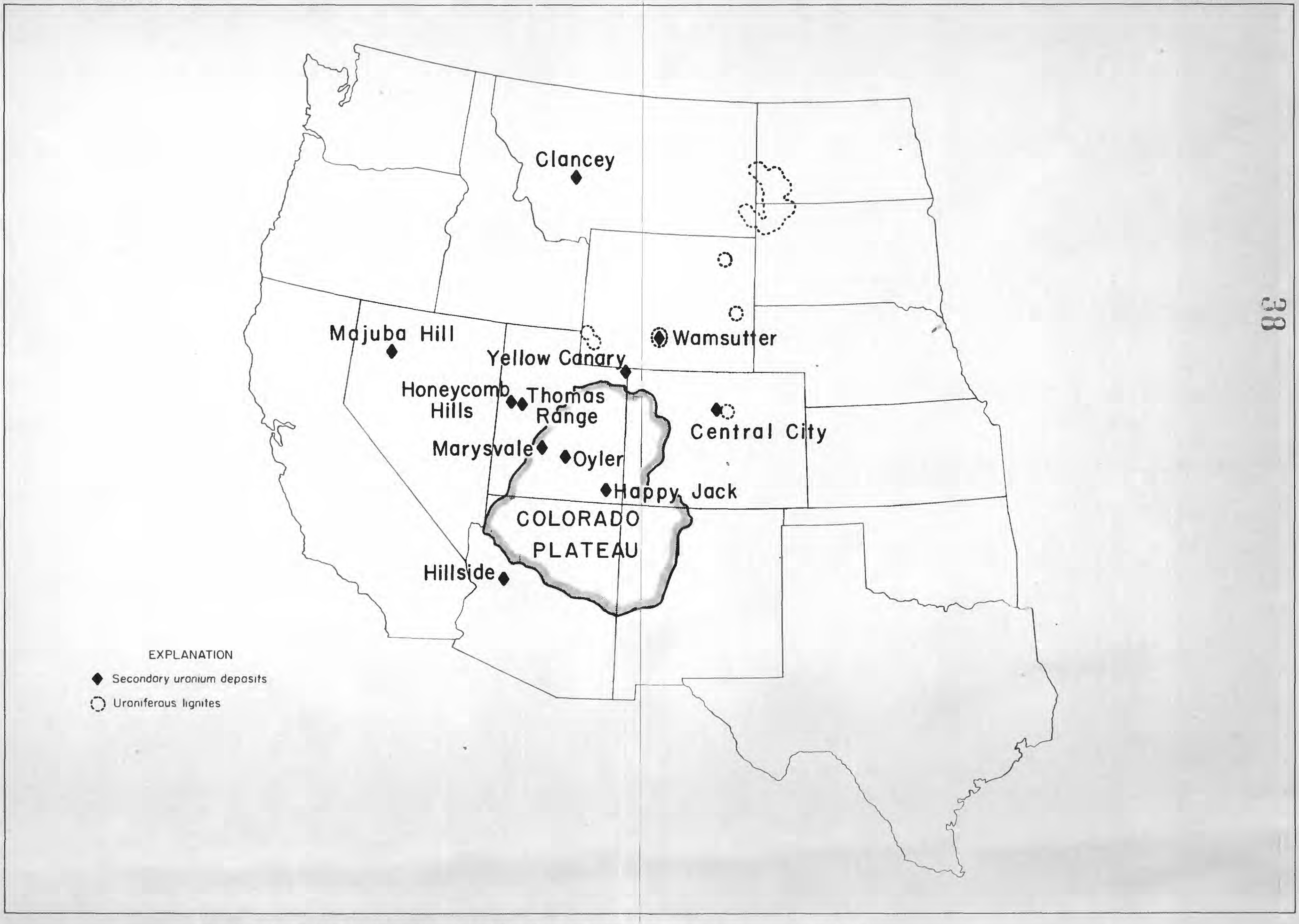


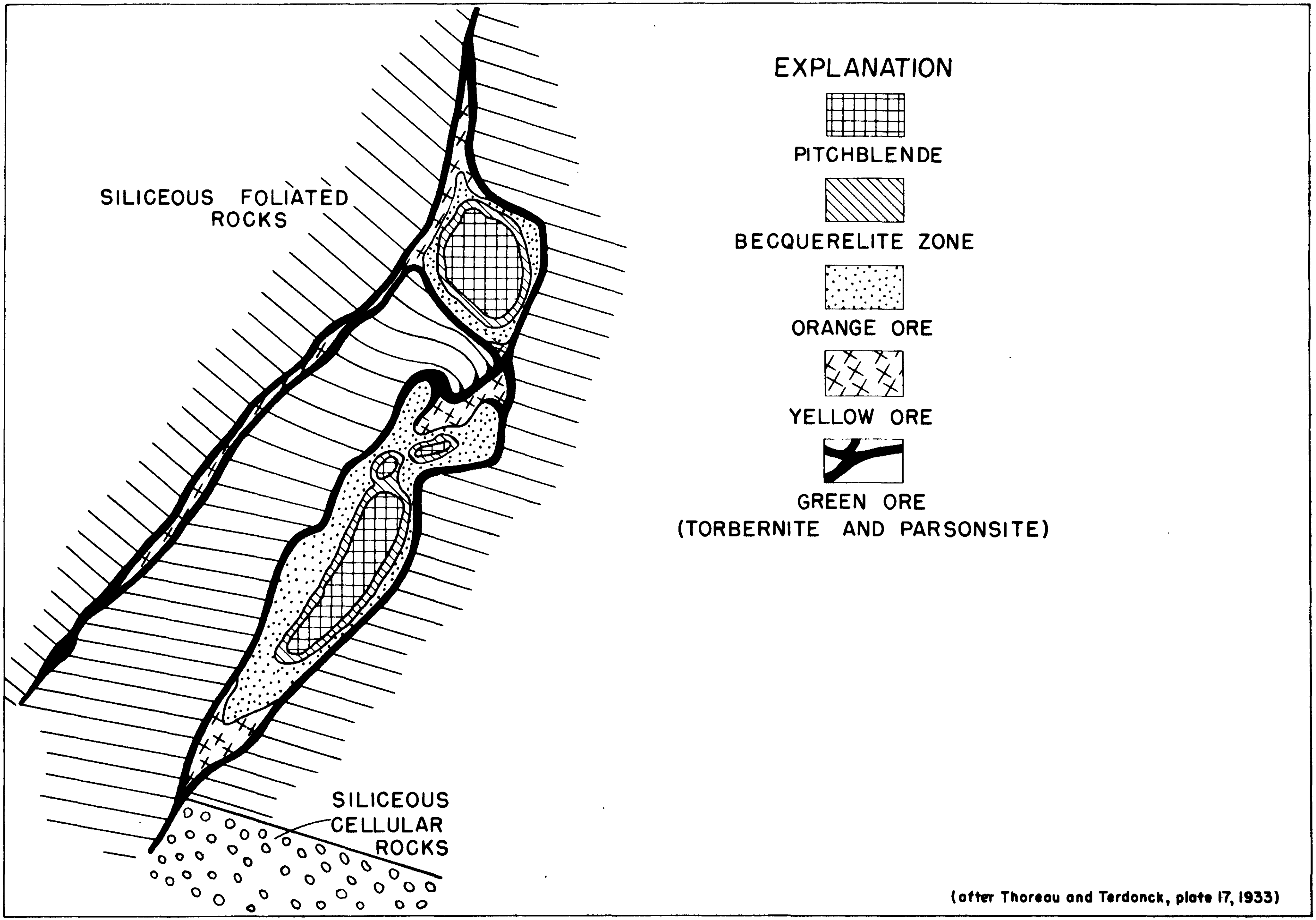
FIGURE 16.–MAP SHOWING LOCATION OF SECONDARY URANIUM DEPOSITS

probably becquerelite. Some uranium oxides associated with organic minerals found in stratigraphically controlled deposits have secondary characteristics.

Interesting comparisons might be made between the secondary uranium minerals found in the United States which may lead to primary ore as the deposits are developed, and the secondary uranium minerals accompanying the great commercial deposits in Canada and the Belgian Congo. Many descriptions of these foreign localities, however, make little mention of the secondary minerals. One of the few good illustrations of secondary minerals accompanying primary uranium oxide is that given by Thoreau and Terdonck (1933), adapted here as figure 17.

Around the pitchblende is a halo of becquerelite. This in turn is surrounded by an orange colored zone composed of curite (a uraniferous hydrate of lead), mixed with kasolite, soddyite, and uranophane. The yellow ore beyond that is schoepite (a hydrated oxide of uranium), together with the silicates soddyite or uranophane. The outside part of the vein is composed of torbernite and parsonite (hydrated phosphates). Thus, from the inside to outside the mineral assemblage is: oxides, hydrates of lead and uranium, silicates, phosphates. All the secondary minerals have been derived apparently from the primary vein pitchblende. The small scale zoning apparent here may be represented on a large scale by zones of secondary uranium minerals above primary deposits in the United States.

In conclusion, secondary uranium minerals form under a great variety of conditions. It is clear that uranium possesses great mobility in some form at surface temperatures. The often observed presence of fluorite suggests that, in some deposits at least, dilute hydrofluoric acid solutions from the fluorite may form complex uranium fluorides that are readily soluble in cold water. Silica gel would be formed. Abundant iron staining in most deposits suggests that uranium is distributed in much the same manner as ferrous or ferric iron during the weathering cycle. It is also known (Rankama, et al., 1950, p. 636), that uranium compounds are adsorbed on iron hydroxide gel and silica gel. The size and mineralogy of secondary deposits are systematically related to the original bulk chemical composition and the erosional environment.



(after Thoreau and Terdonck, plate 17, 1933)

FIGURE 17.–VERTICAL SECTION ACROSS A VEIN, SHINKOLOBWE

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SOME URANIUM DEPOSITS IN SANDSTONE

By

Donald G. Wyant, Ernest P. Beroni,
and Harry C. Granger

ABSTRACT

The uranium deposits in sandstone of the Jurassic Morrison and Entrada formations of the Colorado Plateau are relatively well known and have long been the principal sources of domestic uranium and vanadium. Not so well known are uranium deposits in other sandstones that range from Paleozoic to Tertiary.

Of the uranium deposits in sandstone, some are of the Colorado Plateau type, but many others differ from this type in mineralogy, host rock, localization, and possible origin.

The deposits may be grouped on the basis of mineral or metal assemblage into (1) uranium-vanadium deposits; (2) copper-uranium-vanadium-carbonized wood deposits; (3) uraniferous asphalt deposits; and (4) carbonate deposits.

In general these deposits occur in lenses of argillaceous sandstone or conglomerate interbedded with shales. Common associated materials are iron oxide, carbon, and copper compounds. The localization of some of these deposits appears to be controlled by initial sedimentary features of the enclosing rock, that of others by porosity, fractures, and proximity to the surface. Some of the uranium minerals may have been deposited from ground water, some may have been formed by weathering and oxidation of other minerals, and some may be hydrothermal in origin.

The carnotite and roscoelite deposits in sandstones of the Morrison and Entrada formations of Jurassic age have long been the principal domestic sources of uranium and vanadium. Descriptions of many of these deposits on the Colorado Plateau have been published and the deposits are relatively well-known. Not so well known are uranium deposits in other sandstones that range in age from Paleozoic to Recent.

It is the purpose of this paper to point out the geographic and geologic distribution of uranium deposits in sandstones, some of their characteristics, similarities, and differences. Much of the data on which this paper is based has been accumulated during work on uranium deposits on behalf of the Atomic Energy Commission.

Uranium minerals found in lenses of porous terrestial sandstones containing shale fragments or pellets, or in conglomerates interbedded with shales, are commonly associated with vanadium, carbon, copper, and iron oxide. In their present form nearly all of these deposits are probably epigenetic, although their geologic history is incompletely known. In any event, the uranium appears to have been redistributed by ground water in many of them.

The uranium deposits in sandstones may be grouped on the basis of mineral or metal assemblage into four main groups: (1) uranium-vanadium deposits; (2) copper-uranium-vanadium-carbonized wood deposits; (3) uraniferous asphalt deposits; and (4) miscellaneous deposits, including the caliche-type carbonates and deposits in tuffs. This is only one grouping of several that might be made.

The best known uranium-vanadium deposits are the apparently stratigraphically controlled carnotite deposits in the Salt Wash sandstone member of the Morrison formation in the Colorado Plateau. Similar deposits are known in the Morrison formation northeast of Meeker, Colorado (fig. 18). The roscoelite deposits at Rifle and Placerville, Colorado are in the Entrada formation. These deposits have been adequately described by Fischer (1942) and others.

Uranium-vanadium deposits, however, also occur near Mauch Chunk, Pennsylvania, (fig. 18) (McKeown, 1949; Butler and Bush, 1951) within thin stratigraphic units in sandstones of the Pottsville formation of Pennsylvanian age and in the Cherry Ridge member of the Catskill formation of Upper Devonian age. The uranium has been redistributed by ground water.

Fractures and related faults control the localization of the uranium minerals in sandstone of the Morrison formation at the Mike Doyle prospect (Beroni and King, 1950) in sandstone of the Kaibab limestone of Permian age at Goodsprings, Nevada (Hewett, 1923), and in Laramie limestone of Cretaceous age at the Leyden coal mine (Gott, 1950; McKeown and Gude, 1951).

The deposits containing copper, uranium, vanadium, and carbonized wood are found in sandstones of Permian to Eocene age. In addition to uranium and vanadium they contain varying amounts of copper, silver, cobalt, iron, sulphur, selenium, and carbon. In some deposits carnotite predominates, in others--uraniferous carbonized wood, in still others--copper minerals. Uranium oxide, probably pitchblende, has been found in a few deposits.

Some of the deposits of this type resemble the Colorado Plateau carnotite deposits in vanadium content and apparent lack of structural control. The most important of this type are the Silver Reef, Utah deposits (fig. 18). Deposits at Skull Creek and Garo, Colorado (fig. 1) (Gott, 1951),may also belong in this group. In the Silver Reed district, carnotite, volborthite--a basic copper vanadate--and unidentified uranium minerals are associated with cerargyrite--the silver chloride--carbonized plant remains, and copper carbonates. Selenium is unusually abundant. The minerals are in irregular lenses

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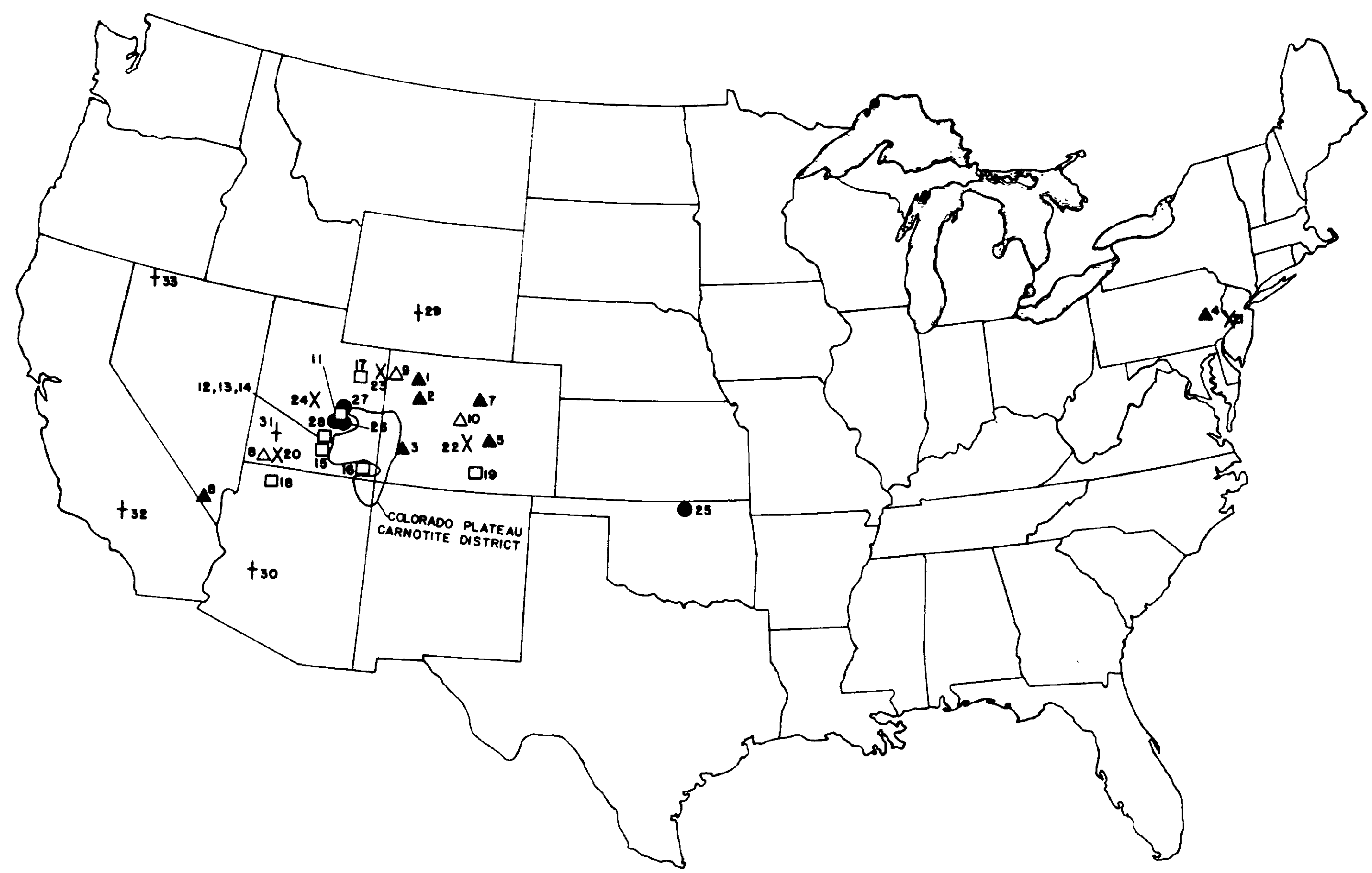

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24 RAJ deposit
25 Staneart property
26 Temple Mountain deposit
27 Lone Tree deposit
28 Red Canyon deposit
29 Lost Creek deposits
30 Ray claims
31 Wooley property
32 Rosamond Hills deposits
33 Virgin Valley deposits

EXPLANATION

TYPES OF DEPOSITS

▲
URANIUM - VANADIUM DEPOSITS

△ COPPER-URANIUM-VANADIUM
☐ COPPER-URANIUM
X URANIUM-VANADIUM-CARBONIZED WOOD
COPPER-URANIUM-VANADIUM-CARBONIZED WOOD DEPOSITS

●
URANIFEROUS ASPHALT DEPOSITS

+
MISCELLANEOUS DEPOSITS (CARBONATES AND TUFFS)

FIGURE 18.- INDEX MAP OF SOME URANIUM DEPOSITS IN SANDSTONES

of sandstone, containing clay pellets within the continental Tecumseh sandstone member of the Chinle formation of Triassic age.

At Skull Creek and Garo, Colorado, carnotite and volborthite with uraniferous carbonaceous shale and carbonized plant fossils are found, respectively, in shale and sandstone in the upper part of the Jurassic Navajo sandstone, and in sandstones of the Permo-Pennsylvanian Maroon formation.

The most economically important subdivision of this second general group is the copper-uranium deposits. They contain little or no vanadium. These deposits have been found in sandstones of Permo-Pennsylvanian to Eocene age. They are abundant in the Triassic Shinarump conglomerate on the Colorado Plateau. The known deposits of this type are in southwestern Utah (fig. 18) (Wyant, et al., 1950; Granger and Beroni, 1950; Granger and Bauer, 1950) in Hack Canyon, Arizona (fig. 18) (Dunning, 1948), and in Huerfano Park, Colorado.

In the Huerfano Park district and in some of the deposits in the Circle Cliffs area (fig. 18) carnotite, carbonized wood, and radioactive iron oxide are the dominant uranium-bearing materials. At the Copper-Globe, Spotted Dog, Oak Creek, and Uinta Basin deposits (fig. 18) torbernite and uraniferous carbonized plant fragments are dominant uranium-bearing materials. In the Oyler mine and in White Canyon, Utah, and in Hack's mine, Arizona, several hydrous uranium oxides, phosphates, and sulfates are abundant near the surface. In the Happy Jack mine in the White Canyon area (fig. 18, No. 16) the secondary minerals grade laterally into copper and cobalt sulfides, and pitchblende occurs about 75 feet from the cliff face.

At the Oyler mine near Fruita, Utah (fig. 18), zippeite, torbernite, and other secondary uranium minerals together with highly uraniferous carbonized wood and hydrocarbons are associated with copper sulfates and carbonates in pod-like lenses at the base of the Shinarump conglomerate. Samples from the mine workings contain from 1.50 to 4.00 percent equivalent uranium, and from 0.33 to 1.22 percent uranium. This excess radioactivity is caused by radium, and calculations suggest that the fresh, unweathered ore might have contained as much as 6.8 percent uranium. These high grade bodies are at the base of the Shinarump conglomerate in zones that represent local irregularities of ancient stream channels. Within these channels, individual ore bodies are localized by still smaller sedimentary structures that resemble monoclinal folds or synclines. In the vicinity of the ore zones, the gray-green, altered Moenkopi shale below the Shinarump is highly calcareous.

Deposits of this type probably represent the weathered part of primary bodies as previously explained.

Another subdivision of the copper-uranium-vanadium-carbonized wood deposits is that in which deposits contain little or no copper. Deposits of this type are found in Triassic, Jurassic, and Eocene sandstones in New Jersey, Colorado, and Utah. At the Bulloch claims near Orderville, Utah (fig. 18) (Beroni, et al., 1951) carnotite, autunite, torbernite, and uraniferous carbonized wood are disseminated, or coat pebbles and fracture surfaces in the Cretaceous Dakota and Jurassic Summerville sandstones. In New Jersey (fig. 18) torbernite occurs in arkoses of the Triassic Stockton formation. Torbernite, or autunite, and uraniferous carbonized wood are present in Cretaceous Dakota sandstone at the Jesus Lode (fig. 18) in Cretaceous Mesa Verde sandstone on the Snow Claims (fig. 18) and in the Eocene Green River formation at the RAJ prospect (fig. 18).

The uraniferous asphalt deposits are a third major group of uranium deposits in sandstone. They have been found in Permian sandstone at the Staneart property in Oklahoma (fig. 18), and in Triassic sandstones and conglomerates of the Shinarump and Chinle formations at the Temple Mountain, Lonetree, and Red Canyon deposits in the San Rafael Swell, Utah (fig. 18).

In the Temple Mountain district, Utah (fig. 18), uraniferous asphaltite is found as void fillings, rounded pellets, vein-like fillings, and as detrital grains in friable sandstone lenses of the Shinarump conglomerate. Carnotite, zippeite, and other secondary uranium and vanadium minerals coat asphaltite grains. Carnotite also forms "rolls" in sandstone that resemble the "rolls" described in the Morrison carnotite bodies. The asphaltite ore bodies are localized in sandstones that fill ancient stream channels. The carnotite in this district appears to have been derived from the asphalt.

The asphalt in all these deposits may be the mineraloid thucholite. Similar highly radioactive pellets have been found in the Oyler mine, the Oak Creek prospect, and at the Four Aces mine in the White Canyon area, Utah (fig. 18).

A fourth group of uranium deposits in sandstone includes caliche-type carbonate deposits, uranium deposits in waterlaid tuffs, and placers. Schroeckingerite at Lost Creek, Wyoming, (fig. 18) is in rounded pellets in Eocene Green River shale or in flakes in the enclosing Eocene silts and arkoses (Page, 1950; Wyant and Sheridan, 1951). Schroeckingerite has been found to depths of 8 feet beneath the surface, but always above the ground-water table. The mineral has been deposited as an evaporite. So far as known, it is limited to a major fault zone and overlies uraniferous lignite.

Uranium minerals have been described in Tertiary tuffs near Aguila, Arizona (Hewett, 1915), at the Wooley prospect in Utah, in the Rosamond Hills, California (Chace, 1950), and in the Virgin Valley (fig. 18) (Staatz and Bauer, 1951). Carnotite, autunite, uraniferous opal, and probably schroeckingerite are the uranium minerals.

Resistant rare earth-thorium minerals containing a little uranium are found in some placer deposits. We know of no deposits containing placer pitchblende.

The origin and genesis of the uranium deposits in sandstones is still an open question. Ground water has played an important role in all of them, either by redistributing uranium from the primary concealed deposits, or introducing uranium from outside sources. The localization of some of the deposits is controlled by fractures, that of others by porous sandstone. In some, a relation to petroleum seems evident. Many may have had a hydrothermal origin. More must be known about uranium deposits in sandstones before a comprehensive explanation of their origin and distribution can be made.

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URANIUM IN BLACK SHALES, LIGNITES, AND LIMESTONES IN THE UNITED STATES

By

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and Ernest P. Beroni

ABSTRACT

Small quantities of uranium occur in carbonaceous deposits at a great many localities in the United States, but the quantity rarely exceeds 0.1 percent. The most common uranium-bearing carbonaceous deposits are the black marine shales, principally of Paleozoic age, exposed in the eastern and central parts of the United States. The uranium content of most of these shales ranges from a few thousandths to a little more than 0.01 percent.

Another type of low-grade uranium-bearing carbonaceous deposit is represented by some of the lignite deposits of Tertiary age in Montana, Nevada, North Dakota, South Dakota, and Wyoming. The uranium content of these uraniferous lignites is comparable to that of the black shales. The concentration of uranium in the lignite ash, however, is considerably greater than in the black shales.

Several widely distributed uranium deposits in limestones, most of which are low-grade, have been discovered recently in Missouri, New Mexico, New Jersey, Utah, and Vermont. The limestones range from pre-Cambrian to Tertiary. In some of these deposits the uranium is associated with phosphatic, carbonaceous, or argillaceous materials. In others secondary uranium minerals occur as fillings in fractures and vugs. At some localities the uranium is associated with contact-metamorphic minerals.

Uraniferous black marine shales have been described by many investigators, but reference to uraniferous terrestrial shales, coals, and carbonate rocks are not common. Recent investigations by the U. S. Geological Survey, made on behalf of the Atomic Energy Commission, have indicated that such deposits are widespread in the United States.

Figure 19 shows the distribution of some of the uraniferous black shales, coals, and limestones in the United States. Figure 20 shows in more detail the distribution of the uraniferous marine carbonaceous shales for which the most data are available. This type of shale is best represented by the Chattanooga shale of Devonian and Mississippian age, where exposed in Tennessee and Kentucky, but its equivalents underlie much of the area between the Appalachian and Rocky Mountains.

The uranium content of that part of the Chattanooga shale shown on figure 20 ranges from between 0.001 to 0.03 percent. In general, the uranium content is greater in the more organic facies, although

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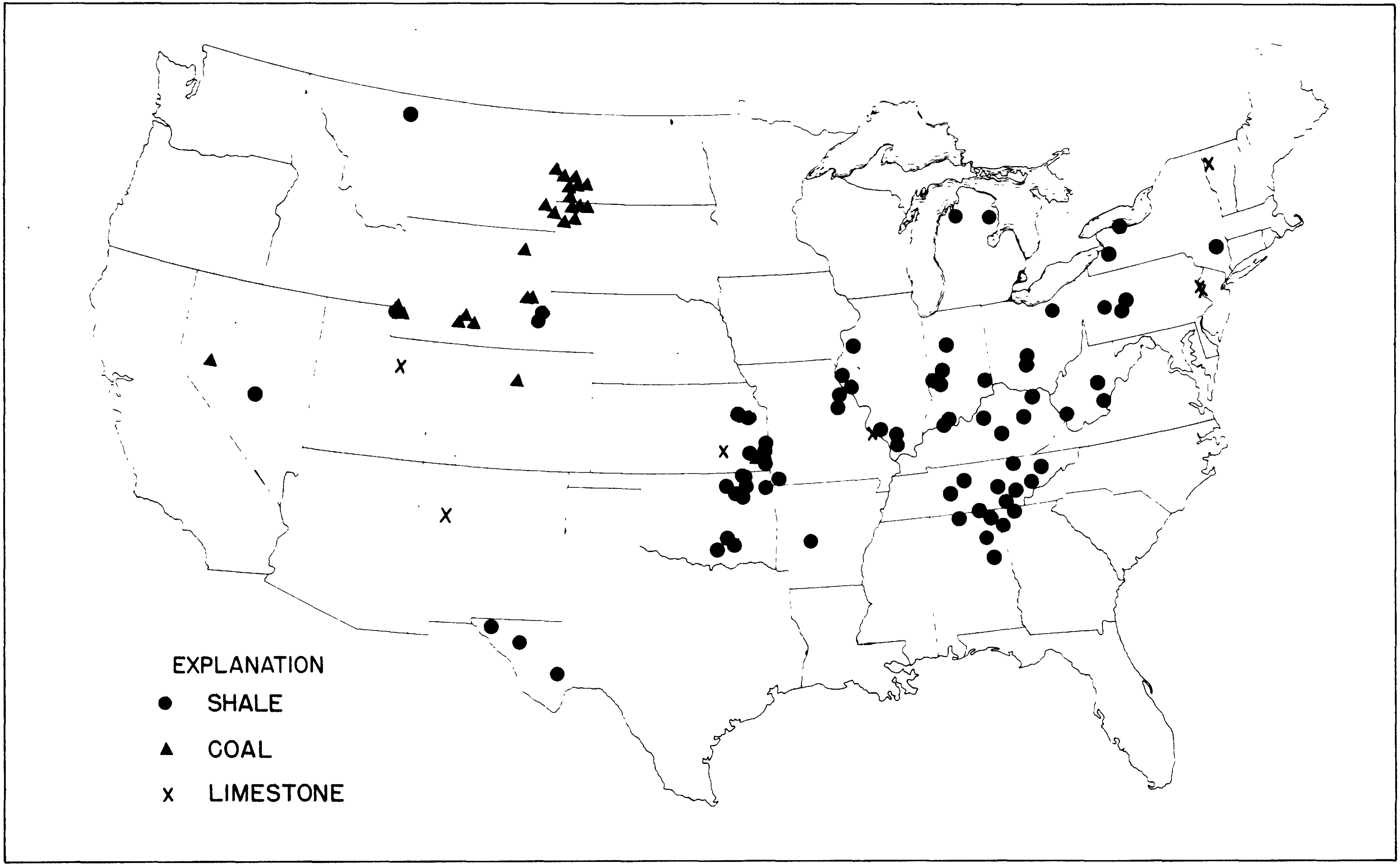

FIG. 19.-DISTRIBUTION OF SOME URANIFEROUS SHALES, COALS, AND LIMESTONES

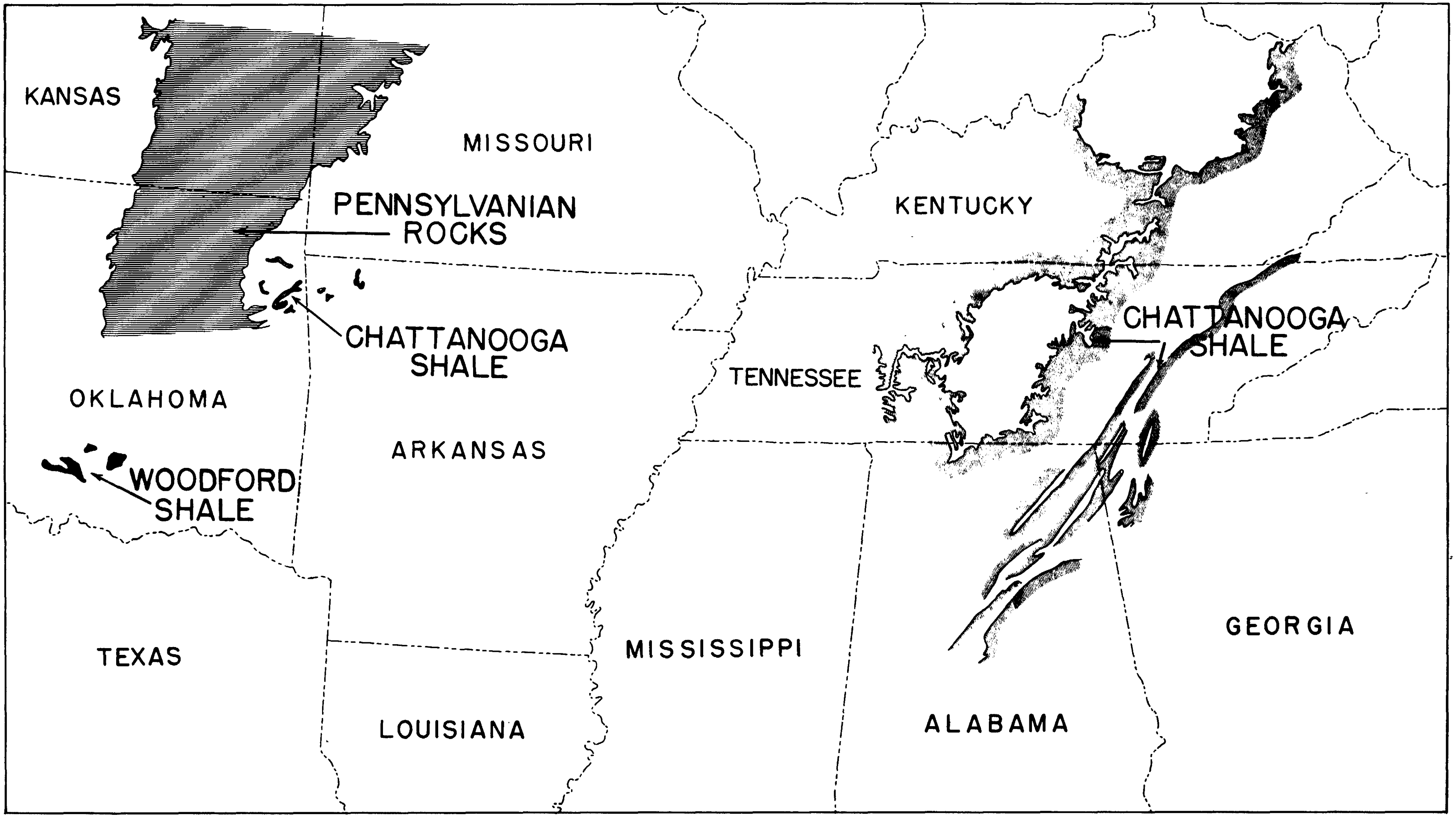

FIG. 20.-DISTRIBUTION OF URANIFEROUS SHALES

no direct ratio of uranium to organic material has been established. A few samples, consisting almost entirely of bitumen, have been found to contain more uranium than the enclosing shale. Analytical data suggest that there is a general correspondence between uranium and the content of iron sulfide and vanadium. The uranium is evenly distributed throughout the shale and apparently is inversely proportional to the carbonate and phosphate content.

Gamma-ray logs of oil wells in Kansas, Oklahoma, West Texas, and New Mexico indicate that the Chattanooga shale, and its equivalent, the Woodford shale, is as radioactive in this region as it is in the eastern United States.

The uranium content of the black Pennsylvanian shales in Kansas and Oklahoma is similar to that of the Chattanooga shale. Phosphatic nodules in these Pennsylvanian shales contain much more uranium than the clastic parts of the bed. Small quantities of thorium also are present in both the shale and the nodules. The shales that contain the greatest amounts of uranium in this area are black, fissile, phosphatic, and carbon-rich.

Samples of carbonaceous marine shale of Pennsylvanian age from an oil well in east-central Wyoming contain from 0.005 to 0.02 percent uranium, which is comparable in grade to the Pennsylvanian carbonaceous shales of Kansas and Oklahoma and the Chattanooga shale in Tennessee and Kentucky. It is perhaps significant that the oil content ranges from about 1 to 5-1/2 percent in the same samples.

The marine carbonaceous shales briefly discussed above are only some of many such shales in the United States. Other shales may be as radioactive or more radioactive than the Chattanooga and Pennsylvanian shales.

Uraniferous coals of Paleozoic, Mesozoic, and Tertiary ages are known in the United States. The greatest concentrations of uranium occur in Paleocene and Eocene lignites in the Dakotas, Montana, and Wyoming, (fig. 21) and in a high ash lignite in Nevada. A few bituminous Pennsylvanian coals in the Mid-continent region and sub-bituminous Cretaceous coal in southwestern Wyoming contain as much as 0.004 percent uranium, but hundreds of others have been tested radiometrically and chemically with negative results.

In the Dakotas, Montana, and part of Wyoming, the greatest concentrations of uranium occur in the

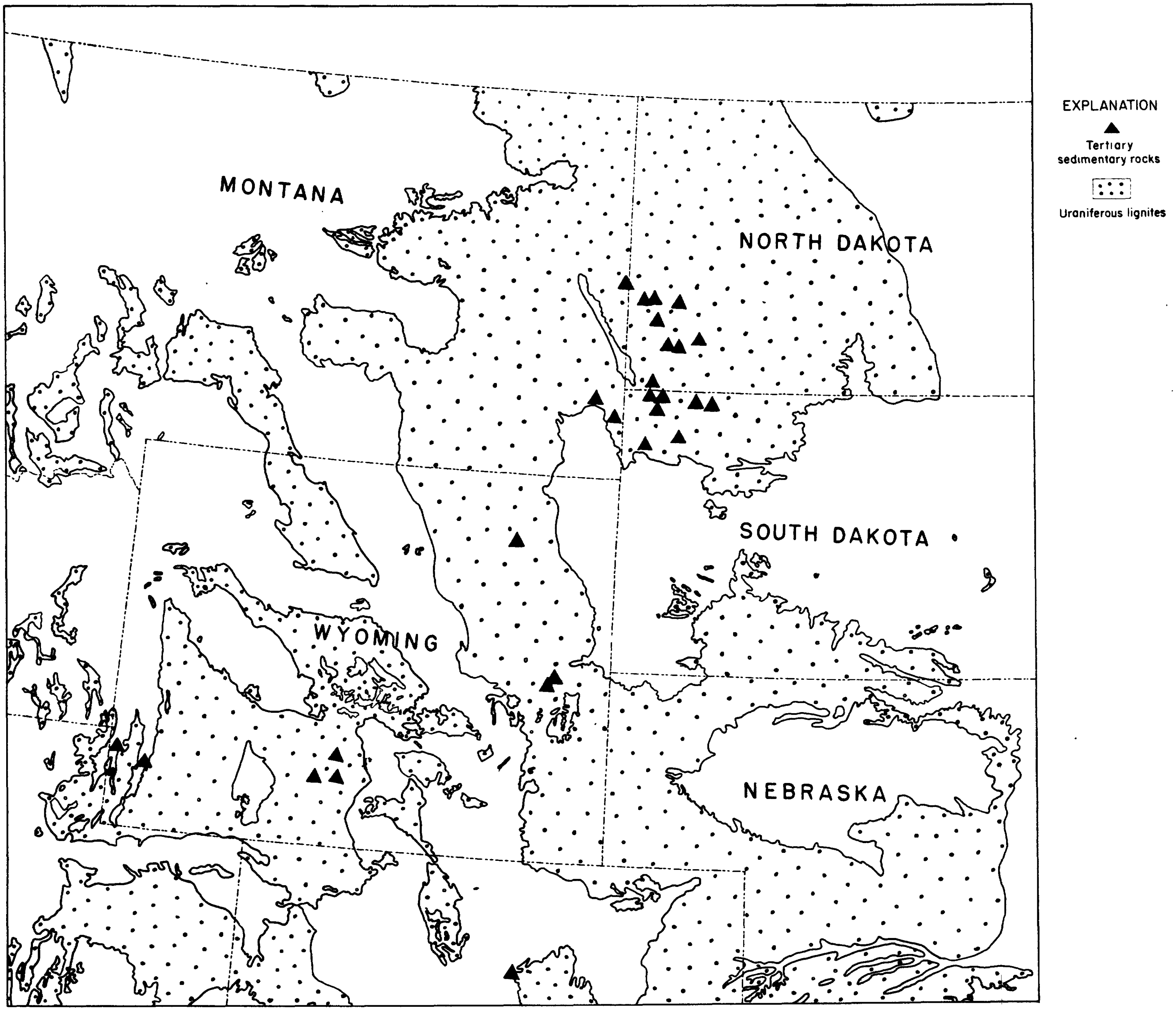

FIG. 21.-DISTRIBUTION OF SOME URANIFEROUS COALS

first group of lignite beds below the Paleocene-Eocene unconformity. The uranium content of the lignite beds is variable, but some contain slightly more than 0.01 percent. The apparent relationship between these lignites and the unconformity between the Paleocene and the Eocene rocks suggests that the uranium may have been leached from volcanic ash in the White River formation and introduced into the lignite by surface waters during post-Paleocene time.

The even distribution, however, of the uranium in the lignite, as indicated by an autoradiograph of one sample from North Dakota, and the absence of any apparent concentration of uranium on fracture planes in this area; suggests that the uranium was present before coalification.

In the Red Desert area of Wyoming uraniferous lignites in the Wasatch formation of Eocene age contain from about 0.002 to 0.007 percent uranium. The presence of about 60 percent more radium than that required for equilibrium with uranium indicates that uranium in the exposed lignite has recently been leached and suggests that fresh lignite contains more uranium.

A high ash lignite of Tertiary age in Churchill County, Nevada, contains as much as 0.05 percent uranium. The extremely high ash content of this lignite, however, seems to preclude a significant concentration of uranium by burning such as can be effected with the other lignites mentioned.

The distribution of most of the uranium deposits that have been found in a limestone or dolomite environment is shown on figure 19. Most of them are low in grade.

Uranium, possibly of syngenetic origin, has been found in a fresh water limestone in the Uintah formation of Tertiary age in northeastern Utah, and in the Milton dolomite of Cambrian age northwestern Vermont. The uranium in the Milton dolomite occurs in slightly petroliferous and phosphatic clay galls.

At Bussen's Quarry in Ste. Genevieve County, Missouri, the Spergen limestone of Mississippian age contains finely disseminated detrital carbonaceous material and purple fluorite. Both the carbonaceous material and the fluorite contain uranium. The limestone encloses thin black shale beds that have been molded into stylolitic structures. The shale is significant because the uranium concentration is more than 100 times greater than it is in the average shales of the Chattanooga and Pennsylvanian type. Carnotite is sparsely distributed in the limestone adjacent to the black shale, and it is thought that the uranium in this mineral was leached from the black shale and transported by ground water.

The deposits near Grants, New Mexico, are being studied in detail by members of the Atomic Energy Commission. The deposit is in the Todilto limestone of Jurassic age. Uranium minerals are associated with hydrocarbon products and minor folds and fractures that are thought by Page [1] to have been caused by intraformational slumping. Pitchblende, carnotite, tyuyamunite, and uranophane are associated with hematite, limonite, pyrite, and fluorite.

Radium- and hydrocarbon-bearing dolomite and limestone of Ordovician and Pennsylvanian age are present in the subsurface of the North Augusta oil field in southeastern Kansas.

In conclusion, uranium is associated with some coals and carbonaceous marine shales, phosphatic rocks, petroleum products, and disseminated carbonized wood fragments throughout the world.

The concentration of uranium in organic marine shales has been the subject of considerable speculation, but the processes responsible for the accumulation have never been demonstrated. It has been variously suggested that the uranium was extracted from the sea water by living organisms, that it was concentrated by colloidal adsorption, or that it was precipitated in the presence of a reducing agent. There seems to be supporting evidence for each of these hypotheses, but the common association of uranium with carbonaceous material suggests that the uranium was most probably concentrated originally by bio-chemical processes. The association of uranium with bituminous shales, asphaltic sandstones, and petroliferous limestones suggests that some crude oils may also serve as distributing agents during the process of dissemination and concentration of uranium. If greater concentrations of uranium occur in the bitumen than in the enclosing shales, as the limited data suggest, it is entirely reasonable that the uranium is carried along with the crude oil as it migrates to points of accumulation in the reservoir rocks. Tomkeieff (1946) quotes data to show that petroleum, on an average, contains 100 grams of uranium per ton, and that oil waters contain 10 grams per ton. Highly uraniferous asphaltic sandstones are present in some breached anticlinal structures, as for example the San Rafael Swell and the Waterpocket fold in Utah. Evidently hydrocarbons migrated into the closed structures, and after removal of the caprock by erosion, all of the petroleum except the residual asphalt escaped. The presence of such highly uraniferous asphalts in former structural traps raises several questions. Was the uranium picked up in the path of the

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[1] Page, Lincoln R., Personnel communication.

migrating hydrocarbons? Was it removed from organic shales from which the petroleum was presumably derived or were small quantities of uranium inherent in the liquid hydrocarbons concentrated by some process of fractionation of the oil?

The presence of relatively large quantities of radium and radon in some oil and gas fields indicates a possible genetic relationship between the products of uranium and hydrocarbons.

Some of the many problems that are deserving of further investigations, therefore, are: (1) the possible migration of uranium in hydrocarbon solutions derived from carbonaceous shales; (2) the possibility of precipitation of uranium compounds from oil solutions; and (3) the effect of polymerization of the hydrocarbons by alpha radiation.

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