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EASTERN AND CENTRAL MONTANA AS
A POSSIBLE SOURCE AREA OF URANIUM

By Frank C. Armstrong

Trace Elements Memorandum Report 930

UNITED STATES DEPARTMENT OF THE INTERIOR
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GEOLOGICAL SURVEY

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Frank C. Armstrong

April 1956

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EASTERN AND CENTRAL MONTANA AS A POSSIBLE SOURCE AREA OF URANIUM

By Frank C. Armstrong

ABSTRACT

Geologic settings are recognized in central and eastern Montana and in a few places in southwestern Montana that elsewhere are similar to the settings for the occurrence of uranium deposits. Several specific areas in Montana seem favorable for the occurrence of uranium.

The alkalic igneous rock province of central Montana is similar to the one of the Colorado Plateau. On the basis of this analogy certain areas in Montana are suggested for prospecting, where the lithologies and/or structural settings are considered favorable for the occurrence of uranium.

Uranium deposits, similar to those in North and South Dakota, may be found in Cretaceous and Tertiary sandstones, lignites, and low-grade coals of eastern Montana; also, the magnetite-bearing beds of certain Cretaceous sandstones may contain fossil placer deposits of radioactive black minerals. The occurrence of uranium in basal conglomerates, quartzites, and sandstones in Africa and Ontario suggests that similar basal sedimentary rocks in central Montana may contain uranium.

Many of the radioactivity anomalies in Montana found from the air are closely associated with the Eagle sandstone; others are associated with Precambrian basement rocks, Late Cretaceous and early Tertiary igneous rocks, or sedimentary rocks of Jurassic-Cretaceous age.

Glacial cover and lack of outcrops locally may hinder prospecting for uranium.

INTRODUCTION

The intensive interest in uranium and the vast amount of effort that has been directed during the past 10 years to the discovery of new deposits have done much to further our understanding of its occurrence. One outstanding result of this work has been the realization that concentrations of uranium, far from being extremely rare, are fairly widely spread and occur in many geologic environments. The idea that an empirical analysis of the distribution of known deposits and the geologic environment of each may afford some basis for directing the search for deposits in new areas has undoubtedly been used by many prospectors. The purpose of this paper is to apply such an empirical analysis coupled with certain broad theories of the origin of uranium deposits to certain geologic environments in eastern and central Montana in which uranium might occur. It is hoped that this discussion may serve to stimulate interest and thinking about exploration and serve as a basis for evaluating the potential of different parts of this large area. The prospecting guides suggested are of the broadest type and are meant to suggest potential uranium provinces rather than specific localities.

Like all speculations about where to prospect and why, the reasons for so doing are subject to many qualifications and reservations. The "where" and much of the "why" is suggested empirically: (1) uranium has been found in eastern and central Montana; and (2) uranium has been found elsewhere in geologic environments similar to those in eastern and central Montana. The rest of the "why" is arrived at deductively by applying possible modes of origin for some uranium deposits. It is realized that the origin of many uranium deposits is an extremely controversial subject, and

that any conclusions deduced from a postulated mode of origin are only as good as the original premises.

The ideas in this report are a product of two years' reconnaissance for uranium in Idaho, Montana, Oregon, and Washington and were first written up in a preliminary form in the spring of 1954. Since that time extensive prospecting for uranium in Montana has resulted in the discovery of a few promising deposits. The writer wishes to acknowledge the help given him by his colleagues and the benefit of discussions with them: in particular, C. E. Erdmann for information about the stratigraphy of central Montana; F. W. Cater for supplying many of the details about the Colorado Plateau uranium deposits; and S. N. Kesten for general discussions about the possibility of uranium deposits in eastern and central Montana. This work was done by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

GENERAL GEOLOGY OF EASTERN AND CENTRAL MONTANA

The Great Plains of eastern Montana are underlain by a thick blanket of continental and marine sedimentary rocks that in places have been folded into broad, open anticlines and synclines (fig. 1). Most of the rocks exposed at the surface are of Late Cretaceous or Paleocene age. In places erosional remnants of rocks as young as Miocene-Pliocene are preserved (Ross and others, 1955).

The Great Plains of central and north-central Montana are underlain by a similar but thinner blanket of continental and marine sedimentary rocks. Most of the rocks exposed at the surface are also of Late Cretaceous age and in general consist of formations slightly older than those exposed in eastern Montana. In the central and west-central part of Montana many of the sedi-

FIGURE 1 — MAP SHOWING LOCATIONS OF SOME URANIUM OCCURRENCES AND RADIOACTIVITY ANOMALIES IN EASTERN AND CENTRAL MONTANA

SCALE
0 6 24 48 66 MILES

mentary formations change from marine on the east to nonmarine on the west. This change of environment of deposition gives rise to the intertonguing of marine shales and nonmarine sandstones and shales; a condition well exemplified by the Colorado shale and the Montana group (Stebinger, 1914). Deformation of the sedimentary rocks in central and north-central Montana has been somewhat more intense than in eastern Montana. Locally they have been bent into sharp folds, as in the Big Snowy Mountains, or bowed up sharply, as along the Rocky Mountain front and around domal igneous mountains like the Little Rocky and Judith Mountains (Dobbin and Erdmann, 1955). In areas of more intense deformation Paleozoic, and locally Precambrian, as well as Mesozoic rocks crop out.

The igneous rocks that core the domal mountains make up part of the petrographic province of central Montana (Larsen, 1940), are of Tertiary age and have been emplaced as laccoliths, stocks, sills, and dikes. In a few places flows have been extruded. They consist of normal granitic types as well as a suite of alkalic rocks (fig. 1) similar to those of the Colorado Plateau. The alkalic rocks include such varieties as syenites, quartz syenites, syenite porphyries, shonkinites (melanocratic syenite with alkaline affinities), and trachyte and phonolite porphyries (fine-grained equivalents of syenite and nepheline syenite, respectively).

SOME TYPES OF URANIUM AND RADIOACTIVITY OCCURRENCES IN EASTERN AND CENTRAL MONTANA

In eastern and southeastern Montana uranium and abnormal radioactivity have been found in many different types of sedimentary rock that range in age from Cambrian to Miocene. "A visible (but unidentified) uranium mineral" occurs in sandstone of the Hell Creek formation (Late Cretaceous) in the Long

Pine Hills area (fig. 1) of eastern Carter County, southeastern Montana (U. S. Geol. Survey, 1954, TET-490). In the same area anomalous radioactivity has been reported from sandstone beds of the Ludlow member of the Fort Union formation (Paleocene) and from siliceous shale of the Arikaree formation (Miocene). In the Ollie area in easternmost Fallon County, uranium in near-ore concentrations has been found in thin beds of sandstone, carbonaceous sandstone, and lignitic material in the Fort Union formation. In the Ekalaka lignite field uranium occurs in ironstone concretions in sandstone of the upper part of the Fort Union formation (Gill, 1954).

Uraniferous lignite has been reported from the Fort Union formation in the Long Pine Hills, in the lower part of the same formation in the Ekalaka Hills (U. S. Geol. Survey, 1954), and in the upper part of the Sentinel Butte member at Blue Buttes just west of the North Dakota line (Beroni and Bauer, 1952).

The Virgelle sandstone (Late Cretaceous), the basal member of the Eagle sandstone, is a coarse-grained, crossbedded, massive sandstone that locally contains abundant magnetite and titaniferous magnetite, and small amounts of zircon, monazite, and garnet. This mineral suite and the littoral fauna (Stebinger, 1914) of the Virgelle suggest that the concentrations of heavy minerals probably accumulated as beach or offshore placer deposits. C. E. Erdmann (written communication, 1953) found abnormal radioactivity in the Virgelle. Because no "radioactive blacks" (uranium-bearing multiple oxides of titanium, niobium, and tantalum) have been reported from the Virgelle, it is assumed that the radioactivity is due to thorium in the monazite.

 The locations of uranium occurrences, abnormal radioactivity, and radioactivity anomalies observed from the air in Montana and referred to below are shown on figure 1.

A strong "kick" on a gamma-ray oil well log has been reported from the Rierdon formation or Sawtooth formation (both Late Jurassic) northwest of East Butte of the Sweetgrass Hills (Erdmann, C. E., written communication, 1954).

At a few places on the crest and flanks of the Pryor Mountains tyuyamunite in ore-grade concentrations has been found recently in the Madison limestone (Mississippian) where it is overlain disconformably (Sloss, 1952) by the Amsden formation (Mississippian-Pennsylvanian) (L. D. Jarrard, oral communication, 1956). These deposits are probably in the Mission Canyon limestone of the Madison group (Blackstone, 1940; Levorsen, 1941). The tyuyamunite fills and coats the walls of fractures and vugs in cherty and silicified breccia zones at or near the top of the Mission Canyon. By analogy with the breccias in the Mission Canyon in the Elkhorn Mountains, the breccia probably developed as the result of solution and collapse of the Mission Canyon at the time of the development of the disconformity between the Madison and Amsden (Klepper and others, in press). Some of the tyuyamunite-bearing breccia is red. The red color suggests that some of the breccia material may be Amsden deposited in sink holes in the top of the Mission Canyon.

In the same area of the Pryor Mountains tyuyamunite also fills and coats the walls of fractures and vugs in thin beds of silicified limestone near the top of the Amsden.

Along the east front of the Beartooth Uplift in south-central Montana radioactivity anomalies have been reported by Stow (1953) at several places in the Flathead quartzite (Cambrian) where it unconformably overlies Archean type rocks. At the Royse claim in this area radioactive material fills joint

openings in the Flathead. Analyses by the U. S. Geological Survey show that the radioactivity is due to the presence of radium in the joint filling.

Radioactivity anomalies observed from the air

The U. S. Atomic Energy Commission has done airborne reconnaissance for radioactivity anomalies in parts of eastern and central Montana. On the anomaly maps available to the writer, the U. S. Atomic Energy Commission (1952, 1953, 1954) plotted 29 positive radioactivity anomalies, and the locations of these anomalies are shown on figure 1; in two places the anomalies are so close together that they cannot be shown individually. The five anomalies shown on figure 1 in south-central Montana on the Beartooth Uplift are in Precambrian rocks; of this group, the four closely spaced ones represent 14 anomalies found on the west side of Boulder River. The two anomalies on the west end of the Big Elk-Shawmut Uplift represent four closely spaced anomalies on the west flank of the Castle Mountains.

The westernmost anomaly on the Crazy Mountains syncline occurs in Upper Cretaceous and lower Tertiary volcanic rocks, and the anomaly in the Judith Mountains north of Lewiston is in Upper Cretaceous and lower Tertiary intrusive rocks. The anomaly northeast of the Pryor Mountains occurs over rocks shown as Jurassic, undifferentiated, on the geologic map of Montana. According to E. E. Jones (1952) the anomaly is in shales of the Morrison formation (Upper Jurassic) and samples taken ~~from pits dug in the shale~~ assayed nil to 0.01 percent U_3O_8 .

The rest of the radioactivity anomalies are in or near the Eagle sandstone, the basal member of the Montana group, or in the Colorado shale (both Upper Cretaceous). If the Virgelle sandstone member of the Eagle is present

and monazite bearing at these localities, the radioactivity anomalies are probably due to thorium in the monazite, but some anomalies may be caused by "radioactive blacks" in the Virgelle or by beds of uraniferous lignite in the Eagle.

Most of the radioactivity anomalies in the sedimentary rocks are on the margins of structurally positive areas. This structural position may reflect only the fact that monazite- or uranium-bearing Virgelle sandstone or uraniferous lignite beds are exposed at the surface on the flanks of folds,

SIMILAR URANIUM OCCURRENCES ELSEWHERE

Colorado Plateau

The thick sequence of sedimentary rocks exposed on the Colorado Plateau is mostly of continental origin and ranges in age from Pennsylvanian to late Tertiary. Tertiary rocks are largely restricted to the margins of the Plateau. Tertiary stocks surrounded by laccoliths and other intrusive bodies (Hunt and others, 1953) have intruded the sedimentary rocks and form the cores of mountains. Soda-rich syenites and andesites are exposed in the La Sal, Henry, Abajo, Carrizo, and Ute Mountains. Dikes and volcanic rocks of the Four-Corners area are subsilicic, potash-rich varieties such as nepheline syenite, shonkinite, leucite basalt, and minette (a biotite-orthoclase syenitic lamprophyre). Similar rocks also occur in the Chuska Mountains in northwestern New Mexico and northeastern Arizona. The sedimentary rocks have been tilted by monoclinal warping, and around the igneous mountains they have been domed and locally turned up sharply by the intrusion of the igneous rocks. In the vicinity of the La Sal Mountains, the sedimentary rocks have been faulted and folded into a series of anticlines.

Considerable faulting has also occurred along the southwest edge of the Uncompahgre Uplift and in the vicinity of the San Rafael Swell (Luedke and Shoemaker, 1953).

Sandstone-type uranium ore deposits on the Colorado Plateau have been found in rocks of Permian through Late Cretaceous age. Most of the deposits are in continental sediments, but a few have been found in marine sediments. Sandstone is the most consistently favorable host rock, but minable deposits have also been found in limestone, carbonaceous shale, shale, tuffaceous sediments, and coal. The most favorable sandstone layers are those that contain interlayered thin beds of mudstone (McKelvey and others, 1955). Organic matter in the sedimentary rocks is an important factor in localizing some uranium deposits.

Although at present no clear-cut structural controls are recognized for most of the ore deposits, the abundance of distributions of metals around the La Sal Mountains shows a gross zonal pattern that is independent of the stratigraphy of the host rocks (U. S. Geol. Survey, 1954, TEI-440, 490). Gold and copper occur in the La Sal Mountains, uranium-vanadium deposits to the east and south of the mountains, and an essentially nonuraniferous copper-rich zone between the two. At a few uranium deposits, structural controls are recognized: the Monument No. 2 and Rajah ore deposits are related to faulting, and southeast of the La Sal Mountains some deposits are found on the flanks of anticlines (Cater, F. A., oral communication, 1954).

Two types of uranium ore occur on the Plateau--black ore and yellow ore. The black ore, discovered only in recent years, generally is not exposed at the surface. It contains uraninite, pyrite, galena, sphalerite, chalcopryrite, selenides, and vanadium minerals (U. S. Geol. Survey, 1954, TEI-490). In the black ore, uranium and vanadium are present in separate

minerals as low-valent ions. The yellow ore consists principally of carnotite with lesser amounts of tyuyamunite, autunite, and other uranium secondary minerals. Locally the yellow ore may contain a little pyrite or be slightly copper-stained. Carnotite and tyuyamunite contain both uranium and vanadium in high-valent states and these minerals are secondary after the black ore (McKelvey and others, 1955).

The uranium deposits are epigenetic, for age determinations of 55 to 75 million years, with the younger determination probably being more nearly correct, have been determined for uraninites from some of the deposits, and these ages are considerably less than those of the host rocks (Stieff and others, 1953).

Northeastern Wyoming

Sandstone-type uranium deposits have been found at several places in northeastern Wyoming. In the Pumpkin Buttes, Monument Hill, and Box Creek areas uranium deposits are in reddish sandstone lenses in the Wasatch formation of Eocene age (U. S. Geol. Survey, 1954, TEI-490; 1955, TEI-590). The uranium minerals appear to be most abundant near where the reddish sandstone grades into the normal buff or gray sandstone of the Wasatch. In the Devil's Tower area ore-grade uranium deposits occur in sandstones in members of the Inyan Kara group of Early Cretaceous age. Most of the deposits are in the Fall River sandstone, but some have been found in the Fuson formation and Lakota sandstone as well. Most of the uranium deposits are in an area of more intense folding on a regional monocline (U. S. Geol. Survey, 1954, TEI-490). At the Carlile mine the ore deposit is associated with carbonaceous material in interbedded sandstones, shales, and siltstones. In the Storm Hill quadrangle uranium deposits are on the east flank of a domal structure (U. S. Geol. Survey, 1955, TEI-590).

North and South Dakota

In southwestern North Dakota a few miles east of the Montana state line yellow uranium minerals have been found in the Tongue River member of the Fort Union formation, and radioactivity anomalies have been reported from the sandstone and shale beds of the Golden Valley formation of Eocene age and the Sentinel Butte and Tongue River members of the Fort Union formation (U. S. Geol. Survey, 1954, TEI-490). Uraniferous opal and carnotite have been found in the Chadron formation of Oligocene age (U. S. Geol. Survey, 1955, TEI-590). In northwestern South Dakota about 50 miles east of the Montana line metatuyamunite and meta-autunite have been found in the Ludlow and Tongue River members, respectively, of the Fort Union formation (U. S. Geol. Survey, 1954, TEI-490). In the southern Black Hills, South Dakota, sandstone-type uranium deposits occur in the Inyan Kara group, principally in the Fall River sandstone. Many of the deposits occur on structural terraces (U. S. Geol. Survey, 1954, TEI-440).

In northwestern South Dakota strippable deposits of lignite that contain uranium in sufficient concentration to be considered ore if it were in sandstone-type ore (the U. S. Atomic Energy Commission did not buy uraniumous lignite in 1955), have been found in the Tongue River and Ludlow members of the Fort Union formation. Uranium-bearing lignite and lignitic shale have been found also in southwestern North Dakota in the Fort Union (U. S. Geol. Survey, 1954, TEI-490; 1955, TEI-590). The sources of the uranium in these deposits are considered to be the slightly radioactive tuffaceous sandstones of the Arikaree formation of Miocene age, and the White River and Chadron formations of Oligocene age (U. S. Geol. Survey, 1954, TEI-440).

Blind River, Ontario

The similarity of the geologic environment at Blind River, Ontario, to that of the uranium deposits of the Rand, Africa, prompted thorough investigation of only slightly radioactive conglomerate at Blind River and led to the discovery of large uranium deposits.

In the Blind River area uranium deposits occur in quartz-pebble conglomerates in Precambrian Mississagi quartzite, the basal member of the Bruce series (Early Huronian), which in this area unconformably overlies Archean rocks. Subsequent to the deposition of the Bruce series the area was uplifted. Granite of unknown age that could be younger than the Bruce series crops out in the Blind River area (Abraham, 1953; Traill, 1954).

The uranium occurs in fine-grained uraninite and brannerite closely associated with fine-grained gold and pyrite disseminated in the matrix of the quartz-pebble conglomerate. Radioactivity is not confined to the beds at or near the base of the Mississagi quartzite and has been found in more than one bed of quartz-pebble conglomerate. Uranium content increases with depth below the surface probably owing to the leaching of the outcrops by dilute sulfuric acid formed by the weathering of pyrite (Phair and Levine, 1953).

POSSIBLE URANIUM-BEARING ENVIRONMENTS IN EASTERN AND CENTRAL MONTANA

Because of their similarity to uranium-bearing areas elsewhere, certain geologic environments in Montana are thought to be potentially more favorable for uranium prospecting than other areas in the state.

(1) Most of eastern Montana is underlain by the Fort Union formation in which a few sandstone-type uranium deposits have already been found nearby

in North and South Dakota and Montana. More sandstone-type uranium deposits may be found in the Fort Union, particularly in the Tongue River member, and in the Hell Creek formation. The Wasatch formation, which crops out along the Wyoming state line about 60 miles east of the Pryor Mountains, may contain sandstone-type uranium deposits similar to those at Pumpkin Buttes, Wyoming.

Additional occurrences of uraniferous lignite may be found in the Fort Union and other lignite- and coal-bearing formations such as the Hell Creek, Judith River, and Eagle sandstone. In a series of experiments Moore (1954) showed that peat, lignite, and subbituminous coal removed 98 or more percent of the uranium from an aqueous solution. Some geologists think it likely that the uranium in lignites was leached by ground water from overlying tuffs or tuffaceous beds and that the lignites extracted the uranium from circulating ground water (U. S. Geol. Survey, 1954, TET-440; Stieff, 1953). If this is true, then many of the lignites and low-rank coals of eastern Montana are potentially uraniferous because the distribution of the erosional remnants of the White River and Arikaree formations, both of which are tuffaceous, indicates that these formations once covered a large part of southeastern Montana. The distribution of the erosional remnants of the Flaxville gravel, which is tuffaceous locally (Collier and Thom, 1917), indicates that at one time the Flaxville also had a much wider distribution in the northeastern part of the state. This fact suggests that uraniferous lignite may be found in the Fort Peck lignite field.

(2) The geologic environment of the petrographic province of central Montana is strikingly similar to that of the Colorado Plateau. In Montana a suite of granitic and alkalic igneous rocks, similar to though more potassic than those on the Plateau, intrude sedimentary rocks of varied lithology that

range from Precambrian to Late Cretaceous in age. Many of these sedimentary rocks are continental sandstones that contain interlayered shales and mudstones and abundant organic remains.

The origin of the Colorado Plateau uranium deposits is an extremely controversial subject and is far from settled. However, if the deposits are in some way genetically related to the rather unusual suite of igneous rocks on the Plateau, as thought probable by some geologists (McKelvey and others, 1955), then the sedimentary rocks intruded by similar igneous rocks in Montana may contain sandstone-type uranium deposits.

The Montana formations listed below are those thought most likely to contain sandstone-type uranium deposits. They are sandstones of continental or mainly of continental origin (except the Colorado shale); most of them contain interlayered shale and mudstone beds; and many of them contain abundant organic remains. Some of these formations are the westward continental equivalents of formations that are marine in the eastern part of the state. The intertonguing of the marine and nonmarine facies produces an interlayering of sandstone and shale or mudstone, a feature that characterizes the most favorable continental sandstone layers on the Plateau (McKelvey and others, 1955).

<u>Formation</u> /	<u>Series</u>	<u>Approximate thickness (feet)</u>	<u>Remarks</u>
Fort Union	Paleocene	4,000*	Lignite-bearing. Contains concretions locally.
Tullock— basal member of the Fort Union	Paleocene	300	Coal-bearing.
Hell Creek	Upper Cretaceous	560	Lignite-bearing. Swamp and fluviatile deposits. Part of Hell Creek formation formerly recognized as Lance formation. Contains volcanic matter.
Willow Creek	Upper Cretaceous	720*	Perhaps correlative with Tullock.
St. Mary River	Upper Cretaceous	990	Perhaps correlative with Hell Creek.
Horsethief sandstone	Upper Cretaceous	360	Believed to correlate with Lennep sandstone. Contains magnetite-bearing beds.
Lennep sandstone	Upper Cretaceous	250-400	"Shallow water or fluviatile sandstone...contains much volcanic material" (Knappen and Moulton, 1931).
Judith River	Upper Cretaceous	500	Lignite-bearing. Contains volcanic ash.
Eagle sandstone	Upper Cretaceous	200-235	Lignite-bearing. Contains cannon-ball concretions. Virgelle sandstone at base is magnetite-bearing.
Two Medicine	Upper Cretaceous	1,950	Correlative with Judith River, Clagget (marine) and Eagle sandstone above Virgelle.
Colorado shale	Upper Cretaceous	1,500-2,000	Mostly marine with interbedded continental sandstones that become thicker and more numerous to the west. Contains abundant organic remains (Cobban, 1951). In southern Elkhorn Mountains dominantly continental (Klepper, M. R., oral communication, 1955).
Kootenai	Lower Cretaceous	450-475	Coal-bearing.

<u>Formation</u> /	<u>Series</u>	<u>Approximate thickness (feet)</u>	<u>Remarks</u>
Morrison	Upper Jurassic	Up to 450	Contains coaly beds at top (Imlay and others, 1948).

/ For correlations of Montana formations see Wilmarth (1932), Perry (1945, 1953), Billings Geological Society Guidebook (1952), and Cobban and Reeside (1952).

The granites in the petrographic province of central Montana probably should be prospected for they may be uranium-rich. In writing of the rocks of the Highwood and Bearpaw Mountains E. S. Larsen, Jr. (U. S. Geol. Survey, 1954, TEI-490) states "the potash-rich mafic rocks are not very high in uranium, but considering their mafic character they might be so considered. In such a series granites might have high uranium content."

(3) The discovery of commercial uranium deposits in a formation as widespread in Montana as the Madison limestone suggests large areas favorable for prospecting. The first areas of Madison to prospect probably should be those that duplicate as nearly as possible the geologic environment of the deposits in the Pryor Mountains. The disconformable relations of Amsden on Mission Canyon in the Pryor Mountains are found in a broad area that extends to the west and north at least as far as the Elkhorn Mountains (Klepper and others, in press; Perry, 1945). Uranium deposits may not necessarily be restricted to the top of the Mission Canyon for collapse solution breccias have been found as much as 200 feet below the top of the formation in the Elkhorn Mountains and 300 feet, in the Pryor Mountains (Blackstone, 1940; Klepper and others, in press).

The area north of Billings and at least as far west as the Big Snowy Mountains may not be as favorable an area in which to prospect the Mission

Canyon because Upper Mississippian beds progressively intervene between the Amsden and Mission Canyon. The disconformity, thereby, is moved stratigraphically upwards until it disappears, and the Amsden rests conformably on the Upper Mississippian Heath formation (Sloss, 1952; Levorsen, 1941).

The Amsden disconformably overlying the Mission Canyon also is considered to be a likely host rock for uranium and should not be overlooked in any prospecting program.

(4) The occurrence of abnormal radioactivity in the Flathead quartzite immediately suggests the possibility of finding uranium deposits in Montana similar to the large deposits at Blind River, Ontario, or the Rand, South Africa. All such quartzites and conglomerates in even remotely similar geologic environments may well be potential host rocks for uranium deposits and probably warrant diligent prospecting. At several places in Montana the Neihart (Precambrian) and Flathead quartzites rest unconformably on Archean rocks, as does the Mississagi quartzite at Blind River. Davidson (1953), in mentioning the broad geologic environments of several large uranium-bearing areas, noted that in each area "the old granitic [Archean] rocks have undergone domal uplift since the covering blanket of sediments was deposited, due presumably to [the intrusion of] 'younger' granites which are not always exposed," and he wondered "whether these similarities are more than coincidences." At several places in central Montana the Archean rocks have been domed by the intrusion of Tertiary granitic and alkalic rocks, and around these intrusions the Neihart and Flathead have been bowed up sharply. By analogy with other localities these areas of domal uplift may be favorable places for the occurrence of uranium deposits and the basal quartzites may be the logical host rocks.

In the Little Belt Mountains (Weed, 1899a, 1899b) both the Neihart and Flathead quartzites unconformably overlies Archean type rocks and locally the Flathead has been intruded by the post-Cretaceous Wolf and Barker granite porphyries. In the Castle Mountains (Weed, 1899a) the Flathead occurs near the Castle granite and locally has been thermally metamorphosed by it. The Castle granite is one of the granites associated with the alkaline petrographic province of central Montana and according to Larsen (U. S. Geol. Survey, 1954, TBI-490) may be uranium-rich. Small amounts of silver, copper, and gold, common associates of uranium, ^{in western Montana,} have been mined from the Little Belt and Castle Mountains, and the geologic setting together with the presence of the mineral associates suggests that uranium deposits may be present.

The Flathead also lies on Archean type rocks in the Bridger Range and along the north front of the Beartooth uplift south and east of Livingston (Iddings and Weed, 1893; Peale, 1896; McMannis, 1952). Near the Wyoming state line south of Livingston, areas of Flathead resting on Archean type rocks are preserved in down-dropped fault blocks. In the Madison and Gallatin Ranges south of Three Forks, Peale (1896) has mapped several miles of the Archean-Flathead contact, and at one place southwest of Three Forks he shows a small area of Archean type rocks unconformably overlain by Belt arkosic sandstones and conglomerates. Several less extensive areas where the Flathead quartzite rests on Archean type rocks are known in southwestern Montana (Ross and others, 1955).

(5) The abnormal radioactivity found in the Virgelle sandstone and the radioactivity anomalies observed from the air over the Eagle sandstone or very close to it, point to the Virgelle as a possible source of uranium even though the abnormal radioactivity of one sample of Virgelle was thought to be due to the presence of thorium. The magnetite-bearing beds of the Horseshoe sandstone likewise appear favorable for the occurrence of uranium.

CONDITIONS AFFECTING PROSPECTING FOR URANIUM IN
EASTERN AND CENTRAL MONTANA

A few ideas have been presented to suggest geologic environments in eastern and central Montana that are thought favorable for the occurrence of uranium deposits. The possibility must be faced, however, that there may be very little uranium in the eastern and central parts of Montana. The writer hesitates to attribute the scarcity of known uranium occurrences to the lack of prospecting, but nevertheless such a lack may in part explain this scarcity.

The presence of thick glacial deposits over a large part of northern Montana east of the Rocky Mountains (fig. 1) (Alden, 1953; Flint and others, 1945) may also help to explain why so few uranium occurrences have been found. In many places, such as the area of the Sweetgrass Arch north of Great Falls (fig. 1), the glacial deposits almost completely blanket the other sedimentary rocks and would mask or greatly dilute the radioactivity anomaly of a uranium deposit in the underlying rocks. In such areas windows eroded through the glacial deposits may afford valuable data when adequately prospected, and drill holes and drill-hole cuttings should be examined for abnormal radioactivity.

Other factors that might be thought to contribute to the lack of known uranium occurrences are leaching of surface deposits during a more humid climate in the past, and the absence of characteristic Colorado Plateau canyon and mesa topography that might have exposed favorable host rocks more extensively. Leaching and absence of Plateau-type dissection are unlikely to be large contributing factors, however, for a short distance south, in

Wyoming, and southeast in South Dakota, where the climate could never have been very different from that of Montana, many occurrences of secondary uranium minerals are known from a terrain no more, and locally less, dissected than eastern and central Montana.

AIDS TO PROSPECTING

Although the distribution and abundance of selenium-concentrating plants has been used successfully as a guide to ore in some places on the Colorado Plateau (Cannon, in press), it may be impossible or extremely difficult to use this prospecting method in Montana even though seleniferous plants are abundant and widespread (fig. 1) (Trelease and Beath, 1949). If this method is used, the results will have to be interpreted with great care because a large part of the plains of Montana is underlain by seleniferous marine shales, such as the Pierre, Bearpaw, and Colorado shales, which support seleniferous vegetation but are not ordinarily favorable host rocks for uranium deposits.

Radioactivity surveys of oil wells and deep seismograph shot holes may prove a useful tool in prospecting for uranium in the plains of Montana.

Uranium analyses of water samples from water wells in the plains of Montana may also help to delimit areas for intensive prospecting. Analyses of surface waters have been used for uranium prospecting; but, to the writer's knowledge, no attempt has yet been made to use well waters for this purpose.

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