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GEOLOGY AND URANIUM DEPOSITS OF PART OF THE BROWNS PARK FORMATION COLORADO, WYOMING, AND UTAH—a preliminary report*

By

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Trace Elements Investigations Report 423

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- A preliminary report -

By P. K. Theobald, Jr. and R. T. Chew, III

ABSTRACT

Uranium deposits and radioactivity anomalies have been found in the eastern half of the area underlain by the Browns Park formation in northwestern Colorado, south-central Wyoming, and northeastern Utah. The deposits are in eolian, lacustrine, and fluvial sandstones, tuffaceous sandstones, and limestones all of which were deposited on two converging pediments during Miocene time. At least one eastern and one western facies of lacustrine and fluvial sedimentary rocks are separated by a belt of eolian sandstones. The facies may be distinguished in the field and by petrographic and heavy-mineral studies in the laboratory.

The uranium deposits in or east of the belt of eolian sandstones may be controlled by fractures in the Browns Park formation. Uranium minerals are associated with abundant calcite and limonite and with some tuffaceous material. The deposits near Miller Hill are too low grade to be of commercial interest; those west of Baggs are small high-grade deposits; and those in the Lay-Maybell area may represent large tonnages of low-grade ore. Trial shipments of acceptable ore have been made from both the Baggs and the Lay-Maybell areas.

Regional geologic studies and further airborne scintillation work are recommended.

INTRODUCTION

The Browns Park formation underlies more than 1,450 square miles of northwestern Colorado, south-central Wyoming, and northeastern Utah. An additional 100 square miles underlain by the formation in southwestern Wyoming, west of the Green River, is not discussed here, nor are the controversial equivalents of the Browns Park formation in the area north of the Great Divide Basin in central Wyoming. Three groups of uranium deposits of commercial interest are in the central and eastern part of the area (pl. 1): 1) in the vicinity of Lay and Maybell, Colo., 2) west of Baggs, Wyo., and 3) on the north and west flank of the Sierra Madre. Radioactivity anomalies and uranium mineral occurrences are common throughout these three areas.

The authors made brief examinations of several uranium deposits and radioactive localities in the Browns Park formation during the summer and fall of 1954 and the summer of 1955. A summary of the observations made on these trips and a review of the general geology of the Browns Park formation are presented here to aid others working in the area. This work is part of a program being conducted by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

GEOGRAPHY

The distribution of the Browns Park formation (pl. 1) lends itself to geographic subdivision into three units: 1) nearly continuous exposures extending east-southeast for 85 miles from Browns Park Valley, Daggett

County, Utah, to a point 7 miles west of Craig, Moffat County, Colo.; 2) nearly continuous exposures extending northeast for 65 miles from Baggs, Carbon County, Wyo., along the west and north flanks of the Sierra Madre to a point 20 miles north of Saratoga, Carbon County, Wyo.; and 3) a series of isolated remnants extending east from Browns Park Valley to Baggs.

The first of these subdivisions is preserved in valleys along the northeast flank of the Uinta Mountains and in the Axial Basin. Here the formation is at a lower altitude and has a surface of lower relief than the surrounding ridges of older rocks. The second subdivision is preserved on an extensive erosion surface sloping away from the higher Sierra Madre. The outer limit of exposure of the formation in this subdivision is marked by a steep erosional scarp where the North Platte and Little Snake Rivers are destroying the older surface. The third subdivision is composed of isolated remnants preserved in structural depressions or on divides flanking the south edge of the Washakie Basin.

The climate of the area is semi-arid. The low relief on the Browns Park formation, the lack of vegetation, and the dry climate allow ready access by automobile to almost all parts of the area, though only two paved roads traverse the formation. Railroad facilities are available at Craig, Colo., and at Rawlins and Saratoga, Wyo.

PREVIOUS WORK

The Browns Park formation and the Bishop conglomerate (shown in part on pl. 1) have been the subject of controversy since they were first described by the Powell, King, and Hayden surveys. A study of these formations in the Uinta Mountains and the Axial Basin has been important in interpreting the anomalous courses of the Green and Yampa Rivers. Powell (1876) was the first to use the terms "Bishop Mountain conglomerate" and "Brown's Park group" though the King survey (1876) recognized the Bishop conglomerate and called it "Wyoming conglomerate". The Browns Park formation was mapped by the King Survey as Green River formation in the Uinta Mountains and as North Park formation in the Sierra Madre.

Powell noted the unconformity at the base of both formations and the faulting of the Browns Park formation. He tentatively set the ages of the formations as late Tertiary, and because of the greater altitude of its exposures, considered the Bishop conglomerate to be the younger.

Gale (1910) also held the opinion that the Bishop conglomerate was the younger formation. He considered the Browns Park formation to have been "laid down in a restricted lake basin" and ascribed the dip of the formation along its outer contact to deposition on a sloping surface. Gale was the first to use the nomenclature "Browns Park formation" to replace Powell's "Browns Park group", and on page 43 he gives the first concise description of the formation: "Consists of loose or slightly consolidated sandy material with local harder sandstone beds and some beds of gravel. Contains much calcareous material in the form of cement or filling between the quartz sand grains. Its color is everywhere chalky or limy white."

Hancock (1915) postulated a flood of Browns Park sediment following subsidence of the east end of the Uinta anticline to produce the relatively low Axial Basin. He suggested that this sediment buried the topographic highs in the newly formed Axial Basin and that the course of the Yampa River was established on the Browns Park formation.

Schultz (1920) shortened Powell's terminology from "Bishop Mountain conglomerate" to "Bishop conglomerate". He thought the Browns Park formation was equivalent to the Bridger formation in the Washakie Basin.

Sears (1924) applied the reasoning of Hancock (1915) to explain the courses of the Yampa and Green Rivers in the Uinta Mountains. He concluded that the Bishop conglomerate was the basal conglomerate of the Browns Park formation and that both, at least as far east as the Little Snake River in Colorado, were derived from the red Precambrian Uinta quartzite. The white color of the Browns Park sandstones would be the true color of quartz grains in the quartzite, leached of interstitial coloring agents. Sears' concept (1924; 1925) of the late Tertiary history is 1) erosion of an extensive surface, "peneplane" sloping away from the Uinta Mountains, 2) deposition of the Bishop conglomerate followed by the finer sediment of the Browns Park formation, and 3) warping and faulting of the margins of the formation to form a flat-bottomed syncline. He notes the predominance of Uinta quartzite pebbles in the conglomerate west of the Little Snake River, "varicolored" pebbles and limestone east of the Little Snake River, chert and chalcedony layers (also mentioned by Powell) in the lower part of the formation west of the Little Snake River, and extensive crossbedding east of the Little Snake River. Sears also mentions a Miocene(?) vertebrate from the Browns

Park formation found by Professor Douglass in the vicinity of Sunbeam, 6 miles northwest of Maybell.

Hancock (1925) described the Browns Park formation in the Axial Basin. The basal part is soft, more or less unconsolidated, reddish and yellowish brown sandstone and conglomerate. The conglomerate is composed of pebbles of schist, gneiss, coarse- and fine-grained white and reddish quartzite, and reddish vein quartz. The basal part is at least 50 feet thick and grades upward to soft, friable chalky-white sandstone. The upper part is composed largely of well-rounded quartz grains, more or less consolidated by calcareous cement. A few layers and masses of hard, somewhat quartzitic sandstone are much darker than the surrounding chalky-white sediments. Hancock found sandstone remnants above the basalt flows on Cedar Mountain, 6 miles northwest of Craig, that he believed were part of the Browns Park formation; therefore, he concluded that extrusion took place during deposition of the formation. He estimates that the total thickness of the formation was 1,500 feet.

Forrester (1937) postulates the following sequence of events: 1) An Oligocene stream breached the Uinta anticline near its axis, and an anticlinal valley (Browns Park Valley) developed. 2) Dry climate with torrential rains concentrated along the Uinta Mountain divide prevailed in Miocene time. The Bishop conglomerate was deposited as an alluvial fan on an extensive pediment sloping away from the mountains, and Browns Park Valley was enlarged to a mature valley. 3) During Pliocene time the relief remained low, and periodic subsidence of the axial part of the Uinta arch reduced the gradient of the anticlinal valley. This led to deposition of the finer Browns Park sediments in the valley and over a more extensive area to the east.

Three articles by Bradley (1935, 1936, and 1945) give the most detailed picture of the history of the Browns Park formation. In the first of these (1935) he describes planation of folded and faulted Eocene rocks by streams from both the Uinta Mountains and Sierra Madre. The Browns Park formation was deposited on the pediments thus formed. Subsequent to deposition a new set of faults was active and some of the older faults were reactivated. Although this late movement accentuated earlier structures, Bradley points out that not all of the Browns Park structures coincide with the Eocene structures, in fact the two may be directly opposed; that, is, anticlines in the Browns Park formation may be superimposed on synclines in the older rocks.

In the second article (1936) Bradley provides a logical argument for the greater antiquity, with higher altitude, of the Bishop conglomerate than the Browns Park formation. He describes two ancient pediments. The Bishop conglomerate was deposited on the Gilbert Peak surface, the older of these. A period of rejuvenation followed this deposition, and a second pediment, the Bear Peak surface, developed 400 to 500 feet below the Gilbert Peak surface. Because the Bishop conglomerate is more resistant than the Eocene rocks, remnants of this formation remain as inselbergs on the Bear Peak surface. As the climate became more arid, the Browns Park formation was deposited on the Bear Peak surface. After deposition of the Browns Park formation the Uinta graben, Axial Basin, and several other structural basins formed. The formation is preserved in these basins. Bradley considers the Browns Park formation to be late Miocene or early Pliocene.

In the third article (1945), Bradley describes the isolated remnants of the Browns Park formation west of Baggs, Wyo., as 75 feet of conglomerate composed of Uinta quartzite pebbles overlain by a thick series of white highly crossbedded sandstone of wind-blown origin and white glassy tuff. At the top are beds of dense quartzite. He shows north-trending and reactivated east-trending faults cutting the formation.

McGrew (1951 and 1953) reviews the paleontologic evidence for subdivision of the late Cenozoic rocks in the Saratoga Valley and on the west and north flanks of the Sierra Madre. He lists middle Miocene vertebrates from the Browns Park formation north of Saratoga, near Craig, and near Split Rock (50 miles northwest of Rawlins). He also lists a late Miocene vertebrate from the Browns Park formation in the vicinity of Craig, and an early Pliocene horse's tooth found in the North Park formation east of Saratoga. McGrew considers that the North Park and Browns Park formations are well defined areally and that the Browns Park formation may have been continuous across the interval between the Sierra Madre and Split Rock. He is undecided about the position of the Bishop conglomerate but suggests in the earlier paper that it is the basal unit of the Browns Park formation.

A detailed description of the Browns Park formation at the north end of the Sierra Madre is given by Love (1953). The formation has a basal conglomerate of pebbles and boulders up to 4 feet in diameter of Precambrian and Paleozoic rocks. This grades upward through intertonguing beds to white and light gray limy sandstones interbedded with thin persistent limestones. On Middlewood Hill, northeast of Miller Hill, the basal conglomerate is 20 to 100 feet thick, and the overlying 927 feet is composed of 93 percent sandstone, 6 percent tuff, and 1 percent limestone. The highest and most consistent radioactivity in the area is in 12 feet of algal limestone 400 feet above the base of the formation.

Love postulates the following sequence of events in the development of the Browns Park formation: 1) erosion of an extensive pediment sloping away from the Sierra Madre, 2) deposition of the basal conglomerate, possibly due to an increase of rainfall, 3) deposition of finer sediment and the appearance of extensive lakes, 4) introduction of tuffaceous material and finer sediment into the lakes, and 5) post-sedimentation warping, faulting, and erosion.

Vine and Prichard (1954) give a brief description of the uranium deposits in the Browns Park formation 6 miles west of Baggs where only 300 feet of the formation remain, the upper part having been removed by erosion. At the base is 75 feet of conglomerate consisting largely of quartzite pebbles and cobbles. Above this is highly crossbedded white sandstone and tuffaceous sandstone. At the top there is a dense quartzite bed.

PRE-BROWNS PARK FORMATION GEOLOGIC HISTORY

The area of outcrop of the Browns Park formation can be divided into three structural subdivisions—the Uinta anticline, the Sierra Madre anticline, and the basin of deposition along the Colorado-Wyoming border north of the Uinta arch and west of the Sierra Madre arch. These are analogous to the three geographic subdivisions described earlier.

The Uinta anticline is described by Forrester (1937) as a broad west-trending anticline developed during the Laramide orogeny (late Cretaceous-

The early history of the third subdivision of the Browns Park formation is summarized by Bradley (1935). North of the Uinta anticline and west of the Sierra Madre anticline, a basin of deposition developed in early Cenozoic time. A thick sequence of Eocene sediments accumulated in this basin. After deposition of the Eocene sequence a belt of west-trending folds and faults developed approximately along the present Colorado-Wyoming state line. This orogenic belt separates the Washakie Basin from the Sand Wash Basin (a shallow basin between the Axial Basin and the Colorado-Wyoming state line). The orogeny was followed by a period of planation probably coincident with the period of pediment formation in the Uinta Mountains and Sierra Madre; the Browns Park formation was deposited on the planed edges of rocks in the orogenic belt.

GEOLOGY OF THE BROWNS PARK FORMATION

During the Miocene epoch, two extensive pediments existed in northwestern Colorado and south-central Wyoming. Browns Park valley opened onto one of these and it spread to the east and northeast from the Uinta Mountains, the other spread to the west and north from the Sierra Madre. Probably beginning in middle Miocene time, sediments derived from the core of the Uinta Mountains began to fill Browns Park valley and cover the pediment to the east. Similarly, sediment from the Sierra Madre covered the adjacent pediment. The events which transformed the pediments to areas of deposition are not understood.

The general stratigraphic sequence of the Browns Park formation is a basal conglomerate of varying thickness overlain by calcareous sandstone. Tuff and limestone are interbedded with the sandstone. The total thickness of the formation is in excess of 1,000 feet. In Saratoga Valley (pl. 1) the Browns Park formation is overlain by the North Park formation and no erosional break is apparent between them. The contact is, however, obscured and is probably a zone of gradation so that estimates of total thickness in that area are difficult. West of the Sierra Madre basaltic flows lie on sandstone of the Browns Park formation. Hancock (1925) considered the flows to be part of the formation rather than younger, so the top of the formation may not be exposed in this area. In the remainder of the area post-Miocene erosion has removed the upper part of the formation.

In general, the basal conglomerate is thickest near the mountain fronts and tapers toward the basin, the junction of the pediments. Love (1953) gives a thickness of 20 to 100 feet near the Sierra Madre, and Sears (1924, p. 285) gives a thickness range "of a few inches to several hundred feet" near the Uinta Mountains. In the area west of Baggs and around Lay the basal conglomerate is commonly absent but locally is as much as 100 feet thick. A general decrease in the size of the gravel is also evident, with coarsest material near the mountains.

Changes in the lithology of the conglomerate suggest that it is for the most part locally derived. In the west the red quartzite of the Uinta quartzite predominates (Sears, 1924, p. 285); farther east, about 18 miles west of Maybell, gray limestone predominates (Sears, 1924, p. 291); in the Axial Basin there is schist, gneiss, granite, quartzite, and vein quartz (Hancock, 1925, p. 24); and near the Sierra Madre there is quartz, "basic Precambrian rocks and brown granite" (Love, 1953, p. 6).

Above the basal conglomerate the formation shows major lateral variation probably because different depositional processes were active in different regions at the same time. In the west, fluvial sandstones with some tuffaceous material are most common. They are generally well bedded with minor, small-scale crossbedding. Near the base of the upper unit is a chert layer.

In the east, lake deposits predominate that consist of clayey sandstones and siltstones and relatively tuffaceous material. In this area there are several limestone beds that show abnormally high radioactivity. A thin section of a sample of arkosic siltstone taken from the Sierra Madre (Locality 1, pl. 1) contains:

Mineral	Volume percent
Clay minerals	52
Quartz	30
Feldspar	15
Hornblende	2
Calcite (cement)	1
Limonite	trace
	100

A sample of a calcareous arkose taken northwest of Craig (Locality 6, pl. 1) has a similar detrital assemblage. Its composition is:

Mineral	Volume percent
Calcite (cement)	39
Quartz	31
Feldspar	22
Chalcedony (clastic)	7
Calcite (fossil fragment), limonite, hornblende, and pyroxene	1
	100

Calcite and feldspar, abundant at Locality 6, and clay, abundant at Locality 1, reflect the change in rock type. The presence of clastic chalcedony at Locality 6, however, reflects a change in mineral suite. These are the only samples that contain significant quantities of hornblende, which was probably derived from the metamorphic rocks of the Sierra Madre.

Separating the principally lacustrine sedimentary rocks in the east from the principally alluvial sedimentary rocks in the west is a belt of eolian sandstone interbedded with both alluvial and lacustrine sandstones and some tuff. This belt which contains the highest-grade uranium deposits found in the Browns Park formation to date is exposed in the large remnants of the Browns Park formation on the Colorado-Wyoming state line west of Baggs (Localities 3 and 4, pl. 1) and in the vicinity of Baggs, Lay, and Craig. The belt approximately coincides with the junction of the two pediments on which the formation rests.

Bradley (1936, p. 182-183) concluded, on the basis of microscopic studies and one mechanical analysis of highly crossbedded sandstones from the south edge of the Washakie Basin, that these rocks were eolian but left the problem open to other interpretations. Three samples of this material, two for mechanical and heavy mineral analyses and one for thin section study, add weight to Bradley's conclusion. The results of mechanical and mineral analyses of the two eolian sandstones from Localities 6 and 13 are shown on plate 2. Opal in the mineralogic analyses occurs as coatings on the grains. It was broken away from the grains during the mechanical analysis.

A sample of eolian sandstone from Locality 4 (not shown on pl. 2) is a dense quartzitic rock. It consists of well-rounded, frosted or pitted, clastic quartz and feldspar grains, extremely uniform in size. Packing of the clastic grains is loose, each grain is coated by a skim of opal, and the interstices are filled by concentric rings of radiating chalcedony needles. The composition of this sample is:

Mineral	Volume percent
Quartz	54
Chalcedony	28
Opal	16
Feldspar	2
	100

The uniformity in grain size noted in this sample persists in the eolian sandstones whose analyses appear on plate 2. Both of these have sorting coefficients very near unity, So=1:1. Although the median size changes approximately one grade between the two samples the shape of the histograms and cumulative curves remains relatively constant. The skewness of Bradley's samples is virtually absent from these two samples which have values of skewness (Sk) very near unity. That these criteria are not absolute is evident from comparison with the sample from locality 12, considered by R. A. Cadigan of the U. S. Geological Survey to be of fluvial or lacustrine origin. This sample, however, is the exceptional case of the three fluvial and lacustrine samples shown while all of the eolian samples show uniformity. All of the grains in the eolian sandstones are well rounded, and their surfaces are pitted. In the field, the eolian sandstones are crossbedded with individual beds and laminae 10 to 40 feet long. In profile the beds invariably show strong concavity upward. Eolian processes are the most logical to explain these characteristics.

Analyses of three fluvial and lacustrine sandstones are also shown on plate 2. Two of these samples, from localities 12 and 15, were analyzed by R. A. Cadigan. The sample from locality 15 shows evidence of much reworking and probably was deposited in a fluvial or lacustrine environment. The sample from locality 12 has a similar composition and shows less evidence of reworking, but probably was deposited in a similar environment. The sample from locality 12 would produce a sandstone similar to that at locality 15 with further reworking. The sample from locality 4 is a lacustrine sandstone that lies below the eolian sandstone described previously.

Two samples from localities 12 and 15 respectively were analyzed (using disaggregated grain counts) also by R. A. Cadigan. He did not find chert but identified feldspar, quartz, and glass shards. In heavy mineral suites, cut to include more of the minerals below a specific gravity of 3.5 than those shown on plate 2, the principal constituents were minerals of the epidote group (zoisite and clinozoisite), hypersthene, hornblende, garnet, and opaques (magnetite, magnetite-ilmenite, ilmenite, and leucoxene).

In addition to the analyses given above, a thin section of a coarse-crystalline tuffaceous limestone from locality 12 was examined and contains the following:

Mineral	Volume percent
Calcite	52
Glass shards	36
Quartz (clastic)	8
Feldspar (clastic)	4
	100

This is the most tuffaceous rock identified from the group of samples, though the clay in the lacustrine samples from localities 1 and 4 may be altered volcanic material and the samples from localities 12 and 15 (plate 2) contain abundant glass shards. The glass shards in this sample are quite delicate with abundant thin, sharp edges. There is no evidence of water transport of the shards, and their fall must have been cushioned to preserve the delicate shapes—probably in standing water. The calcite occurs as large, optically continuous crystals in which the clastic particles are incorporated. This is apparently a lacustrine, mixed clastic and chemical sedimentary rock.

Mineral suites obtained in this study show differences that lead to the opinion that the finer sedimentary rocks as well as the basal conglomerate were in large part locally derived. It appears possible that more detailed mineralogic studies may allow subdivision of the Browns Park formation into at least two distributive provinces. A rough indication of these provinces is given by the presence of clastic chert at localities 4, 6, 7, and 13. In the field, this chert is an obvious constituent of the rocks in the western part of the eolian belt where as much as 30 percent of the clastic fragments appear to be chert. Nearer the Sierra Madre no chert was found in either the field or laboratory examinations. In contrast the rocks near the Sierra Madre contain a relatively large proportion of amphiboles and pyroxenes.

Garnet may provide some clue to source areas, but the data available now is insufficient for reasonable interpretation of its distribution. The fluctuation in the proportion of garnet in the heavy minerals within the eolian belt is evident on plate 2. Color variations in the garnet are also marked; at locality 4 they are a clear red, at locality 6 many are colorless, and at locality 13 they are reddish brown. At locality 13 the fine-grained zircons also have anomalous colors, with shades of pink and yellow common.

Calcite cement and calcareous concretions are abundant in the eolian sandstone belt. Small fractures are filled with calcite. Portions of the rock indurated by calcite cement are often outlined by rims of intense limonite staining. In addition, limonite stained beds commonly occur near the base of the formation. Uranium minerals most commonly occur in the high-lime beds, to which limonite is a guide.

The eolian belt, which contains many beds of fluvial and lacustrine origin, may be interpreted as a basin feature between fluvial sedimentary rocks derived from the Sierra Madre and those derived from the Uinta Mountains. At locality 2, a brief examination was made of a uranium deposit where the upper part of the Browns Park formation is composed of arkosic, fluvial sandstones and conglomerates. If this locality is characteristic of the formation along the west flank of the Sierra Madre, the lacustrine deposits may be confined to the area north of the Sierra Madre. This interpretation would agree with speculation that the North Park formation rather than the Browns Park formation rests on the pediment north of the Sierra Madre. However, little information is available on the Browns Park formation along the west flank of the Sierra Madre, and it is possible that the eolian belt may be a border feature separating the principally alluvial from the principally lacustrine facies of the formation.

Little information is available on post-Browns Park formation structure. Bradley (1935 and 1945) shows that north- and east-trending, high-angle faults cut the formation west of Baggs, and Hansen and Bonilla (1954) show an east-trending fault that cuts the formation in Browns Park Valley. Montagne (1953) has found similar faults cutting the North Park formation in Saratoga Valley. Most authors are in agreement that the Browns Park formation in the Axial Basin has been folded into a shallow syncline and that a broad anticline warps the Browns Park formation north of the Sierra Madre. In the Lay-Maybell area, east- and north-trending, calcite-filled joints show anomalous radioactivity. These may reflect a structural trend similar to that found by Bradley along the south side of the Washakie Basin.

URANIUM DEPOSITS

The first published mention of uranium deposits in the area is by Wilmarth (1953), at a locality just north of Browns Park Valley. The deposit is not in the Browns Park formation, and from relations to faults described in the paper it is probably a pre-Browns Park, copper-uranium deposit more closely related to the deposits near Skull Creek (Beroni and McKeown, 1952).

Uranium deposits and radioactivity anomalies occur at numerous localities in the eastern half of the area underlain by the Browns Park formation. Physical exploration and development work are in progress on these deposits near Lay and Maybell, west of Baggs, at the junction of Savery and Little Savery Creeks (Locality 2, pl. 1), and on Miller Hill (Locality 1, pl. 1). Traverses with airborne scintillation equipment cover the Browns Park exposures in Wyoming (Henderson, 1954a, b, c, d, e) and most of the exposures in Colorado (Johnson, 1955a and b). The anomalies found during these traverses fill many of the gaps between known deposits. Results of carborne radioactivity traverses of the roads indicate that the formation has, in general, lower background radioactivity than the older rocks, and for this reason anomalies appear sharper.

The deposits in the Miller Hill area are generally too low grade to be of commercial interest. West of Baggs, the deposits are small but of generally higher grade than other areas of the Browns Park formation. In the Lay-Maybell area the deposits are larger but of lower grade than those at Baggs. It is possible that large tonnages of ore may be developed in this area.

Several deposits have been prospected on Miller Hill and along the rim of the bluff north of Miller Hill (Locality 1). Radioactive calcareous sandstones and limestones are exposed in this area and airborne equipment has detected numerous anomalies in the Browns Park formation between Miller Hill and Saratoga. Description of these deposits is given by Love (1953) who lists 13 analyses from the area, most of them from algal limestone, which range from 0.003 to 0.15 percent uranium. Assays as high as 0.94

percent uranium have been reported from the area. The radiometric analyses average 33 percent higher than the chemical analyses. He considers some of the uranium to be syngenetic, deposited with tuffaceous material in lakes, and some to have been leached from older rocks and deposits in the Browns Park formation. He gives two associations common to the radioactive localities: a high percent of both calcium carbonate and tuffaceous material.

At the junction of Savery and Little Savery Creeks, Locality 2, pits and trenches expose radioactive beds in the Browns Park formation. The largest trench exposes a coarse-grained sandstone 15 to 20 feet below the fine-grained indurated sandstone which caps the bluff between the streams. Radioactive zones occur in the coarse-grained sandstone, apparently resulting from concentrations of uranium minerals (meta-autunite?) in and adjacent to conglomeratic sandstone lenses and clay seams. One grab sample from this locality contains 0.22 percent equivalent uranium and 0.21 percent uranium.

Prospecting and development work has been in progress on numerous claims covering the remnant of the Browns Park formation west of Baggs, Wyoming (Locality 3). Near the richest deposits, the formation is an even-bedded medium- to coarse-grained sandstone; the eolian characteristics of the rocks in the Colorado deposits are missing. Radioactivity is in indurated limonite-stained beds or irregular calcareous zones outlined by limonite staining. Manganese oxides may occur with the uranium minerals. Analyses of three grab samples from the area are:

eU (percent)	U (percent)
2.4	2.59
2.2	1.43
0.92	0.57

In two selected samples from this locality W. F. Outerbridge identified uranocircite and meta-autunite. The area is described by Vine and Prichard (1954), who found that the uranium content ranges from 0.004 to 3.21 percent in 19 samples. These samples are out of equilibrium; the radiometric analyses average 340 percent greater than the chemical analyses. They report that uranophane and schroeckingerite were identified in selected samples. Vine and Prichard prefer a hypothesis of leaching from overlying, now removed, tuffaceous material to provide a uranium source. Alternatively they suggest leaching from underlying beds, but they cast doubt upon hydrothermal origin.

Deposits in the Lay and Maybell area are in the belt of eolian sandstone. In this area they are high in lime; analyses of ore-grade samples are as high as 30 percent calcium carbonate. At one deposit midway between Lay and Maybell (Locality 12) tuffaceous material is abundant in calcite-rich sandstones. Uranium prospects and radioactivity anomalies in this area are shown on plate 3, and specific localities discussed in the text are located on plate 1.

Northwest of Craig (Locality 5) anomalous radioactivity occurs in poorly sorted arkosic sandstone and conglomerate, presumably near the base of the Browns Park formation. This conglomeratic unit is at least 100 feet thick, is impregnated by limonite, has a maximum grain size of 2 inches, and has an average grain size of five-eighths-inch. The unit is radioactive, averaging 0.035 mr/hr (milliroentgens per hour) and reaching a maximum 0.05 mr/hr. Average radiometric background in the Lay-Maybell area is 0.015 to 0.020 mr/hr. A channel sample from one of the most radioactive zones contains 0.03 percent U_3O_8, no vanadium, and no copper.

Prospect pits at the Eskridge property (Locality 7) are in beds more than 100 feet above the base of the Browns Park formation. In the most radioactive pit medium- to fine-grained well rounded sand in a tuffaceous(?) matrix forms crossbedded units about 3 feet thick. Thin-bedded contorted siltstones as much as 4 inches thick are interbedded with the sandstones. Limonite is abundant along contacts, bedding planes, and fractures and forms Liesegang rings in the sandstones. Calcite concretions as large as 1 foot in diameter occur in the sandstones, gypsum seams are abundant in the siltstones, and some jarosite occurs in the sandstones.

Two limonite-stained zones 80 feet long and 2 feet thick are radioactive, usually 0.05 to 0.12 mr/hr with a scintillation type counter but reaching a maximum of 0.25 mr/hr. The highest radioactivity is in siltstone, but the most consistent radioactivity is in sandstone. A channel sample from the property contains 0.02 percent U_3O_8, 0.07 percent V_2O_5, and 0.09 percent copper. It is inferred from an exposure of limonitic material across the canyon from the pit, that the deposit trends N. 35° W. Other prospect pits scattered throughout the area northwest of the Eskridge property have similar lithology, less limonite, and radioactivity only 2 or 3 times background (0.015 to 0.025 mr/hr).

The Bobcat group (Locality 8) is in beds only 15 to 20 feet above the base of the Browns Park formation where it lies unconformably on the Lance formation. The Browns Park formation consists of crossbedded conglomerate beds about 1 foot thick and fine-grained sandstone containing well-rounded grains in a tuff or clay matrix. A persistent radioactive siltstone seam 6 to 8 inches thick is associated with limonite streaks or pods in sandstone in the most radioactive prospect pit. Jarosite occurs along the bedding and in the sandstone near the mineralized zone. Gypsum veins as much as 1 inch thick parallel the bedding, locally contorting it. The siltstone seam, exposed for 30 feet, has a maximum radioactivity of 0.30 mr/hr, and a channel sample of the seam contains 0.03 percent U_3O_8, less than 0.1 percent V_2O_5, less than 0.001 percent copper, and 28.6 percent $CaCO_3$. Other prospect pits in the same area have similar lithology, with less conglomerate and less radioactivity.

The Sugar Loaf group (Locality 9) contains two separate deposits in sandstone at least 150 feet above the base of the Browns Park formation. The topographically higher deposit is about 75 feet above and 100 feet west of the lower deposit. Fine- to medium-grained clayey sandstones form beds 4 to 8 feet thick at the lower claim of the group. The finer-grained beds are indurated with authigenic silica, but the coarser beds are less well cemented. The mineralized area is highly fractured, and clay slickensides, limonite, jarosite, and gypsum are common along the fracture planes. The ore deposit is controlled by fractures, and yellow and green uranium minerals coat some of the fracture planes. The deposit trends north and is exposed by two short drifts and several prospect pits for at least 300 feet.

It has a vertical exposure of about 50 feet. A channel sample from one of the drifts contains 0.25 percent U_3O_8, 0.05 percent V_2O_5, and 0.07 percent copper.

At the higher deposit of the Sugar Loaf group, well-rounded medium-grained thin-bedded to massive sandstone is exposed. Limonite- and jarosite-stained zones parallel bedding and form concretions, some manganese stain is visible, and some gypsum occurs along fractures. Radioactivity as high as 0.25 mr/hr and averaging 0.18 mr/hr is in a limonite- and hematite-stained, hard, gray orthoquartzite lens that is 150 feet long and 4 feet thick. A 4-foot channel sample of the orthoquartzite, taken from a prospect pit that is 200 feet long, 50 feet wide, and 10 feet deep, contains 0.04 percent U_3O_8, 0.05 percent V_2O_5, and no copper.

Shipments of ore totaling 48 tons and averaging 0.19 percent U_3O_8 and 0.10 percent V_2O_5 have been made from the Sugar Loaf group.

The Cedars Mining Company is developing claims about 100 feet above the base of the Browns Park formation southwest of Lay (Locality 10). The formation here is composed of conglomeratic beds 15 to 20 feet thick overlain by fine-grained sandstone and interbedded with medium- to coarse-grained, irregular- and thin-bedded sandstone. The grains in the conglomerate are well-rounded, average one-eighth inch in diameter, have a maximum intermediate diameter of three-fourths inch, and are composed of black quartz, yellow siltstone, sandstone, and limestone.

The upper part of the conglomeratic unit is radioactive, usually 0.25 to 0.40 mr/hr with a maximum of 1.0 mr/hr. Limonite, jarosite, manganese stain, and caliche are common along fractures, and some yellow and light-green uranium minerals coat sand grains and fracture planes. In the most radioactive area green uranium minerals, including uraniferous opal identified by M. E. Thompson of the Geological Survey, are associated with limonite, hematite, gypsum, and some jarosite. Sabugalite, an alumino-autunite, has been reported from this area. The radioactive zone is at least 1,500 feet long, 75 to 100 feet wide, and has a trend of N. 25° W. There is a strong correlation of radioactivity with iron and manganese in the zone, and both decrease in amount to the north.

Analyses (in percent) of three channel samples from the most radioactive area are:

U_3O_8	V_2O_5	Cu	Lime
0.035	<0.10	0.004	0.4
.03	.13	None	—
.02	.05	.04	—

A shipment of 1,600 pounds of ore from this area averaged 0.27 percent U_3O_8 and 0.06 percent V_2O_5.

At the Gertrude group (Locality 11) two bulldozer cuts expose radioactive well-rounded medium-grained quartz-rich sandstones about 125 feet above the base of the Browns Park formation. In the upper cut limonite is abundant in streaks parallel to bedding and as concretions; hematite, jarosite, and gypsum occur along fractures. Radioactivity in the upper cut ranges from 0.18 to 0.23 mr/hr in a manganese-stained zone outlined by limonite and hematite staining. This zone is 10 feet long and 6 inches thick. A channel sample of the ore zone contains 0.009 percent U_3O_8, less than 0.1 percent V_2O_5, less than 0.001 percent copper, and 32.1 percent $CaCO_3$.

In the lower cut the clayey, possibly tuffaceous, sandstone may be subdivided into three units. In the lower unit—exposed thickness 8 feet—limonite specks are abundant; and radioactivity ranges from 0.20 to 0.35 mr/hr. A channel sample across 4 feet of this unit contains 0.08 percent U_3O_8, 0.07 percent V_2O_5, and no copper. Yellow and green uranium minerals are disseminated in a zone 1 foot thick and 20 feet long which overlies the lower unit and forms the second unit. Radioactivity in this zone ranges from 0.5 to 0.7 mr/hr and diminishes at the east end of the zone. A channel sample from the ore zone of the second unit contains 0.98 percent U_3O_8, 0.03 percent V_2O_5, and no copper. The uppermost unit has an exposed thickness of 6 feet and is characterized by the absence of both limonite specks and visible uranium minerals. Preparations to mine the ore shown in these cuts are underway.

During the winter of 1954-1955 the Gertrude property was drilled and additional ore blocked out to a depth of at least 100 feet. The top ore horizon, which is about 4 feet thick and 3 feet below the surface, has been exposed in one bulldozer cut. A channel sample of this ore contains 0.55 percent equivalent U_3O_8, 0.13 percent chemical U_3O_8, 0.02 percent V_2O_5, no copper, and 1.2 percent $CaCO_3$. Plans for building a mill to process the ore from these claims were announced in August 1955. The mill will be located near Maybell.

A shipment of 10 tons from the Gertrude group reportedly assayed 0.28 percent U_3O_8, 0.02 percent V_2O_5, and 5.7 percent $CaCO_3$.

Deposits of the Buffalo Head Mining Company (Locality 12) are in a thick unit of lenticular, interbedded fine- to medium-grained tuffaceous sandstones, probably 150-250 feet above the base of the Browns Park formation. Radioactivity as high as 0.30 mr/hr occurs in a gray fine-grained massive sandstone with some limonite streaks. Visible uranium minerals are concentrated along fractures. A channel sample from this occurrence contained 0.23 percent equivalent U_3O_8, 0.21 percent chemical U_3O_8, 0.03 percent V_2O_5, no copper and 0.6 percent $CaCO_3$. Other radioactivity as high as 0.04 mr/hr occurs in lenses of limonitic sandstone. A channel sample of one of these lenses contains 0.02 percent chemical U_3O_8 and no vanadium or copper.

The deposits 2 miles north of Maybell (Locality 13) are in alternate laminae of clean white coarse- to fine-grained eolian sandstone. Although the crossbedding laminae are usually well defined, the radioactive zones are irregular and frequently crosscutting. Most of the radioactivity is in hard calcite-cemented zones that are outlined by limonite-stained zones. In one trench these zones are most common in a horizontal sandstone bed 2 feet thick that truncates the underlying crossbedded sandstone. At this deposit a vertical, east-trending fracture is filled with sand and cemented by calcite. A hand specimen of this fracture filling produces radioactivity of 0.3 mr/hr over a background of 0.03 mr/hr. Many of the indurated, radioactive zones are cut by similar fractures, but no radioactivity was noted in these. In places indurated zones appear to spread from older fractures.

Analyses of two grab samples and one 8-foot channel sample from radioactive zones north of Maybell are:

	eU (percent)	U (percent)
Grab sample	0.002	----
Grab sample	.009	0.011
Channel sample.	.027	.053

X-ray powder pattern studies by W. F. Outerbridge of the U. S. Geological Survey, of a selected sample from Locality 13, gave a meta-autunite-type pattern.

The Shell group (Locality 14) is in irregularly bedded medium-grained silty sandstone in the lower 10 feet of the Browns Park formation. Radioactivity that may be traced for 300 feet is as high as 0.32 mr/hr and averages 0.15 mr/hr; it is associated with limonite and minor manganese staining on fractures. A channel sample of the radioactive zone contains 0.031 percent U_3O_8, less than 0.1 percent V_2O_5, 0.002 percent copper, and 4.8 percent $CaCO_3$; analyses of 0.04, 0.05, and 0.12 percent U_3O_8 have been reported from this zone.

A prospect containing an oil seep in medium-grained crossbedded sandstone about 100 feet above the base of the Browns Park formation at the town of Elk Springs, 24 miles southwest of Maybell, is radioactive; it averages 0.05 mr/hr and attains a maximum of 0.15 mr/hr. Sandstones adjacent to the seep contain abundant limonite and jarosite in zones parallel to and cutting across the bedding. A channel sample of sandstone at the seep contains 0.02 percent U_3O_8, 0.04 percent V_2O_5, and 0.03 percent copper.

ORIGIN AND CONTROLS OF URANIUM DEPOSITS

All known uranium occurrences in the Browns Park formation are in or east of the belt of eolian sandstones. The distribution may be due to lack of prospecting west of the belt, but this is unlikely considering the rate at which deposits are being found in the Lay-Maybell area and the number of prospectors combing the country. The belt of eolian sandstones approximately coincides with the lowest part of the original basin of deposition, and it coincides with the present topographic low. The asymmetric distribution of the deposits suggests that the uranium source was to the east. Two possible sources are inferred: the Precambrian complex of the Sierra Madre and the Park Range, or the late Cenozoic igneous rocks along the west flank of these mountains.

Love (1953) postulates that uraniferous tuff was deposited in lakes where algal limestones of the Browns Park formation were forming, and also that some of the deposits on Miller Hill may be reconcentrations (either syngenetic or epigenetic) of uranium from the tuffaceous debris. Vine and Prichard (1954) prefer the hypothesis that the deposits near Baggs were formed by leaching from former, overlying tuff and reconcentration of the uranium in lower beds of the Browns Park formation. They also suggest that this process may have concentrated uranium in older formations underlying the Browns Park formation. Both these hypotheses stress igneous activity. A better understanding of the igneous rocks along the Colorado-Wyoming border between Dixon and Steamboat Springs is requisite to understanding the uranium deposits.

Localization of radioactivity along east- and north-trending fractures in the Lay-Maybell area suggests that uranium-bearing solutions followed these planes of weakness. Post-Browns Park formation faults along similar trends are mapped by Bradley (1935 and 1945), and most of the dikes north of Craig also follow these trends. The fractures would serve as channels for migration of either meteoric or hydrothermal solutions.

Love (1953) describes the association of uranium with calcite, limonite, and tuffaceous material at Miller Hill. The association with calcite and limonite, and to a lesser extent the association with tuffaceous material, persists in deposits throughout the Browns Park formation. No evidence of localization by clay minerals or permeability traps has been uncovered. The absence of carbonaceous material from the Browns Park formation is distinctive. It is possible that calcite is the precipitating agent, producing a basic environment and causing precipitation of both uranium and iron from acid solutions.

RECOMMENDATIONS

Regional mapping of the area underlain by the Browns Park formation, shown on plate 1, should be undertaken to study possible relations of the uranium deposits to: 1) facies changes within the formation, 2) Miocene and later structural features, 3) structure of the rocks underlying the formation, and 4) igneous rocks north of Craig and west of Dixon. Some of this mapping has already been started by the Geological Survey. The Browns Park formation probably is present in much of the area between Steamboat Springs and Dixon. This area should be mapped and evaluated for its uranium potential. Petrographic and heavy-mineral studies should coincide with the mapping to establish the sedimentary history of the formation.

Additional airborne-scintillation-counter work should include outcrops of the Browns Park formation south and southwest of Maybell and northwest of Steamboat Springs. Drilling should penetrate at least 200 feet below the Browns Park formation both in search of ore and for geologic information. The possibility of ore-grade deposits occurring in the Mesa Verde formation, as they do between Skull Creek, Colo., and Vernal, Utah, should not be overlooked.

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