Preliminary Report on the Uranium Deposits in the Miller Hill Area, Carbon County, Wyoming

By J. D. Love

Trace Elements Investigations Report 315

UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

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Dr. Phillip L. Merritt, Assistant Director
Division of Raw Materials
U. S. Atomic Energy Commission
P. O. Box 30, Ansonia Station
New York 23, New York

Dear Phil:

Transmitted herewith are six copies of TEI-315, "Preliminary report on uranium deposits in the Miller Hill area, Carbon County, Wyoming," by J. D. Love, January 1953.

We plan tentatively to publish Part I of this report as a Survey circular, and are asking Mr. Hosted to approve this plan. Final decision on publication, however, can be reached only after a more complete review of the material and sources of information.

Sincerely yours,

V. E. McKelvey
for W. H. Bradley
Chief Geologist

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UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

PRELIMINARY REPORT ON URANIUM DEPOSITS IN THE MILLER HILL AREA, CARBON COUNTY, WYOMING*

By

J. D. Love

January 1953

Trace Elements Investigations Report 315

This preliminary report is distributed without editorial and technical review for conformity with official standards and nomenclature. It is not for public inspection or quotation.

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

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By J. D. Love

ABSTRACT

A sequence of radioactive rocks of Miocene (?) age, the Browns Park formation, in the Miller Hill area of southern Wyoming is more than 1,000 feet thick. The formation crops out in an area of approximately 600 square miles, and consists of a basal conglomerate, tuffs, tuffaceous limy sandstones, and thin persistent radioactive algal limestones.

Uranium is concentrated in both algal limestones and in tuffaceous limy sandstones. The uranium is believed to have been deposited at least in part with the sediments, rather than to have come in at a later date. The highest uranium values were found in a widespread algal limestone bed, which contains as much as 0.15 percent uranium. Values of 0.01 percent uranium or more were obtained from 8 samples taken from approximately 220 feet of stratigraphic section in the Browns Park formation.

This is the first reported occurrence of limestone source rock from Wyoming that has been found to contain a commercial grade of uranium. The economic possibilities of the area have not been determined adequately and no estimates of tonnage are warranted at the present time.

An airborne radiometric survey was made by the Geophysics Branch of the Geological Survey, of the west half of the area, recommended by

the writer for investigation. Ground check of all anomalies reported at that time showed that they were in localities where the background radiation was much higher than average. Additional localities with high background radiation were found on the ground in the area east of that which was flown.

INTRODUCTION

The Miller Hill area is located in Carbon County, southern Wyoming. (See index figure on Plate 1.) The writer recommended the area for airborne radiometric survey because (1) tuffaceous Miocene rocks in other areas are known to be slightly radioactive; (2) the Browns Park formation, of Miocene (?) age, overlaps carbonaceous sandstones and coal beds in the Morrison, Cloverly, Frontier, Mesaverde, Lance, Fort Union, and Wasatch formations in this region; (3) many analyses of water from Oligocene, Miocene, and Pliocene rocks in adjacent regions show appreciable quantities of uranium now being leached out by ordinary ground water; and (4) it is reasonable to assume that leaching probably went on in the past as well as the present, with the result that secondary concentrations of uranium could be expected in favorable host rocks that were accessible to uranium-bearing ground waters.

On October 27, 1952, the U. S. Geological Survey flew a series of lines in the west half of the Miller Hill area, using a scintillation-detector-equipped DC-3 plane; J. D. Vine of the U. S. Geological Survey served as geologist and observer. The anomalies which were noted in the airborne radiometric survey of the western part of the Miller Hill area are shown on plate 1 and have been described in TEM-606 (Meuschke and Moxham, 1953).

J. D. Vine and the writer spent October 29 to 31 in the field, checking the anomalies reported in the airborne survey, describing the stratigraphy, sampling the rocks and water, and doing reconnaissance mapping. Because of the lateness of the season and the high altitude, no extended field work was attempted. Shortly after the investigation was concluded, the area was covered with snow and no further work could be done. The southern half of the area is not accessible to cars in the winter and is not inhabited at that time of the year.

The writer is responsible for mapping of the algal limestone marker bed within the Browns Park formation (pl. 1), for the cross-section, for the stratigraphic data, and for the terminology used. Gene Del Mauro, a graduate student at the University of Wyoming, spent the field season of 1952 making a detailed geologic map of the Miller Hill area for a thesis and he kindly gave the writer permission to use a part of his map. The writer wishes to acknowledge the assistance of J. D. Vine, who first observed the anomalies from the plane, who helped with the ground investigations and sampling, and who aided in many other ways. The cooperation of J. L. Meuschke and R. M. Moxham ~~of the Geophysics Branch of the~~

~~Geological Survey~~, who were in charge of the airborne radio~~metric~~ survey, ~~is acknowledged. Norman M. Denson~~ helped in many ways to facilitate the work on this project. Mr. Lewis F. Rader, Jr., and his associates gave prompt and efficient service on chemical and radiometric analyses. The work was done on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission.

GEOGRAPHIC SETTING

Miller Hill is a dissected plateau (figs. 1, 2, and 3) extending northward from the Sierra Madre in southern Wyoming. This plateau has an average elevation of 8,000 to 8,500 feet. To the east, north, and west, the elevation drops off about 1,000 feet along the major drainages. The area straddles the Continental Divide; drainage to the east and north goes into the North Platte River, and drainage to the west goes into the Colorado River system, by way of Little Snake River.

There are no towns or state or federal highways in the area. Rawlins, the county seat of Carbon County, is 19 miles to the north. The area is accessible by many roads, including several that are graded and one that is gravelled. The area is sparsely settled, and only the northern part is inhabited all year around. Sheep and cattle ranching is the only industry. Several wells have been drilled for oil without success. The Hatfield oil field is about 9 miles to the north, along the main road to

Figure 1. --View looking northeast down Big Sage Creek. Tbp is Browns Park formation; Jm is Morrison formation; Jn is Nugget sandstone; T_Rc is Chugwater formation. Note plane surface on which Browns Park formation was deposited.

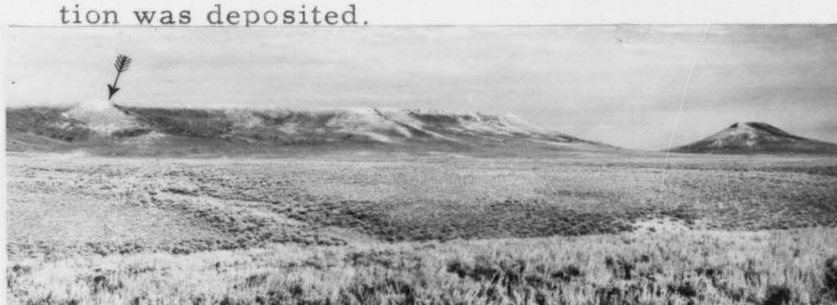

Figure 2. --View looking north across Sage Creek Basin. On skyline are northwesternmost outcrops of algal limestone marker bed capping high ridge of Browns Park formation. Arrow indicates the same point as the right arrow in figure 3.

Figure 3. -- View looking west from locality VW-1256. Sage Creek Basin is in right distance. High ridge at left and on distant skyline is held up by algal limestone marker bed in Browns Park formation. Arrow at left indicates spur on which locality VW-1244 is located. Arrow at right indicates point shown by arrow on figure 2.

Rawlins. Vegetation is sparse throughout the entire area and bedrock is comparatively well exposed.

GEOLOGIC SETTING

Miller Hill is an erosion remnant of moderately resistant, nearly horizontal strata of Miocene (?) age resting unconformably on the crest of a Laramide fold, which is reflected in the older rocks and extends north from the Sierra Madre (Love, et al., 1952). The Laramide fold, forming the Miller Hill and Hatfield anticlines, continues northward nearly to Rawlins, where it terminates in the complexly folded and thrust-faulted structure known as the Rawlins Uplift, where the pre-Cambrian and Paleozoic rocks are exposed. To the east in the Saratoga Valley gently folded Cretaceous strata are overlain by nearly horizontal Miocene and Pliocene rocks. To the northwest is the Great Divide or Red Desert Basin, filled with lower Eocene and older rocks that are only slightly folded except near the eastern margin where folding is more intense. To the southwest is the Washakie Basin, another Tertiary structural basin filled with nearly horizontal rocks, and separated from the Red Desert Basin by the Wamsutter Arch.

STRATIGRAPHY

Comparatively little geologic work has been published on the Miller Hill area. Collier (1925) made the first moderately detailed geologic and structure contour map. Buehner (1936) remapped part of the area and extended his mapping farther to the east. Larson and Vieaux (1951) published a structure contour map of the western dome of the Miller Hill anticline. Gene Del Mauro has completed the most recent and most detailed geologic map of the area. All available mapping, including the work by Del Mauro, has been compiled on the geologic map of Carbon County (Weitz and Love, 1953).

No pre-Cambrian or Paleozoic rocks are exposed in the area, but they are known from a number of wells and are described briefly here because, as indicated on the cross-section accompanying the geologic map (pl. 1), they are unconformably overlapped by the uranium-bearing Miocene (?) rocks.

Pre-Cambrian rocks

The pre-Cambrian rocks, exposed in the core of the Sierra Madre, 5 miles to the south of the mapped area, consist chiefly of granite, granite gneiss, schists, and ultramafic rocks, cut by abundant white quartz dikes or veins. The quartz is so abundant that it forms one of the conspicuous constituents of the basal conglomerate in the Tertiary rocks of this area. In the southern part of the mapped area, the Shell Oil Company, Rawlins No. 1 well, sec. 27, T. 17 N., R. 88 W., encountered biotite schist at a depth of 2,090 feet.

Cambrian rocks

The Cambrian rocks are not exposed in the area but the Shell well completely penetrated the Cambrian section, which here is 285 feet thick. The rocks consist chiefly of reddish to gray hard coarse-grained to medium-grained sandstone with some half-inch green mudstone partings in the upper portion. Many of the sand grains are frosted and rounded. The lower 100 feet contains many clear glassy quartz pebbles a quarter of an inch or more in diameter and some gray chert or quartzite fragments. The sand grains are commonly much more angular than those higher in the section. A number of oil shows were encountered in several tests in the area. The rocks are considered to be Cambrian on the basis of stratigraphic position and similarity of lithology with fossiliferous Cambrian strata at Rawlins, 19 miles to the north.

Mississippian rocks

The Madison limestone, of Mississippian age, rests directly on the Cambrian rocks, and consists chiefly of massive blue-gray to cream-colored limestone containing some chert. An arkosic limy sandstone is at the base. The top of the Madison limestone is a subject of controversy because of limestones in the overlying sequence, and therefore the thickness of the formation is a matter of interpretation. The writer is of the opinion that the thickness of the Madison limestone is about 80 feet in the wells drilled within the Miller Hill area.

Pennsylvanian rocks

Rocks of Pennsylvanian age are represented by the Amsden and Tensleep formations, which are not subdivided in this report because the contact between them is rather indefinite. The combined thickness of the sequence is about 600 feet if the writer's interpretation of the base is correct. The upper 300 feet, comprising most of the Tensleep sandstone, is almost entirely white to dark gray fine-grained sandstone which becomes more limy near the base. Sand grains are moderately rounded. Some red partings are present. The Shell well encountered numerous oil shows.

The sandstone section is underlain by about 50 feet of bluish-green, gray, and tan limy dolomite and limestone. Below this is an alternating sequence about 120 feet thick, of red and green shale containing chert nodules, thin limestones and dolomites, and sandstone. The lower 130 feet of section is largely purple, red, brown, and white limestone with red shale partings, underlain by a basal sandstone. Most of the sequence is considered to be of Pennsylvanian age, but the lower limestone may be of Mississippian age. Some workers consider it part of the Madison limestone.

Permian rocks

The Permian rocks consist of about 225 feet of lavender to gray limestone and dolomite interbedded with red sandy shale. Most of the redbeds are in the upper half of the sequence and the lower part is gray sandy limy dolomite, some of which is oil-stained in several test wells drilled in the area. These rocks correlate with the Phosphoria formation of areas to the west and north.

Triassic rocks

The Triassic rocks are represented by the Chugwater formation. The upper part of this formation is exposed in the area and the lower part is known from a number of wells drilled for oil. The entire formation is about 1,100 feet thick and consists of red sandy shale and red siltstone. About 425 feet below the top is the Alcova limestone member, 10 feet thick, and consisting of purplish-gray hard dense limestone. This member is a widespread marker bed in south-central Wyoming. The overlying portion of the Chugwater formation consists almost entirely of red silty claystone and siltstone with a conspicuous ocher-colored zone 10 to 15 feet thick, 50 feet below the top. No sandstones and limestone pellet conglomerates, such as are typical of the Jelm formation in areas to the east, are present here. The lithology, on the contrary, is similar to that in the Popo Agie member of the Chugwater formation, which occurs above the Alcova limestone member in areas farther north.

Jurassic rocks

Nugget sandstone

The Nugget sandstone ranges from 60 to 97 feet in thickness and is red to white, medium-grained, with abundant large rounded frosted quartz grains in a finer grained matrix. Bedding is remarkably even in part and cross-bedded in part. The sandstone is commonly moderately soft and porous and is one of the best aquifers in the region. On Big Sage Creek, many of the springs which furnish water for the town of Rawlins, emerge from the outcrops of the Nugget sandstone.

Sundance formation

The Sundance formation is divisible into two units. The lower one is 45 feet thick and consists of pink, brown, and gray very fine-grained non-glauconitic limy sandstone. The upper unit is about 90 feet thick and consists of greenish-gray to yellowish sandy glauconitic shale and shaly sandstone containing abundant marine fossils.

Morrison formation

The Morrison formation consists of 225 to 275 feet of greenish-gray to palely variegated hard and soft siliceous claystones and siltstones, with interbedded thin nodular limestones and thin silty fine-grained sandstones. It crops out in many parts of the area and commonly forms slopes below cliffs of the overlying formation.

Cretaceous rocks

Cloverly formation

The Cloverly formation crops out extensively in the southern and northwestern parts of the area and consists of about 100 to 150 feet of gray to tan sparkly clean angular porous sandstone interbedded with black and dark gray silty shale partings. In many places the basal bed is a chert pebble conglomerate which attains a maximum local thickness of about 50 feet. The overlying sandstones are ferruginous, cross-bedded, and commonly form cliffs and ledges. Some are slightly carbonaceous.

Thermopolis shale

The Thermopolis shale consists of two members, a lower black shale about 50 feet thick, overlain by the Muddy sandstone member which ranges in thickness from 30 to 50 feet. The lower black shale member is very fine-grained and very soft. It thickens to the north and thins out to a feather edge south of the area. The Muddy sandstone member is a gray to brown ferruginous cross-bedded sandstone with angular grains. Some beds are carbonaceous. Black silty shale partings are common.

Mowry shale

The Mowry shale is one of the most distinctive units in the area. The contact with the overlying Frontier formation is a matter of some dispute, but if the writer's interpretation of the contact is correct, the Mowry shale is about 350 feet thick. It consists chiefly of hard black siliceous shale that weathers silvery gray and breaks into rectangular slabs on which are impressions of many fish scales. Numerous thin bentonite beds are present. Thin quartzitic brown sandstone beds occur at various horizons.

Frontier formation

The Frontier formation consists of about 700 feet of gray and brown sandstones in beds 10 to 70 feet thick, alternating with an equal or greater amount of gray to black sandy and silty shale. Selection of both the bottom and top of the formation is an arbitrary matter. The sandstones are moderately coarse-grained, porous, carbonaceous in part, and moderately lenticular.

Niobrara formation

The Niobrara formation is a soft sequence of gray to yellowish limy shales with two chalky limestone beds in the upper part. The thickness is about 1,200 feet, depending on the interpretation of the basal and upper contacts. The writer places the base at the contact with the uppermost conspicuous Frontier-type sandstone and the top above the uppermost white limestone, where the shales become sandy. The sequence is quite fossiliferous throughout. About 500 feet above the base is a zone of limestone concretions ranging in thickness up to about 50 feet. About 600 and 1,100 feet above the base are two 50-foot beds of white to gray slabby sandy limestone.

Steele shale

The Steele shale forms broad valley outcrops in the northern part of the area and these continue for several miles to the east, north, and west. The formation is about 3,500 feet thick in this area, and consists of a monotonous sequence of gray sandy shales, with numerous thin sandstones in the upper 1,000 feet. The entire formation contains marine fossils.

Mesaverde formation

The Mesaverde formation does not crop out within the map area but forms prominent cliffs and hogbacks on the northeast, north, and west flanks of the Miller Hill-Hatfield anticline. The thickness is approximately 2,000 feet. The formation consists chiefly of gray to brown fine-grained to medium-grained sandstones, numerous coal beds and carbonaceous shales, and some gray sandy shales. The shales are more abundant in the middle part and the sandstones and coal beds in the upper and lower parts.

Lewis shale

The Lewis shale forms broad valley outcrops along the west flank of the Miller Hill anticline but is not present within the map area. The formation consists of about 1,800 feet of soft gray to yellowish-tan sandy shale, with some thin fine-grained sandstone beds.

Lance formation

The Lance formation consists of about 4,000 feet of alternating ferruginous brown and gray sandstones, white sandstones, and gray, brown, and black sandy shales. Numerous thin coal beds and partings are present throughout the formation. The sandstones are moderately fine-grained and many are so resistant that they form escarpments.

Tertiary rocks

Fort Union formation

The Fort Union formation of Paleocene age is present to the west of the mapped area and forms broad outcrops along the west flank of the Miller Hill anticline. Because the formation is unconformably overlapped by younger rocks, the thickness varies considerably from place to place. An average figure is about 2,500 feet. The lower 1,000 feet or more is chiefly soft gray, rusty brown, and black shale interbedded with fine-grained ferruginous sandstone. Conglomerates occur at the base and in the upper part of the formation. Fragments of Mesozoic rocks are more abundant in the lower part and Paleozoic rocks in the upper part. Sandstones and coal beds are present throughout but are more abundant in the upper half.

Wasatch formation

The Wasatch formation of lower Eocene age overlaps a considerable part of the Fort Union formation west of the mapped area. The thickness is variable, considerably more than 1,000 feet in places. The lower part contains conglomerates and arkosic grits derived from pre-Cambrian rocks. These become much coarser-grained from south to north. Overlying this facies are carbonaceous shales, coal beds, variegated claystones, and gray to ferruginous brown sandstones.

Browns Park formation

The Browns Park is the only Tertiary formation within the mapped area. It crops out throughout the southern and western parts and these outcrops continue southward to the Colorado-Wyoming state line, covering an area of about 600 square miles. The formation in this area has never been described in detail and has commonly been referred to either as the "Bishop conglomerate" or the North Park formation. McGrew (1951) first called attention to the fact that both Miocene and Pliocene rocks were present in the Saratoga Valley to the east and he called the Miocene sequence the Browns Park formation. No fossils have been found in this sequence in the Miller Hill area so it is correlated with the Browns Park formation in the Saratoga area on the basis of continuity and lithologic similarity.

The formation is divisible into two members. At the base is a conglomerate which ranges in thickness from about 20 feet in the southern part of the mapped area to nearly 100 feet of interbedded conglomerate and sandstone on the north face of Miller Hill (figs. 4 and 5). At the latter locality there are some boulder beds with boulders of pre-Cambrian and Paleozoic rocks as much as 4 feet in diameter embedded in a matrix of angular to subrounded fragments 2 to 4 inches in diameter. Here the upper 15 feet of the conglomerate becomes finer-grained and abundant highly-rounded black chert, quartzite and quartz pebbles 1/4 to 1/2-inch

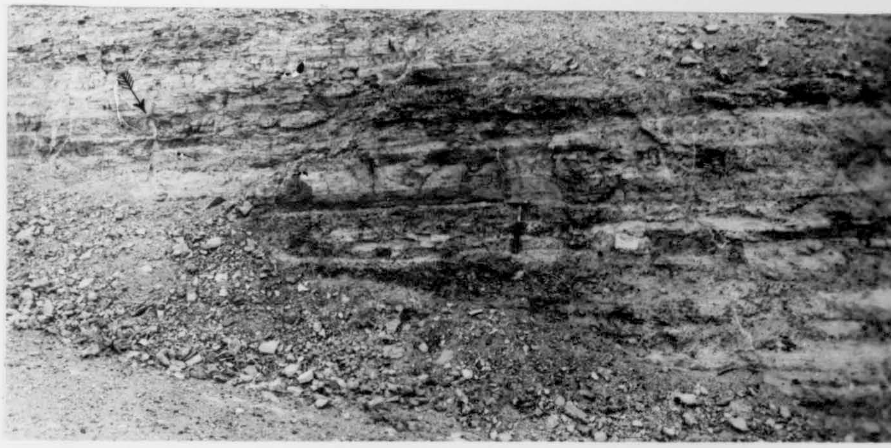

Figure 4.--Upper part of basal conglomerate of Browns Park formation. Outcrop is along road cut near top of Miller Hill in northwest part of area. Note even bedding in black chert pebble conglomerate and in light-colored tuff. Arrow indicates point shown in center of figure 5.

Figure 5.--Detail of lithology in conglomerate of Browns Park formation. Face shown is that indicated by arrow in figure 4. Note black chert pebbles.

in diameter occur in well-bedded layers, intertongued with fine-grained drab to brown thin-bedded tuff and tuffaceous sandstone (figs. 4 and 5).

Throughout the region, the most conspicuous feature of the conglomerate is the abundance of white quartz pebbles. The black chert pebbles are similar to those described in the Bishop conglomerate in areas to the west and southwest, but there is some doubt as to the correlation. Within the mapped area these pebbles were observed only on Miller Hill. Until more information is available, the conglomerate sequence is considered to be a basal facies of the Browns Park formation.

The remainder of the Browns Park formation consists of white and light gray limy sandstones interbedded with thin persistent limestones. The most complete section of the formation within the mapped area is on Middlewood Hill, where approximately 1,000 feet of strata are present. There was no time for a detailed examination of these rocks but a generalized description is as follows:

Unit	Thickness (feet)	Lithologic character	Uranium content
15	500	Sandstone, white to light gray, very tuffaceous, soft, fine-grained to coarse-grained, evenly bedded, with numerous resistant limy layers that form persistent ledges. Top of unit is top of Middlewood Hill.	No analyses
14	100	Sandstone, white to gray, limy tuffaceous, interbedded with white crystalline nodular sandy tuffaceous limestone; one such limestone 2 feet thick at top of unit has the following analysis (VW-1241):	eU 0.016% U 0.012%

13	12	Algal limestone marker bed, gray, hard, very ragged and nodular (figs. 6, 7, 8, 9) on weathered surfaces, with some tuffaceous sandy beds 1 to 2 feet thick in lower two-thirds; pseudo-oolitic in lower 2 feet and contains abundant vertical root tubes, some of which fluoresce brilliant yellow under ultraviolet light; top 6 feet contains masses and fracture fillings of dark gray to brown chalcedony and opal; chalcedony and limestone both quite radioactive; unit is widely persistent throughout area and appears to have abundant algal growths.	Many analyses, the lowest 0.005% eU and 0.003% U, the highest 0.19% eU and 0.15% U
12	25	Sandstone, gray, grading into sandy limestone, highly nodular, weathering into ragged porous ledges; has appearance of calcareous tufa in part.	No analyses
11	55	Sandstone, gray, limy intergrading with gray sandy limestone similar to overlying unit, but softer in lower half and forms slope; about 1 foot of dark gray tuff 35 feet below top.	No analyses but moderate radioactivity 10' above base
10	30	Sandstone, gray, hard, very limy, weathering into ragged ledges. Sample from top 6 inches (VW-1245) shows:	eU 0.009% U 0.01%
		Sample from 1 foot of section 4 feet above base (VW-1246) shows:	eU 0.008% U 0.007%
9	50	Sandstone, white to light gray, soft, fine-grained, very tuffaceous, micaceous in part; numerous black grains but very few red ones.	No analyses
8	10	Sandstone, rusty brown, ferruginous, soft, coarse-grained and finely pebbly.	No analyses

Figure 6.--Uranium-bearing limestone in Browns Park formation. Arrow indicates man standing on south-west end of uranium deposit in algal limestone marker bed at locality VW-1248. This is one of the two richest uranium deposits found in the area.

Figure 7. --Section of Browns Park formation at locality VW-1256. Arrow at left indicates point on algal limestone marker bed shown in figure 9. Arrow at right shows point on marker bed indicated by right arrow in figure 8.

7	15	Tuff, white to gray, very soft, light weight, interbedded with some gray sandstone.	No analyses
6	5	Sandstone, rusty gray, hard, cross-bedded to evenly bedded, fine-grained; forms slabby ledge.	No analyses
5	40	Tuff, chalky white, thin-bedded to irregularly bedded, nodular in part; interbedded with some gray fine-grained tuffaceous sandstone.	No analyses
4	40	Sandstone, gray, soft, interbedded with gray tuff.	No analyses
3	10	Quartzite, iron gray, fine-grained bedded, very hard; breaks with conchoidal fracture into sharp angular fragments; a very persistent unit.	No analyses
2	35	Sandstone, gray, hard, slabby, with frosted rounded quartz grains; interbedded with drab soft blocky tuffaceous claystone.	No analyses
1	20-100	Conglomerate, gray, composed of boulders of pre-Cambrian and Paleozoic rocks as much as 4 feet in diameter but averaging about 2 inches; most conspicuous lithology is white coarsely-crystalline quartz in great abundance; fresh exposures show a predominance of dark green to black basic pre-Cambrian rocks and brown granite.	No analyses
	957-1037	Approximate total thickness of Browns Park formation in this locality.	

Contact between Browns Park formation and Nugget sandstone (fig. 1). This contact is a remarkably plane surface, not only in this locality but in other places where it could be observed, regardless of the resistant or

Figure 8.--Typical outcrop of algal limestone marker bed in section of Browns Park formation at locality VW-1256. Arrow at left indicates exposure shown in figure 9. Arrow at right shows man for scale.

Figure 9.--Detail of algal limestone marker bed at locality VW-1256. Locality is at point indicated by left arrow in figure 8. Note hammer in center of picture. Limestone at this point contains 0.01 percent uranium and chalcedony in upper limestone ledge contains 0.008 percent uranium.

weak character of the underlying rocks, and regardless of the attitude of these rocks.

The most persistent and remarkable unit in the formation is here called the algal limestone marker bed (unit 13 in preceding section). This bed can be followed throughout the southwestern part of the mapped area (See geologic map and figs. 2 and 3), and either it or a similar bed extends for many miles to the south. The lithology is consistent wherever the unit was examined. The limestone is commonly gray, hard, massive to irregularly bedded and contains abundant structures that are probably algal growths. These are embedded in softer tuffaceous sandy rock that weathers away more easily than the growths, so that weathered surfaces are characteristically ragged and pitted (fig. 9). Structures resembling oolites are common in the lower part and many root tubes in vertical position are present. The upper part of the limestone is more massive and purer than the lower part. It is brittle and highly fractured in places and these fractures are filled with brown to gray chalcedony.

This marker bed contains by far the greatest concentration of uranium found to date in the area. The appearance of the bed in outcrop is shown in figures 2, 3, 6, 7, 8, and 9.

Quaternary deposits

Alluvium

There is comparatively little alluvium within the mapped area, and that is confined to the bottoms of the major stream valleys. The deposits are thin and consist of locally derived sand, gravel, clay, and silt brought in from the steep sides of the valleys and deposited where stream gradients lessen.

Landslide debris

Landslide debris is confined to the north-facing and east-facing escarpments of Miller Hill. Ground water has seeped out from the basal conglomerate of the Browns Park formation where it overlies Cretaceous shales. These shales have become saturated and slumped down steep slopes at the foot of the escarpment of the Browns Park formation. This action leads to sapping of the escarpment, rejuvenation of the seeps, more saturation of the shales, and repetition of the whole cycle. The landslide debris is a mixture of Cretaceous shale, and Miocene (?) tuff, sandstone, and conglomerate.

URANIUM DEPOSITS

General statement

No appreciable amount of radioactivity in rocks older than the Browns Park formation was detected on the ground with a portable scintillation ~~detector~~ survey meter, and only one airborne anomaly in these older rocks was recorded. The anomaly, which is in the Morrison formation, had not been reported at the time of the field check. The highest uranium values in the Browns Park formation were found in the algal limestone marker bed, which is about 335 to 400 feet above the base of the formation. This bed contains a maximum of 0.15 percent uranium at localized spots where, because of bedding-plane outcrops and the resistant character of the limestone, samples could not be dug out to a depth of more than 1 foot.

Description of deposits

Sample localities and corresponding numbers are shown on the geologic map (pl. 1) and are tied in to the generalized stratigraphic section.

Locality VW-1248

Locality VW-1248 contains the most significant concentration of uranium found to date in the area. Figure 6 shows the appearance of the locality. The uranium occurs in a zone along the stripped upper bedding surface of the algal limestone marker bed. This surface is so hard that no profile could be made and even chip samples were difficult to obtain. The zone of high radioactivity is approximately 160 feet long, and is 6 to 12 feet wide. The southwest end is obscured by younger rocks and alluvium. Several peaks of radiation intensity are present through the length of the deposit and these were sampled. Most of the samples were taken from within a few inches of the surface because to go deeper one would need a rock drill and dynamite or powder.

Three feet northeast of the southwest end of the deposit, sample VW-1248 was cut. It contains 0.15 percent equivalent uranium and 0.075 percent uranium. Approximately 24 feet to the northeast, sample VW-1249 contains 0.21 percent equivalent uranium and 0.13 percent uranium; 49 feet farther northeast sample VW-1250 contains 0.098 percent equivalent uranium and 0.096 percent uranium; 48 feet farther northeast sample VW-1251 contains 0.089 percent equivalent uranium and 0.097 percent uranium; 12 feet farther northeast sample VW-1252 contains 0.028 percent equivalent uranium and 0.017 percent uranium. Northeast of this point the intensity of radiation diminishes and no more samples were taken.

The host rock constituting the algal limestone marker bed is about 10 feet thick, gray, very hard, fractured, and massive. Numerous brown masses and fracture fillings of chalcedony are present. A few spots of bright yellow fluorescence under ultraviolet light were observed in the limestone and chalcedony but they are not common. No uranium mineral was observed. It is not known in what form the uranium occurs. No tonnage estimate can be made for this deposit until drilling, blasting, and more sampling are done.

Locality VW-1253

Locality VW-1253 is approximately 200 feet due west of locality VW-1248 and is at the same stratigraphic horizon, at the top of the algal limestone marker bed. The area of highest radiometric readings is a circle about 10 feet in diameter. The limestone is considerably fractured and it was possible to sample to a depth of nearly 1 foot below the surface of the marker bed. Sample VW-1253 shows 0.19 percent equivalent uranium and 0.15 percent uranium through nearly 1 foot of section. Here again there is no possibility of determining the thickness, extent or tonnage of the deposit without drilling, blasting, and more sampling.

Locality VW-1256

Locality VW-1256 is about a mile southwest of locality VW-1253, and at the same stratigraphic horizon, in the algal limestone marker bed. Here an excellent cross-section of the bed is present (figs. 7, 8, 9). The radioactivity in the marker bed appears to be no greater here than along strike in adjacent localities. Here the marker bed crops out in a gray, hard, nodular ledge about 12 feet thick, and is weathered to a very ragged surface; some tuffaceous sandy beds 1 to 2 feet thick occur in the lower two-thirds of the ledge. Some oolitic structures and root tubes oriented vertically occur in the lower 2 feet. The top 6 feet of the marker bed contains masses and fracture fillings of brownish-gray chalcedony. A random sample of the limestone (VW-1256) representing about 1 foot of section contains 0.012 percent equivalent uranium and 0.01 percent uranium. A random sample of the chalcedony (VW-1257) contains 0.012 percent equivalent uranium and 0.008 percent uranium. Judging by the radioactivity measurements at the outcrop ~~scintillation-detector readings~~ similar analyses could be expected from many places along the marker bed in this vicinity.

Locality VW-1247

Locality VW-1247 is about three-fourths of a mile southeast of locality VW-1256, where the county road from Middlewood Hill to Sage Creek Basin crosses the limestone marker bed. The limestone is almost identical in lithology and thickness to that at locality VW-1256. Brownish-gray chalcedony is abundant. The limestone is very hard and essentially massive. A random sample from about 1 foot of section near the top of the limestone (VW-1247), taken at a point 100 feet south-east of where the road crosses the ledge, shows 0.019 percent equivalent uranium and 0.016 percent uranium. However, scintillation-detector readings are just as high on the same ledge northwest of the road, and presumably the uranium content would be about the same there too.

Locality VW-1244

A rough stratigraphic section was measured at locality VW-1244 and 3 samples from a stratigraphic interval of 120 feet were collected. The locality is on the west face of a prominent spur (fig. 3) capped by the limestone marker bed. The bed here consists of about 10 feet of gray hard slabby algal limestone with much secondary chalcedony. A sample from 1 foot of section at about the middle of the limestone (VW-1244) contains 0.005 percent equivalent uranium and 0.003 percent uranium, the lowest analysis obtained from the marker bed anywhere in the area. A sample from 2 feet of sandstone 80 feet below the marker bed (See unit 10 in measured section.) (VW-1245) contains 0.009 percent equivalent uranium and 0.01 percent uranium. Another sample taken 24 feet stratigraphically lower, from a similar hard gray limy tuffaceous sandstone (VW-1246) contains 0.008 percent equivalent uranium and 0.007 percent uranium.

Locality VW-1241

Locality VW-1241 is in the middle of the graded county road from Middlewood Hill to Sage Creek Basin, about a quarter of a mile northeast of where the road crosses the algal limestone marker bed and about 100 feet stratigraphically above the bed (see unit 13 in measured section). The rock consists of about 2 feet of white crystalline sandy tuffaceous limestone. A sample from the top 6 inches (VW-1241) shows 0.016 percent equivalent uranium and 0.012 percent uranium. The area of high radiation extends along the road for about 50 feet. The bed is eroded away on the south side of the road and disappears under younger strata north of the road.

Localities not sampled

Two localities showing radioactivity well above background are present along the road about half a mile north-northeast of locality VW-1241, at about the same or a slightly higher horizon. Judging by the scintillation-detector readings, the uranium content probably is about the same as that at VW-1241.

GROUND WATERS

General statement

The role of ground water in leaching, transporting, and redepositing uranium is considered here to be potentially very significant because in many areas where the strata are much less radioactive than here, ground waters contain appreciable quantities of uranium. Therefore, a number of representative springs in the Miller Hill area were sampled for analysis. The water was collected in plastic bottles to which nitric acid had been added.

Description of localities sampled

Locality VW-1254

At locality VW-1254 a water sample was collected from a spring at the base of the Browns Park formation, where the basal conglomerate overlies the Mowry shale, just north of where the graded county road reaches the crest of Miller Hill. The spring was frozen at the time of sampling so the water sample (VW-1254) was not too clean. It shows 0.010 parts per million uranium. The flow is very small and could not be accurately gauged because of the ice.

Locality VW-1255

At locality VW-1255 a sample of water was collected from a small spring coming out of the base of the hard blocky quartzite described as unit 3 in the measured section of the Browns Park formation. The flow is about 2 gallons per minute from this particular spring but there is a series of springs in this area with a considerable total flow. The locality is on the southwest side of the Middlewood Hill-Sage Creek Basin road where it crosses a small tributary of Big Sage Creek. The sample (VW-1255) contains 0.006 parts per million uranium.

Locality VW-1242

Locality VW-1242 is along the Rawlins pipe line road near the top of the high hill just north of Big Sage Creek. A small spring flows from the basal conglomerate of the Browns Park formation very close to the contact with the Morrison formation, just north of a small green house belonging to the town of Rawlins. The spring flows about 1 gallon per minute. The conglomerate is unusually indurated at this locality and consists of abundant fragments of quartz and schist in a silicified sandstone matrix. Water sample VW-1242 contains 0.002 parts per million uranium.

Locality VW-1243

Locality VW-1243 is the site of one of the big springs coming out of the Nugget sandstone along the bottom of Big Sage Creek, on the south side. The Nugget sandstone is very soft, porous, and permeable. The spring flows about 10 to 20 gallons per minute of cold water. Sample VW-1243 contains 0.002 parts per million uranium. The system of springs at this locality is most interesting and worthy of detailed study. The town of Rawlins has conducted some experiments with fluorescent dyes to determine the area of intake where these waters go underground. Much of the water enters the Browns Park formation 8 miles to the southeast. The rate of migration of this water has been determined but the data are not yet available to the writer. It is not known where the water passes from the Browns Park formation into the Nugget sandstone, or what the uranium concentration in the water is while it is still in the Browns Park formation.

THEORY OF ORIGIN OF URANIUM DEPOSITS IN THE BROWNS PARK FORMATION

The distribution of an appreciable quantity of uranium through several miles of linear outcrop of the algal limestone marker bed, the absence of any of the easily recognizable uranium minerals, and the general lack of alteration of the dense massive limestone suggest that some of the uranium was deposited along with the limestone. It is true that a considerable amount of chalcedony was introduced into fractures and in places along the few bedding planes, but ~~scintillation-detector readings~~ outcrop measurements of radioactivity and the chemical analysis VW-1257 indicate a lower uranium content in the chalcedony than in the limestone. Strata containing significant quantities of uranium both above and below the marker bed do not contain chalcedony at the sampled localities. All the uranium-bearing beds have two features in common, (1) a high calcium carbonate content, and (2) a considerable amount of tuffaceous material. Thin sections are being prepared, but at the time this report is written no petrographic data are available on the character of the tuffaceous material.

There is no evidence of Tertiary igneous intrusive rocks or flow rocks within or near the area. Those at Battle Mountain, 25 miles to the south, are basalts. None of the deep wells drilled in the area have encountered any evidence of Tertiary igneous activity.

More regional observations, as well as detailed studies, and chemical and petrographic analyses should be obtained before any defensible theory of origin can be formulated, but as a working hypothesis the writer suggests that intermittent volcanic eruptions during Browns Park time either in Colorado, Utah, Idaho, or Yellowstone National Park may have furnished radioactive ash that was deposited in extensive shallow lakes where algal limestones were being formed. It is conceivable that algae may have concentrated uranium in favorable areas, thus accounting for the spotty distribution observed in the field. A reasonable hypothesis to account for the presence of uranium in the chalcedony is that after fractures were developed by post-Miocene arching of the area, ground waters containing both silica and uranium derived from the tuffaceous material in the Browns Park formation deposited chalcedony in the limestone. When deformed, the hard, brittle limestone would not only develop fractures more readily than the sandstone and shale beds, but also fractures developed in the limestone would tend to remain open longer than those in the overlying and underlying softer beds. This may explain why there is more chalcedony in the limestone.

From the preceding suggestions, however, it should not be inferred that all of the uraniferous limestone deposits are considered as syngenetic. The data are insufficient to determine whether they are syngenetic or epigenetic.

TERTIARY AND QUATERNARY HISTORY OF THE AREA

The writer believes that there are possibilities of significant uranium deposits in rocks older than the Browns Park formation, that the uranium in such deposits may have been leached by ground waters out of the Browns Park formation or younger rocks that once were present in the area, and that the structural history and topography of the area during Tertiary and Quaternary times influenced the circulation of these ground waters.

Close of Cretaceous time

The general area of the Sierra Madre was uplifted in a broad fold at the close of Cretaceous time. The sedimentation record indicates that folding and vigorous erosion continued through Paleocene time. Conglomerates in the lower part of the Fort Union formation contain Cretaceous rock fragments, while those in the upper part contain Paleozoic rock fragments. Chemical decomposition of carbonate rocks occurred on a regional scale, for there are few limestone and dolomite rock fragments in the conglomerates.

Eocene time

The pre-Cambrian cores of the Sierra Madre and the Rawlins Uplift were breached by the time the first Eocene rocks were laid down. Intermittent uplift occurred throughout Eocene time with the most violent earth movements occurring during early Eocene time in the area about 40 miles to the east on the flanks of the Medicine Bow Mountains. Giant boulders were deposited close to the localities of greatest deformation, and finer-grained rocks were deposited in adjacent basins. Gentle arching between these basins and along the mountain flanks followed the sharp folding and thrust-faulting, but these latter movements had only minor effects on the types of sediments that were being deposited.

Oligocene time

There is no record of what happened in the Miller Hill area during Oligocene time. In the Medicine Bow Mountains to the east and the Granite Mountains to the north Oligocene tuffs, which are slightly radioactive, were deposited on a surface of rugged relief. In the Miller Hill area the Browns Park formation was deposited on a remarkably plane surface so it is presumed that this was developed at the close of Oligocene time and that any Oligocene strata that may once have been deposited here were stripped off during the development of this surface.

Miocene (?) (Browns Park) time

In the Sierra Madre, there must have been a rugged highland area of pre-Cambrian rocks with a pediment surface extending northward from it through the Miller Hill area, across resistant and non-resistant Paleozoic and Mesozoic rocks, at the beginning of Browns Park deposition. It is not known whether the deposition of the basal conglomerate was a result of uplift of this highland area or whether it was merely a function of increased precipitation. Browns Park time was one of general crustal stability in this area, with the development of extensive lakes in which algal limestones were deposited and in which much volcanic ash fell. After the deposition of the basal conglomerate, the Sierra Madre never again furnished much coarse-grained material and the north end of the range as well as the Miller Hill-Hatfield anticline extending north from it were essentially buried in fine-grained debris. Much of this debris is of volcanic origin, but the location of the volcanos furnishing the ash is not known.

Pliocene time

No Pliocene strata are present in the Miller Hill area but the North Park formation of Pliocene age is present over a wide area 15 miles to the east in the Saratoga Valley. There both the North Park and Browns Park formations are folded and faulted. In the Miller Hill area the Browns Park formation dips about 2° S and strikes N. 75° E. On Miller Hill the base of the formation is at an elevation of more than 8,000 feet and is still dipping southward, while in the Rawlins area, 20 miles to the north, the same formation is down-faulted to a position only 6,800 feet above sea level (Barlow, J. A., Personal communication, 1953). It is apparent, therefore, that in post-Browns Park time, and likely subsequent to early Pliocene time (when the North Park formation was deposited), a broad eastward-trending anticlinal fold developed in the area between Miller Hill and Rawlins. Subsequently, a normal fault developed along the north flank and the north block was dropped at least 1,000 feet.

Pleistocene time

The entire region except for the upland in the Miller Hill area was deeply eroded during Pleistocene time, and the cycle is continuing today. The Pliocene fault scarp at Rawlins was subjected to intensive erosion and the resulting erosional scarp retreated 25 miles to the south, to Miller Hill. More than 1,000 feet of rock has been removed from the areas to the east, north, and west of Miller Hill during this time and practically all the debris was carried out of the area. This drastic change in topography has altered the direction of migration of ground waters from south to the north, northeast, and northwest.

SIGNIFICANCE OF TERTIARY AND QUATERNARY DEPOSITS IN THE SEARCH FOR NEW URANIUM DEPOSITS

Analyses of ground waters indicate that small amounts of uranium are being leached out of the Browns Park formation and carried into areas where older rocks outcrop. It is logical to assume that leaching went on during earlier geologic times, with the result that secondary concentrations of uranium could be expected in favorable host rocks that were accessible to uranium-bearing ground waters.

A consideration of the positions of the major basin areas and the location of the post-Browns Park arch between Miller Hill and Rawlins indicates that there must have been extensive southward and southwestward migration of ground waters from the flank of this arch during part of Pliocene and Pleistocene time. The migration in these directions would logically have continued until southward retreat of the erosional escarpment held up by the Browns Park formation (the escarpment initially formed at the Rawlins normal fault) proceeded far enough to change the direction of migration to north, northeast, and northwest as it is today.

The Browns Park formation directly overlies porous and permeable carbonaceous and ferruginous sandstones in the Morrison formation, Cloverly formation, Muddy sandstone member of the Thermpolis formation, and Frontier formation. The following younger formations have carbonaceous sandstones in greater abundance and with greater thickness, porosity, and permeability, and in addition, contain many beds of coal: Mesaverde formation, Lance formation, Fort Union formation, and Wasatch formation. It is known from observations on the Rawlins water supply springs along Big Sage Creek that large volumes of water flow along beds in the Browns Park formation. Such waters migrating southward down dip through what are believed to be uranium-bearing source rocks, on the south flank of the post-Browns Park arch could easily pass into the upturned and eroded edges of these underlying sandstones and uranium carried by these waters could be expected to concentrate in the most favorable environment for deposition. The most porous rocks are, in general, the conglomerates. Those in the Fort Union formation are overlapped progressively from north to south by the Wasatch formation. Those in the Wasatch formation become coarser-grained from south to north along the west flank of the Miller Hill anticline. These factors have an important bearing on the selection of most favorable areas in which to search for uranium deposits.

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