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GEOLOGY OF URANIUM MINERALIZATION
IN THE BROWNS PARK FORMATION,
CARBON COUNTY, WYOMING AND
MOFFAT COUNTY, COLORADO

By
Warren Stephen Lewis
1977
A thesis submitted to the Faculty and the Board of Trustees of the Colorado School of Mines in partial fulfillment of the requirements for the degree of Master of Science.

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ABSTRACT

Uranium occurrences in the Browns Park Formation in northwestern Colorado and southern Wyoming are herein studied. The Browns Park Formation is up to 1800 feet thick with a basal conglomerate unit that is 0-300 feet thick. Stratigraphically, the Browns Park overlies formations from the Precambrian Uinta Mountain Group to the Eocene Bridger Formation. Petroleum is produced from various rocks in the underlying section, particularly in the Weber, Entrada, Morrison, Dakota, Lance, and Fort Union Formations, in the numerous oil and gas fields of northwestern Colorado. Northwest-trending folds and faults are developed in the older rocks such that hydrocarbons can migrate upward into the overlying Browns Park Formation. Much of the uranium mineralization in the Browns Park beds occurs near faults along which hydrocarbons or $\text{H}_2\text{S}$ gases may have migrated. Mineralization occurs along faults, in amoeba-shaped lenses roughly following bedding, and in pockets near a horizontal contact between upper oxidized sandstone and lower reduced, gray, pyritic sandstone. Reduction of uranium-bearing ground waters to form these deposits resulted from the presence of pyrite or $\text{H}_2\text{S}$ gas and/or hydrocarbons migrating upward into the Browns Park Formation. Sulfate-reducing bacteria may have fed upon the hydrocarbons precipitating the pyrite and/or the uranium from solution. Deposits occur beneath highly tuffaceous
sandstones which were an important source of uranium. Faulting along anticlinal structures beneath the Browns Park Formation seems to be a common characteristic of mineralized areas and these favorable geologic settings in the overlying Browns Park beds are prime targets for future exploration.
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INTRODUCTION

Purpose

The purpose of this thesis is to describe and interpret the geology of uranium deposits in the Browns Park Formation in northwestern Colorado and southernmost Wyoming. The two chief areas of mineralization are the Poison Basin area in Carbon County, Wyoming, west of Baggs (pl. 2) and the Maybell-Lay area in Moffat County, Colorado (pl. 1). By detailed examinations of the geology of these areas, it was hoped that the various structural, stratigraphic, and geochemical controls of uranium mineralization could be understood.

Location

The Poison Basin area, as defined in this work, is located in Carbon County, Wyoming, in parts of Ts. 12 and 13 N. and Rs. 92 and 93 W. just five miles west of Baggs, Wyoming. The Maybell-Lay area is much larger and lies in Moffat County, Colorado, in part of Ts. 5-7 N. and Rs. 92-96 W., about 15 miles west of Craig, Colorado, with the main mineralization between the small communities of Maybell and Lay.

The area is accessible from Denver by taking U. S. Highway 40 to Craig, Colorado. Thirty miles west of Craig on U. S.
Highway 40 is the center of the Maybell-Lay area, and 41 miles to the north on State Highway 13 is Baggs, Wyoming. The Poison Basin area can be reached from Baggs by turning west on the Poison Buttes Road north of town and driving about five miles to the west. Both areas are well traversed by county maintained roads off of which many less trustworthy roads lead. Some interesting areas were impossible to reach by car because of road quality or lack of roads, so walks of several miles were often necessary for complete coverage of the area.

Topography and Climate

The general topography is that of gentle rolling hills with low, steep buttes. Dry gullies with steep sides dissect some areas. The Poison Basin area lies in a dish-shaped synclinal valley north of the Little Snake River. The Maybell-Lay area is generally along the valley of the Yampa River and its tributary, Lay Creek.

Outcrops of the Browns Park Formation where the uranium occurs are usually of poor quality due mostly to the soft, friable nature of the sandstone so that low sandy hills develop with few, good, unslumped exposures. Good exposures can be found in some of the gullies, cliffs along the Yampa River, road cuts, strip mines, and prospect pits.
The climate is semi-arid with most of the precipitation occurring in the winter and spring as snow. The flood plains of the main drainages were irrigated mostly to grow hay for raising cattle and sheep. Other areas are sparse and dry with sage brush, cacti, and juniper trees the main forms of vegetation. Animal life evident during the summer consists mainly of antelope, lizards, prairie dogs, mosquitoes, and rattlesnakes.

Previous Investigations

Previous geologic work began with Powell (1876, p. 44) who named the Browns Park Formation. In this early reconnaissance work, he also recognized the unconformable nature of the Browns Park over all older strata, and the occurrence of tectonic episodes after deposition of the Browns Park Formation. Hancock (1915) was mainly concerned with the history of the Yampa River. He correctly interpreted the canyons through Juniper and Cross Mountains as being superposed from great thicknesses of Browns Park beds that originally covered both structures. Sears (1924) and Bradley (1936, 1945) compiled a history of Browns Park deposition and attempted to define its relationship with the Bishop Conglomerate. The fossil studies of Peterson (1928) and McGrew (1953) have made the greatest contributions toward establishing the Miocene age of the Browns Park Formation.
Work on the uranium has been limited to several short articles by Love (1953), Vine and Prichard (1954), Grutt and Whalen (1955), Grutt (1957), and Bergin and Chisolm (1956).

Methods and Scope of Research

Most of the work of this report was done in the vicinity of open pit mines where exposures were good and alteration associated with uranium mineralization could be best examined. Areas with underlying pyritic sandstone were mapped and compiled with other geologic data on U.S. Geological Survey topographic maps and transferred to a base map prepared with U.S. Geological Survey 15 and 7½ minute quadrangle maps during the course of this work, with some faults and attitudes of beds altered to fit field observations. Radioactivity measurements were made with a Precision 11lb scintillation counter measuring milliroentgens per hour which was calibrated to a standard each day before field work began. Petrography was done with 10- and 14-power hand lenses as well as examination of a limited number of thin sections.
Acknowledgements

The author is indebted to Richard H. DeVoto, thesis advisor, and Earth Sciences, Inc., of Golden for generating the idea and support for this thesis. Thanks are also extended to Professors Harold Bloom and Joseph Finney, members of my thesis committee, Frank Abshier and Charles Marchand of Earth Sciences, Inc., and Michael Brownfield of the U.S. Geological Survey for their helpful advice and discussions.
GENERAL GEOLOGY

The two areas considered in this work both lie at boundaries or transition zones between different geologic terrains. Sand Wash Basin, the surface of which is covered by Tertiary formations and Quaternary terrace gravels lies between the Poison Basin and Maybell-Lay areas (figs. 1 and 2). The Poison Basin area lies on the Cherokee anticline which separates Sand Wash Basin from Washakie Basin (fig. 2). The Maybell-Lay area lies near the eastern end of the Uinta uplift where it breaks up into a series of northwest-trending anticlines. One of these anticlines, the Axial Basin anticline cuts across the southern part of the Maybell-Lay area (pl. 1). To the south of the area, are Piceance Basin, the northern end of the Grand Hogback, and the White River uplift. To the east of the area are the Sierra Madre and Park Range uplifts.
Figure 2. Regional structure map showing oil and gas fields.
STRATIGRAPHY

The Browns Park Formation is the unit which contributes most to the understanding of the uranium deposits, since it is both the source and host of the uranium. Underlying units do have importance as sources of reductants necessary to precipitate uranium. Detailed stratigraphic and petrographic analysis of these units would serve no purpose to this thesis, however, discussions of them as possible sources of hydrocarbons and/or H₂S gases are definitely relevant to the objectives of the thesis.

Precambrian

Uinta Mountain Group

The oldest rocks exposed in the area are the Uinta Mountain Group of probable Algonkian age. These rocks are found for the most part in the Uinta Mountains west of the Maybell-Lay area, but outcrops also occur in the cores of the Cross Mountain and Juniper Mountain uplifts. Sears (1924) believed the total thickness to be at least 12,000 feet. Lithologies include conglomeratic sandstone, quartzite, chert, and red sandy shale.
Precambrian granites lie below the Uinta Mountain group, the contact being an unconformity. These granites have always been covered near the thesis area. They do crop out to the east in the Park Range and Sierra Madre uplifts.

Cambrian

Sawatch or Lodore Group

Abrassart and Clough (1955, p. 67) noted 47 to 203 feet of Cambrian rocks unconformably above the Uinta Mountain group at Juniper Mountain. There is a terminology problem with them being called the Lodore group in northwestern Colorado, and the Sawatch sandstone to the east. At Cross Mountain, Kanizay (1955, p. 61) reports these rocks to be 280 feet thick. The basal part consists of variegated and sandy shales with conglomeratic sandstones and quartzite above. No hydrocarbons have been reported from this interval.

Mississippian

Madison Limestone

The Madison Limestone correlates with the Leadville of central Colorado. Kanizay (1955, p. 61) reports 433 feet of it on Cross Mountain while Abrassart and Clough (1955, p. 67) measured 270 feet at Juniper Mountain. The lithology is fine
grained, calcite-cemented limestone that is porous and dolomitic in places. Hydrocarbons have not been found in the few holes drilled to the Madison in northwestern Colorado.

**Pennsylvanian**

**Morgan Formation**

The Morgan Formation was measured by Abrassart and Clough (1955, p. 67) to be 1018 feet at Juniper Mountain and by Kanizay (1955, p. 61) to be 955 feet at Cross Mountain. Konishi (1959) believes there is as much as 1500 feet in the Iles dome area. It is mapped as three units, the lower part being predominantly sandstones and shales, while the upper two parts are thick recrystallized limestones with intercalated fine-grained sandstones and shales. Some oil staining was found in the Morgan in the Iles oil field (fig. 2) (Konishi, 1959, p. 85).

**Maroon Formation**

The Maroon is thought to be a lateral facies of the Weber Formation. Its lithologies are red shales, sandstones, and conglomerates with intercalated thin limestones and siltstones. It is almost pinched out as it extends northward to the southern part of the Maybell-Lay area. Just to the south of the Maybell-Lay area at the Iles dome and Wilson Creek oil field, thicknesses
of over 1000 feet of Maroon beds are reported by Kenoshi (1956, p. 85). In contrast, Kanizay (1955, p. 61) finds no Maroon at Cross Mountain, nor is it found in the subsurface near Maybell (Lauman, 1965, p. 16). Slight oil staining is reported in the Maroon by Kenoshi (1959, p. 85) at the Iles dome (fig. 2).

**Weber Formation**

The Weber is mostly massive or cross-bedded sandstone that is fine grained with calcite cement in many places. Kanizay (1955, p. 61) reports 790 feet of Weber at Cross Mountain. At Juniper Mountain, the Weber is covered or faulted away. The Weber is the principal petroleum reservoir rock at Rangely oil field in the Piceance Creek Basin, the largest oil field in Colorado, and at the Elk Springs oil field (fig. 2). Gas has been found in the Weber at the Thornburg oil field and small shows were found in the Weber at the Iles field. Other large stratigraphic accumulations of oil are possible in the Weber Formation in the Maybell-Lay area.
Permian

Goose Egg Formation

The Goose Egg Formation, a stratigraphic equivalent of the Park City and Phosphoria Formations unconformably overlies the Weber Formation. At Cross Mountain it consists of 23 feet of yellow and brown, medium-grained sandstones (Kanizay, 1955, p. 60). It thickens up to 40-75 feet at the Iles dome area where additional lithologies, red shales and gray anhydrite beds occur. The top 30 feet is oil stained at Iles dome (Konishi, 1959, p. 87).

Triassic

Moenkopi Formation

The Moenkopi Formation has lithologies consisting predominantly of red to yellow shales with interbedded siltstones and sandstones. Kanizay (1955, p. 61) reports 696 feet at Cross Mountain. Lauman (1965, p. 19) reports 455 feet at the Wilson Creek oil field. It is covered at Juniper Mountain. The interval has had oil production in the Danforth Hills field (Konishi, 1959, p. 87).
Shinarump Conglomerate

This unit is composed of coarse sandstones and conglomerates. Only 13 feet occurs at Cross Mountain (Kanizay, 1959, p. 61), and it is probably absent throughout most of the thesis area.

Chinle Formation

The lithologies of the Chinle Formation include red shales, mudstones, sandstones and a few thin limestone beds. Kanizay (1955, p. 61) reports 220 feet at Cross Mountain, and Lauman (1955, p. 20) reports 320-415 feet at the Iles dome. There is oil production from fractures in the Chinle Formation at the Iles dome field.

Jurassic

Entrada-Navajo Formation

The Entrada and Navajo are considered as one unit because the Carmel Formation is not present between them in northwestern Colorado. Buff to light gray, fine- to medium-grained sandstones are present in both. The lower Navajo tends to be cross-bedded while upward into the Entrada the bedding becomes parallel. This unit totals 824 feet at Cross Mountain (Kanizay, 1955, p. 61), more than 250 feet at Juniper Mountain (Abrassart and Clough, 1955, p. 66), and 240 feet thick at the Iles dome field (Konishi,
1959, p. 89) where it is the main oil producing interval. Hydro-
carbon accumulations are present in the Entrada at Temple Canyon,
Wilson Creek, Thornburg, Moffat, Maudlin Gulch, and Danforth
Hills oil fields (fig. 2).

**Curtis Formation**

The Curtis Formation is composed of light to dark green
shale, sandy shale, and thin-bedded limestones. Some of the
sandstones are oil stained. Thicknesses are 140 feet at Iles
Mountain, 91 feet at Cross Mountain and 95 feet at Williams
Fork field. Abrassart and Clough (1955, p. 67) report 45 feet
at Juniper Mountain.

**Morrison Formation**

In northwestern Colorado the Morrison Formation is divided
into two members. The lower Salt Wash Member is composed of
gray, massive, cross-bedded, medium-grained sandstones with
thin shale beds and limestones. The upper Brushy Basin Member
consists of variegated shales, intercalcated with sandstones,
mudstones, and limestones. Abrassart and Clough (1955, p. 67)
report a thickness of 486 feet at Juniper Mountain, while there
is 466 feet present at Cross Mountain (Kanizay, 1955, p. 61).
Oil has been found in the Morrison at Iles done, Moffat, Danforth
Hills, Maudlin Gulch, Wilson Creek, and Temple Canyon oil
fields (fig. 2).
Cretaceous

Dakota Formation

In northwestern Colorado, the interval defined here as the Dakota Formation includes units that have been called in northwestern Colorado, the Cloverly Formation, Fuson Shale, Buckhorn Conglomerate, Cedar Mountain Formation and the Fall River Formation. The Dakota consists generally of two units as seen near Juniper Springs. The lower unit is a conglomeratic sandstone overlain by variegated shales and siltstones. The upper unit is a fine- to medium-grained sandstone. The Dakota is about 190 feet thick at Juniper Springs, 145 feet at Cross Mountain (Kanizay, 1955, p. 61), and between 180 and 195 feet thick in the Iles dome field (Lauman, 1965, p. 25).

The Dakota sandstone produces oil at the Williams Fork and Moffat dome fields and gas at the Thornburg dome field. Traces or shows of hydrocarbons have been found in nearly every field where the Dakota Formation has been tested in northwestern Colorado. In addition, hot springs in the southern part of the Maybell-Lay area emanate from the Dakota and contain H₂S, according to analyses posted at Juniper Hot Springs.
Mowry Shale

The lithology of the Mowry is a siliceous shale with a bentonite bed at the top. Though it is a shale, it does produce small amounts of oil from fracture porosity at the Iles dome and Moffat fields. In northwestern Colorado, it is fairly consistently reported to be between 80 and 90 feet thick.

Frontier Formation

Lithologies in the Frontier consist of interbedded, lenticular, quartz sandstones and shales. Thicknesses reported are 125 feet at Cross Mountain (Kanizay, 1955, p. 61), 310 feet at Iles Mountain (Lauman, 1965, p. 26), and 200 feet in the Maybell quadrangle (McKay and Bergin, 1974). Small amounts of oil and gas are found in the Frontier Formation at Iles dome, Thornburg dome and Bell Rock dome oil fields (fig. 2).

Mancos Shale

The Mancos is consistently approximately 5000 feet thick in northwestern Colorado and includes dark gray, black, and calcareous shales with some sandstones in the upper 1200 feet. None of these sandstones are present at Cross Mountain, nor are they seen in exposures of the Mancos in the Maybell-Lay area. Thus, the Mancos should be relatively impermeable in the Maybell-Lay area. Where the Browns Park sands rest above it,
the Mancos should contain the migration of uraniferous ground waters within the Browns Park aquifer, a possibly important factor in forming the uranium mineralization. There is fracture production of oil from the Mancos at the Craig dome and Moffat dome fields.

Mesaverde Group

The Mesaverde Group is mapped here as two units, the Iles Formation and the Williams Fork Formation. Its total thickness varies from 2500 to 3500 feet in northwestern Colorado. The lower Iles Formation intertongues with the upper parts of the Mancos. Lithologies of the Iles consist of fine-grained sandstones, carbonaceous shales, and coal beds that increase in number going upward in the section. Hydrocarbon traces were found in the basal Iles at the Bell Rock dome.

The sandstones in the Williams Fork Formation are more discontinuous than in the Iles and coal beds much more abundant. Many of the sandstones are red from burning of adjacent coal. Gas has been found in the Williams Fork at Baggs, Lay Creek and Hiawatha fields.
Lewis Shale

The Lewis Shale consists of dark gray calcareous shales and sandstones with a few thin limestones. It is 560 to 1400 feet thick in the thesis area thinning drastically to the southwest. It produces gas in the Baggs field.

Lance Formation

The Lance Formation is from 900 to 1500 feet thick in the thesis area and includes the lenticular Fox Hills Sandstone at its base (McKay and Berkin, 1974). Lithologies include interbedded carbonaceous shales, coals, claystones, siltstones, and sandstones. Above the Lance is an unconformity which causes thinning of the formation to the southwest. The Fox Hills Sandstone produces gas at the Baggs field and has hydrocarbon traces in the Hiawatha and Thornburg fields.

Tertiary

Fort Union Formation (Paleocene)

The Fort Union consists of interbedded non-marine, gray-green shales, carbonaceous shales, coals, sandstones and conglomerates. It varies from 1280 to 2500 feet thick (McKay and Berkin, 1974). Gas is produced from the Fort Union Formation at Baggs and Powder Wash fields.
Wasatch Formation (Eocene)

Two members are included in the Wasatch in this area, the Hiawatha Member and above it the Cathedral Bluffs Member. They are essentially the same lithology, but are separated by the Tipton Shale Member of the Green River Formation where it is present. In general, the lithology of the Wasatch is variegated red, yellow, white, and green mudstones, claystones, sandstones and a few conglomerates. The total thickness is approximately 5000 feet in the area. Lenticular sandstones of the Wasatch produce gas at Baggs, Powder Wash, Hiawatha, and White River dome fields.

Tipton Shale (Eocene)

This unit, composed of drab gray shales, mudstones, marlstones, sandstones and oil shales, is 70 feet thick in the Poison Basin area (Cronoble, 1969, p. 15) and 200 feet thick just northwest of Maybell (McKay and Bergin, 1974). It pinches out completely a few miles west of the Poison Basin.

Browns Park Formation

Location

The Browns Park Formation, host rock for the uranium mineralization, occurs on the northern flank of the Uinta Mountains and on the crest of the Axial Basin anticline on
the southern edge of the Sand Wash Basin (fig. 2). It is also found west of the Park Range and Sierra Madre uplifts, as well as in small grabens or half grabens on top of the Cherokee anticline, which separates the Sand Wash Basin from the Washakie Basin to the north. The Browns Park unconformably overlies all rocks from the Eocene Bridger Formation to the Precambrian Uinta Mountain Group.

**Lithology**

The Browns Park can be divided into two units on the basis of lithology (fig. 3). The first is a lower conglomeratic unit varying from 0 to 300 feet in thickness. The upper unit consists of 1200 to 1800 feet of medium- to fine-grained sandstone. The conglomeratic unit has shale lenses and some clay in the matrix, otherwise, there is a striking lack of shales throughout the section. Most of the Browns Park originally present has been removed by erosion. In the Maybell-Lay area, the maximum thickness of Browns Park is about 1000 feet. In the Poison Basin area, the maximum thickness of Browns Park is 300 feet.

The conglomeratic unit varies significantly in its lithologic characteristics as well as in thickness. At Cross Mountain, Kanizay (1955, p. 60) observed 100 feet of massive conglomerate with unrounded, cobble-sized clasts and a clay matrix. In the Maybell-Lay area (NW4, sec. 17, T. 6 N., R. 94 W., pl. 1) there is 35 feet of light-brown massive conglomerate containing
Browns Park Formation

Upper Sandstone Unit
1200–1800 ft.

Lower Conglomeratic Unit
0–300 ft.

Underlain by Precambrian to Miocene rocks

Figure 3. Stratigraphic Column, Browns Park Formation.
boulder-sized clasts near the bottom and cobble-sized clasts throughout. The matrix is arkosic sand and mud. Above the massive section are 25 feet of thin-bedded, pebble conglomerates that grade upward into the sandstone unit. In the Poison Basin (secs. 9 and 10, T. 12 N., R. 92 W., pl. 2) the conglomerate is pebble-sized and thin-bedded with an arkosic sandstone matrix. Lenses of medium- to coarse-grained arkosic sandstone and small pockets of ash were also observed. The sands are limonite stained and sometimes calcite cemented. Generally, the conglomerate is poorly exposed in the Poison Basin, but appears not to exceed 70 feet and is not present beneath the sandstone unit at the western end of the Poison Basin.

Clasts in the conglomerate are predominantly derived from the Uinta Mountain Group. Red quartzite and chert clasts from the Uinta Mountain Group are a distinctive feature of the conglomerate wherever it is found. South of Sand Wash Basin, clasts of limestone from Paleozoic formations such as the Madison and Morgan are also important constituents of the conglomerate. Because of the conglomerate's massive nature of well-exposed outcrops, no indications of transport direction were observed. Clasts in the conglomerate, however, indicate that streams depositing the lower unit carried material from the Uinta Mountains, Cross Mountain, or Juniper Mountain where source rocks occurred. Therefore, these streams flowed in easterly or northerly directions.
Porosity and permeability in the conglomerate vary greatly. Where the matrix is clay or well-cemented, the conglomerate is sealed from passage of ground waters and other fluids. However, where the conglomerate is observed in the Maybell-Lay and Poison Basin areas, the matrix is chiefly sand and usually not well cemented, if at all.

The upper sandstone unit in all areas where it was observed in good outcrops consists almost entirely of fine-to medium-grained, well-rounded sandstones. There is a tendency for some sandstones high in the section to be very fine-grained, while medium-grained sandstones predominate within 600 feet of the base of the Browns Park. Sorting is always very good with only minor amounts of clays present.

In the Maybell-Lay area, bedding is generally parallel, with no beds being continuous for any great distances. The beds generally vary in thickness from one to ten feet. The thickest beds tend to be massive. Some beds have cross-strata dipping over 30 degrees with transport directions varying from northwest to northeast. Limonite-stained and gray pyrite-bearing sands are common and are mapped on plate 1. Also, lenses of gray pyrite-bearing sand are present and generally follow bedding though they can be observed to cut across bedding in some places.
In the Poison Basin parallel bedding was observed near the northern edge of the basin on scattered outcrops. However, in the interior of the basin, only large sets of cross-strata have northerly dips well in excess of 30 degrees. Gray pyritic sandstone and limonitic sandstone occur close to the surface underneath much of Poison Basin and are mapped on plate 2. Often limonite occurs in lenses dipping parallel to cross-strata.

In all areas, the upper sandstone unit is almost completely composed of chert, quartz, and volcanic fragments in well-rounded grains. Most grains show some signs of secondary enlargement with silica overgrowths. The volcanic fragments consist of broken glass shards and fragments from welded tuffs. In both cases, the volcanic grains seem to be transported after original deposition. The glass shards were probably broken during this transportation. The tuff fragments represent welded tuff beds that were broken up, rounded, and redeposited within the sandstone beds. Minor amounts of hornblende, opaque minerals, feldspars, biotite, and muscovite are also found. Bradley (1936, p. 184) observed rounded tourmaline and garnet grains in minor amounts. In general, the welded-tuff fragments and hornblende are found throughout the section. The glass shards are found only in small amounts throughout the section except for high in the section in
various places where they are often the dominant constituent. These highly tuffaceous zones have also been reported to contain augite and hypersthene (Bergin and Chisolm, 1956, p. 195).

Generally, the upper unit of the Browns Park Formation is friable and uncemented. Cement does exist, mostly clear, coarsely crystalline calcite, throughout the section in scattered lenses, along faults and in the vicinity of uranium mineralization. Lower in the upper unit as well as along some faults, chalcedony is also found as a cement.

The upper sandstones are very porous and permeable. Calcite-cemented beds and ash lenses are too discontinuous to serve as much of a permeability barrier. Therefore, all fluids entering from either above or below, were easily taken into the ground water system along with any dissolved species they contained.

**Depositional History**

By the time of deposition of the last Eocene rocks, the Uinta, Park Range, Sierra Madre, and White River uplifts had all become positive physiographic features, and fluvial processes had formed successively lower pediments on the flanks of these uplifts. Bradley (1936), working on the geomorphology of the Uinta Mountains, found evidence of two Miocene erosion surfaces. The oldest and highest surface, Bradley named the
Guilbert Peak surface. The Bishop conglomerate was deposited upon it. Neither the Bishop conglomerate nor the Guilbert Peak surface are preserved as far east as the areas concerned in this thesis. The second erosional surface, the Bear Mountain surface, was cut below the level of the Guilbert Peak surface. The Browns Park conglomerate was deposited on the Bear Mountain surface. Though the Browns Park conglomeratic unit and the Bishop conglomerate are often considered to be lateral equivalents, according to Bradley, they were deposited at slightly different times, separated by a short period of erosion. The Browns Park Formation is slightly younger than the Bishop conglomerate.

At some point, the streams cutting the Bear Mountain surface changed from an erosional to a depositional environment. Bradley (1936, p. 178) believes that this change was caused by a minor change in climate. Structural adjustments on the flanks of the mountain ranges and/or subsidence of Sand Wash Basin are also possible causes of the change from erosion to deposition.

Deposition of the Browns Park conglomeratic unit probably took place in a braided stream or alluvial fan environment in an arid climate. High energy and proximity to source are indicated for the conglomerate by the large size and rounded
nature of the clasts in outcrops of the conglomeratic unit found south of Sand Wash Basin. The clasts found in the conglomerate in the Maybell-Lay area could easily have been derived from rocks subjected to erosion on the Juniper Mountain dome.

The conglomerate contains smaller-sized, rounded clasts in the Poison Basin, indicating a greater distance of transport and a probable lower-energy stream transport, probably due to being farther away from the mountains where stream gradients were not as steep. In the Poison Basin the conglomerate thins to the west and is not present at all beneath the sandstone unit at the far western edge of the Browns Park outcrops in the Poison Basin area. This suggests that the source of the conglomerate in the Poison Basin area is to the east in the Park Range and Sierra Madre uplifts rather than in the Uinta Mountains to the southwest. Cronoble (1969, p. 19) has suggested the same source. Also, axes of the few conglomerate filled channels observed in outcrop appear to be oriented east-west.

Environments of deposition of the upper sandstone are a low energy fluvial environment and a possibly eolian environment. Features are present that are often associated with eolian environments such as frosted, well-rounded grains, good sorting, abundant air-fall tuffaceous material within the sandstone and dune-shaped sets of steeply dipping cross-beds. Transport
directions to the northwest and northeast indicate a southern source for the Browns Park sandstone in both the Maybell-Lay and Poison Basin areas. These transport directions reflect prevailing wind directions present in the thesis areas now and perhaps also during the time of Browns Park. Whether transported by eolian or fluvial processes, the upper sandstone unit probably has a source area different from the lower conglomeratic unit which was derived from the Uinta Mountains. The Uinta Mountains became either wholly or partially engulfed by Browns Park sandstone, which is found high upon the flanks of Juniper Mountain, and in small remnants near the upon the crest of the Uinta Mountain (Hancock, 1915, and Sears, 1924). Meander loops cut into the Precambrian rocks in the Uinta Mountains, Cross Mountain and Juniper Mountain by the Green and Yampa Rivers indicate superposition of the stream courses through large thicknesses of Browns Park sands which must have engulfed these former topographic highs (Hancock, 1915). Engulfed by Browns Park the Uinta Mountains could hardly be considered a source for it. The White River uplift or perhaps areas further to the south are more likely sources.

Tuffaceous material becomes more abundant upward in the Browns Park section (fig. 3). Nearby volcanism probably increased toward the end of Browns Park time represented in
the thesis area. Others working in the Browns Park Formation have defined a vertical change from a non-tuffaceous or fluvial facies into a tuffaceous or eolian facies (Bergin and Chisolm, 1956, p. 195; Michael Brownfield, verbal communication, 1974).
STRUCTURAL GEOLOGY

Regional Structures

Structures in the region including the two areas of this thesis are shown in figures 1 and 2. The outcrop of the Browns Park Formation and the Sand Wash Basin, the Piceance Basin, and the Washakie Basin are shown on figure 2. The major uplifts, the Sierra Madre-Park Range uplift, the White River uplift, and the Uinta uplift are shown on figure 1. Another large scale structure, the Axial Basin anticline is an eastern continuation of the Uinta uplift. The trend of the Uinta uplift extends to the southeast into the Axial Basin anticline which in turn projects into the White River uplift. The Cross Mountain and Juniper Mountain anticlines both trend north-south across the Uinta uplift-Axial Basin anticline trend. The Cherokee anticline trends east-west, plunging westward with small subsidiary folds. The Park Range-Sierra Madre uplift trends northwest in contrast to the east-west trends of the Cherokee anticline, Axial Basin anticline and Uinta uplift.

Important secondary structures are closely associated with the large scale structures. The Juniper Mountain and Cross Mountain anticlines occur as domes along the crest of the Axial Basin anticline. Monoclines and reverse faults
occur at boundaries between many of the uplifts and basins. The steeply dipping Grand Hogback monocline is the boundary between the Piceance Creek Basin and the White River uplift (fig. 2). The Maybell monocline forms the boundary between the Axial Basin anticline and the Sand Wash Basin. Reverse faulting occurs north and south of the Uinta uplift, east and west of the Cross Mountain, and northeast and southeast of Juniper Mountain (pl. 3). The Cherokee anticline separates the Sand Wash Basin from the Washakie Basin.

The structural relief from Juniper Mountain to the center of Sand Wash Basin is approximately 25,000 feet. From the Park Range to the center of Sand Wash Basin, the structural relief is more than 29,000 feet. The Cherokee anticline, a less significant structure, has a structural relief of only 1500 feet to the center of Sand Wash Basin and less than 2000 feet to the center of Washakie Basin (Haun, 1962, pp. 11-12).
Structural Preservation of Browns Park Formation

A period of post-early Miocene erosion removed practically all of the Browns Park Formation from areas where it had been deposited on the northern flank of the Uinta Mountains and across large areas of the Sand Wash and Washakie Basins. A period of normal faulting, during and after the Miocene, protected some areas of the Browns Park rocks in graben and half-graben structures. One such area, which includes the Maybell-Lay area, extends from a down-dropped portion in the crest of the Uinta uplift on the west in the northwestern corner of Colorado eastward along the crest of the Axial Basin anticline (fig. 2). This graben was formed by a collapse of the eastern end of the Uinta uplift which at one time probably extended southwest to the White River uplift.

The Cherokee anticline which separates the Sand Wash and Washakie Basins also suffered a tensional episode, with block faulting along its crest. Two outliers of Browns Park were preserved in grabens or half-grabens along the Cherokee anticline. One of these is the Poison Basin area of this thesis, and the other is to the west, north of Powder Wash (fig. 2). In addition, there are scattered remnants of Browns Park rocks in the Sand Wash Basin, plus areas in highlands on the flanks of the Park Range and Sierra Madre uplifts.
Structures in the Poison Basin Area

The Wasatch Formation underlies the Browns Park beds everywhere in the Poison Basin area. The structural setting of the Poison Basin area generally consists of the Cherokee anticline with a subsidiary anticlinal fold to the north. Faults in the Poison Basin area generally trend west-northwest, at slight angles to the trend of the Cherokee anticline. The two anticlines and the syncline shown on plate 2 are broad, gently dipping structures. No beds on the flanks of the structures dip as much as ten degrees and dips ranging from one to five degrees are most common. Folding is expressed in the Browns Park Formation, although the fold axes are shifted from the fold axes in the underlying Wasatch and Tipton beds. An angular unconformity between the Wasatch and Browns Park beds indicates that much of this folding occurred before deposition of the Browns Park Formation.

The fault responsible for preserving significant thicknesses of Browns Park beds in the Poison Basin area is mapped across sections 5, 6, 8, 9, 10, and 15, T. 12 N., R. 92 W. South of the fault, the Browns Park Formation is less than 50 feet thick. North of the fault, in recent exploratory drill holes at the Poison Buttes, from 250 to 300 feet of Browns
Park was drilled before reaching the underlying Wasatch Formation. Maximum displacement of the fault is between 200 and 250 feet in section 6, T. 12 N., R. 92 W., with the northern block being downthrown, preserving larger thicknesses of Browns Park beds in the resulting half graben than would have been left without the fault. Displacement diminishes to the southeast and northwest on the fringes of the Poison Basin area. If the fault is continuous with a major fault mapped in the subsurface by Cronoble (1969, Pl. IV), then it dips slightly to the northeast at depth and is a normal fault.

The other two mapped faults (sections 4 and 6, T. 12 N., R. 92 W.) have much less throw than the major fault mentioned above. The faults have near vertical dips. Displacement of the fault in section 4 is about 20 feet, being downthrown to the north. Displacement of the northern fault in section 6 was impossible to determine, though Cronoble (1969, Pl. I) shows it as downthrown to the south. Other faults of comparable magnitude undoubtedly exist in the Poison Basin area but are undetectable.
Structures in the Maybell-Lay Area

The structural geology of the Maybell-Lay area is more complex than in the Poison Basin area. In the Maybell-Lay area, the Browns Park is underlain by formations ranging from the Precambrian Uinta Mountain Group to the Tertiary Wasatch Formation. These older formations lie beneath the unconformity at the base of the flat-lying or gently-dipping Browns Park Formation in a variety of inclinations, determined by the major local structures; the Axial Basin anticline, the Juniper Mountain dome, the Maybell monocline, and the Lay anticline. These structures are in places related to faults which displace the beds beneath the unconformity and in places also extend into the overlying Browns Park Formation.

The Axial Basin anticline trends west-northwest to northwest across the southern part of the mapped area in pls. 1 and 3. Everywhere in the mapped area, the crest of this anticline is covered by the Browns Park Formation which was deposited after the folding and, therefore, has not been affected by the fold. Beneath the Browns Park beds, the Mancos Shale and older rocks are all affected by folding of the Axial Basin anticline in the mapped area (pl. 3). Dips measured in the Mancos by Bergin (1959) are ten to fifteen degrees to the northeast off the northeastern flank of the fold and ten to thirty degrees to the southwest off
the southwestern flank of the fold. The Axial Basin anticline plunges northwest and southeast, away from the Juniper Mountain dome.

The Juniper Mountain dome occurs along the trend of the Axial Basin anticline, exposing the Precambrian Uinta Mountain Group, the Cambrian Sawatch Formation, the Mississippian Madison Limestone, and the Pennsylvanian Morgan Formation. These beds dip 20 to 40 degrees on the western flank of the structure, 10 to 20 degrees on its northern flank, 30 to 40 degrees on its southern flank, and about 20 degrees to the southeast where the beds are deformed near a bounding fault. Juniper Mountain is raised along reverse faults on its south, southeast, and northeast sides (Ritzma, 1969). Deposition of the Browns Park Formation covered Juniper Mountain at the end of the Miocene. During and after Browns Park deposition, high-angle normal faulting off the flanks of the structure formed the halo of faults expressed in the Browns Park Formation, northeast and southeast of the dome.

The Maybell monocline is a sharp fold indicating a major basement fault at depth which affects the gently-dipping, pre-Miocene rocks so that their dip steepens to approximately 60 degrees to the north on the southern flank of the Sand Wash Basin. The monocline trends approximately east-west across the northwestern part of plate 1. East of the fault
that trends north-south near the boundary between T. 7 N.,
R. 95 W. and T. 7 N., R. 94 W., the trend changes to northeast
and the dips abruptly decrease, so that the structures dies
out in a short distance to the east. Many of the beds affected
by the Maybell monocline are hydrocarbon-bearing in northwestern
Colorado and the eastern end of the monocline occurs beneath
the most prolific uranium-producing area in the Browns Park
Formation (pl. 1, pits 1, 3, 4, 5, and 6).

The Lay anticline is completely covered by the Browns
Park Formation and trends northwest across the northeastern
portion of plate 1, parallel to the trend of the Axial Basin
anticline. The Lay anticline has dips of less than fifteen
degrees on its southwestern flank. Dips reach a maximum of
seven to twelve degrees on its northeastern flank. The Lay
anticline is expressed in the Lance Formation as well as beds
below the Lance. The Browns Park Formation, deposited later,
is unaffected by this fold.

The Browns Park Formation has been only moderately de-
formed by some of these structures. Generally it rests with
an angular unconformity upon older rocks that have been de-
formed prior to the deposition of the Browns Park by these
structures, so that dips in the Browns Park are generally
less than ten degrees. In the southern portion of plate 1,
the Browns Park is generally flat-lying. The Lay syncline, developed in Browns Park beds, trends east-west across the northern part of plate 1. It was possibly formed in the same episode as probable post-Browns Park time faults discussed later in this section. Its occurrence, overlying the Lay anticline on the eastern portion of plate 1 probably results from sagging in the crest of that anticline. Dips in the Browns Park beds on the northern flank of the syncline are five degrees or less near the axis, but increase to as much as 30 degrees farther north. Dips on the southern flank of the syncline are from one to ten degrees. The trend of the syncline is east-west across most of plate 1, but turns to the southeast in the eastern portion of plate 1.

Some faults in the Maybell-Lay area suffered displacements prior to, during, and after deposition of the Browns Park Formation. Faulting prior to deposition of the Browns Park in the Maybell-Lay area consists predominantly of reverse faults related to uplift of the Juniper Mountain dome (Ritzma, 1969, 1971). The Browns Park Formation covers these faults in nearly all places, so that exact location of them is impossible. From estimation of missing section between nearly adjacent points on either side of the fault in section 4, T. 5 N., R. 95 W., vertical displacement on it can be estimated to be from 500 feet to 1000 feet.
Faulting of the Browns Park beds in the Maybell-Lay area is compiled on plate 1. The data were obtained as reported on a U. S. Geological Survey open file map (Bergin, 1959), as well as faults mapped by the author from exposures on hills and in gullies and pits. The faults are nearly vertical and show no signs of horizontal displacement where their traces can be observed. Vertical displacement along faults can sometimes be observed to be in excess of 20 to 30 feet in pits, but the depth of pits does not allow measurement of displacement much beyond this. The fault trending north-south through pit 1 on plate 1 is shown in cross-section by Bergin (1959) to have displacement of 300 feet. Drill logs show that the Browns Park is 700 feet thick on the western side of the fault and 1000 feet on its eastern side. Significant uranium mineralization in the vicinity of the fault occurs in Browns Park beds where it occurs above subcropping Mancos Shale.
URANIUM MINERALIZATION

General Description

Uranium deposits observed in this study have certain structural and stratigraphic characteristics in common. They occur in faulted areas on the flanks or near crests of anticlines. Some of these faults may have occurred during the deposition of the Browns Park Formation or even during mineralization. The deposits occur in fine- to medium-grained sandstones, which do not contain many glass shards. Yet, in both areas studied, tuffaceous sandstones probably at one time existed stratigraphically above the present level of mineralization.

Localities of anomalous radioactivity and pits where economic amounts of uranium have been mined are shown on plates 1 and 2. Definition of an anomalous radioactivity locality is a surface locality where the scintillation counter showed at least twice the normal background amount of radioactivity for the general area. Areas of gray, pyrite-bearing sandstone are also mapped on plates 1 and 2. On plate 1, the pyrite-bearing sandstone in varying intensities is mapped where it occurs at the surface. On plate 2 the pyrite-bearing sandstone is mapped where it is believed to be close to the
surface. Many pits and drill holes indicate a bleached, non-pyritic sandstone in the top 10 to 70 feet showing a sharp boundary with pyrite-bearing sandstone below. Localities of uranium mineralization shown on plates 1 and 2 occur near or in these areas of pyrite-bearing sandstone. Generally, there is a tendency for the scintillation counter to show an increased reading at boundaries between pyrite-bearing and non-pyrite-bearing sandstone.

Regionally, in the Maybell-Lay area, there are no large concentrations of any elements usually associated with uranium, such as selenium, molybdenum or vanadium (Bergin and Chisolm, 1956, p. 194). Some test pits north of pits 5 and 6 (plate 1) did show above average molybdenum contents according to a former employee in the mill, but this has not been substantiated.

In the Poison Basin area, selenium contents higher than 100 parts per million are found in the Poison Buttes (Grutt and Whalen, 1955, p. 128). These buttes have for a long time been known to have selenium contents high enough to poison cattle. The names Poison Buttes, Poison Basin, and Poison Draw indicate these experiences. All the pits on the periphery of the Poison Buttes area show much lower values, only one sample of thirty being above 50 parts per million and over half with negligible selenium content (Vine and Prichard,
1955, p. 6). At pit H in the Poison Basin, a blue oxidized molybdenum mineral, ilmenite, can be seen on pit walls.

**Poison Basin Area**

**Surface Mineralization**

Initial discoveries of uranium mineralization in both the Maybell-Lay and the Poison Basin areas were by airborne radiometric surveys. Prior to mining activities, the Poison Basin area had significant surface mineralization that was formerly present in the vicinity of pits A, B, C, and D, section 4, T. 12 N., R. 92 W., plate 2. Other localities in sections 1 and 2 of T. 12 N., R. 93 W., and section 36 of T. 13 N., R. 93 W., have been examined, but none have shown radioactivity of twice the background value.

**Mineralization in Pits**

Most of the uranium mineralization that is still observable in pits in the Poison Basin area is either concentrated at the edges of gray sandstone lenses, or in ore bodies at the horizontal contact between the upper, oxidized sandstone and lower, gray, pyritic sandstones. Small, tabular, ore bodies may have been oriented along the northwest-trending fault in pit A, but no evidence of this is now present.
The lens bodies are in a sandstone with large sets of trough cross-stratification, instead of the horizontal bedding that is most evident in the Maybell-Lay area. This lithologic difference has an effect both on the orientation and shape of the lens ore bodies. Figure 4 shows the northwestern wall of pit D, where the mineralizing processes seem to have preferred certain sets of cross-strata to others. In one case uranium mineralization is concentrated along the boundary of two sets, and along cross-strata themselves.

Many of the ore bodies in the Poison Basin are in small pockets near contacts between the gray pyritic and white oxidized sandstone. The contact, though not always level, is very sharp at depths of 10 to 70 feet. Many of the pits have not been dug down to the contact, but have had oxidized ore bodies removed from just above it. Pits A, G, and H did reach the gray pyritic sandstone and large amounts of oxidized ore were mined. Pit A shows the contact at a depth of 15 feet and a high water table (fig. 5). The mineralization remaining on the walls seems to be in the gray sandstone. Also noticeable on this wall are black and reddish streaks. The black could be either hydrocarbon traces or manganese oxides, and the red might be traces of selenium. In pit G, the contact between oxidized and unoxidized sandstone can be
Figure 4. Pit D, northwestern wall, Poison Basin Area.
seen at the bottom of the pit and upward it seems to break up into lens-shaped pyritic bodies, controlled by cross-strata (fig. 6).

Controls of Mineralization

Economic uranium mineralization in the Poison Basin is controlled both structurally and stratigraphically. Mineralization in the area occurs only in the Browns Park Formation which was structurally preserved by its position between the Cherokee anticline and a subsidiary fold to the north. Also the southernmost fault shown in cross-section on plate 2 downdropped 250 feet of Browns Park which would not have normally been preserved. Thus, a favorable sandstone host rock has been preserved above reductants, including H₂S and methane, in the South Baggs gas field, the position of which is partially controlled by the Cherokee anticline.

Lithologies of the Browns Park Formation present in the Poison Basin area are limited to the lower conglomerate unit and non-tuffaceous, trough cross-beded sandstones of the upper unit. These sandstones include both oxidized and gray, pyrite-bearing portions. Before the latest cycle of erosion, there was a much thicker section of Browns Park beds in the Poison Basin which probably included tuffaceous sandstones, because tuffaceous sandstones are present in outcrops of Browns Park beds to the northeast in Wyoming around the
Figure 6. Pit G, western wall, Poison Basin Area.
Miller Hill area, which are believed to represent a higher stratigraphic level than Browns Park beds around the Maybell-Lay or Poison Basin areas (Love, 1953). The volcanic fragments were the most likely source for the uranium.

Introduction of reductants into the Browns Park beds from underlying beds, possibly including the Wasatch, Fort Union, Lance, and Lewis Formations, was probably accomplished by small faults and associated fracturing. Pits A, B, and C are in the immediate vicinity of the fault in section 4, T. 12 N., R. 92 W. (pl. 2). All pits show some minor fractures and faults associated with uranium. Due to the lack of horizontal marker beds, faults of considerable displacement could have been overlooked. Reductants spread throughout the area shown in plate 2 through the porous sandstones aided by the faults and fractures. Uranium-bearing oxygenated ground waters percolated downward, oxidizing much of the pyritic sandstone and precipitating uraninite at the oxidation-reduction interface.
Maybell-Lay Area

Surface Mineralization

Many localities exist in the larger Maybell-Lay area where surface radioactivity is at least twice the background value. These localities are marked and numbered on plate 1 to correspond to references in the text. There are many claims and prospect pits neither noted on plate 1 nor emphasized in discussion because the areas did not show significant radioactivity. Many claims are filed and prospect pits dug solely on the basis of limonite staining or very slight increases in radioactivity, but these do not represent significant surface occurrences of uranium mineralization.

Locality 1, section 29, T. 7 N., R. 94 E. is a large limonite-stained hill, known as Buffalo Head, which rises 500 feet to the north of Lay Creek. The top of the hill is 350 to 400 feet stratigraphically above the level of uranium mineralization in pits 1, 2, and 3 to the north. A major, vertical fault that strikes N. 30° W. and is upthrown to the west, occurs in the area. To the east a smaller fault occurs parallel to the major one. Most of the bulldozer trails and prospect pits cut into the side of the hill show no significantly anomalous radioactivity. Background radioactivity near Buffalo Head was measured as .025 millirontgens per hour.
In one small prospect pit, a maximum reading of .052 milli-roentgens per hour was taken on a limonite-streaked area of its wall.

Locality 2, section 27, T. 7 N., R. 94 E., is a large prospect pit occurring in a pyritized area near the intersection of two faults (fig. 7). One of the faults, a vertical fault, runs through the prospect pit. The sandstone in this pit is fine-grained and cemented with chert. Surrounding the fault, the sandstone is gray and pyrite-bearing. Fracture surfaces of this gray sandstone are coated black and dark brown. Lenses of white and yellowish sandstone also occur in the prospect pit. Background radioactivity in the surrounding area is .02 milliroentgens per hour. The yellowish and white lenses showed radioactivity values varying from .07 to .10 milliroentgens per hour. Readings taken on fracture surfaces of the gray sandstone ranged from .17 to .40 milliroentgens per hour.

Locality 3, section 8, T. 6 N., R. 94 W., is a prospect pit on the western edge of the intensely pyritized area north-east of Juniper Mountain. The Browns Park Formation in this area is friable and uncedented except for limonite in orange and brown-streaked areas. Small-scale fracturing can be seen on the walls of the prospect pit. Normal background radioactivity for the area is .03 milliroentgens per hour. The pit
had radioactivity of .07 milliroentgens per hour on the limonite streaks.

Localities 4 and 5, section 9, T. 6 N., R. 94 W., are north of Juniper Springs along a county road. Prospect pits occur on either side of the road in intensely pyritized sandstone. The walls of the pits are limonite stained. Background radioactivity in the general area is .03 milliroentgens per hour. To the east of the road, locality 4 has a radioactivity of .21 milliroentgens where there is some green "bloom" of oxidized uranium minerals. Locality 5 shows radioactivity of .30 milliroentgens per hour where some secondary, yellow uranium occurs.

Locality 6, section 10, T. 6 N., R. 94 W., occurs to the east of localities 4 and 5 near the base of the Browns Park Formation in intensely pyritized sandstone. Background radioactivity of the area is .03 milliroentgens per hour. Radioactivity readings of .10 to .11 milliroentgens per hour occur in a shallow prospect pit.

Locality 7, section 15, T. 7 N., R. 94 W., occurs on a small hill to the east of a series of faults. Background radioactivity in that vicinity is .02 milliroentgens per hour. On the surface of the hill, radioactivity is as high as .04 milliroentgens per hour. In a small prospect pit on the western side of the hill in a lens of gray sandstone, a reading of .05 milliroentgens per hour was observed.
Locality 8, section 13, T. 7 N., R. 96 W., occurs north-west of Maybell in a small area of lightly pyritized sandstone. Several prospect pits have been dug in the area, showing yellow, brown, and orange streaks in a fine-grained, uncemented sandstone. Background radioactivity of the general area is .02 milliroentgens per hour. On one prospect pit wall, in an area containing a secondary uranium mineral at the edge of a limonite-stained area, a reading of .042 milliroentgens per hour was observed.

Locality 9, section 20, T. 7 N., R. 95 W., occurs north of Maybell in a very small area of lightly pyritized, fine-to medium-grained sandstone. Background radioactivity of the general area is .02 milliroentgens per hour. In areas of yellow-streaked sandstone, readings as high as .05 milliroentgens per hour have been measured. At the edge of a small lens of calcite-cemented, gray, pyrite-bearing sandstone, where it has a thin limonite rind, a reading of .075 milliroentgens per hour was observed.

Locality 10, section 2, T. 5 N., R. 96 W., occurs on a slope west of Deception Creek, low in the Browns Park section, near its contact with the Mancos Shale. A fault, striking N. 70° W. and dipping 80 degrees to the south, can be traced through the area. Gray, pyritized sandstone, limonite stained in outcrop, occurs around the fault and intertongues with white
sandstone to the north. Background radioactivity in the area is .02 milliroentgens per hour. Limonite-stained outcrops give readings as high as .05 milliroentgens per hour.

Locality 11, section 3, T. 5 N., R. 96 W., occurs west of locality 10 near the same fault as at locality 10. Background radioactivity is .02 milliroentgens per hour. Fractures in the limonite-stained outcrops contain a black substance, possibly hydrocarbons. The highest radioactivity reading observed at the limonite-stained outcrop was .20 milliroentgens per hour.

Locality 12, section 12, T. 7 N., R. 92 W., occurs north of Big Gulch in the far eastern area of plate 1. The area is low in the Browns Park section, near the contact with the Lance Formation. The sandstone is lightly pyritized, showing in outcrop in shallow prospect pits as limonite streaking. Background radioactivity is .02 milliroentgens per hour in the general area. A reading of .041 milliroentgens per hour was observed on a limonite-streaked wall of one of the prospect pits.

Mineralization in Pits

The ore bodies indicated by present-day exposures in the mined-out pits in the Maybell-Lay area fall into three categories: those directly associated with and occurring along faults; those consisting of flat-lying, amoeba-shaped,
gray sandstone lenses with ore concentrated at the edges and periphery of the lenses; and those at the horizontal contact between the upper, oxidized sandstone and lower gray pyritic sandstones.

Ore bodies directly related to and along strike with faults are best represented by the northern parts of pits 5 and 6 (plate 1). Figure 8 shows the eastern portion of the northwestern wall of pit 5 where ore has been mined up to the northern fault which is the outer boundary of the ore body. The steep wall had precarious footings in friable sandstone, so it was very difficult to get a good distribution of data points of radiometric uranium readings. Generally, the diagram (fig. 8) indicates that the greatest concentrations of uranium occur near boundaries of the brown limonitic sandstone with the white sandstone. The limonitic zones indicate secondary oxidation of pyrite on the edges of the gray pyritiferous sandstone. A minor mineralization of gray pyritic sandstone occurs in an intertwining relationship with white sandstone to the south in pit 5 (fig. 9). The portions of the pit to the south of the main fault zone in the pit seem to have contained economic lens-shaped ore bodies.

Ore mined directly from the fault zones constitutes a small percentage of the total ore that has been mined from the Maybell-Lay area. The ore body in the fault zone in pit 5
Figure 8. Pit 5, northwestern wall, Maybell-Lay Area.
Figure 9. Pit 5, Maybell-Lay area, facing west.
was as much as 50 feet wide. The ore along faults in other pits in the Browns Park Formation seems to be on the order of inches in width. The fault ore bodies are always accompanied by and sometimes actually connected to the lens ore bodies.

Lens-shaped bodies of uranium mineralization occur in every pit studied in the thesis. They account for a large percentage of the ore that has been mined. Pit 1, being about 180 feet deep, has collected a large lake within 60 feet of the ground surface and has had the greatest quantities of ore taken from it, predominantly from lens bodies (fig. 10). Most of the ore came from three large amoeba-shaped lenses of reduced sandstone occurring at depths of 10 to 180 feet, being 1000 feet in length in the east-west direction and as thick as 20 to 30 feet (McKay and Bergin, 1974). Only small gray lenses on the western side of pit 1 remain of the middle ore body (fig. 11). The centers of the lenses are weakly cemented with calcite, while weakly anomalous radiometric uranium values occur near their edges and on their fringes. The eastern end of the uppermost ore body is associated with a fault and a small secondary solution front at the eastern end of pit 1.

Several shallow lens bodies have been removed from portions of pit 3 that are less than 20 feet deep. Figure 12 shows a portion of pit 3 that has been excavated to about
Figure 10. Pit 1, Maybell-Lay Area, facing west.
50 feet deep. Here, the gray lens has an outer layer of reddish-brown limonite alteration. The highest values for radiometric uranium are in the limonite zone or in small nearby lenses of an undetermined yellow oxidized mineral.

Figures 13 and 14 show more of these lens ore bodies, some of which are faulted and offset. Figure 14 of the north wall of pit 4 indicates that the fault zone itself is mineralized, so fault movement may have occurred both during and after mineralization.

Some of the uranium mineralization occurs in the immediate vicinity of the contact between upper, white, oxidized sandstone and lower, gray, pyritic sandstone. This horizon is below the level of most of the Maybell-Lay area pits. In pit 1, this horizon is probably hidden well below water level. The only pit exposing this horizon is pit 2. In figure 15, on the northern wall of pit 2, the significant mineralization is limited to an orange layer, a foot thick at the horizontal contact. Relict pyrite can be seen above the contact. The mineralization layer was probably much thicker in the area mined out.
Figure 14. Pit 4, northern wall, Maybell-Lay Area.
Figure 15. Pit 2, northern wall, Maybell-Lay Area.
Controls of Mineralization

In the Maybell-Lay area, as in the Poison Basin area, the mineralization has been controlled both structurally and stratigraphically. The Browns Park Formation is host to all economic uranium deposits, and its upper tuffaceous section probably provides the main source of uranium. The Browns Park conglomerates and sandstones show great permeability and porosity as an aquifer for ground waters in the Maybell-Lay area. Mineralizing solutions and fluid reductants were undoubtedly able to pass through these rocks and ultimately form uranium deposits. The uranium mineralization is mostly contained in the Browns Park sandstones that are not highly tuffaceous. Grain size varies from fine- to medium-grained throughout the Maybell-Lay area. Locally, the uranium mineralization shows a tendency to occur in sands of coarsest grain size.

Gray, pyrite-bearing sandstone occurs low in the section, around faults, and in the interior of isolated lenses. At or near the ground surface, the pyrite oxidizes to form limonite, causing a tan to brown color. Calcite and occasionally chalcedony cement occur within the gray sandstone. Figure 16 shows gray, pyrite-bearing sandstone in contact with overlying white, oxidized sandstone. Uranium mineralization generally occurs near the edges of these masses or
Figure 16. Contact between oxidized and pyritic sandstones in Browns Park Formation, Maybell area. (Section 2, T. 6 N., R. 92 W.)
lenses of gray pyrite-bearing sandstone, either as uraninite within the gray sandstone or as oxidized minerals just outside of it. Oxidized minerals were identified as uranophane, schroeckingerite, and metaautunite (Grutt and Whalen, 1955).

Plates 1 and 3 show pyrite-bearing sandstone overlying subcropping formations from the Weber through the Wasatch. Most of the pyrite-bearing sandstone seems to define an arc following the strike of the Mancos Shale and the Iles and Williams Fork Formations of the Mesaverde Group. Out of six uranium pits and twelve significant, surface, anomalous uranium localities studies in the Maybell-Lay area, four pits and three anomalous uranium localities overlie subcropping Mancos Formation, and two pits and three localities overlie subcropping Mesaverde Group. The Chinle and Lance Formations subcrop beneath one anomalous uranium locality each. All of these strata are oil and/or gas bearing.

Faulting seems to have been of greatest importance in localizing uranium mineralization in the Maybell-Lay area (pl. 1). Faulting probably provided passageways through underlying rocks up into the host Browns Park sandstone along which fluid reductants could have traveled. Oil and gas reservoirs which were formerly capped by impermeable rocks could have been released upward into the Browns Park Formation when faulting broke the upper seal.
Regional structure of the Maybell-Lay area also was important in forming the uranium deposits. The high structural position on a flank of the Juniper Mountain dome increased the probability that oil and gas reservoirs would occur in the area, as they do in most of the anticlines of northwestern Colorado. Also important were the regional structural adjustments which caused deposition of the Browns Park, a favorable host and source for uranium above a potential supply of reducing agents.
Post-Mineralization Effects

It is believed by this author that formation of the gray, lens-type ore bodies and concentration of ore at the boundary between upper bleached sandstone and lower pyrite sandstone are caused by later redistribution of the original pyrite. High amounts of oxidized uranium minerals at upper stratigraphic levels indicates that original uraninite or coffinite was attacked by later oxidizing solutions that carried off much of the uranium, distributing some of it at the bottom of the zone of surface oxidation. Later erosion of the Browns Park Formation probably removed many other economic deposits.
Distribution of uranium and associated elements in the Browns Park Formation and other sandstone uranium deposits is of great help in attempting to determine geochemical environments of mineralizing solutions. Selenium, iron, molybdenum, vanadium, sulfur, and arsenic are often reported in anomalous concentrations near sandstone uranium deposits in the western United States. These elements have also been found to be anomalous in the Maybell-Lay and Poison Basin areas with the exceptions of vanadium and arsenic (Bergin and Chisolm, 1956). Transport and precipitation of uranium and these associated elements can be accomplished in ground waters flowing through the host sandstone at near surface conditions of temperature and pressure. The ground waters carrying these elements must have been of proper Eh and pH, to carry ions or complexes of these elements simultaneously. By considering the mobility of each element, an allowable range of geochemical conditions for the mineralizing solutions can be determined.

Uranium is mobile in both the +4 and +6 oxidation states. Mobility of uranium with a valence of four is limited to pH's less than three, which is unlikely throughout most of the Browns Park because ground waters in contact with tuffs and
silicate rocks are made slightly alkaline (Granger and Warren, 1969). Uranium in the +6 state ($UO_2^{+2}$) is mobile over a wide range of pH's in oxidizing environments. If $CO_2$ is present in the ground water, as it frequently is, $UO_2^{+2}$ will combine with carbonate ions to form $UO_2(CO_3)_2^{-2}$ or $UO_2(CO_3)_3^{-4}$ which are also highly mobile in oxidizing environments. The presence of uranium limits the ground water to oxidizing conditions while pH is not restricted.

The presence of selenium in sandstone uranium deposits, however, indicates an alkaline pH. Selenium cannot be taken into solution under natural conditions at pH values of less than seven (Harshman, 1970). Selenium can be carried in solution under oxidizing, alkaline conditions as $SeO_4^{2-}$ or $SeO_3^{2-}$ ions. Granger (1969) believed that selenium was carried in solution as a complex with sulfur, $SeSO_3^{-}$ that is not stable except under alkaline conditions. It is highly doubtful that solutions carrying both uranium and selenium could have existed except under oxidizing, alkaline conditions. Since selenium is associated with uranium in significant amounts in both the Maybell-Lay and Poison Basin areas, uranium-bearing solutions in the Browns Park Formation must have existed under alkaline, oxidizing conditions.

Other elements, common in sandstone uranium deposits, also form ions stable in oxidizing, alkaline solutions.
Molybdenum goes into solution as MoO$_4^{2-}$, vanadium as V$_4$O$_{12}^{4-}$, and arsenic as AsO$_4^{3-}$. Iron, however, is an exception as it is not mobile except under acid or reducing conditions. Most Fe$^{+2}$ ions in alkaline, oxidizing solutions would oxidize and precipitate as Fe$_2$O$_3$ or FeOOH before being carried very far. Most of the iron was probably mobilized and precipitated as pyrite in a reducing environment generated by upward migrating H$_2$S gas or hydrocarbons. All these metallic elements could have been derived from tuffaceous sediments within the Browns Park Formation.

When uranium-bearing solutions entered reducing environments already containing pyrite, uranium precipitated as uraninite (UO$_2$). Selenium combined with iron to form ferroselite (FeSe$_2$). Molybdenum precipitated as jordisite (MoS$_2$). Whatever small amounts of vanadium and arsenic that were in solution in the Browns Park Formation, probably precipitated as montroseite (VOOH), and arsenopyrite (FeAsS), respectively. Oxidized minerals found at or near surface today, such as meta-autunite (Ca(UO$_2$)$_2$(PO$_4$)$_2$.8H$_2$O), ilsemannite (Mo$_3$O$_8$·nH$_2$O), and most of the limonite, formed from the minerals that were stable in reducing environments when they were exposed to surface oxidizing environments.
FUTURE EXPLORATION

There are still ore reserves present in the vicinities of the two mineralized areas discussed in this thesis. Pockets of mineralization nearby have recently been discovered and others probably will be. However, with the great amount of drilling done every year, in the Poison Basin, near the pits between Maybell and Lay, and in the heavily pyritized area north of Juniper Springs, it is doubtful that a significant ore body remains to be found in those areas. In situ, leaching, and heap leaching of tailings may extract uranium where past technology and economics failed.

Perhaps the best hope for finding a major uranium deposit in the Browns Park Formation is to go outside of the known mineralized areas and look for similar favorable features. Areas of Browns Park with possible underlying traps for petroleum, post-Miocene or late Miocene faulting, and high uranium values in ground water would be favorable for exploration. The best indication of faulting is limonite staining on the ground surface. However, many faults do not show at the surface in any manner and yet ore could still be associated with them at depth. Cross Mountain is an uplift similar to Juniper Mountain and may have similar late faults surrounding it with associated ore and pyritization only at
depth. Another outcrop of Browns Park besides the Poison Basin exists near the crest of the Cherokee anticline. This outlier north of Powder Wash also presents good potential.

New methods and ideas could be useful in exploration in the Browns Park. Radon methods using etches on film could detect hidden deposits. Because of the scarcity of shales in the Browns Park section gases emanated by uranium deposits may reach the surface more easily. Any methods improving abilities to detect these gases, such as helium and radon, could be particularly important in the Browns Park. Trace elements such as selenium or molybdenum may provide clues to general areas of mineralization; however, later redistribution of these elements has for the most part disturbed spatial relations, as seems apparent upon examination of trace element data in old TEI reports (Bergin and Chisolm, 1955; Prichard, 1955).
CONCLUSIONS

From the geochemical associations discussed in a previous section, it is probable that uranium was transported through the Browns Park sandstone as complexes with carbonate ions, in a slightly alkaline, oxidizing, aqueous solution at near-surface conditions of temperature and pressure. The reducing agent responsible for precipitating uranium oxide was probably pyrite. No concentrations of organic debris are associated with the uranium mineralization in the Browns Park beds. No organic debris was found in the course of the field work nor has any been reported by other authors working in the area. Direct precipitation of uranium on organic debris is not a significant process in either area of this thesis. Pyrite, on the other hand, occurs in proximity to all uranium mineralization in the Browns Park. Granger and Warren (1969) have shown that partial oxidation of pyrite results in the formation of unstable sulfur oxide species such as $\text{SO}_3^{-2}$ and $\text{S}_2\text{O}_3^{-2}$, which break down to form $\text{HS}^-$, a powerful reducing agent. By this model, oxidizing uraniferous solutions entering pyritized ground would cause the production of $\text{HS}^-$ which will precipitate reduced uranium oxide ($\text{UO}_2$).

The pyrite was probably originally formed by sulfate-reducing bacteria feeding on hydrocarbons that were introduced
into the Browns Park Formation from below. Iron was available from small amounts of ferrous iron in ground water or iron in ferromagnesian minerals and sulfur came from sulfate ions in ground water. Hydrocarbons were probably supplied along faults from oil and gas reservoirs below the Browns Park. Pockets of gas have been found in the Browns Park Formation in the Poison Basin area (Grutt, 1957). Also dead oil has been found in pits 5 and 6 of the Maybell-Lay area. Hydrocarbons may have also been supplied to ground water from coal beds. \( \text{H}_2\text{S} \) gas, migrating upward with petroleum may also have reacted with iron to form pyrite and perhaps precipitated uranium at the same time.

The mineralizing processes could have begun during the time of deposition of upper, eolian Browns Park sands and tuffs. The Browns Park Formation was about 1800 feet thick at this time. Below the Browns Park beds in the Maybell-Lay and Poison Basin areas were sealed-in oil and gas reservoirs. Ground waters in the Browns Park probably contained carbonate, sulfate, and ferrous iron ions in solution.

The first step leading to uranium mineralization was a period of late or post-Browns Park high-angle faulting around the Juniper Mountain dome and along the Cherokee anticline. Oil and gas were released from their sealed-in reservoirs along these faults. In the Maybell-Lay area the oil and gas
were probably in the Dakota Sandstone sealed above by the Mancos Shale until faulting occurred. Oil and gas may have migrated from other deeper petroleum-producing formations such as the Morrison, Entrada or Weber. In the Poison Basin area, gas migrated up faults from reservoirs in the Fort Union Formation sealed above by the Wasatch Formation. Gas could also have migrated from deeper reservoirs in the Lewis Shale.

Upon entering the Browns Park Formation from below, these hydrocarbons spread easily throughout much of the porous and permeable sandstone. The distribution of hydrocarbons throughout these regions of Browns Park sandstone was possible to an even greater extend in faulted and fractured areas. At higher stratigraphic levels, the more porous sandstone lenses adjacent to faults received the oil and/or gas while nearby sands received very little or were untouched. This left the Browns Park with large oil- or gas-saturated areas, especially along faults and fractures and in the more porous sandstones intersected by or near these faults.

Sulfate-reducing bacteria thrived in these sands where hydrocarbons provided an abundant source of food. Sulfate and reduced iron (Fe\(^{+2}\)) were in solution in ground waters that entered the sands. Bacterial reduction of the sulfate in the presence of iron formed pyrite. Iron was probably
originally brought into solution from ferromagnesian minerals indigenous to the Browns Park Formation. Pyrite probably formed in greatest density in those areas where the bacterial reducing action was favored by the heaviest hydrocarbon saturation. This explains the presence of pyrite-bearing sandstones in the areas near faults on plates 1 and 2.

Downward percolating water in the upper Browns Park picked up uranium from tuffaceous sandstones. The uranium was brought into solution in low concentrations as carbonate complexes. When this slightly oxidized, uranium-bearing ground water came into contact with pyrite in the sandstone, partial oxidation of pyrite released HS\(^-\), a powerful reducing agent. Reduction of uranium in solution with a valence of six to a valence of four caused uranium oxide (UO\(_2\)) to precipitate at the edges of the bodies of gray, pyritic sandstone. Pyrite also reprecipitated at the same place.

Some low-grade uranium deposits have been reported recently in the Maybell-Lay area, close to faults, entirely within what are now masses of pyritized sandstone. Since uranium should be precipitated predominantly at the edges of the pyritized ground, the sequence of mineralization described above, probably took place more than once, perhaps several times. The faults may have become active at several different
times, transmitting $\text{H}_2\text{S}$ gas and/or methane and subsequent pyritization further into the Browns Park sands with each episode of fault movement. Uranium precipitated at the conclusion of the first episode of fault movement became engulfed by pyritized ground created by further episodes.

$\text{H}_2\text{S}$ gas may have migrated up faults and directly precipitated uranium in ground water. This would have limited the time of ore formation to that brief interval when $\text{H}_2\text{S}$ was able to migrate up the faults, however. Precipitation of uraninite by pyrite is believed to be the most likely mechanism of mineralization by the author.
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