Geology and Uranium Deposits of the Southern Part of the Powder River Basin, Wyoming

GEOLOGICAL SURVEY BULLETIN 1147-D

Prepared on behalf of the U.S. Atomic Energy Commission

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By WILLIAM N. SHARP *and* ANTHONY B. GIBBONS

CONTRIBUTIONS TO THE GEOLOGY OF URANIUM

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GEOLOGY AND URANIUM DEPOSITS OF THE SOUTHERN PART OF THE POWDER RIVER BASIN, WYOMING

By WILLIAM N. SHARP and ANTHONY B. GIBBONS

ABSTRACT

The Powder River Basin in northeastern Wyoming is a physiographic unit bounded on the west by the Bighorn Mountains, on the south by the Laramie Mountains, and on the east by the Black Hills. The northern end is mainly open. Sedimentary rocks, ranging in age from Cambrian to Oligocene, overlie the crystalline basement and total as much as 13,000 feet in thickness. The Fort Union Formation of Paleocene age and the Wasatch Formation of Eocene age crop out over most of the central part of the basin and are the geologic units of particular interest to this study.

The Fort Union Formation is represented by about 3,000 feet of continental deposits and is divided into a lower unit composed dominantly of fine-grained sandstone and an upper unit characterized by white-weathering clayey siltstone.

The Wasatch Formation, which unconformably overlies the Fort Union, consists of approximately 1,000 feet of clay and siltstone containing thick lenses of coarse-grained, arkosic sandstone. The Wasatch is separable areally into two facies—a partly peripheral, generally drab, fine-grained facies, and a central generally coarse grained facies. The coarse-grained facies is subdivided according to two predominant colors of sandstone—drab and red. The red coloring, due to hematite, is restricted to a relatively narrow zone along the axis of the basin. Not all the sandstone lenses within this zone are red; some are drab throughout, and others are only partly red. The color contacts in partly red lenses are irregular and lobate in shape, in general are very sharp, and in many places crosscut the sedimentary structures.

The Powder River Basin was relatively stable during and after Eocene time, but structures indicative of minor instability are found. Faults and a fold trending parallel to but located east of the basin axis are inferred. These structures also underlie the elongate zone of red sandstone in the Wasatch Formation.

The uranium deposits in the basin occur in the lensing sandstone units of the Wasatch Formation within the area of predominantly red sandstone. The largest known deposits are near the edge of the zone of red sandstone, and all deposits display some detailed spatial relation to a red color boundary within the sandstone lens. The uranium minerals consist mainly of uraninite and tyuyamunite, which occur both in concretionary masses and as disseminations in uncemented sandstone. In some deposits tyuyamunite and other yellow uranium minerals are related to manganese-rich nodules.

The areal distribution of red sandstone and of the uranium deposits within the basin, in addition to the similarity of the deposits, strongly suggests a regional common control for the development of both features. Local control is also indicated by the close association of each deposit to the red color contacts in a specific sandstone lens. The results of this study support contentions that the red sandstone zone in the Wasatch and the uranium deposits are related in time and in origin. Neither feature is the cause of the other, but both are the results of the same sequence of events.

The process of concentrating the uranium, vanadium, and manganese began with moderate folding along the axis of the basin. This folding disturbed the geochemical equilibrium within the Wasatch sediments. Among the ultimate results of this disturbance were a change of yellow and brown limonite to red hematite along the axis of the fold, a concentration of uranium-vanadium-manganese in the same zone, and the development of generally consistent mineral relations in the numerous deposits. The uranium is thought to have been derived from the clastic material which was deposited in the basin and formed the sandstone lenses.

INTRODUCTION

The Powder River Basin of northeastern Wyoming lies between the Black Hills on the east and the Bighorn Mountains on the west and extends from the Laramie Range northward into southern Montana. The basin occupies 12,000 to 15,000 square miles of rolling grassland, badlands, and sand dunes and includes most of Campbell, Converse, Johnson, and Sheridan Counties (fig 1). This report covers the area of about 2,500 square miles in the southern part of the basin south of Pumpkin Buttes.

Uranium deposits were discovered late in 1951 near Pumpkin Buttes, in the central part of the Powder River Basin. Inasmuch as the geology of the basin was almost unknown, studies were undertaken to determine the geologic relations and origin of the uranium deposits, the ore potential of the area, and geologic guides to exploration for new deposits. The investigation was started in the area around Pumpkin Buttes and was later extended southward into the area of uranium deposits described in this report. The work was done by the U.S. Geological Survey on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission.

FIELDWORK AND ACKNOWLEDGMENTS

The fieldwork for this report was done in 1955 by W. N. Sharp and A. M. White, assisted by Donald R. Larson, and in 1956 by W. N. Sharp and A. B. Gibbons. Reconnaissance geologic mapping was done on aerial photographs and topographic maps at scales of 1:34,000 and 1:24,000. Areas of mining and prospecting activity were mapped in detail at scales of 1 inch=200 to 600 feet. The regional geologic map (pl. 1) is a compilation of these data at a scale of 1:62,500. The relatively great detail shown on some parts of the map in contrast to

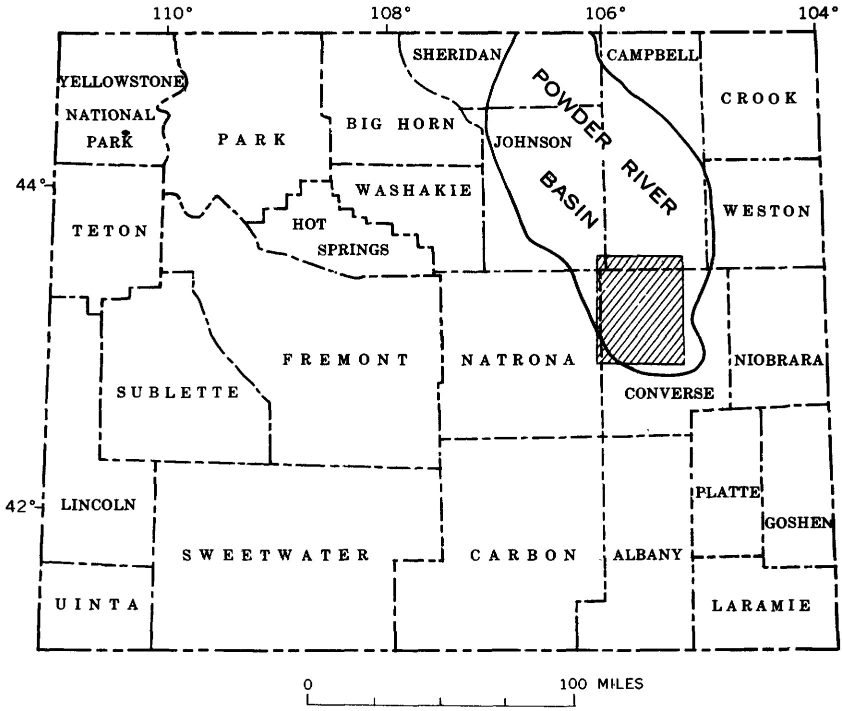

FIGURE 1.—Index map of Wyoming, showing Powder River Basin and the mapped area.

the lack of it on other parts reflects the completeness of mapping rather than the complexity of geology.

The many ranchers in the area were most cooperative throughout the fieldwork; among these were J. R. Morton, Walter Reynolds, Joe Reynolds, Rhea Tillard, Richard Hornbuckle, Mick Hardy, Jack Werner, Herman Werner, Fred Taylor, Roy Copp, and Morley Archibald. The cooperation of mine owners and operators was helpful in sampling and in mine studies.

PREVIOUS WORK

The first geologic investigation in the southern part of the basin was made in about 1900 when N. H. Darton carried out a reconnaissance survey of the geology and underground water resources of the central Great Plains (Darton, 1905). In 1907, the U.S. Geological Survey began examination of the coal fields in the Western States for the purpose of classifying public lands. During the next 8 years, geologic investigations were carried out in several coal fields that fringe the southern part of the basin (Wegemann, 1912; Wegemann and others, 1928; Shaw, 1909). Of the early workers, Wegemann contributed the most, and to him belongs the credit for identifying rocks of Wasatch age in the basin (Wegemann, 1917). Before that time, beds throughout the basin, with the exception of beds of the White River Group capping Pumpkin Buttes, were considered to be Fort Union. Wegemann, about 1915, also made some observations on the lithology of the Wasatch and Fort Union Formations and on the nature of the contact between these formations along the valley of the Dry Fork of the Cheyenne River (Wegemann and others, 1928). In 1924, Dobbin reviewed earlier unpublished data and did fieldwork in the northeastern part of the area and along the valley of the Dry Fork of the Cheyenne (Wegemann and others, 1928; Dobbin and Barnett, 1927).

In 1952, beds capping the Pumpkin Buttes were proved by fossil evidence to be of White River age (Love, 1952), as Darton (1905, pls. 35 and 44) had previously inferred.

GEOLOGIC SETTING

The Powder River Basin is a large structural as well as physiographic basin almost completely surrounded by structural highlands, which, so far as is known, predate the Tertiary sedimentary rocks within the basin. The Powder River Basin is bounded on the east by the Black Hills uplift; on the south and southwest by the Hartville uplift, the Laramie Mountains, and the Powder River lineament; and on the west by the Bighorn Mountains uplift. On the north, the Powder River drains a large part of the basin through a low structural saddle west of the northern Black Hills in southeastern Montana.

The Belle Fourche River and forks of the Cheyenne River, flowing eastward, drain the eastern part and most of the southern part of the basin. The North Platte River drains a narrow belt along the south edge of the basin. The prominent, flat-topped Pumpkin Buttes, the most conspicuous physical features of the basin, are along the drainage divide between the Belle Fourche and Powder River systems.

The Powder River Basin is underlain almost completely by freshwater sedimentary rocks of the Wasatch Formation of Eocene age. Immediately underlying the Wasatch Formation, the Fort Union Formation of Paleocene age crops out as a band around the periphery of the Wasatch. Older rock units of Cretaceous and Paleozoic age crop out discontinuously around the borders of the basin. Consoliated rocks younger than the Wasatch beds, belonging to the White River Formation of Oligocene age, cap the Pumpkin Buttes in the central part of the basin and truncate Fort Union beds at the south edge of the basin.

The southern part of the basin is generally less incised than other parts, and badlands make up only a small part of the area. Most of it is characterized by rolling grasslands separated by broad valleys.

Some of the higher areas, which are almost level, have been informally named flats (pl. 1). They are bounded in part by conspicuous erosional escarpments and are thought to represent parts of a former erosion surface. These flats, the high-level terraces along the North Platte River, and the Great Pine Ridge hogback along the west edge of the area are the most conspicuous features of this part of the basin.

The report area (fig. 1 and pl. 1) includes all the outcrops of the Wasatch Formation in the southern Powder River Basin, except for irregular eastward extensions, as well as most of the outcrops of the underlying Fort Union Formation. Rocks of the White River Formation of Oligocene age and of the Lance Formation of Late Cretaceous age crop out only locally, and they will not be discussed at length in this report. These rocks are well described in other publications (Winchester, 1912; Wegemann, 1917) and were included on the map mainly for completeness.

Gravel deposits cap many of the hills and ridges in the area, particularly near the south boundary. Much of the material appears to be residual, let down from the once overlying conglomerate of the White River or Wasatch. Windblown sand covers a large area southwest of the basin, and prevailing southwest winds have carried into the area broad fingers of this sand which now overlie Lance and Fort Union Formations in two places.

STRATIGRAPHY

LANCE FORMATION

The Lance Formation of Late Cretaceous age is the oldest rock unit shown on plate 1 of this report. The rocks of this unit are not considered pertinent to the study of the uranium deposits of the Powder River Basin and were not given much attention in the field. Briefly, however, the formation is represented in the area by several thousand feet of thin-bedded, brown to gray sandstone and shale. Much of the upper part of the formation is banded by numerous dark carbonaceous shale beds and thin coal seams. The Lance Formation is conformably overlain by the Fort Union Formation.

FORT UNION FORMATION

The Fort Union Formation of Paleocene age is represented in the southern part of the Powder River Basin by about 3,000 feet of poorly to semiconsolidated continental deposits. In the map area these deposits may be divided into a lower member of predominantly flat-bedded fine-grained sandstone which underlies Great Pine Ridge and prominent hills near Douglas, and an upper member mainly of white-weathering siltstone, dark-brown ironstone, and coal. Because the correlation of these units with the Tongue River, Lebo, and Tullock

Members of the Fort Union as recognized elsewhere in the Powder River Basin is uncertain (Love and others, 1955), they will be referred to in this report simply as lower and upper members of the Fort Union Formation (pl. 1).

LOWER MEMBER

The lower, or sandy, member of the Fort Union Formation in the southern Powder River Basin conformably overlies the Lance Formation of Late Cretaceous age. This member, typically exposed on the west face of Great Pine Ridge escarpment, is composed mainly of white, pinkish, or pale-orange flat-bedded fine-grained clay-rich sandstone. Silty claystone and coal occur also as minor constituents. Thin laminae of pale-gray clay and thin ferruginous layers accentuate the bedding in the sandstone of Great Pine Ridge.

The lower member of the Fort Union Formation is locally coal bearing, notably in the area south of the Platte River between Careyhurst and Douglas. The coal here occurs in a sequence of prominent sandstone lenses, thin-bedded clayey siltstones, and extremely dense and numerous ironstone layers. E. W. Shaw (1909) described and mapped these coals.

UPPER MEMBER

The upper member of the Fort Union Formation consists of 1,000 to 1,600 feet of sedimentary rocks characterized by white-weathering clayey siltstone, many brown ironstone lentils, and coal beds. Thin fine-grained sandstone beds are present but not conspicuous. This member is better known than the underlying or overlying rocks because it contains the important coal beds of the Powder River Basin. Various areas of outcrop are briefly described by Wegemann (1912, p. 446) and Shaw (1909, p. 156). The thick subbituminous coals of this member have been mined extensively in the past and at the present time are being utilized locally for development of electric power.

The silty upper member of the Fort Union Formation is less resistant to erosion than the units above and below it and tends to form valleys. Where the Great Pine Ridge escarpment is prominent, as in the area north of Glenrock, the upper member of the Fort Union forms a broad dip slope and swale separating the escarpment from the similarly high standing and sandy country which is underlain by the lowermost part of the Wasatch Formation. The upper reaches of Sand Creek, north of T. 34 N., drain such a swale. The gently sloping, sage-covered terrain north of the Platte River, northwest of Douglas, is underlain by this upper member.

WASATCH FORMATION

The Wasatch Formation of early Eocene age, about 1,000 feet thick, unconformably overlies the Fort Union Formation. In the southern part of the Powder River Basin, the Wasatch Formation consists of clay and siltstone containing thick lenses of coarse, crossbedded arkosic sandstone. Thin beds of coal or carbonaceous shale are common in some areas. Like the rocks in the Fort Union Formation, the sedimentary rocks in the Wasatch are only semiconsolidated. The gray-weathering siltstone and claystone are moderately compacted, whereas the sandstone beds are generally friable.

Interstitial calcite locally binds the sand grains into concretionary masses of various sizes and shapes. Two characteristic shapes of concretions are the spherical kind, to which Pumpkin Buttes owes its name, and the log-shaped concretions which are as much as 50 feet long and 5 feet wide. Calcite cement in the sandstone lenses of the Wasatch commonly is moderately concentrated in thin layers of drab or red sandstone at red color boundaries, particularly in lenses containing uranium deposits. In some lenses calcite concretions as much as 1 foot across are arranged along the color boundary in a particular calcite-cemented zone. In addition to calcite, other cementing materials in sandstone lenses of the Wasatch Formation are hematite, limonite, manganese oxides, pyrite, and barite.

Most of the sandstone lenses are rich in clay, and some—mostly those in the central part of the area—contain a conspicuous white montmorillonite clay component. Some lenses contain so much montmorillonite that the outcrops are noticeably white. Volcanic ash, from which the montmorillonite formed, apparently was a significant original component of the sandy fill in these channels.

The sandstone of the Wasatch is arkosic. Quartz and microcline are the two most abundant minerals, and plagioclase is third. This sandstone contains only a small percentage of heavy minerals, of which epidote, garnet, magnetite-ilmenite, chlorite, biotite, and muscovite are the most common. Hornblende, monazite, tourmaline, apatite, zircon, kyanite, andalusite, and rutile are fairly abundant in some samples. Some of the detrital grains are rock fragments of mica and hornblende schist, chalcedonic quartz, chert, and quartzite. The conglomeratic facies at the south edge of the basin contains pebbles of the above-mentioned rock types, pebbles of pink granite, and elongate fragments of pink feldspar.

FACIES

Although it was not possible to divide the Wasatch Formation of the Powder River Basin into stratigraphic members, an areal separation of the formation into two facies was made, based in part on previous work in the northern part of the basin. A dominantly fine grained facies flanks the basin on three sides, and a dominantly coarse grained facies is present in the central and southern parts of the basin (pl. 2). The fine-grained facies, particularly well represented on the northwestern and eastern flanks of the basin, consists of thinly interbedded siltstone, fine- to medium-grained sandstone, and coal or carbonaceous shale. Southward and toward the center of the basin, siltstone and carbonaceous shale decrease in amount, thick lenticular sandstone beds become more prominent, and sandstone makes up as much as one-third of the formation.

Within the coarse-grained facies, the grain size of the sands increases generally southward. In the Pumpkin Buttes area the sands are medium coarse; in the part of the Wasatch outcrop traversed by the Cheyenne River, the sands are coarse grits; at the south extremity of the outcrop of the Wasatch Formation, pebble conglomerate appears as lenses and stringers in the coarse grit. In addition to this increase in grain size of the sand, the sandy units themselves thicken generally from north to south. Sand lenses as much as 150 feet thick have been mapped at the southwest edge of the outcrop of the Wasatch.

COLOR OF SANDSTONE LENSES

Most sandstone lenses within the Wasatch Formation are dull shades of gray, yellow, or brown. In places, particularly in the central part of the area, the sandstone is very light gray to white owing to an abundance of white clay. In a well-defined zone along the axis of the basin, however, some of the sandstone is predominantly reddish pink and grayish red. Some lenses are only partly red, and some are entirely drab. The red tint, where present, commonly affects a large, continuous mass of the sandstone lens and does not occur as isolated splotches of color. The contacts of red color within any partly red sandstone lens are generally very sharp but irregular in plan and cross section. Contacts are generally convex into the drab sandstone; lobes and long arms of red color commonly extend into drab sandstone.

Neither position nor extent of red color within individual sandstone lenses is controlled by any apparent feature of the rock. Color contacts transect grain-size changes and crossbedding within the sandstone without visible change in direction or character. The upper parts of some lenses are red, as are the lower parts of others, but the red color may range from the upper part to the lower part of a lens without conforming to its dip or shape. The red and drab sandstones both commonly contain 1 to 3 percent iron. The red sandstone contains hematite, whereas the drab sandstone contains mainly hydrated iron oxides.

The red sandstone is restricted to an area about 70 miles long and 5 to 20 miles wide. The long axis of the red sandstone zone closely parallels the axis of the basin. It extends from near Douglas, at the south edge of the basin, to several miles north of the Pumpkin Buttes in the central part of the basin (pl. 2).

The boundary of the red sandstone zone is more easily delineated in some parts of the basin than in others. Color changes in the sandstone are generally distinct in the central part of the basin around Pumpkin Buttes, and in this area the boundary is readily mappable. South of the Buttes, in Converse County (pl. 2), the boundary is less easily mapped because the gently rolling topography provides few and poor exposures, and the bleaching of the drab and red sandstone to grayish white or white is widespread.

The bleached sandstone contains abundant white montmorillonite clay. The alteration of volcanic ash to montmorillonite apparently caused the enclosing sandstone to lose its characteristic color. The bleached sandstone contains about half as much total iron as the colored sandstone. The iron is not present as free oxides but as a component of the clay. Some of the iron, which colors the sandstone, probably was taken up into the clay, and the remaining iron was reduced to a state in which it was removed from the rock. This is thought to be true because iron is common in montmorillonite, and the amount of iron contained is probably largely a function of the iron content of the environmental solutions at the time of clay development. Montmorillonite containing 8 percent iron may still be white (Ross and Hendricks, 1945, p. 63). The specific mechanism by which some of the iron was mobilized and removed from the rock during the development of the clay is not clearly understood, but the direct relation between the formation of the clay and the bleaching of the sandstone seems manifest. The bleached sandstone contains four to five times more clay than does the colored sandstone. The clay content of the sandstone of the basin, either red or drab, is generally less than 1 percent; that of the bleached white sandstone is from 2 to 4 percent. This clay coats the sand grains and also occurs as conspicuous cottonball-like segregations between the grains.

Clay was separated from one white sandstone sample and was analyzed for ion-exchange capacity, exchangeable cations, and total iron before and after leaching. The clay and total iron content of the sandstone was also roughly determined.

Base exchange properties of montmorillonite from the white sandstone, Pat 4 claim, Converse County, Wyo., determined by H. C. Starkey, are as follows:

Sample serial No.	Capacities for exchangeable cations					Sum of capacities for exchangeable cations	Determined total base exchange capacity
	Milliequivalents per 100 grams of sample						
	Na	Ca	Mg	H	K		
279805	2.1	46.6	12.3	0.6	--------	61.6	91.4

Analysis by colorimetric method for total iron as Fe_2O_3 was made by D. L. Skinner on the bulk clayey sandstone and on the clay fraction. The clay in the sandstone amounted to 3.8 percent of the whole sample. The bulk sandstone contained 1.15 percent total iron; the clay component carried 3.59 percent total iron before leaching for base exchange capacities and 3.04 percent total iron after leaching. The leachate contained 0.36 percent total iron; 0.19 percent was lost in the process.

AGE

The early Eocene age of the rocks herein called Wasatch was established in the Pumpkin Buttes area north of the area described in this report (Wegemann, 1917). Within the report area only one fossil of diagnostic value has been reported to date. Roland W. Brown has identified *Salvinia* sp. from a collection of fossil leaves submitted in 1956 by D. Y. Meschter of the Atomic Energy Commission. In the Rocky Mountain region *Salvinia* sp. is believed by Brown to be restricted to fresh-water sediments of Eocene age or younger. The collection came from a mudstone lens about 20 feet above the prominent coal bed which crops out in the east bank of Willow Creek in sec. 6, T. 37 N., R. 72 W. (D. Y. Meschter, 1956, written communication). The coal lying just below the stratum containing *Salvinia* previously had been considered to mark the approximate contact between the Eocene Wasatch and the Paleocene Fort Union Formation. The coal is underlain by the white-weathering siltstone and dark-brown ironstone of the upper member of the Fort Union Formation and is overlain by the thick gray clay and coarse-grained sandstone typical of the coarse-grained facies of the Wasatch Formation. This lithologic change has been the basis for mapping the Fort Union-Wasatch contact in the southern Powder River Basin.

WHITE RIVER FORMATION

The rocks of the White River Formation of Oligocene age have been removed by erosion from most of the Powder River Basin. They presently overlie the Fort Union Formation in only the southernmost part of the map area and are generally flat lying, resting on an erosion surface that truncates the upturned beds of the older rocks.

The formation is represented by crudely bedded white clayey sandstone and boulder conglomerate, and white and pink claystone.

FORT UNION-WASATCH CONTACT

The separation of early Tertiary rocks in the Powder River Basin into the Fort Union and Wasatch Formations is based on published data by Wegemann (1917). However, some doubt has persisted as to the nature of the boundary between the two units because they are similar in appearance and are so nearly conformable throughout much of their extent that a specific contact is difficult to distinguish. The two units are conformable throughout most of the southern part of the basin and lie in a regular manner one entirely above the other. Along the flanks of the southern part of the basin they are measurably disconformable. However, in the central part of the basin material typical of the Wasatch occupies a troughlike space equivalent to part of the Fort Union interval, and the two types of material are bedded conformably. This central conformable part of the Wasatch is difficult to distinguish from a facies of the Fort Union.

Lithologic and contact features of the two formations, as mapped and interpreted in the southern part of the basin, strongly support the idea of two largely discordant formations separated by an erosion surface. This idea is not a new one but has been advanced tentatively by earlier workers. Wegemann (1917) and Hose (1955) described the Kingsbury Conglomerate Member of the Wasatch Formation along the Bighorn Mountains front north of the project area as unconformably overlying the Fort Union (pl. 2). Wegemann (1917) commented also about an apparent unconformity along the Dry Fork of the Cheyenne River in the southern part of the basin. Wegemann's reasons for suggesting an unconformity are much the same as those presented in this paper. The Wasatch of the Powder River Basin is interpreted to resemble the Wasatch of the Bighorn Basin to the west (Sinclair and Granger, 1911), in that it occupies a slight structural depression and also an erosional trough cut into beds of the Fort Union.

The relations of the two units are best exposed along the valley of the Cheyenne River in the southern part of the basin. The valley crosses the basin and, except for a narrow, thin remnant in the central part, cuts through beds of the Wasatch exposing the Fort Union rocks below.

The unconformity between beds of the Fort Union and Wasatch, which is marked by a somewhat irregular surface (section *B–B′*, pl. 3), is best expressed by the relations of several coal beds to the lithologic change on both flanks of the basin as well as by visible differences in dip of beds of the Wasatch and Fort Union along the flanks of the basin. In the central part of the basin, however, where the two units are concordant, other criteria are necessary to support a disconformity. Differences in appearance, composition, and physical properties are features that suggest that the units are separate entities.

The coal beds at the western limit of outcrop dip about 2° to the east; they flatten in attitude eastward and become virtually flat lying at the eastern limit of exposure, which is a few miles west of the Ross Road. At this location where the coal disappears the lithology of the rocks at the level of the coal changes abruptly from typical Fort Union to typical Wasatch in which coarse-grained sandstone lenses become conspicuous.

East of this Fort Union-Wasatch contact several flat-lying coal beds within the Wasatch may be mapped throughout a distance of 10 to 12 miles to the center of the basin. One coal bed (No. 4 on section *B–B′*, pl. 3), at its westernmost exposure, marks the Fort Union-Wasatch contact; when traced 10 miles to the east, it is about 400 feet above the contact (section *B–B′*, pl. 3).

These well-exposed coal beds, within sections of typically Fort Union and Wasatch lithology, apparently approach an inclined boundary of lithologic change—the Fort Union-Wasatch contact—along the western Cheyenne River valley and there abruptly lose their identity. None of these coal beds cross the Fort Union-Wasatch contact. The same can be said also for the thick, coarse-grained sandstone lenses. Although thick sandstone crops out close to the boundary of lithologic change, none transects it. This noninterfingering relation seems incompatible with the facies concept.

The same relation between typical lithologies of the Fort Union and Wasatch and included coal beds also is conspicuous along the Cheyenne River valley on the east side of the basin (section *B–B′*, pl. 3). In this region, two prominent coal beds mark the top of the Fort Union at different places. These coals are the "D" coal bed of Dobbin (1927) and the "H" coal bed of Wegemann (1917). Although they had previously been mapped as the same coal, fieldwork of the present project shows that the "H" coal exposed in the Cheyenne valley near the center of the basin is 200 feet stratigraphically lower than the "D" coal exposed along the north rim of the Cheyenne valley toward the east edge of the Wasatch outcrop. Both of these coals divide the Fort Union and the Wasatch in parts of their respective areas of outcrop, but they do not transect the boundary of change.

Samples of coal beds in the Wasatch and Fort Union Formations were analyzed to determine if the trace-element content might distinguish coal of one formation from that of another. The analyses (tables 1 and 2) showed no significant difference between the coal samples.

The discordance of Fort Union and Wasatch bedding may be seen at many places near the edges of the basin where the abrupt change in lithologic type is well exposed. For example, in T. 34 N., R. 37 W., an interval of Wasatch section that includes reddish coarse-grained flat-lying sandstone units overlies a drab section of thin-bedded claystone, siltstone, and coal, all dipping northward at 1½°. In T. 35 N., R. 74 W., flat-lying coarse-grained sandstone caps west-trending ridges for several miles and directly overlies well-exposed thin-bedded clay-

TABLE 1.—*Chemical analyses, in percent, of coal samples from Fort Union and Wasatch Formations, southern part of the Powder River Basin, Wyo.*

[Analyses of samples, serial Nos. 237021–237024 made by C. G. Angelo, R. P. Cox, and J. S. Wahlberg, and for Nos. 249801–249805 by C. G. Angelo, J. P. Schuch, J. S. Wahlberg, and Claude Huffman, Jr.]

Field No.	Serial No.	Location	Formation	Elements					
				eU	U	V_2O_5	Mo	P_2O_5	Ash
S55-61-1	237021	"G" coal of Wegemann.	Fort Union	<0.001					
CC-1-332	237022	Core hole "Monument Hill" CC-1.	Fort Union (?).	<.001					
CC-3-285	237023	Core hole "Manning" CC-3.	Wasatch	<.001					
CC-3-456	237024	do	Fort Union	<.001					
S56-117	249801	Bed "B" of Dobbin on Reno Flat.	Wasatch	<.001	0.0002	<0.1	<0.001	0.20	10.5
S56-128	249802	Coal pit ±20 13-35-75	Fort Union		.0002	< .1	<.001	<.05	8.1
S56-129	249803	Coal pit ±10 34-46-75	do		<.0001	< .1	<.001	<.05	3.9
G56-101	249804	"D" coal of Dobbin at Antelope mine.	do		<.0001	< .1	<.001	<.05	4.3
G56-106	249805	"D" coal west of Antelope mine.	do		.0010	< .1	<.001	.36	7.5

TABLE 2.—*Semiquantitative spectrographic analyses, in percent, of coal samples from Fort Union and Wasatch Formations, southern part of the Powder River Basin, Wyo.*

[Analyst, R. G. Havens; M, major component; Tr, trace. Elements not looked for: Si, Na, Cs, F, Rb]

Elements	Field No.				
	S56-117-1	S56-128-1	S56-129-1	G56-101-1	G56-106-1
Al	7	7	7	7	M
Fe	7	3	7	7	3
Mg	M	7	7	7	7
Ca	M	M	M	M	M
Ti	.3	1.5	.15	.3	.3
Mn	.3	.15	.3	.15	.015
Ag	0	Tr.	Tr.	Tr.	Tr.
B	.15	.07	.3	.15	.15
Ba	.3	.03	.15	.3	1.5
Be	0	.0007	0	0	.0003
Co	.0015	.003	.003	.003	.003
Cr	.003	.015	.007	.007	.007
Cu	.015	.07	.015	.03	.03
Ga	.003	.0007	.0007	.0015	.007
La	0	.015	0	0	.015
Mo	.003	.0015	.007	.0015	.0015
Nb	.0015	0	0	0	.003
Ni	.007	.015	.007	.007	.007
Pb	.015	.0015	.003	.003	.015
Sc	0	.007	.0015	.003	.003
Sn	.007	0	0	0	0
Sr	.3	.15	.3	.3	.7
V	.007	.07	.015	.015	.015
Y	.003	.007	.007	.003	.015
Yb	.0003	.0007	.0003	.0003	.0015
Zr	.015	.03	.007	.015	.03

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stone, siltstone, coal, and carbonaceous shale which dip eastward about 2°. The lower contact of this sandstone at one place appears to be a scour contact. Farther north in T. 38 N., R. 76 W., there are several prominent erosional remnants of flat-lying coarse-grained yellowish-tan sandstone of the Wasatch, underlain by thin-bedded Fort Union rocks that dip 1½° to 3° eastward. Along the eastern part of the Cheyenne River valley the "D" coal, in its outcrop closest to the Wasatch contact, dips 1½° to 2° NW., whereas thin coaly shale beds in the Wasatch at the same altitude west of the boundary are flat lying.

The Wasatch and Fort Union generally differ in appearance; the Fort Union lacks the thick coarse-grained sandstone lenses of the Wasatch and the clay and siltstone components differ in appearance. The Fort Union consists of thin interbedded clay, coal, shale, and sandstone beds in a regular sequence or cyclic arrangement. The fine-grained beds of the Wasatch are generally more massive and in a far less regular sequence. The Fort Union is white weathering, whereas the Wasatch is drab weathering. Montmorillonite is the chief clay mineral in the Wasatch Formation, whereas kaolin dominates in Fort Union rocks throughout the basin. Heavy-mineral fractions of the Wasatch, as described in the following section, consist largely of relatively unstable minerals; the Fort Union contains mostly durable minerals, including some species not found in the Wasatch, suggesting perhaps a different source and a different parent rock.

SEDIMENTARY PETROLOGY OF SANDSTONE OF THE FORT UNION AND WASATCH FORMATIONS

Heavy mineral studies were made on 6 samples of sandstone from the Fort Union Formation and 13 from the Wasatch Formation. The samples were cleaned by elutriation, graded for size by screening, and the heavy fractions separated in bromoform. The heavy minerals for 12 of the sands were studied in the $-30+100$ mesh fractions and in the $-100+200$ mesh fractions so that total figures for the percentage of heavy minerals in two size grades could be compared. Heavy minerals average 0.37 percent by weight of the $-30+100$ fractions and 1.66 percent of the $-100+200$ fractions.

Table 3 lists the detrital minerals identified in these sandstones. Abundance is roughly indicated by the number given each mineral occurrence. Roundness and sphericity of the heavy mineral grains were estimated by comparison with a set of graduated grain outlines (Krumbein and Sloss, 1951, p. 81). The average roundness of these grains is near 0.4; their average sphericity is about 0.7. The shape of the grains varies greatly, but the subangular shape is most typical.

Most of the heavy minerals have their normal properties, and for this reason, the succeeding brief notes present only details that will serve to individualize these mineral occurrences.

TABLE 3.—*Heavy minerals in sandstone of the Wasatch and Fort Union Formations*

[1, rare; 2, not common; 3, common; 4, abundant; 5, dominant]

Sample	Formation	Locality: Sec.	Locality: T. (N)	Locality: R. (W)	Metallics	Muscovite	Biotite	Chlorite	Pink Garnet	White Garnet	Epidote A	Epidote B	Hornblende	Actinolite	Tremolite	Monazite D	Monazite E	Spinel	Apatite A	Apatite B	Sphene	Tourmaline	Rutile	Kyanite	Andalusite	Zircon	Descriptive remarks
S56-58-0 [1]	Wasatch	3	37	73	2		2		3		4								3	3		1	1			2	Tan-red and cloudy zircon. Yellow-brown rutile.
106-1	do	36	37	74	1	3	2	2	2		2	2	3	3	1		1		1		2			1		1	Rare zircon includes tan-red variety.
121-1	do	2	38	75	2	1	3	1	2		4	3		1			1		1	2	1			1		1	Dark-zoned and colorless zircon.
124-1	do	20	34	73	4	2	2	3	2		4	3				2		1	1		1		1			1	Tan-red and short prismatic, brown zircon. Purple zircon.
133-1	do	13	37	74	2	5	2	2			1			1					1			1	1			1	Tan-red zircon very rare.
137-1	do	36	38	74	3	2		4	2		4			1					1		1	1	1			1	Tan-red and pale pink zircon.
142-1	do	8	37	75	3	2	2	4	2		3	3					2	1	2			1				1	Short prismatic, brown zircon. Tan-red and pink zircon.
146-1 [2]	do	27	38	73		1		3	2		4					1			1	1	1	1	1			1	Rounded basal buttons of brown tourmaline.
148-1	do	34	38	73		1	2	1	2		3		3	3					1		1	1	1	1		1	Yellow-brown and red-brown rutile.
153-1	do	6	40	75	3		2	1	3		4	3		1			1		2	1	1	1	1	1		1	Tan-red, brown and colorless clear zircon.
173-1	do	10	41	74	4	1	2	1	4	1	3	2		1			1		2	1	3	1	1	1		1	Sphene as flattened crystals.
185-0 [3]	do	3	37	73	4	3	1	1	4		4		1	3	1	1						1	1	1		1	Tan-red and colorless zircon.
Red P-Q	do	8	45	76	3		2	3	3		3		1	2	1			1	1		1	1	1	1		1	Pink, colorless, purple, and dark-brown zoned zircon.
G56-105-2	Fort Union	5	40	70	3	2	1	1	3		1	1							3	1	2	2	1			2	Rounded sphene and tourmaline. Purple zircon.
117-1	do	10	39	71	3	3			2										3			3	2			1	Common purple zircon and yellow-brown rutile.
S56-122-1	do	12	38	77	4	4	2		1		1	1							1		2	2	2	1	2	1	Sparse garnet or epidote. Some cloudy zircon.
131-1	do	15	36	75	3	4	2	4	3		3	2							2		1	1	1		1	2	Pink rounded zircon. Some blue-green tourmaline.
160-1a	do	9	37	74	4	3	3	2	2		3	2							1		1	1	1	1	1	1	Tan-red and short prismatic, brown zircon.
160-1b	do	9	37	74		2	3	3	2		3	3							2		1	1		1	1	1	Tan-red and brown zircon. Blue-green tourmaline.

[1] Pat mine. [2] Hardy Fee mine. [3] Fly mine.

Magnetite and ilmenite are both found in the sands but ilmenite more commonly.

Biotite is mostly deep brown. Chlorite occurs in many varieties. Muscovite is common and generally much altered to clay minerals.

The garnet is mostly pink or red. Colorless garnet is uncommon. Brown garnet is extremely rare.

Epidote occurs in two forms: as deep yellow-green, pleochroic fragments of striated prisms; and as white, sugary, fine-grained, rounded detrital aggregates. Euhedral zoning shows in thin sections of the green variety, but this characteristic does not appear when the grains are immersed in oils.

The hornblende of these sands is green and shows all gradations into actinolite. No brown hornblende is evident.

Tremolite is a constituent of the sands but some of the colorless grains counted as tremolite have *n*Y 1.629, unmistakable amphibole cleavage at 56° and 124°, a large negative optic angle, and parallel extinction. These grains may be anthophyllite.

Monazite occurs as two distinct varieties. Monazite D is a rounded reddish variety with a resinous luster. Monazite E occurs as broken and worn dark-brown translucent grains. The monazite-bearing sands examined contain one variety or the other, but not both at any one locality.

The green, clear isotropic mineral identified as spinel may possibly be green garnet.

Apatite occurs mostly as smooth, rounded grains. Prismatic apatite, some with a dark pleochroic core, is less common.

Sphene occurs as well-rounded grains or pale-yellow flattened prisms. No diamond-shaped crystals are evident.

Most of the tourmaline of these sands is brown. Blue-green tourmaline occurs but is much less common than the brown varieties.

Most rutile of these sands is dark, red brown, and nonpleochroic. Yellow-brown pleochroic rutile is common in the sandstone of the Fort Union on the east side of the Powder River Basin.

White, transparent kyanite without perceptible blue pleochroism is fairly common.

Andalusite occurs as ragged grains, white to pale pink, and usually elongate parallel to the *c* axis. Some of the grains are pleochroic in pink.

Zircon occurs in many varieties differing from one another in color, shape, and in number and kind of inclusions. Red-purple pleochroic zircon (sample Red P–Q, table 3) is common on the east edge of the basin and in the ore sand from the Pumpkin Buttes area. In the southern part of the basin it is rare. Horseflesh zircon, a slightly rounded, tan-red variety, opaque-looking under the binocular microscope, is common in the southern part of the basin, as is a slightly rounded, very dark brown, euhedrally zoned variety.

The composition of the interstitial clay for 20 sandstone samples from the Wasatch Formation and 3 from the Fort Union Formation was determined. Clay derived from sandstone in the Wasatch exhibited an X-ray pattern showing montmorillonite to be the predominant clay mineral. Kaolinite and sericite were present in most clays but gave only minor reflections. The three slides of clay prepared from sandstone in the Fort Union showed kaolinite to be the predominant clay mineral. Montmorillonite was present in very minor amounts.

Whether the predominance of kaolinite in the clays of the Fort Union is as general as the above results suggest is uncertain, because only three determinations were made on materials from both sides of the basin. The predominance of montmorillonite in clays of the Wasatch Formation is very strongly indicated, however, because the 20 determinations represent widely scattered localities in the southern part of the basin, and also because determinations made of clay from sandstone in the Wasatch in the Pumpkin Buttes area also indicated the predominance of montmorillonite.

STRUCTURE

The southern part of the Powder River Basin seems to have been relatively stable during and after Eocene time. Some significant structural features are suggested, however, by a study of bedding attitudes and by postulating a relationship between linear surface features and basin structure. Features of the resulting basin-wide structural pattern are closely related to the ore deposits.

The dips of beds in the Wasatch Formation throughout the area range from less than 1° to as much as 2½°. At the fringes of the basin the Fort Union dips basinward from 2° to as high as 20°. Dips in the Wasatch are difficult to measure directly, and most of the values of dip shown on plate 2 were obtained by using the three-point method on conspicuous sandstone lenses and coal beds that are mappable for several miles.

The axis of the basin in surface rocks curves abruptly in the northern part of the map area to a position far east of the basin axis in the basement rocks (pl. 2). This nonconformity of surface position with basement position of the axial trace is anomalous because elsewhere in the basin, particularly farther north, the axial traces on the basement and at the surface are subparallel and relatively close together.

To realize fully what the change in position of the trough in surface rocks might mean it is necessary to explain a second significant structural feature of the southern part of the basin. This feature embraces three widely separated but alined linear surface grooves which are mapped as fractures in the surface rocks and are believed to be crestal tension fractures (pls. 1 and 4). These three fractures trend northwest and lie along a common northwest line that parallels the structure contours drawn on the Precambrian floor of the basin. These structure contours were taken from a map compiled by F. W. Osterwald (1956, p. 333).

Displacement is not apparent along the fractures; consequently they are considered to be surficial breaks formed as a result of incipient anticlinal folding parallel to the basin axis. At depth the inferred structure could be either an anticlinal bend of a terrace or a more prominent anticlinal arch. Northwestward extension of the line joining the fractures traverses an area east of Ross in which a slight anticlinal fold or terrace feature seem to exist in the gently eastward dipping surface strata (structure indicated at Pine Tree Spring in section *E–E′*, pl. 3).

The surface structural features in the southern part of the Powder River Basin suggest that rocks have been subjected to folding, in part post-early Tertiary in age, along a line parallel to the basin axis. The folding is not only manifest in surface crestline fractures but also in abrupt eastward displacement around the locality of inferred anticlinal structure of the normal surface trend of the basin axis in the area north of Ross. It is believed the structures visible at the surface are considerably more prominent at depth.

At the northwesternmost edge of the area on Great Pine Ridge, several faults cutting the Fort Union and the underlying Lance Formation have been mapped by Horn (1955) and are shown on plate 1.

GEOLOGIC HISTORY

Since Precambrian time the history of the Powder River Basin has consisted largely of subsidence and sedimentation, so that now the Cambrian sedimentary rocks overlying the Precambrian basement are buried to a depth of 15,000 feet along the axis of the basin. Subsidence and the deposition of sediment continued into earliest Tertiary (Paleocene) time when the Fort Union Formation was deposited.

The fine sands and silts of the lower member of the Fort Union are, like the rest of the early Tertiary rocks, flood-plain deposits. The fine grain size indicates deposition by streams of only moderate vigor. The thick sequences of well-sorted sand suggest much rehandling of the detrital material before its eventual burial. Slow subsidence of the basin in early Fort Union time may account for such features of these deposits. Occasional beds of coal record local swampy conditions.

The change from the massive fine sand and silt of the lower member of the Fort Union to the silt, clay, coal, and minor sand of the upper member marks the end of the balance between deposition and subsidence recorded in the lower sequence. The landscape of late Fort Union time may have consisted of a swampy, forested lowland threaded by shallow, shifting streams. These streams, capable of transporting sand, were laden also with the mud which at high-water stages was carried out into the flood plain to settle out as a layer of overbank silt. The stability of late Fort Union time is recorded best by coals 20 to 100 feet thick formed in widespread swamps which remained cut off from normal sediments during the entire time represented by the deposition of the coal. Accumulation of coal-forming material on this scale means that deposition of detrital sediment generally failed to keep pace with subsidence during much of late Fort Union time.

The source of the Fort Union Formation in the project area is less certain than the source of the overlying Wasatch Formation, which will be discussed later, because no crossbedding and grain-size data are available. Yet inasmuch as the Fort Union in the southwestern part of the basin appears to contain nearly the same heavy mineral suite as the Wasatch, the Fort Union sedimentary rocks were probably derived from a source in the Laramie Range. An additional clue to the source of the Fort Union sedimentary rocks is furnished by the disappearance of thick coals at the south end of the Fort Union outcrop. This suggests that the supply of detrital material was more adequate in the south than elsewhere, as would follow if the material came from the south. The Fort Union Formation in the southeastern part of the basin has a similar lithology but a different suite of heavy minerals. This suite is dominated by durable minerals (table 3, samples G56–105–2 and G56–117–1) and includes varieties not found in other areas; it suggests a source in older sedimentary rocks rather than in crystalline rocks.

Following deposition the Fort Union was mildly to rather strongly deformed along the flanks of the basin by renewed uplift of the adjacent positive areas. Part of this movement seems to have taken place before the deposition of the overlying Wasatch Formation. At several places on the west side of the basin, gently tilted strata of the Fort Union underlie apparently flat lying sandstone in the Wasatch.

On the flanks and northern part of the basin, the fine-grained facies of the Wasatch Formation (pl. 2) represents a continuation of the conditions which governed deposition of the upper part of the Fort Union Formation. Toward the south and in the center of the basin, however, with the advent of Wasatch time, a new set of conditions began to govern sedimentation.

The thick coarse-grained lensing sands that mark the beginning of Wasatch sedimentation in the southern part of the basin record an increase in size and in transporting power of the depositing streams. These streams probably were aggrading their courses fairly rapidly, perhaps rising on broad natural levees of sandy material. At time of floods such levees would be breached and the lower areas on either side of the stream course would receive a layer of overbank silt and clay. Thus the channel sand and flood-plain silt and clay were deposited contemporaneously, resulting in a sequence of beds characterized by rapid lateral shifts in lithology. In the area occupied by the coarse-grained facies of the Wasatch Formation, swampy interstream areas did not remain isolated from periodic incursions of silt-bearing floodwater; hence, thick coals did not accumulate.

Three lines of evidence bear upon the location of the source of the Wasatch sediments. These are: 1, direction of coarsening of sediments, 2, direction of dip of crossbedding in sandstone, and 3, mineralogy of sediments.

The coarse-grained facies of the Wasatch dominates the south end of the formational outcrop, and this facies itself becomes coarser southward. These facts indicate a southern source for the Wasatch sediments. The same conclusion was reached from a study of the directions of crossbedding of the sandstone of the Wasatch in the southern part of the basin. Plate 1 shows that these crossbeds almost invariably dip north or northwest as if the depositing streams had flowed north and transported material in that direction.

The mineral composition of the sediments provides information as to the source area. The heavy-mineral composition of some sandstone beds in the Wasatch (table 3) shows that such relatively unstable species as epidote, hornblende, mica, and apatite dominate the heavy residues. This tendency toward preservation of nonstable species also is shown in the light fraction by the presence of abundant microcline which, like the unstable heavy minerals, is fresh. The mineralogical composition of these sands strongly suggests a nearby source in crystalline rock. Erosion of sedimentary rock would provide higher proportions of durable minerals such as zircon, tourmaline, magnetite-ilmenite, rutile, and quartz, and a corresponding dearth of less durable constituents.

Additional information concerning the nature of the source was obtained from a study of the detrital grains. Subangular shape of most of the grains suggests that they did not travel far. The freshness of such easily weathered minerals as microcline and hornblende in these sands suggests mechanical erosion of an arid highland area rather than erosion of a humid lowland where sluggish drainage and a cover of vegetation favor chemical decay of bedrock.

The northern part of the Laramie Range seems a logical source for the Wasatch sediments. This rugged highland, just south of the Powder River Basin, has a complex core of plutonic rocks capable of supplying all the varieties of heavy minerals in the sandstone of the Wasatch. If this conclusion is correct, it follows that the North Platte River, which today separates the basin from the Laramie Range, had not come into existence by early Eocene time.

In summary then, the geologic history of the early Tertiary Period can be inferred from certain features of the Fort Union and Wasatch Formations. Fort Union rocks were laid down during a long period of stable conditions. Then, rather abruptly, uplift began along the flanks of the basin and the streams along the central axis of the basin began active erosion. Some of the Fort Union beds were removed and in the resulting erosional trough sands and overbank silt of the Wasatch began to accumulate rapidly. As the central part of the basin filled the streams continued to cut away the outcropping Fort Union on the flanks, so that a transgressing inclined unconformity moved out from the central part of the basin across the Fort Union. The coals in the Fort Union were cutoff by erosion, and thin coals in the Wasatch were laid down in back-water areas while the thick sand lenses continued to build up principally in the central part of the basin.

Following the end of Wasatch deposition at the close of early Tertiary time, there is a break in the sedimentary record. The succeeding beds are those of the Oligocene White River Formation which overlie the Wasatch unconformably at the one place within the basin (Pumpkin Buttes) where they are preserved. The former extent of the White River Formation in the Powder River Basin is uncertain. Its presence as a caprock on Pumpkin Buttes in the central part of the basin and its occurrence in the Bighorn Mountains and Laramie Range, the Black Hills, and Hartville Uplift suggest that this formation once covered most of the basin (Love, 1952, p. 4–5).

No White River rocks overlie the Wasatch Formation in the project area, yet the presence of coarse lag material on several hills and flats may indicate the former existence of a caprock of the White River at these places. The granitic boulders found on the hill occupied by bench mark "Petrified" (U.S. Coast and Geodetic Survey) in sec. 10, T. 34 N., R. 73 W., could not have come from the present watersheds of the streams draining the area. Owing to the proximity of these boulders to the Laramie Range it is possible that they came from the south. If they did come from the Laramie Range in White River time,

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the present course of the Platte River would then not only be younger than early Eocene but also younger than early Oligocene.

After the deposition of the White River Formation the uranium deposits of the Powder River Basin were formed. Age determinations show uraninite from both the Pumpkin Buttes area and the southern part of the basin to be between 7 and 13 million years old (Sharp and others, 1963). This means that the deposits formed during Miocene and Pliocene time under an unknown but probably considerable thickness of Wasatch and White River sediments.

The present geomorphic cycle began sometime in the late Tertiary. Within the basin, extensive remnants of a previous cycle of erosion form the flats shown on plate 1. These broad, gently rolling interfluves are considered to represent a former continuous surface formed when the streams were at levels 200 to 300 feet above their present beds. Robertson Flat (pl. 1) is a small remnant of a surface plainly antedating the widespread rolling surface above which it is perched. This flat, in sec 33, T. 40 N., R. 71 W., near Robertson's Ranch on State Highway 59, correlates well with Manning and Allemand Flats to the west (sec. *C–C′*, pl. 3).

It is uncertain when the wide valleys of the present cycle of erosion began to be incised. The downcutting appears to have been pulsational. Unconsolidated bouldery deposits cap what may be a dissected terrace level along the Cheyenne River and other major streams. One example of such a deposit occurs at "Bend" (U.S. Coast and Geodetic Survey) triangulation station in sec. 17, T. 38 N., R. 71 W. The deposit, which lies an estimated 70 to 80 feet above the present channel of the Cheyenne River, contains blocks and rounded cobbles as much as 2 feet in diameter consisting of the following materials: silicified wood, quartzite, sedimentary ironstone, and pink granite. Similar deposits cap adjacent hills at the same level.

Further evidence that stream downcutting has been interrupted during the present cycle is the presence of large quantities of fill along the courses of tributaries of all the main streams. As much as 30 feet of poorly sorted, coarse, dull-brown, unconsolidated fill is exposed in gullies cut during the latest pulse of downcutting activity.

URANIUM DEPOSITS

The uranium deposits of the Powder River Basin, including the Pumpkin Buttes area which has already been described in some detail (Sharp and others 1963), are restricted to sandstone units within the Wasatch Formation, and all are similarly related to certain features of the host rocks. The deposits are directly associated with the zone along the central part of the Wasatch outcrop that contains the red to pink sandstone. This red sandstone zone, extending from Pumpkin

Buttes southward to a point a few miles north of Douglas, contains all the significant uranium deposits of the basin (pl. 2).

Uranium deposits in the red sandstone zone appear to be more numerous in certain restricted areas along the trend of the zone. Such areas are separated by wide tracts barren of deposits or containing only sparse minor deposits. This apparent localization of deposits has led to division of the red sandstone zone into named areas. The Pumpkin Buttes area, about 350 to 400 square miles, contains several hundred more or less evenly distributed deposits. In the southern part of the basin the uranium-bearing areas are the Turnercrest, the Monument Hill, and the Box Creek areas. The uranium deposits of these areas are shown by number on plate 1 and each is briefly described in table 4. Analytical data on samples from many of these localities are given in table 5.

TABLE 4.—*Description of uranium localities in the southern part of the Powder River Basin*

[Localities shown by number on pl. 1]

Locality	Location			Description of locality (S, indicates analytical data on samples given in table 5)
	Sec.	T. (N)	R. (W)	
1	15	34	73	Radioactive spots, 0.12 mr per hr (milliroentgens per hour) in greenish-tan sandstone on low spur capped by red calcareous sandstone; no uranium minerals seen (S).
2. Jackalope mine	31	35	71	Yellow uranium minerals in manganese-oxide concretions in red and gray sandstone and conglomerate. Manganese-oxide concretions occur within calcareous zone 15 ft above base of sandstone and crop out for 50 ft along slope of small knob.
3	19	35	71	Sparse uranium minerals in calcareous fracture fillings in fine-grained gray calcareous sandstone also occur dispersed in coarse limy sand; exposed in pits cut into a limy sandstone lying below level of Sundquist mesa.
4	25	35	72	Yellow carnotite on coaly material and clay slivers; exposed in bulldozer trenches cut into mottled dark-red to white or buff ferruginous sandstone containing minor conglomerate beds.
5. Mesa No. 4 claim	24	35	72	Yellow carnotite around coaly material exposed in bulldozer cut at edge of draw. Host rock is coarse to conglomeratic sandstone streaked with red gray and brown. Carnotite also associated with clay chunk in wall of pit.
6. Box Creek Co. drill holes	12	35	72	Shallow drill hole (20 ft deep at most) brings up radioactive (0.5 mr per hr) cuttings of gray sandstone with red clay chips and brown carbonaceous sand.
7	12	35	72	Color change in thin generally red sandstone at base of ridge. Color contact radioactive (0.2 mr per hr). No uranium minerals seen.
8	12	35	72	Southward extension of Lamb No. 3 mine to nose. See locality 9.
9. Lamb No. 3 mine	12	35	72	Yellow uranium minerals disseminated in coarse drab sandstone along red color contact and coating fractures in ferruginous basal layer. Exposed in 4–12-ft-deep cut. Drilled area on nose to south of pit shows uranium minerals. Holes enter red sandstone at 15–20 ft.
10. Jackalope No. 13 claim	12	35	72	Disseminated green uranium minerals associated with red clay chips in fine-grained gray sandstone. Mineralized sandstone is a 2-ft-thick layer of a 40-ft-thick sand channel filling in clay, exposed along bank of draw.

TABLE 4.—*Description of uranium localities in the southern part of the Powder River Basin*—Continued

Locality	Location			Description of locality (S, indicates analytical data on samples given in table 5)
	Sec.	T. (N)	T. (W)	
11. Box No. 4 mine	1	35	72	Yellow disseminated uranium minerals in drab sandstone generally at contact with red sandstone. Exposure in pit at site of A.E.C. drilling. Mined in 1955.
12. Cannonball No. 10 mine	1	35	72	Yellow uranium minerals associated with mottled red and gray limy zones and coaly clay fragments and galls in coarse tan sandstone. Exposed in pit about 50 ft long and 7-8 ft deep.
13. Wells prospect	34	36	72	Sparse yellow uranium minerals associated with small clay gall-trashy zones along red-drab color contact in 20-ft-thick coarse-grained sandstone. Outcrop is at base of ridge.
14. Prospect pit	1	35	72	Yellow uranium minerals associated with clay streaks and coalified wood in mottled red and gray sandstone. Exposure is in a 20 by 20 by 6 ft pit on ridge top. One spot of manganese oxide was present.
15. (D-7 mine) Pruitt & Neff	28	37	73	Yellow uranium minerals associated with carbonaceous material in coarse white altered sandstone. Several zones of pink sandstone were noted. Exposure is a cut 100 by 200 by 6 ft deep.
16	21	37	73	Outcrop of medium-grained calcareous tan sandstone is radioactive (up to 0.25 mr per hr in 2 places). No uranium minerals noted.
17	15	37	73	Several small areas of anomalous radioactivity. Largest area about 15 by 20 ft at outcrop of a limonitic zone in gray to white clayey sandstone at contact with reddish sandstone gave up to 0.3 mr per hr. Remainder of sandstone is not radioactive.
18	1	37	73	Three small occurrences of yellow uranium minerals in a coarse gray-white feldspathic sandstone with minor zones of red color. Uranium minerals are near base of the 20 ft thick sandstone unit. Manganese oxide nodule with uranium minerals was exposed.
19	3	37	73	A pit 300 (N-S) by 100 (E-W) by 25 ft deep exposes small isolated patches of uranium minerals disseminated in tan silty to white coarse-grained sandstone. A vague red-drab color boundary crosses the pit (SE-NW). Most of the mineral occurrences are associated with coaly trash along this boundary.
20. (Pat No. 8 mine) Kerr-McGee.	3	37	73	Variety of uranium minerals, including black uraninite, associated with coaly material in host sandstone. Mining mostly in a zone about 10 ft thick near middle of 20-30 ft thick coarse, pale, clay-rich sandstone, lowest of two sandstones exposed in a 60 ft. deep trench. Red color appears in barren east wall of trench, west wall of which has the uranium minerals in drab sandstone.
21. Monument Hill manganese locality.	3	37	73	Yellow uranium minerals in manganese oxide accretionary masses in sandstone. Masses are numerous near top and center of sandstone which is white in some areas, white and pink in others.
22	10	37	73	Radioactive zones along outcroppings of red and gray sandstone. Uranium minerals possibly present.
23. (D-10)	10	37	73	Sparse visible yellow uranium minerals in wind blowout in gray-white sandstone exhibiting dim red color boundary. Abundant fossil wood and numerous calcareous concretions.
24. (Dad 17) Gen. Custer Uranium Co.	9	37	73	Yellow uranium minerals in coaly trash in very coarse grained gray-white to yellow-brown sandstone. Sand contains limonitic streaks, red clay galls, and dark-red concretions. Exposed in a 3 ft-deep bulldozer cut at bottom of draw.
25. Thompson Claims	15	37	73	Yellow uranium minerals underlie a calcareous ledge 1-2 ft thick in sandstone. Ledge is about 3 to 5 ft beneath original ground surface. Uranium minerals disseminated in the very coarse sandstone around coalified wood fragments.

TABLE 4.—*Description of urnaium localities in the southern part of the Powder River Basin*—Continued

Locality	Location			Description of locality (S, indicates analytical data on samples given in table 5)
	Sec.	T. (N)	T. (W)	
26	34	38	73	Radioactive greenish ferruginous base of sandstone that is red east of radioactive spot and yellowish gray to west. Radioactivity associated with a coaly layer. Sandstone is the coarse clayey lower sandstone exposed along Cheyenne River.
27. Dead Cow mine	3	37	73	Mined in 1954. Consists predominantly of yellow uranium minerals disseminated in grayish sandstone at and close to pink color boundary. Workings consist of series of adjoining shallow trenches.
28	27	38	73	Forty-foot deep drill hole bottomed in radioactive sand. A manganese oxide concretion found at this locality contained yellow uranium minerals. No uranium minerals observed in drill cuttings.
29	28	38	73	Radioactive calcareous concretionary masses in gray-white to pink coarse sandstone. Also radioactive ferruginous spots around coalified wood in the sandstone.
30. Mined area of Kerr-McGee Co.	27	38	73	Yellow uranium minerals interstitial to very coarse light-colored clayey sandstone occur just below surface on ridge. Exposures are two shallow cuts. A.E.C. drilling just to northwest showed red color in sandstone.
31. Hardy Fee mine	27	38	73	Yellow uranium minerals in cream-colored zones lying near bottom of pit 30 ft down into a single unit of pale very coarse clayey sandstone. Uranium minerals concentrated around coaly slabs.
32.	22	38	73	Area drilled by A.E.C. in 1956; ore-grade material found at depth.
33. Birthday claims	6	38	74	Radioactive ferruginous zones (0.25 mr per hr maximum) in medium-grained gray sandstone. Sand is calcareous, has some clay galls and coaly material. Exposed in several bulldozer cuts 10–12 ft deep. No uranium minerals seen.
34. Moore Fee claims	23	40	75	Green uranium minerals and high radioactivity in a thin surficial zone about 30 by 30 ft. Uranium minerals concentrated around coaly material in a coarse sandstone especially near a contact between red and gray color in the sand. Area has been drilled by operator.
35. Ross Anomaly	6	40	75	One manganese oxide concretion containing yellow uranium minerals found near radioactive contact (up to 0.02 mr per hr) between red and gray colors in medium-coarse sandstone. Area has been drilled by A.E.C. and private prospectors.
36. Betty Mine of Sundance Oil and Uranium Co.	25	41	74	Green uranium minerals sparsely disseminated in gray sandstone near color contact between gray and red sandstone. Contact trends N. 30° E. Also uranium minerals in zone of trash and red clay galls. Radioactive ore from basal ferruginous conglomerate layer, 1–1½ ft thick has little visible uranium mineral. Area mined in 1956.
37. Little Betty	25	41	74	Long bulldozer cut 10–12 ft deep shows pale coarse sandstone above red sandstone. Radioactivity associated with ferruginous layers.
38. Key Claims mine North American Uranium Co.	30	40	73	Hard dark ferruginous layer (8–12 in. thick) at base of coarse sandstone shows sparse yellow uranium minerals and high radioactivity. Layer is at bottom of 15 ft-deep pit. Contact between red and tan sandstone seen in pit walls follows zone of clay gall and pebble conglomerate, has sparse uranium minerals. Mined 1956.
39. Powder River Minerals pit.	19	41	73	Yellow uranium minerals associated with red podlike, calcite-rich concretions at red color boundary in coarse-grained sandstone, also with ferruginous basal pebble conglomerate. An open pit exposes sandstone, red and white, down to contact with a clay bed at 15 ft. Deposit was mined in 1955.

TABLE 4.—*Description of uranium localities in the southern part of the Powder River Basin*—Continued

Locality	Location			Description of locality (S, indicates analytical data on samples given in table 5)
	Sec.	T. (N)	T. (W)	
40. Prospect pits	19	41	73	Yellow uranium minerals along red calcareous layer 4-6 in. thick near base of sandstone. Exposed in 12-ft-deep trench north across draw from locality 38. Mildly radioactive spots in greenish-black, ferruginous basal conglomerate of sandstone unit exposed in three shallow pits.
41. Prospect pits	19	41	73	Two pits located 100 yds apart. Northwest pit shows yellow uranium minerals thinly disseminated in pebble conglomerate and grit 3 ft below surface. Southwest pit is down 6 ft in red sandstone below radioactive soil zone (0.25 mr per hr).
42	24	41	74	Several radiating trenches cut in yellow sandstone near ridge top. Red calcareous sandstone appears in south wall of east-west trench. No uranium mineral visible.
43	26	41	74	Several bulldozer trenches along east side of north-south draw. Radioactive clay gall seams in 30-ft-thick coarse red to yellowish-gray sandstone. Near base of sandstone a dark iron-oxide cemented mass is radioactive (0.08-0.12 mr per hr).
44	31	42	73	Radioactive zone in this red sandstone lens that crops out around Turner Ranch-house hill. Yellow uranium minerals in outcrop 100 yds north of house.
45. Hank claims	27, 34	42	73	Mild radioactivity 0.01 mr per hr at one place on claims. Claims area is soil-covered; has one outcrop of pink sandstone.
46. Reno lease (Wirkkalla claims).	34	42	73	Uranium minerals as yellow coatings on sand grains and clay galls in a 2 ft thick, loosely consolidated, coarse-grained clayey sandstone. Radioactivity of mineralized exposure is 0.04 mr per hr. Area has been drilled by operator.
47	25	42	74	Mild radioactivity (0.05 mr per hr) in 6-ft pit in gray clay overlying 30-ft-thick pink and white sandstone near dam. Slight radioactivity in a limonitic spot in sandstone.
48. Boyles Pit	9, 16	37	73	Area has been drilled extensively, first by Kerr-McGee Industries, then by Boyle Bros. Several drill holes at the site cut a radioactive white coarse-grained sandstone that contained sparse yellow uranium minerals. Boyle Bros. plan to mine an inferred ore body by open pit.
49	26	38	73	Small radioactive spots, some with visible yellow uranium minerals, occur along fault surfaces in a red to pink sandstone unit. The fault zone (with but little evident displacement) trends N. 42° W. to N. 58° W. and dips 68° E. Movement appears to have been normal. Two shallow trenches are cut along the zone and expose the shear surfaces and the base of the red sandstone and the underlying gray clay. No mining is done.
98	23	42	75	One strongly radioactive spot in a slightly radioactive area about 100 by 100 ft in sandstone capping a small topographic nose.
99	21	42	75	Radioactive spots in soil on ridge. Fairly strong radioactivity in a wind blowout in white sandstone on west side of ridge. No visible uranium minerals.
127	30	42	75	Yellow uranium minerals in pods in coarse-grained yellow sandstone associated with red sandstone. Part of a radioactive zone 5 ft thick extending around nose of grassy ridge 50 ft above stream bottom.
128	35	42	77	Moderate radioactivity on west slope of grassy ridge underlain by light-gray and red calcareous sandstone. No uranium minerals visible.
129	23	41	77	Fort Union Formation, Great Pine Ridge. Radioactive siliceous ironstone caps a north-south ridge. Ironstone in more or less continuous layers and underlying white to reddish fine-grained massive sandstone which is nonradioactive.

TABLE 4.—*Description of uranium localities in the southern part of the Powder River Basin*—Continued

Locality	Location			Description of locality (S, indicates analytical data on samples given in table 5)
	Sec.	T. (N)	T. (W)	
140	20	42	76	Yellow uranium mineral in a dark-green to gray pod in gray medium-grained sandstone. Radioactivity of general area underlain by sandstone is moderately high.
141	28	42	76	Radioactive brown carbonaceous papery shale on east bank of a ravine, associated with a moderately radioactive red sandstone soil.
155	25	41	77	Moderately radioactive ironstone in Fort Union Formation of Great Pine Ridge.
162	14	41	77	Similar to locality 155 above.
163	23	41	75	Airborne radioactivity anomaly in area underlain by widespread sandstone. Detailed lithology is not known.
165	23	42	77	Moderate radioactivity in wind blowout on sandstone-capped ridge.
176	16	42	75	Moderate radioactivity in sandstone capping ridge. Detailed lithology not known. Uranium minerals probably present.
177	29	42	75	Sparse uranium minerals in dominantly drab sandstone on broad low nose.
178	29	42	75	Several hundred feet north of locality 177. Yellow uranium minerals in sandstone exposed on broad low nose.
181	21	42	75	Moderate radioactivity in sandstone capping low nose.
187	35	42	77	Radioactive spot in red sandstone.
189	5	41	76	Moderate radioactivity (0.1 mr per hr) in fine-grained friable, green to buff calcareous sandstone. Sandstone exposed in wind blowout 200 yds north of Taylor Ranch. Three shallow pits exposed sandstone.
190	12	42	75	Moderate radioactivity associated with fine-grained calcareous, gray to brown sandstone exposed in pit. Mild radioactivity associated with thin green shale bed and red sandstone in nearby pits.
191	8	41	75	Moderate radioactivity in gypsiferous gray clayey siltstone poorly exposed in a wind blowout. A sandstone unit probably was eroded from immediately above this site.
192	32	37	72	Sparse yellow uranium minerals associated with red sandstone.
193	24	37	73	Yellow uranium minerals in drab sandstone near red color contact.

The Turnercrest area is about 20 miles south of the Pumpkin Buttes and is separated from the buttes area by a belt containing less red sandstone and few known uranium occurrences. Turnercrest is the northernmost area of the southern basin and is the smallest area in size and number of deposits. Besides several small undeveloped occurrences, four producing mines are located here: the North American Key Claims mine (No. 38, pl. 1), the Sundance Betty and Little Betty mines (No. 36 and No. 37), and the Powder River Minerals mine (No. 39). The area lies at the east edge of the red sandstone zone, and all the deposits are at the limit of red color in the sandstone unit that contains them.

About 18 miles south of the Turnercrest area is the Monument Hill area, perhaps the best known mining area in the basin. Between the two areas few red sandstone outcrops are found, although thick drab sandstone units are conspicuous. Across this intervening terrain, the

TABLE 5.—*Analytical data on samples from the southern part of Powder River Basin*

[Localities shown by number on pl. 1]

Locality	Sample	eU	U	V_2O_5	MnO	$CaCO_3$	CO_2	Fe_2O_3	Additional	Sample description and type
		Values in percent except as noted								
1	G56-124-1	0.019	0.009	<0.1	----	----	----	3.65	Se=3 ppm	Gray silty sand, ferruginous and carbonaceous, from radioactive zone.
9	S55-15-1	.21	.22	.13	----	----	----	----	----	Gray sandstone containing yellow minerals. Selected sample.
11	S55-19-X1	.43	.22	.55	5.03	0.74	----	21.08	----	Clay gall, highly radioactive, from conglomeratic sandstone.
	7b	.19	.12	.19	.13	18.0	----	1.72	----	Buff-gray outer part of calcareous sandstone concretion. Yellow minerals.
	7r	.15	.009	.12	.26	29.2	----	7.07	----	Red core of same concretion, as above.
	1	.39	.57	.45	----	----	----	----	Se=5 ppm	Red and buff fine sand. No uranium minerals.
	4	.27	.30	.19	----	----	----	----	----	Coarse-grained gray sandstone with abundant yellow minerals.
	6	2.8	3.25	----	----	----	----	----	----	Grab sample of coaly slab from zone of coarse-grained gray sandstone. Yellow minerals.
12	S55-18-1	.037	.013	----	----	----	----	----	As=10 ppm	Gray coarse-grained clayey sandstone from ore pile. Visible uranium minerals.
	S55-18-7	.41	.62	----	----	----	----	----	Se=10 ppm Sb=1 ppm Zn=20 ppm As=60 ppm Se=20 ppm Sb=1 ppm Zn=10 ppm	Grab sample of gray-white coarse to conglomeratic sandstone from ore pile on Box No. 10 claim.
	3	.15	.32	----	----	----	----	----	----	Gray-brown sandstone with overlay of green uranium minerals.
15	S55-27-2	.070	.006	<.1	.006	.35	----	1.40	----	Loose, coarse ferruginous sandstone, radioactive, without visible uranium minerals.
16	S56-186-1	.039	.014	<.1	.31	21.6	----	.93	P_2O_5=0.5	Selected radioactive sample of tan calcareous sandstone.
19	S56-185-1	.007	.006	<.1	----	----	----	1.08	Se 4=ppm	White and pink very coarse clayey sandstone.
	3	.14	.24	.12	----	----	----	1.29	Se 20=ppm	Coarse gray sandstone, with yellow minerals and coaly chips.
20	W55-58-B	.23	.48	<.1	.008	.47	----	2.42	----	Gray sandstone with interstitial yellow minerals.
	58-D	.006	.006	----	----	----	----	1.48	----	Coarse red sandstone from calcite concretionary mass.
20	S55-58-3	.002	----	<.1	.012	.3	----	2.19	----	Coaly material veined with gypsum and uranium minerals.
	S56-58-8	.62	.96	.14	----	----	----	2.32	Se=2700 ppm	Fine-grained sandstone with greenish-brown color. Odorous.
	9	2.9	5.05	.35	----	----	----	2.19	Se=4200 ppm	Yellow uranium minerals concentrated in gray sandstone.

TABLE 5.—*Analytical data on samples from the southern part of Powder River Basin*—Continued

Locality	Sample	eU	U	V_2O_5	MnO	$CaCO_3$	CO_2	Fe_2O_3	Additional	Sample description and type
		Values in percent except as noted								
21	AEC-25409	8.63	7.23	.60	------	------	-----	------	--------------	Selected samples of manganese oxide concretion containing yellow uranium minerals.
	TW-161	2.1	2.32	.65	24.8	------	-----	------	--------------	
	AEC-F12476	13.0	16.1							
23	S55-69-1	.031	.014	<.1	.10	19.0	-----	.55	--------------	Calcareous hard, medium-grained gray-white sandstone.
26	S56-148-1	.025	.001	<.1	<.001	.3	-----	3.26	--------------	Greenish ferruginous basal sandstone.
30	S55-25-1	.58	1.22	.41	------	------	-----	------	--------------	Coarse-grained gray sandstone containing yellow uranium minerals.
35	S56-153-1	.002	-------	<.1	.08	16.3	-----	1.80	P_2O_5=0.6------	Red sandstone.
	2	.002	-------	<.1	<.001	.5	-----	1.23	P_2O_5<0.5------	White sandstone.
	3	1.2	1.37	.14	1.19	14.4	-----	12.1	P_2O_5=0.5------	Manganese oxide nodule containing uranium minerals. Grab sample.
36	S56-114-1	.15	.16	.14	------	------	-----	5.59	Se=200 ppm--	Grab of ore from trashy ferruginous basal conglomerate.
31	S56-146-1	.002	-------	<.1	.009	5.5	-----	.59	P_2O_5<.05------	Coarse-grained clayey light-colored sandstone.
38	S56-115-2	.026	.049	<.1	------	------	-----	9.33	Se=100 ppm--	Grab sample of altered clay below basal conglomerate.
39	W55-6b-1	.28	.32	.18	.10	10.0	-----	2.42	--------------	Gray sandstone with red mottling and disseminated uranium minerals.
	2	.15	.14	.21	.025	.52	-----	8.68	--------------	Ferruginous basal conglomerate with green uranium minerals.
	3	.046	.010	<.1	.20	14.4	-----	2.29	--------------	Gray sandstone with small red calcite concretions.
40	S56-178-1	.041	.009	<.1	------	3.1	-----	10.81	P_2O_5=.07------	Dark basal ferruginous conglomerate.
46	-----------	------	.072	.37	------	------	-----	------	--------------	Representative sample from exposure showing uranium minerals.
47	S56-176-1	.002	-------	<.1	.05	.5	-----	1.80	P_2O_5<.05------	Grab sample of red sandstone from radioactive color contact.
	2	.003	-------	<.1	<.001	.5	-----	.90	P_2O_5<.05------	Grab sample of gray sandstone.
99	AEC-1079	.136	.127	.10	------	------	-----	------	--------------	Grab sample of radioactive sandstone.
	TW-74	.034	.006	.03	.04 (Mn)	------	-----	------	--------------	Grab sample of white sandstone.
127	TW-104	8.5	11.24	1.99	.031 (Mn)	------	-----	------	--------------	Selected grab sample of sandstone rich in yellow uranium minerals.
128	103	.017	.003	.04	.543 (Mn)	------	-----	------	--------------	Grab sample of radioactive sandstone.
129	105	.029	.018	.08	.038 (Mn)	------	-----	37.30	--------------	Dark-brown ironstone.
140	AEC-25316	.33	.51	.32	------	------	-----	------	--------------	Selected sample of dark-gray pod.
141	25314	.017	.017	.05	------	------	-----	------	--------------	Grab of brown papery shale from 2 ft deep cut.

TABLE 5.—*Analytical data on samples from the southern part of Powder River Basin*—Continued

Locality	Sample	eU	U	V_2O_5	MnO	$CaCO_3$	CO_2	Fe_2O_3	Additional	Sample description and type
		Values in percent except as noted								
176	1080	.009	Tr.	.03						Grab sample of radioactive sandstone.
		1.05	1.01	.47						Selected sample probably with visible uranium minerals.
177	AEC-1065	.051	.0085	.03						Grab sample of sandstone with visible uranium minerals.
178	1068	1.34 3.21	1.96 4.87	1.42 2.39						Grab samples of sandstone with visible uranium minerals.
189	25401	.026	.009	Tr.						Grab sample of radioactive sandstone.
190	25402	.017	.009	Tr.						Grab sample of gray-brown sandstone.
191	25400	.085	Tr.	.06						Grab sample of clayey siltstone.

drainage valleys of the Antelope, Sand, and Bear Creeks trend eastward. The drainage divides separating the creeks are among the highest in the basin. A small patch of red sandstone forms the caprock on the Antelope Creek-Sand Creek divide, suggesting that red sandstone units may once have bridged the gap between the Turnercrest and Monument Hill areas but since have eroded away.

The Monument Hill area, named for a prominent rock monument on the drainage divide south of the Dry Fork of the Cheyenne River, has many red sandstone outcrops and contains some of the largest mines of the basin. In 1956, the Hardy Fee mine (No. 31) on the north side of the Dry Fork was the largest mine in the basin. The Dead Cow mine (No. 27), worked in 1953, and the Pat No. 8 mine (No. 20, on pl. 1) are on the south side of the Dry Fork. Other mines in the area include the D–7 mine (No. 15), first worked in 1953, and the Thompson Prospect (No. 25). The Monument Hill area is on the west edge of the narrowest part of the red sandstone zone in a region where formation of clay from volcanic ash in some of the sandstone units has bleached out diagnostic color.

The southernmost area of uranium deposits, the Box Creek area, is about 12 miles southeast of Monument Hill and extends southward from Box Creek to Sundquist Flat. The terrain that separates the Monument Hill and Box Creek mining areas includes the valley of Box Creek and most of Highland Flats, but few uranium deposits are known in this area. The major deposits in the Box Creek area are in the Box 4 (No. 11), Cannon Ball 10 (No. 12), and Lamb 3 (No. 9) mines. The Box Creek area is on the east edge of the red sandstone zone near the lobate south end.

The apparently irregular distribution of uranium deposits in the southern part of the basin may be related to two factors, one topographic and one lithologic. The deposits appear to be arranged in eastward-trending bands, controlled in part by the prominent eastward-trending trunk drainages separated by broad, prominent divides. The divides offer the best exposures and the best chance of finding deposits although distribution of the deposits may be more random than the grouping on the divides and along the slopes suggests. The lithologic factor is that deposits are many where red sandstone is abundant or at least conspicuous. The intervening areas, virtually barren of deposits, are almost devoid of visible red sandstone lenses.' Thus, the apparent concentration of deposits at intervals along the red sandstone zone is a result of irregular distribution of red sandstone in the zone and predominant transverse trend of major drainage.

The deposits almost everywhere display some detailed relation to the red color boundary in a sandstone unit. Sandstone lenses containing both red and drab sandstone are the units favorable for uranium deposits because it is at the contact between these two color phases that uranium deposits are found. The bulk of the uranium minerals in such deposits is concentrated in the drab sandstone at or close to a red color contact. The minerals seem to form larger concentrations where the color contact is highly irregular. The major uranium deposits that have been mined in the basin are not only located at a color change within a sandstone unit, but are located also in units very near the boundary of the red sandstone zone in the basin (pl. 2).

Calcite cement in the sandstone near uranium deposits is unevenly distributed and seems to be related in time to both the red color and the uranium minerals. Calcite in a discontinuous layer 2 to 6 inches thick commonly cements sandstone along color contacts. At most uranium occurrences, this hard layer is radioactive and yellow uranium minerals are visible. Calcite concretions occur locally along color contacts; in uranium occurrences found in drab sandstone these concretions are commonly rimmed by a zone several inches thick that is rich in yellow uranium minerals. Calcite concretions in red sandstone generally do not have uranium minerals disseminated in or around them unless uraninite (or in some places manganese oxide) is also present in the concretion.

Most of the mineralized rock forms bands, zones, and irregularly shaped bodies that in many places conform to the shape of the red color contact. The actual shape of deposits is difficult to define because the uranium minerals occur in a variety of habits, and the limits of deposit are not always definite and visible. A typical ore body lies within the drab sandstone and is bounded on one side by the sharp contact with barren red sandstone and on the other by an assay boundary consisting of material too lean to be ore. Deposits are as much as 100 feet long, 50 feet wide, and 10 feet thick. Most uranium-bearing material consists of yellow oxidized uranium minerals unevenly disseminated in friable sandstone or in sandstone partly cemented with both early and late calcite. Small dense concentrations of yellow uranium minerals are common around coalified woody fragments within the body of disseminated material, and fractures may be coated with hydrated uranium minerals. Much of the uranium occurs as uraninite which cements and coats sand grains to form accretionary masses a few inches to several feet across. These masses invariably are associated with pyrite and coalified wood and no doubt owe their origin and survival in a near-surface oxidizing environment to these two associates.

Uraninite masses are randomly spaced in the deposits of disseminated material in drab sandstone or within the red sandstone component of the deposit where they are locally surrounded by a narrow band of gray sandstone. The masses found in red sandstone seem to be all highly calcareous and partly sealed off from the general oxidizing environment of the sandstone. All the uraninite accretionary masses are surrounded by a thick halo rich in yellow oxidized uranium minerals.

Nodules and irregular concretionary masses of manganese oxide containing yellow uranium minerals are found in the southern part of the basin but are more common in the Pumpkin Buttes area. This material is uniform in appearance and mineralogy and wherever found it is at or very near the surface. As the manganese-uranium nodules occur within red sandstone at varying distances from the contact with drab sandstone, they are not necessarily closely associated with color changes.

Ages for the deposits in the Powder River Basin have been calculated by Lorin Stieff and others of the U.S. Geological Survey, using lead/lead and lead/uranium isotopic ratios. Material for these determinations has come mostly from the Pumpkin Buttes area, but one specimen of uraninite-bearing rock came from the Pat No. 8 mine in the Monument Hill area of the southern part of the basin. The ages determined from the lead/uranium ratios (Pb_{206}/U_{238} and Pb_{207}/U_{235}) in uraninite samples from both the Pumpkin Buttes area and the southern part of the basin range from 7 to 13 million years. The material from the Pat mine gave a lead/uranium ratio that indicated a maximum age of 13 million years, comparable to ages of material from the Pumpkin Buttes area. A Pb_{207}/Pb_{206} age estimate has not been completed on the Pat mine material; however, the Pb_{207}/Pb_{206} ratios in materials from the Pumpkin Buttes area were very high but gave consistent age values of about 425 million years. This anomalous age value indicates that older radiogenetic lead was carried with the uranium to the present site, and the resulting age estimate approaches that of the source material of the Powder River Basin uranium (Sharp and others, 1963).

MINERALOGY OF URANIUM DEPOSITS

The uranium deposits of the southern part of the Powder River Basin have a relatively simple suite of uranium and associated minerals in comparison with deposits in some other areas of similar nature. Minerals in oxidized ore consist almost entirely of vanadates, carbonates, and silicates. Sulfates may be present but none have been positively identified. The relatively simple mineralogy is reflected in the general chemical characteristics of the ore. With the exception of vanadium, manganese, and iron, few metals (as cations or anions) are abundant in the uranium deposits of the Wasatch Formation. Copper, lead, zinc, molybdenum, and phosphorus are either not detectable or are in trace amounts only in local samples and in mill pulps. Arsenic is present in moderate amounts. Vanadium, though widespread principally in the minerals carnotite and tyuyamunite, rarely is present in more than a 1:1 ratio with uranium. Manganese occurs almost exclusively in nodules in a highly oxidized state.

The ores thus far mined in the Powder River Basin are above the ground-water level, and all mining to 1956, even to depths of 60 feet, has been in the zone of oxidation. Local zones of low redox potential are maintained by presence of pyrite and coalified wood, generally in calcite-cemented sandstone. Unoxidized ore has been found thus far in the form of small, angular to rounded black masses generally localized by fragments and slabs of coalified wood. Uraninite is the only uranium mineral so far identified in samples of this material from the southern part of the Powder River Basin. Coffinite has been identified in some coal-uraninite mixtures in the Pumpkin Buttes area, however, and may exist in the southern part of the Basin. Unoxidized ore material is characterized also by conspicuous amounts of pyrite. Pyrite associated with uraninite fills the interstitial space at places in the sandstone, and small blebs of pyrite occur within the uraninite.

The known uranium minerals and common associated minerals that have been identified by optical or X-ray methods, or a combination of both, are the following:

Ore minerals	
Vanadates	
Carnotite	$K_2(UO_2)_2(VO_4)_2 \cdot 1\text{–}3\ H_2O$
Tyuyamunite	$Ca(UO_2)_2(VO_4)_2 \cdot 7\text{–}10\ \frac{1}{2}\ H_2O$
Carbonates	
Liebigite	$Ca_2(UO_2)_2(CO_3)_3 \cdot 18H_2O$
"Zellerite"	$Ca(UO_2)(CO_3)_2 \cdot 3\text{–}4H_2O$
Unknown yellow minerals	
Silicates	
Uranophane	$Ca(UO_2)_2(SiO_3)_2(OH)_2 \cdot 5H_2O$
Phosphates	
Autunite	$Ca(UO_2)_2(PO_4)_2 \cdot nH_2O$ (one minor occurrence)
Oxides	
Uraninite	$(U^4U^6)\ O_2$
Associated minerals	
Pyrite	FeS_2
Vermiculite-septechlorite intergrowth	$(OH)_2(Mg,Fe)_3(Al,Si)_4O_{10}\text{–}(Fe_2Al)(SiAl)O_5(OH)_4$
Gypsum	$CaSO_4$
Calcite	$CaCO_3$
Barite	$BaSO_4$
Manganite	$Mn_2O_3.H_2O$
Pyrolusite	MnO_2
Selenium mineral(?)	Se(?)

MINERAL DESCRIPTIONS

Uraninite.—Uraninite is the sole virtually unoxidized uranium mineral known in deposits of the southern part of the basin. It coats and cements sand grains to form accretionary masses from a few inches to 3 feet across (fig. 2). Calcite is commonly abundant in these masses. The uraninite is pitch black, brittle, and extremely finely crystalline. In the polished sections examined, uraninite occurs as bands and void fillings and exhibits shrinkage cracks, which may suggest deposition as colloidal-sized particles. The fineness of the mineral is also evident from the broad, diffused nature of the lines in X-ray powder patterns.

Carnotite-tyuyamunite.—The stable vanadates, carnotite and tyuyamunite, disseminated in the sandstone are the principal ore minerals in the deposits. Generally the minerals are mixed and individually indistinguishable. At places sandstones rich in these minerals appear more greenish-yellow than yellow. X-ray analysis indicates that the greenish-yellow material is largely tyuyamunite, whereas lemon-yellow to bright-yellow material is mainly carnotite.

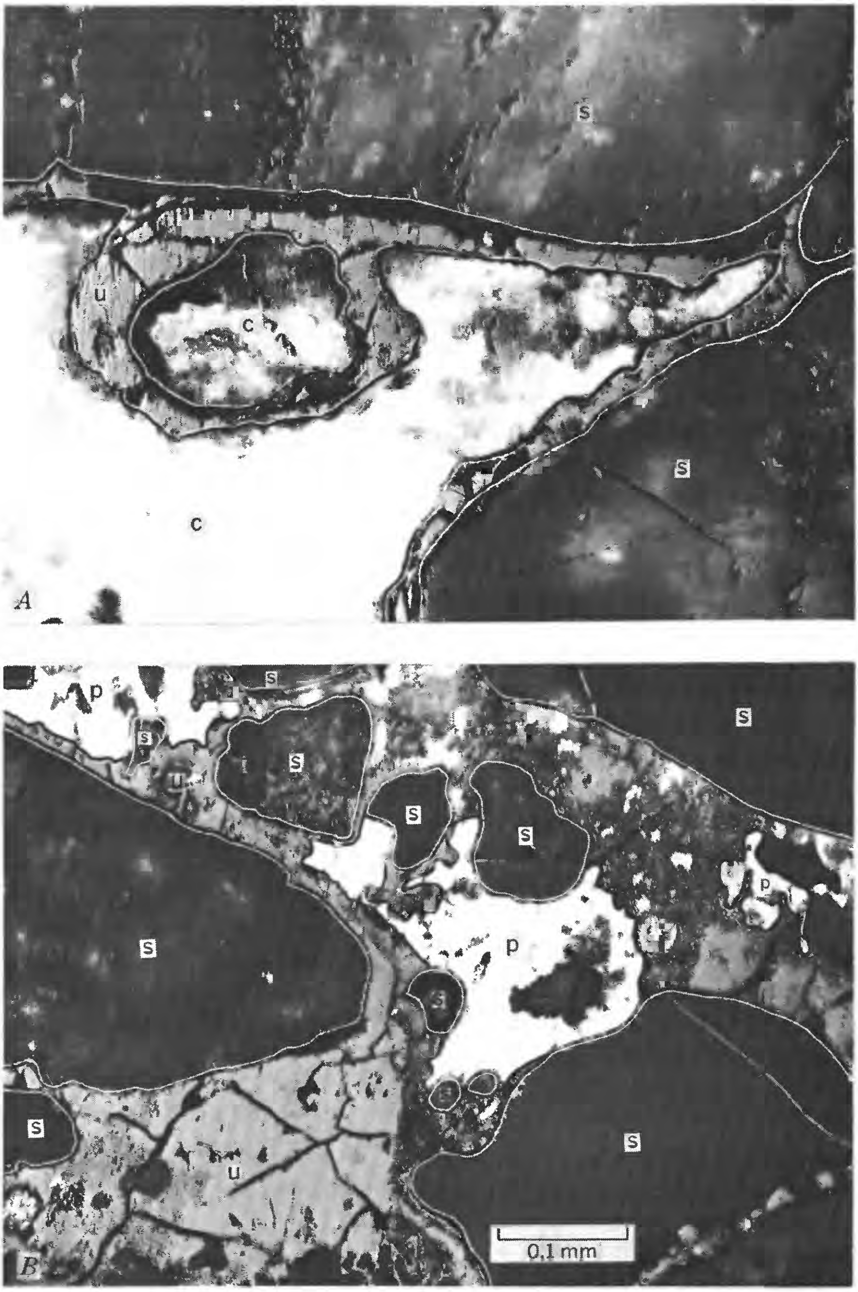

FIGURE 2.—Photomicrographs of uraninite in sandstone, southern part of the Powder River Basin, Wyo. *A*, uraninite (u) coating sand grains (s) in calcareous sandstone from Pat No. 8 mine. Cavity is filled with calcite (c) colored yellow by alteration products of uraninite. Crossed nicols. *B*, uraninite (u), showing shrinkage cracks, fills interstitial space and coats sand grains (s); Pat No. 8 mine. Associated pyrite (p) also fills interstitial space. Crossed nicols.

A brownish-orange resinous form of carnotite occurs with uranophane in some small deposits containing many black manganese oxide masses and nodules. This orange carnotite, thought to be in an unusual hydration state, is very common in the Pumpkin Buttes area. It is almost entirely restricted to the manganese nodules.

Liebigite.—The clear green carbonate, liebigite, is found in several widely separated mines in the basin. It is particularly common in the lower part of Pat No. 8 pit where it coats fractures in calcareous sandstone and fills shrinkage cracks in masses of coalified wood in moist sandstone. Some cracks one-fourth of an inch across are only partly filled, and the mineral surface displays good minutely stepped crystal terminations. In the coal, liebigite is associated with amber-colored barite and gypsum, both apparently earlier than liebigite. Light-yellow microcrystalline balls of an unidentified uranium mineral dot the liebigite coating in some larger openings. Liebigite strongly fluoresces light green whereas the light-yellow mineral is nonfluorescent.

Zellerite.—The uranyl carbonate zellerite is found at several places in the lower part of Pat No. 8 pit in the uranium-rich oxidation halos surrounding uraninite-bearing pods. The mineral is present as light-yellow to white fibrous vein fillings or as cotton balls of radiating fibers localized in narrow openings (fig. 3). Associated minerals are gypsum, carnotite-tyuyamunite, liebigite, and uraninite. The mineral was noted in 1955 because of its unusual appearance. The X-ray powder pattern was that of no known mineral, but it matched the pattern of a mineral found in the Gas Hills area by H. D. Zeller (oral communication, 1956). R. G. Coleman subsequently has made a study of the Gas Hills material and proposed the name zellerite for the new species (written communication, 1957).

Optical properties of the Powder River Basin mineral parallel the properties of Gas Hills zellerite. Some optical and X-ray data of zellerite from Pat No. 8 mine are given as follows:

Optical properties

$nX = 1.536 \pm 0.005$
nY----
$nZ = 1.598 \pm 0.005$

Extinction parallel; elongation length slow; pleochroism in intermediate oil (1.56), parallel to length, clear light green, perpendicular to length, bright yellow brown; faintly fluoresces light green in short wavelength ultraviolet light.

X-ray powder data

[S, strong; M, medium. Copper radiation, nickel filter]

d (Å)	I	d (Å)	I	d (Å)	I
9.20	S	3.79	M	2.30	M
4.80	M	3.34	M	2.03	M
4.70	S	3.18	M		
4.55	S	3.05	M		
4.29	S	2.92	M		

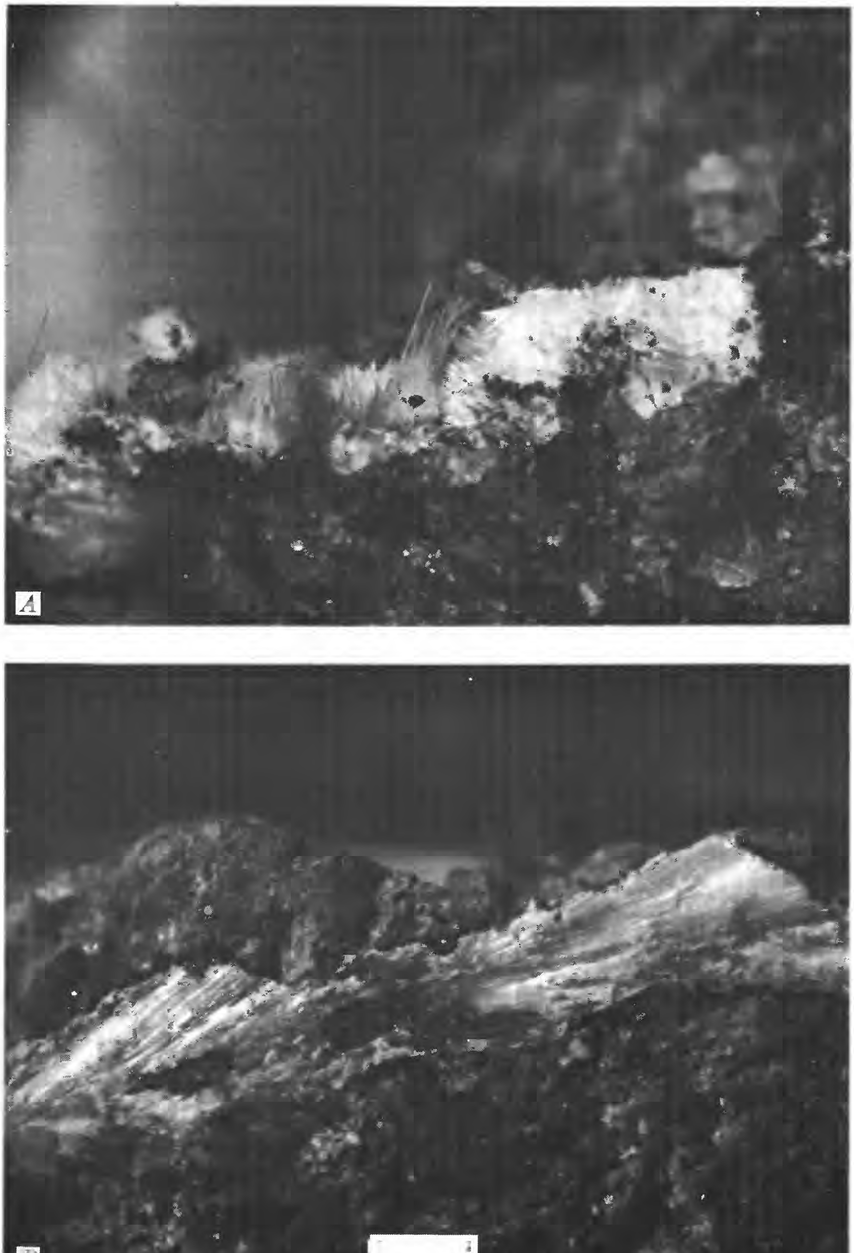

FIGURE 3.—Zellerite, a new uranium carbonate from Pat No. 8 mine, Wyoming. Photograph of hand specimen. *A*, clumps of radiating fibers in open space implanted on gypsum. *B*, fibrous arrangement of mineral filling small fracture.

In his comments on zellerite from the Gas Hills, Coleman (written communication, 1957) states that the mineral apparently forms in the early stage of oxidation where calcite is in excess of pyrite and that enough carbonate must remain despite the action of oxidizing pyrite to complex with the uranyl ion. High acidity created by the breakdown of abundant pyrite would dissolve these carbonates.

Zellerite and liebigite, both carbonates, are closely associated with vanadates in the Pat No. 8 mine. This association of carbonates with vanadates is not common on the Colorado Plateau.

Uranophane.—The uranyl silicate, uranophane, occurs mostly in association with carnotite in the manganese oxide nodules and accretionary masses found at or very near the surface throughout the basin. In addition to its prevalence in deposits of manganese oxide nodules, it occurs in limonitic parts of zones of disseminated ore. Radiating blades of uranophane are embedded in interstices between calcite grains; minute cotton balls of almost pure white uranophane have formed on joint cracks coated with hydrated iron oxides. Uranophane also is found scattered throughout disseminated ore, cementing and coating sand grains that are associated with carnotite-tyuyamunite. The common habit is minutely fibrous. In thin section uranophane is conspicuous because of its intense yellow coloring and anomalous blue interference color.

The presence in the Powder River Basin of uranophane mixed generally with vanadates probably reflects, as does the presence of carbonates, a lack of sufficient vanadium to combine with all uranium. In the ore zone, where conditions were dominantly oxidizing, slightly alkaline, and uranium solubility was high, uranium was fixed into the relatively insoluble silicate where reactive silica was available.

Available silica must have been abundant in the manganese oxide nodules because uranophane is abundant and well developed. Manganese oxides have replaced quartz grains and in doing so must have released silica to form uranophane with any uranium that was not securely held by vanadium.

Autunite.—Uranyl phosphates are not common in the deposits of the Powder River Basin. Ore and mill pulp analyses show little phosphorus, indicating that such minerals occur sparsely if at all. Autunite was found in the Betty mine as minute, sparsely distributed green scales confined to the parting planes of a large dark-gray clay slab in a conglomerate zone containing much plant debris. The carbonaceous clay probably was substantially rich in phosphate and supplied the anion for the local occurrence of a phosphate mineral.

Unidentified yellow minerals.—Two specimens of what is probably the same mineral were taken from the Pat No. 8 mine. This mineral, which does not match exactly the properties of any uranium mineral known to the authors, may be becquerelite ($7\,UO_3 \cdot 11\,H_2O$). It occurs as bright-yellow microcrystalline aggregates. The becquerelite(?) in specimen S56–58–3b occurs as coatings on coalified wood; that of specimen S56–58–02 is implanted on and mixed with gypsum crystals which coat a small open space developed by alteration of a sulfide-uraninite-coal pod. Under the microscope each specimen appears to consist mainly of a single mineral or of closely related minerals. The dominant mineral is yellow to orange yellow, finely crystalline, and bladed in crystal habit. Rosettes and platy structures are common to the material from both samples; fibrous structure is apparently rare. The optical properties of becquerelite(?) from the two samples are very close, as is evidenced in the following tabulation. The X-ray powder data are closely related but exhibit small differences which may be due to variations in the state of hydration of minerals from the two samples.

Some of the optical and X-ray properties are given below:

Sample S56–58–02

$nY=1.729$
Birefringence, moderate.
Biaxial, negative.
Pleochroism, green to yellow.
$r<v$ strong.
$2V=25°–30°$
Anomalous blue interference color.

Sample S56–58–3b

nY-1.739
Birefringence, moderate.
Biaxial, negative.
Pleochroism, green to yellow.
$r<v$ strong.
$2V=$ ca. 30°
Tendency to anomalous blue color as well as 1st order green.

Strongest reflections of X-ray powder data

[S, strong; MS, medium-strong; M, medium. Copper radiation, nickel filter]

d(Å)	I	d(Å)	I
8.75	S	8.60	S
6.10	M	7.90	S
5.50	M	5.49	M
4.38	M	4.35	M
3.50	} M	3.90	M
3.45	}	3.49	} M
3.03	MS	3.41	}
		3.02	S

Microchemical tests of the material were made for vanadium, calcium, carbonate, and sulfate; all were negative.

The yellow mineral believed to be becquerelite is accompanied in sample S56–58–3b by a small amount of another uranium mineral thought to be the sulfate uranopilite. It has an index of refraction of $nY=1.635 \pm .005$ and a banded asbestiform structure with conspicuous curved, vermiform habit.

Such minerals as becquerelite and uranopilite, if present in the deposits of the southern part of the Powder River Basin, probably are restricted to the halos of oxidized minerals surrounding uraninite-bearing masses. The presence of these minerals reflects a lack of anions such as phosphate, arsenate, and vanadate which form stabler less soluble minerals.

Associated minerals.—Uranium minerals are associated in the deposits with several common gangue minerals such as calcite, gypsum, pyrite, hydrated iron oxides, and barite. Less common gangue minerals include vermiculite-septechlorite intergrowths, manganite, and pyrolusite. Of all these minerals, vermiculite-septechlorite is the most unusual, because it is conspicuous in only one deposit and occurs in an unusual habit. The vermiculite-septechlorite intergrowths are apparently of diagenetic origin, and they cement sand grains as would iron oxides or calcite (fig. 4). With the possible exception of pyrite, these mineral intergrowths are the most abundant component in the ore zone of the Key Claims mine.

The ore zone of the Key Claims mine is a dark greenish-gray to black basal layer, 1 to 2 feet thick, in a thick sandstone lens. The zone is well defined by its dark color, which is due to cementing minerals including vermiculite-septechlorite, pyrite, uraninite, calcite, and iron oxides.

The vermiculite-septechlorite is dark greenish gray to light greenish brown and forms narrow fibrous-appearing bands along sand grain boundaries. At places, it entirely fills the intergranular void, although in general calcite fills the center of the interstice (fig. 4). The vermiculite-septechlorite material appears fibrous (fig. 4) under the light microscope, but the fibers resolve into small plates under the electron microscope. X-ray diffraction studies made on natural-state, heat-treated, and glycolated material disclose the double-phase character of the material and the probable mineralogic identities of the phases. A chemical analysis showed the material to have a high iron content (23.6 percent Fe_2O_3 and 7.03 percent FeO), and this suggests that the septechlorite phase is probably septechamosite.

Pyrite and uraninite occur in the cemented sandstone much as they do elsewhere in the basin. Pyrite is distributed as small blebs and masses filling intergranular voids. Uraninite coats sand grains and fills interstices at localized spots in the rock. Pyrite and uraninite seem to be approximately contemporaneous; some blebs of pyrite enclose uraninite, and some uraninite masses fill in around masses of pyrite. Both are earlier than the vermiculite-septechlorite that covers them.

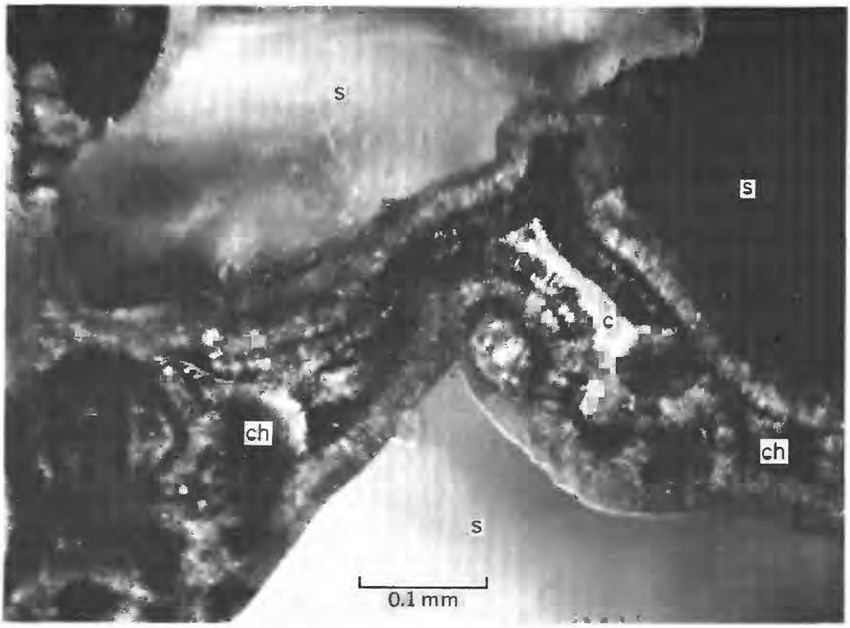

FIGURE 4.—Vermiculite-septechlorite intergrowth (ch) cementing sand grains (s). Bands of fibrous appearance are light greenish gray to dark grayish green; white calcite (c) fills in center of intergranular space. Key Claims mine, Wyoming. Crossed nicols.

The soil of the Powder River Basin and much of the bedrock bear anomalous amounts of selenium. Several plants that have an affinity for selenium manifest the general distribution of the toxic metalloid.

Selenium in the Wasatch Formation seems to be concentrated in the uranium deposits. The greatest concentration of selenium, however, commonly does not occur in the part of the deposit that is richest in uranium or apparently in any specific mineral. In the Pumpkin Buttes area at the Blowout mine, native selenium crystals occur in pink sandstone that contains but little uranium.

As mining progressed in Pat No. 8 mine, moist sand with a noticeable mercaptanlike odor was found in several places. Some of the material, which was highly ferruginous and uraniferous (5 percent uranium), contained 4,200 ppm selenium. Other samples containing less uranium contained 2,700 ppm selenium. The mineral in which the selenium occurs is not known. A simple rinsing technique similar to that used for separating the native selenium from sand in the Blowout mine was tried here without success.

Part of the selenium in the Wasatch Formation is believed to come from the alteration of pyritic masses in the sandstone. Pyrite formed in the sedimentary environment within the ore zones is very rich in selenium; some pyrite in the Pumpkin Buttes area contained as much as 3 percent selenium.

GROUND-WATER STUDIES

A relation between uranium deposits and high uranium content in well and spring water was sought by means of general sampling and analysis of water sources in the southern part of the basin. This study was intended also to give information on the geochemical environment in which migration and concentration of uranium took place.

Ground-water samples were analyzed for several substances including the anions HCO_3^-, $CO_3^=$, and $SO_4^=$. The analytical results are given in table 6. Of a total of 32 samples, 10 are thought to be from Fort Union strata; the remaining 22 probably represent ground water in the Wasatch.

Uranium content of the samples ranges from 0.0005 to 0.2200 ppm. The highest amount of uranium in water in the Fort Union is 0.008 ppm, an amount significantly lower than the average of 0.028 ppm uranium for water in the Wasatch. Averages for other water components are: $SO_4^=$, 182 ppm; HCO_3^-, 238 ppm; and $CO_3^=$, a trace in all samples checked. The hydrogen ion concentration, expressed as pH, of all water samples ranges from 7.6 to 8.4; the average is 8.0. Ground water in the southern part of the basin is rich in dissolved solids, slightly basic, and contains more than the common amount (generally less than 3 parts per billion) of uranium in ground water.

Nine water samples (two duplicates) of the group from the southern part of the basin have a uranium content anomalously high for the basin and many times a median value for ground water. Samples W55–47, 52, and 53, S55–42, S56–103, 104, 105, 107, and Tw–210 range in uranium content from 0.041 to 0.220 ppm. The highest value (0.220 ppm) is from W55–47; a second sample from the same source taken one year later contains 0.130 ppm.

The water sources containing anomalously high amounts of uranium form a group embracing an area about 10 miles across; the source of sample 104 is at the center of this area. This group does not overlie an area of known uranium deposits but is offset from the southwest edge of the Monument Hill deposit area. The significance of this grouping is not known. The area of high-uranium water wells contains no red sandstone in outcrop; white clay-rich sandstone is dominant in the area. The abundant uranium in the ground water of the area may simply reflect the commonly altered condition of the sandstone here, assuming that surface characteristics of the sandstone continue with depth. However, it is also worth considering that the anomalously high uranium content of the ground water in this largely unexplored area may indicate buried ore bodies at depth.

TABLE 6.—*Analytical data of well and spring water, southern part of the Powder River Basin, Wyo.*

[Analyses of samples 236063–236066 by J. P. Schuch and E. C. Mallory; 245618–249527 by J. P. Schuch and Irving Frost; 82082–87671 by J. P. Schuch, Wayne Mountjoy, and Irving Frost]

Field No.	Laboratory No.	Location			Description	Probable formation	U (ppm)	pH	$CO_3^=$ (ppm)	$SO_4^=$ (ppm)	HCO_3^- (ppm)
		Sec.	T. (N)	R. (W)							
W55-29	236063	19	37	72	Carl Manning east well; windmill	Fort Union	0.0040				
45	72	6	37	72	Joe Reynolds camp well, artesian	do	.0005				
46	70	6	37	72	Joe Reynolds West Cheyenne well; artesian	do	.0005				
47	73	36	37	74	Reynolds west ridge well; windmill	Wasatch	.2200				
48	71	31	38	73	Hornbuckle west well, artesian	Fort Union	.0005				
52	65	20	37	73	Reynolds abandoned farm well; windmill	Wasatch	.0640				
53	68	17	37	73	Reynolds west Duck Creek well; windmill	do	.0560				
S55-39	236064	19	35	71	North Sundquist Flats spring	do	.0120				
41	67	29	35	72	Morton abandoned farm well; windmill	do	.0010				
42	66	36	36	73	Vollman southeast well; windmil	do	.0540				
S56-103	245618	27	36	74	Badger mine turnoff well; windmill	do	.0420	8.1	Tr.	50	253
104	19	36	37	74	Reynolds west ridge well, windmill, repeat of W55-47 after lapse of 1 year.	do	.13	8.4	Tr.	45	253
105	20	1	36	74	Reynolds west draw well; windmill	do	.0700	8.1	Tr.	157	272
107	21	17	37	73	Reynolds west Duck Creek well, windmill, repeat of W55-53 after lapse of 1 year.	do	.0410	7.7	Tr.	102	253
113	22	17	40	73	Fred Taylor well; artesian	do	.0015	8.3	Tr.	275	190
134	246449	12	37	74	Harris well of Hornbuckle, artesian	do	.0023	8.0	Tr.	384	247
135	50	33	38	73	Hornbuckle Ranch spring	do	.0015	7.9	Tr.	267	231
143	51	25	39	74	Hardy new well, artesian	do	.0008	8.2	Tr.	191	202
144	52	19	39	73	Hardy house well; artesian	Fort Union	.0030	8.3	Tr.	146	202
147	53	34	38	74	Henry West well; windmill	Wasatch	.0200	7.8	Tr.	242	240
151	54	23	40	75	Moore-Ross road well; artesian	do	.0013	8.0	Tr.	74	320
153	55	9	40	74	Copp house well; artesian	do	.0015	8.2	Tr.	70	231
156	249523	23	38	73	Hardy mine well; artesian	Fort Union	.0006	8.2	Tr.	81	209
158	24	3	38	73	Hardy south well; artesian	Wasatch	.0007	7.6	Tr.	113	199
166	25	17	38	71	Tillard east Cheyenne well; artesian	Fort Union	.0005	7.7	Tr.	74	174
171	26	35	39	71	Morton Cheyenne bridge well; artesian	do	.0006	7.9	Tr.	74	177
180	27	31	41	73	Moore, Betty, mine well, windmill	Wasatch	.0019	7.6	Tr.	745	196
TW-180	82082	28	38	73	Bill Store, windmill	Fort Union	.008				
205	87665	5	42	73	Turner Ranch, windmill	Wasatch	.002				
208	68	24	39	73	Carson Ranch, windmill	do	<.005				
210	70	35	37	74	Mason Ranch, windmill	do	.14				
211	71	2	34	73	Smith Ranch, windmill	Fort Union	<.005				

Gas bubbles are noticeable in many of the open-flowing wells throughout the basin. The U.S. Bureau of Mines, Department of Health and Safety, analyzed a gas from a conspicuously gassy well, No. 134, as follows:

CO_2 (percent)	O_2 (percent)	CH_4 (percent)	Inert gas as N (percent) by difference	Total
0.56	3.34	0.056	96.05	100.006

The gas is considered to be air, in large part modified by reactions with components of the water. Hydrocarbon and possibly CO_2 have been added.

ORIGIN OF URANIUM DEPOSITS AND RELATED FEATURES

The uranium deposits and the red sandstone zone with which they are associated seem to be closely related effects of a single set of geochemical changes. These changes were imposed in a strikingly uniform manner over a large but sharply defined part of the Wasatch outcrop lying partly in the report area and partly in the Pumpkin Buttes area to the north.

Any attempt to explain the origin of the deposits must consider the following salient features of the Powder River Basin uranium province:

1. The concentrations of uranium and vanadium in economically significant deposits accompanied locally by accumulations of manganese.
2. The uniform character of the deposits and the fact of their occurrence in many sandstone lenses generally isolated from one another and all enclosed in a formation of impermeable siltstone-claystone beds.
3. A well-defined regional zone in which most of the sand lenses are red or largely red, although the claystone and siltstone enclosing the sandstone lenses are gray everywhere.
4. The detailed characteristics of red color and red color boundaries in sandstone lenses including continuity, freedom from control by sedimentary structures of the sandstone, sharpness of contact, and calcite rims along many color contacts.
5. The conspicuous association of uranium deposits with the red sandstone zone and a relation to the boundaries of red color in individual sandstone lenses.

Uranium, vanadium, and manganese apparently can be concentrated in sedimentary rocks by various geochemical mechanisms, consequently, point 1 is not diagnostic. Point 2, regional uniformity in a group of hydrologically isolated deposits, however, is not equally compatible with all processes of origin. Similarly, the distribution of red sandstone in the basin, the restriction of red color to sandstone, the detailed characteristics of red color contacts in sandstone lenses, and the close association of uranium deposits to red color and to color boundaries, do not conform with any simple regional mechanism for their origin.

A regional geochemical and mineralogic change may readily arise out of a regional transfer of material, brought about by a regional circulation of hydrothermal solutions or of ordinary ground water. In the Wasatch rocks of the Powder River Basin, however, it is difficult to see how mass transfer of material could have occurred other than very locally. The impermeable siltstone-claystone separating the permeable sandstone lenses would bar the passage of ground-water solutions, heated or unheated, unless it were cut by extensive fractures serving as channelways. A few continuous fractures are known to exist in the Wasatch rocks and some are in areas of red standstone with numerous uranium deposits, but these fractures are not sites of unusual alteration. There is no indication that they functioned as access routes for altering solutions from whatever source.

Other features of geology besides a lack of channelways discredit the idea that the ore deposits and the reddening of the sandstone are the work of circulating solutions. The sharpness of contacts between red and drab rock in the individual sandstone lenses and their evident freedom from control by gravity or bedding do not suggest alteration by circulating fluids.

Evidence of the origin of the uranium deposits under sedimentary environmental conditions is provided by a study of minor metal ratios in pyrite nodules in barren and mineralized sandstone in the Pumpkin Buttes area. The relation $Ni/Co>1$ seems to be a well-established characteristic of pyrite of sedimentary environments; generally $Ni/Co<1$ is characteristic of pyrite developed in hydrothermal environments (Fleischer, 1955, p. 1004). The Pumpkin Buttes pyrite was found to have $Ni/Co>1$, consequently the pyrite and the uranium minerals with which it is mainly contemporaneous are accordingly judged to have had an origin related to the sedimentary rocks and their environment.

Evidence is lacking for transfer of material between the sandstone lenses of the Wasatch Formation and possible outside sources of uranium, vanadium, and manganese, leading to the conclusion that the uranium deposits in the separated sandstone lenses originated by the concentration of substances originally present in disseminated form within the lenses. This process of intralens accretion of uranium, vanadium, manganese, and calcite, and the formation of a red sandstone zone, are the results of a change in chemical environment within the sandstone lenses in part of the Wasatch Formation. The change in environment apparently was very similar for all sandstone lenses throughout the affected part of the formation because the alteration has been similar. The fundamental cause for such a change seems to have been structural deformation.

The red sandstone zone in the basin lies across the trend of Tertiary folds. In the Pumpkin Buttes area the broad north end of the zone overlies the intersection of two gentle anticlinal folds. In the southern part of the basin an anticline or anticline terrace bend is believed to extend northwestward through the entire area, almost coincident with the southern part of the red sandstone zone. It seems that mild Tertiary deformation was most pronounced in this elongate zone and that the remainder of the basin, underlain by Wasatch rocks, was relatively unaffected.

The zone of red sandstone in the Wasatch Formation, with its scatter of ore bodies, may be a geochemical effect of the anticlinal folding. The folding, though more prominent at depth, may have caused local increase in heat and pressure in the Wasatch rocks, and the accompanying changes in the regional chemical environment could cause, under certain circumstances, conspicuous alteration of the Wasatch rocks associated with the folding. Within the restricted area of the red sandstone zone, the conversion of brown limonitic minerals to red hematite and the concentration of certain originally disseminated components of the sandstone units into ore deposits are two prominent mineralogic changes believed to record such an environmental change.

The sequence of events in the evolution of the ore deposits and related features in the Powder River Basin is not completely understood; however, the following hypothesis is presented as a beginning to a solution. Concentrations of calcite in the deposits and a rim of concretionary calcite commonly present at the contact of red and drab sandstone suggest that the redistribution and concentration of uranium, vanadium, and manganese within each sandstone lens, and the development of hematite, were controlled by the same factors that controlled the solution and concentration of calcite. The local controlling factor is considered to have been the partial pressure of CO_2, which determined the amount of CO_2 present as a separate phase in the system and also the HCO_3^- concentration. The concentration of CO_2 and HCO_3^- provided a means for the solution and migration of the uranium and vanadium as complex ions (Bullwinkel, 1954). Also the development of hematite from hydrated iron oxides directly or by partial solution and reprecipitation seems likely in an environment rich in CO_2. Furthermore, by postulating that zones rich in CO_2

had formed in sandstone lenses either by addition of CO_2 produced by decay of organic matter or by change in pressure of an initial CO_2 component due to changes in lithostatic and hydrostatic load, a means is at hand to explain the sharp boundaries of the red color in partly red sandstone lenses. The red of the sandstone would develop in the zones of highest CO_2 concentration. The amount of CO_2 apparently exceeded the solubility in H_2O and a dense fluid phase developed (Garrels and Richter, 1955). The boundary of such a phase would be irregular but sharp as might be the interface of two liquids of different compositions. The two liquids though miscible, if not mixed, would act independently as solvents for some compounds not soluble in both liquids. The shapes of the red color contacts and the relations of the deposits to the containing beds suggest that the density of the ore fluids was close to that of pore water. The reactions of bicarbonate and carbonate ions with uranium and vanadium to form complexes would be much greater within the zones rich in carbon dioxide than elsewhere.

The deposits in the Wasatch Formation of the Powder River Basin may have developed generally in the following manner. Upon a general decrease in total gas pressure within a sandstone lens, calcite would precipitate first outside the boundary of the CO_2-rich zones because of initially lower CO_2 partial pressure. As a result the relative concentration of bicarbonate, hydrogen, and carbonate ion within the CO_2-rich zone would increase greatly. Under this environment the carbonate, bicarbonate, and the complex uranium and vanadium ions in the zones would migrate to the rims of the zones, that is, toward the places of lower concentration. The ultimate result would be a calcite-rich rim at the boundary of the CO_2-rich zone and a concentration of uranium and vanadium compounds against and within this rim. Very locally, such as around coalified woody material, different environments might form within the CO_2-rich zones to account for the reduced forms of uranium, vanadium, and iron which precipitated and formed the uraninite, paramontroseite, and pyrite masses.

In summary it seems that only in the sandstone lenses of the Wasatch Formation could the particular circumstances develop that produced the uranium deposits of the Powder River Basin. The sandstone units contained the proper components; they were overlain by 1,000 to 2,000 feet of sediment, and a part of them was subjected to the particular conditions of pressure and temperature associated with anticlinal folding so that a dense CO_2 phase developed and separated from pore water. This particular environment, which provided a means for the migration and accumulation of metals and the reddening of the sandstone, probably persisted within relatively narrow limits of pressure and temperature and apparently terminated abruptly. The abrupt change in the CO_2 environment came about possibly through a decrease in lithostatic load allowing the CO_2 to expand greatly, mix thoroughly with pore water, and ultimately disappear, leaving as persisting features the red sandstone zone, the sharp red color boundaries, and the accumulations of uranium and vanadium minerals.

A more detailed account of the evolution of the deposits is given in a report by Sharp and others (1963), which covers the Pumpkin Buttes area of the Powder River Basin.

MINE DESCRIPTIONS

The geology of the deposits is strikingly similar throughout the Powder River Basin, although mineralogic features peculiar to a single locality are found also. The same mineralogy and paragenetic sequence are evident from mine to mine, and a close relation of uranium minerals to red color contacts is conspicuous at almost every deposit.

The mines to be described in this section span the range of variation in the uranium deposits of the southern part of the Powder River Basin. The Box No. 4, Lamb 3, Betty, and Key Claims typify deposits which have not been affected by formation of montmorillonite and the coincident bleaching of sandstone color. The Pat No. 8 and Hardy Fee mines are both in the poorly defined zone of white sandstone (the zone of sandstone alteration).

BOX NO. 4 MINE

The Box No. 4 mine, formerly owned by Harland D. Fowler, is in sec 1, T. 35 N., R. 72 W., Converse County, Wyo. (loc. 11, table 4 and pl. 1). It lies within the Box Creek area just north of Sundquist Flat (pl. 1) and approximately 22 miles north of Douglas, Wyo. Of this distance only the first 7 miles, from Douglas to Orpha, may be traveled over paved road. From Orpha an improved dirt road serving the Morton Incorporated Ranch extends to the vicinity of the mine. The Box No. 4 deposit was worked in 1955 but not in 1956.

The deposit at this mine is considered typical of deposits unaffected by alteration of volcanic material to clay and attendant bleaching of sandstone. Intersecting trenches oriented N. 20° W. and N. 70° E. are cut to a miximum depth of 30 feet in a single sandstone unit and locally into an underlying clay bed. The medium-coarse to conglomeratic sandstone is relatively free from interstitial clay.

The Box No. 4 deposit is on the east margin of the red sandstone zone and is a good example of the regional relation of uranium deposits to red-tinted sandstone. Concentrations of uranium minerals in the pit follow a lobate contact between red to pink and drab sandstone. This color contact, marked in many places by a hard dark grayish-red calcite-rich rim, transects bedding at all angles. Greenish-yellow oxidized uranium minerals, predominantly tyuyamunite, appear in the drab sandstone a few inches to a few feet from the color boundary at several places. Across the color boundary the red sandstone is barren. The map and cross section *B–B′* on plate 5 show the close relation of uranium minerals, coalified wood fragments, and color contact.

A basal layer of the sandstone in the northwest cut is highly ferruginous and is especially rich in yellow uranium minerals where the color contact approaches it at a low angle. Section *A–A′* on plate 5 shows ore minerals concentrated in the wedge between the color contact and the lithologic contact of sand and clay. In the central workings of the mine a similar condition exists. Yellow uranium minerals are abundant near the base of the sandstone unit under a slightly inclined tongue of red color. Many hard calcareous sandstone concretions are part of this ore zone. The concretions, 6 to 12 inches across, are dark red throughout and contain irregular splotches of black manganese oxides. Yellow uranium minerals are concentrated around the peripheries of the concretions and coat some of the fractures that cut them, but generally the cores of the concretions are barren.

Part of the ore material from this zone consists of many ellipsoidal clay galls in ferruginous trashy grit. These clay galls, 2 to 5 inches long, are very radioactive and when first exposed show no recognizable uranium minerals. Soon after exposure to air and a drying atmosphere shrinkage cracks coated with yellow minerals form. The newly exposed galls are dark gray to black, almost submetallic in appearance. When broken, the galls show a black to dark-gray banded outer shell enclosing a mottled gray and lavender core. These galls are so unusual in structure, appearance, and apparent composition that separations were made of their different zones, and the two parts were analyzed by X-ray diffraction and semiquantitative spectrographic methods. The outer black shell is composed mostly of manganese oxide in the form of pyrolusite. The core material is a mixture of quartz and clays, predominantly montmorillonite. Spectrographic analysis shows the shell to be richer in manganese than the core and the core to be richer in aluminum and calcium. Small but measurable amounts of boron, lanthanum, and lithium are also present in the core, whereas there is no detectable amount of these elements in the shell. The core of the galls is highly radioactive in contrast to the manganese-rich shell which is only slightly radioactive. A partial chemical analysis of the core material, in percent, shows: eU, 0.43; U, 0.22; $CaCO_3$, 0.74; MnO, 5.03; Fe_2O_3, 21.08; and V_2O_5, 0.55.

PAT NO. 8 MINE

The Pat No. 8 mine is in sec. 3, T. 37 N., R. 73 W. (loc. 20, table 4 and pl. 1). It is the older of the two large producing mines of the Monument Hill area and lies near the Hornbuckle Ranch on a gentle north-facing slope which drains directly into the Cheyenne River. Pat No. 8 mine is approximately 35 miles north of Douglas, Wyo., from which it is readily accessible, most of the distance being over good dry-weather dirt roads.

In October 1956, workings consisted of a single trench elongate N. 10° E. and 60 feet deep at its deepest point. The section exposed in the trench consists of an upper coarse-grained sandstone, a lenticular middle unit of gray siltstone, and the lower coarse-grained sandstone which is the principal uraniferous unit. The lower sandstone, a coarse calcareous grit containing abundant interstitial clay, is at least 20 feet thick and forms the bottom of the trench (pl. 5).

Most of the ore produced from the Pat No. 8 mine came from near the middle of the lower sandstone where an irregular zone approximately 10 feet thick contains disseminated yellow uranium minerals. A mixture of carnotite and tyuyamunite is unevenly distributed throughout the ore zone. Liebigite occurs as an apple-green filling in cracks in coalified wood slabs and in incipient fractures in locally well cemented sandstone. Zellerite, a carbonate mineral like liebigite, forms finely fibrous whitish crusts on sand grains and also fills cracks in coalified wood. A platy yellow mineral tentatively identified as becquerelite is irregularly associated with zellerite in the coaly material. Uraninite and pyrite cement sand grains to form masses as much as 2 feet across; these masses are invariably associated with large fragments of coaly material.

Pat No. 8 mine lies on the west margin of the red sandstone zone of the Powder River Basin at a color boundary in the two closely spaced sandstone lenses. Sandstone of the mineralized west wall is yellowish gray or tan, but red coloring appears on the mostly grayish-white, montmorillonite-rich rock that makes up the barren east wall. The change from red to drab take place chiefly along the centerline of the mine cut (pl. 5).

By October 1956, a total of approximately 6,000 tons of ore had been produced; since that time another 2,000 to 3,000 tons has been produced. The ore grade is estimated to average about 0.25 percent uranium.

BETTY MINE

The Betty mine is in sec. 25, T. 41 N., R. 74 W., Converse County, Wyo. (loc. 36, table 4 and pl. 1). It is one of a cluster of open pit mines and prospect holes opened in the locally uraniferous basal part of a widespread sandstone unit (pl. 1).

Workings of the Betty mine consist of a single large pit, approximately square in plan, with walls trending N. 20° W. and N. 70° E. At its deepest part, near the base of the west wall, the pit exposes 30 feet of interbedded sandstone and conglomerate. There is a thick lens of gray siltstone in the northwest corner of the pit; it pinches out to the south and east within a short distance (pl. 5).

Uranium minerals occur in two distinct relations in the Betty pit. Thinly disseminated green uranium minerals are visible in coarse drab sandstone toward the south end of the pit's west wall. Here uranium is concentrated in a zone beneath a low-dipping contact between red sandstone and the underlying drab sandstone.

The ore piles at the Betty mine, however, were found to consist not of the sparsely mineralized drab sand, but of a hard radioactive rock with little visible uranium mineral. This material is mined from a zone of trashy, ferruginous, clay-gall conglomerate exposed near the bottom of the deepest part of the pit. Radioactivity measured along this zone was as high as 0.6 to 0.8 mr per hr (milliroentgen per hour). A discontinuous layer of hard purplish-red calcite-rich sandstone approximately follows the conglomerate zone. This calcite layer seems even more closely associated with uranium than is the conglomerate, because where the two zones diverge, it is the calcite zone which continues to be mineralized. Such a divergence can be observed in the west wall of the pit (pl. 5). Just below the point where the gray siltstone wedge pinches out to the south, the calcite zone leaves the conglomerate zone in a wide loop. A sharp color contact along this segment of calcite zone is visibly mineralized on its concave (drab-colored) side. The convex side of the looping calcite zone is in red-tinted sandstone and is barren.

In detail, the uranium minerals of the conglomerate and calcite zone tend to occur in fractures in clay galls and in and around coalified wood. This characteristic occurrence near material with decided reducing powers suggests that uranium may have been originally concentrated in these places in a reduced state, as uraninite or coffinite; however, only oxidized uranium minerals have been seen in the Betty pit. One of these minerals is autunite, $Ca(UO_2)_2(PO_4)_2 \cdot 10\text{–}12H_2O$, hitherto unreported from the apparently phosphorus poor geochemical province of the Powder River Basin. The green fluorescent autunite occurs as minute scales on partings in one large clay gall. Other important uranium minerals at the Betty mine are uranophane and tyuyamunite.

The Betty pit lies on the east edge of the regional red sandstone zone.

KEY CLAIMS MINE

The Key Claims mine is in the Turnercrest area, sec. 20, T. 41 N., R. 73 W., Campbell County, Wyo. (loc. 38, table 4 and pl. 1). Workings consist of a chevron-shaped trench, 20 feet deep, with a total length of about 250 feet. The cut exposes a crossbedded and generally coarse grained sandstone down to its contact with an underlying clay (pl. 5).

A red-drab color contact is exposed in the trench walls. At the north end of the trench the contact sweeps down to a basal zone at a low angle. Local small concentrations of yellow uranium minerals are scattered along this contact where coaly trash is more abundant. However, ore from the mine has come entirely from a hard dark-gray calcareous layer at the base of the sandstone. Extension of the pit to the north and south appears to reflect the trend of the contact between the dipping color boundary and the uranium-bearing part of the basal layer.

The basal layer, 8 to 12 inches thick, consists of coarse to fine sand cemented mainly by a dark fibrous-appearing intergrowth of vermiculite and septechlorite which coats the sand grains in a radial manner and completely fills much of the interstitial space. Other cementing minerals of the basal ore zone include calcite, pyrite, uraninite, and hydrous iron oxides. Calcite fills the core of the larger spaces and generally cements the rock components. Pyrite and uraninite are found together in the interstices as small blebs coated, like the sand grains, with vermiculite-septechlorite.

At places uraninite coats sand grains, pyrite and uraninite together fill interstices, and vermiculite-septechlorite coats the surface of uraninite and pyrite. Some small blebs of uraninite are enclosed in a pyrite (or marcasite) shell. Thin sections indicate that uraninite and pyrite are contemporaneous. A few pyrite blebs seen in Key Claims ore have enclosed a small particle of unidentified metallic mineral, which in polished section is strongly anisotropic and dark gray with a purple cast.

Yellow oxidation minerals have formed in much of the basal ore zone on incipient fractures and larger openings. Most of this oxidized material appears to be uranophane.

The mine probably produced several hundred tons of ore before October 1956, and several hundred tons more probably have been mined since. The ore grade is estimated to average about 0.2 percent uranium.

LAMB NO. 3 MINE

The Lamb No. 3 mine (loc. 9, table 4 and pl. 1) is in sec. 12, T. 35 N., R. 72W., on rangeland controlled by Morton Inc. of Douglas, Wyo.

The mine is reached from Orpha, Wyo., by way of the Morton Ranch Road.

Mining began at the site in the summer of 1955 after a drilling program outlined a narrow zone of ore-grade material at shallow depth. By the fall of 1955 several hundred tons of good-grade ore had been stockpiled and additional mining had begun on an adjoining site a few hundred yards south of the original cut.

The Lamb No. 3 mine consists of a bench cut into the west slope of a ridge which is a northern extension of the Sundquist Flat surface. In October 1955, when mining virtually ceased, the cut bench was about 250 feet long and about 125 feet wide, and the working face was about 12 feet high.

The host rock is a very coarse grained to conglomeratic sandstone lens more than 20 feet thick that thins to a featheredge down the slope of the hill. The thin edge of the sandstone is red to pink. The color changes uphill along a fairly distinct color contact to the normal drab and brown ferruginous tones. Yellow uranium minerals occur in the drab to brown ferruginous sandstone along the color contact in scattered rich pods and individual zones of disseminated-type ore material.

A basal ferruginous layer of the sandstone overlies clay throughout the cut area. At places this dark-brown iron-oxide-cemented sandstone contained sufficient yellow uranium minerals as coatings on cracks and sand grains to be ore, which is apparently the product of secondary enrichment.

The dominant ore material consisted of yellow minerals, predominantly tyuyamunite, disseminated in friable sandstone, and apparently localized by zones rich in coalified plant trash. Several small manganese oxide nodules that contained yellow uranium minerals were found in this cut.

A cut in the south extension of the Lamb mine area exposes geologic features similar to those described in the original cut. Red sandstone fringing the featheredge of the sandstone host unit is in line with a continuation of the red color boundary that marks the ore zone at the original Lamb No. 3.

HARDY FEE MINE

The Hardy Fee mine in sec. 27, T. 38 N., R. 73 W., lies in a shallow drainage swale just north of the Cheyenne River in Converse County, Wyo. (loc. 31, table 4 and pl. 1). It is one of the largest mines in the Monument Hill area and in the basin. Work at the Hardy Fee site began in the summer of 1956. The claim area had been drilled in 1954 as part of a program of exploration by the Atomic Energy Commission. By the autumn of 1956 an intensive drilling program was well under way and an open pit approximately 300 feet across had been excavated to a depth of more than 30 feet.

Excavating the Hardy Fee pit involved the removal of large quantities of fill. The north and south walls of the nearly square pit, almost from top to bottom, consist entirely of brown, sulfatic fill. The east wall reveals a buried hill of white clay-rich sandstone rising to about half the height of that wall; the west wall is entirely of gray-white and tan very coarse grained sandstone.

Thin local disseminations of a yellow uranium mineral are associated with a zone of brown ferruginous stain in the sandstone hill of the east wall. A small faintly pink patch was observed in this wall. The sandstone of the west wall also shows a local patch of pink color, and toward its base it contains local disseminations of a yellow uranium mineral.

The most conspicuous uranium concentrations seen, however, were associated with large and small masses of coalified wood scattered in a thin zone just above the contact of the sandstone with an underlying lens of dark clay. The workings penetrate this dark carbonaceous clay only at the deepest part of the pit. The uraniferous zone overlying it consists of hard dark sandstone cemented with calcite and iron oxides and contains local partings of dark carbonaceous siltstone.

The abundance of white clay in the sandstone of the Hardy Fee pit and the relict character of red color in the walls indicate that this mine lies in the zone of clay alteration. Apparent bleaching of the sandstone attendant upon clay formation obscures the relation between mineralization and the contact between red and drab sandstone known to occur in the pit.

Red color appears in the same sandstone lens where it crops out south and east of the pit (pl. 1) but is absent in outcrops north and west of the pit. Thus the red color that appears in the pit walls is about the most northwesterly occurrence of red color in the ore-bearing unit and evidently marks the approximate position of a once well defined color contact.

GUIDES FOR PROSPECTING AND EXPLORATION

In the southern part of the Powder River Basin, deposits of uranium minerals are confined to sandstone units of the Wasatch Formation and not to claystone-siltstone beds. The uranium deposits almost without exception occur near the boundary or edge of the red color in any sandstone unit. Sandstone units characterized by a sudden change in color, from red to drab, should be investigated, particularly along the zone of color change.

A color contact in a sandstone is irregular in plan and in cross section; consequently the actual contact may curve and may have long arms extending in any direction below the surface. Exploration along exposed color contacts should be over such a width to allow for this irregularity of form.

Not all the sandstone units of the red sandstone zone of the basin seem to have color contacts. Some of the sandstone units appear to be completely drab or completely red. At many places where color seems to be continuous, deposits have been found at color changes not exposed in outcrop. Consequently, completely red or drab sandstone units within the red sandstone zone may contain ore deposits.

A study of well-water samples has disclosed that an area southwest of Monument Hill contains water that is anomalously high in uranium. Although sandstone units exposed within the area are white and drab and generally nonradioactive, the area seems to be worthy of more detailed examination. The high uranium content of the ground water could mean buried uranium deposits and an extension at depth of the red color boundary westward from the Monument Hill area.

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