Geology of the Puddle Springs Quadrangle Fremont County, Wyoming

By PAUL E. SOISTER

CONTRIBUTIONS TO ECONOMIC GEOLOGY

GEOLOGICAL SURVEY BULLETIN 1242-C

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

A study of most of the western part of the Gas Hills uranium district, with emphasis on geology of the ore-bearing Wind River Formation

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1967

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

William T. Pecora, *Director*

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

TABLES

CONTRIBUTIONS TO ECONOMIC GEOLOGY

GEOLOGY OF THE PUDDLE SPRINGS QUADRANGLE FREMONT COUNTY, WYOMING

By Paul E. Soister

ABSTRACT

The Puddle Springs quadrangle is near the south-central edge of the Wind River Basin in central Wyoming. It includes most of the western part of the Gas Hills uranium district, and the original uranium ore reserves totaled at least 1 million tons.

Although Cambrian, Mississippian, and older Pennsylvanian strata may be present in the subsurface, all drill holes have bottomed in or above the Tensleep Sandstone of Pennsylvanian age. At least 16 oil and gas test holes have been drilled, and they penetrate formations of Permian, Triassic, Jurassic, and Cretaceous age. Rocks exposed at the surface include the Mowry Shale of Early Cretaceous age, Frontier Formation and Cody Shale of Late Cretaceous age, Wind River Formation of early Eocene age, Wagon Bed Formation of middle and late Eocene age, and pediment gravel and alluvium of Quaternary age.

Only the ore-bearing Wind River Formation, which underlies about half the quadrangle, was studied in detail. Composite thickness of this formation is about 826 feet, but the greatest thickness in any one locality now is about 600 feet. The formation includes a lower fine-grained member, the coarse-grained Puddle Springs Arkose Member, and an upper transition zone.

The lower fine-grained member ranges in thickness from 0 to about 130 feet and is composed of siltstone, fine-grained sandstone, claystone, a few beds of partly coaly carbonaceous shale, and a thin irregular basal bed of conglomerate.

The Puddle Springs Arkose Member is more than 500 feet thick and consists of massive coarse conglomeratic arkosic sandstone and beds of granite granule-to-boulder conglomerate, fine-grained sandstone, siltstone, claystone, and carbonaceous shale. This member has all the known uranium deposits in the quadrangle. The arkose is generally oxidized and yellow to gray at the surface but is unoxidized and greenish to bluish gray near and below the water table. Two granite cobble-and-boulder conglomerate beds were mapped in the Puddle Springs quadrangle; they are about 10–30 feet thick and 100 feet apart stratigraphically. The lower of the two, the Dry Coyote Conglomerate Bed, contains many uranium deposits; most uranium deposits in the quadrangle lie from 150 feet below to 50 feet above this bed. The overlying Muskrat Conglomerate Bed has no known uranium deposits.

The upper 120 feet of the Wind River Formation consists of arkose, typical of the Puddle Springs Arkose Member, interbedded with bentonitic mudstone, typical of the Wagon Bed Formation; it is thus called the upper transition zone of the Wind River Formation.

The pre-Tertiary rocks dip northward about 5°–12° off the flank of the Sweetwater uplift; the Granite Mountains, about 8 miles south of the quadrangle, form the core of the uplift. Northwest-plunging folds modify the northerly regional dip, and at least one of these anticlines may have a high-angle reverse fault along its crest.

The folds were deeply eroded before deposition of the Wind River Formation, and there is several hundred feet of relief on the pre-Wind River surface. As a result of post-Miocene subsidence of the Sweetwater uplift, the Tertiary rocks dip southward at very low angles and are broken by east-trending normal faults. These faults have at least a few hundred feet displacement, some are several miles long, and along virtually all of them the downthrown side is on the north. The combination of erosion, subsidence, and faulting has produced several small basins where uranium deposits occur.

Original uranium ore reserves of the quadrangle probably totaled at least 1 million short tons with an average uranium content of 0.25 percent. Mining has been continuous since 1955 and a uranium mill is in operation (1965) in the quadrangle. Uranium minerals occur in arkosic sandstone, conglomerate, siltstone, and carbonaceous shale. The ore deposits generally are blanketlike bodies in arkosic sandstone or in siltstone. The largest ore deposits of the district are at or near the ground-water table and are only partly oxidized. More than 40 authigenic minerals compose or are associated with the deposits; they include minerals of arsenic, selenium, and molybdenum, as well as minerals of uranium. Coffinite and uraninite are the main ore minerals in the unoxidized deposits; meta-autunite, phosphuranylite, an unnamed yellow uranium phosphate, and uranophane are the main ore minerals in the oxidized deposits.

Radiochemical analyses indicate a Pleistocene age for at least some of the uranium deposits. Possible sources of the uranium and associated elements include tuffaceous beds of post-Wind River rocks, arkose of the Puddle Springs in arkosic sandstone or in siltstone. The largest ore deposits of the district solutions associated with volcanic activity in middle and late Eocene time southeast of the district. The available evidence favors the theory that arkosic sediments of the Puddle Springs are the main source of the uranium and that migration and deposition is still in progress. Solution, migration via vadose and ground water, and redeposition of the uranium during Pliocene(?), Pleistocene, and Recent time, somewhat as Gruner (1956) suggested in his multiple migration-accretion hypothesis (Economic Geology, v. 51, no. 6, p. 495–520), probably account for the uranium deposits of the Gas Hills district. Important factors in the occurrence of deposits here include high porosity and permeability of the Puddle Springs Arkose Member, presence of carbonaceous material, and physical barriers to passage of vadose and ground water.

INTRODUCTION AND ACKNOWLEDGMENTS

The Puddle Springs quadrangle is in eastern Fremont County near the geographic center of Wyoming. Physiographically and structurally it is near the south-central edge of the Wind River Basin (fig. 1, pl. 1).

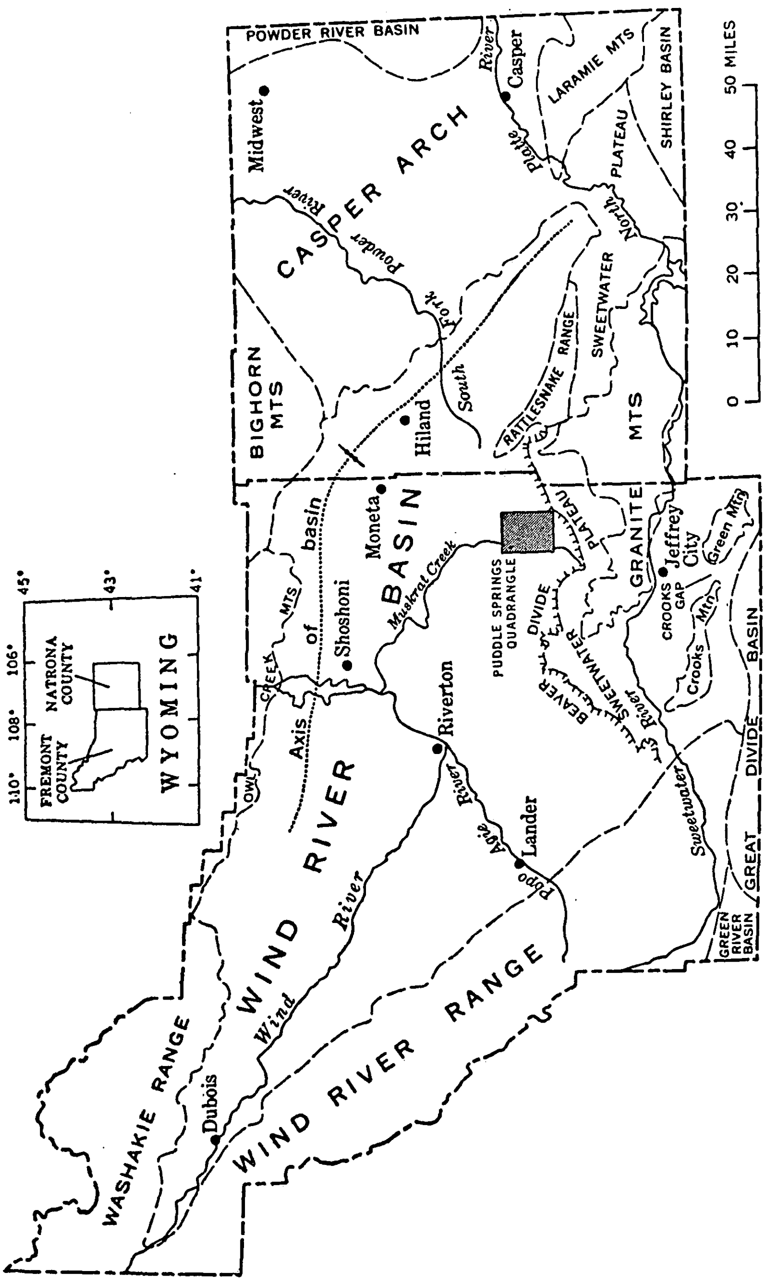

FIGURE 1.—Location of Puddle Springs quadrangle.

The Beaver Divide, just south of the quadrangle, is the southern physiographic edge of the basin and north edge of the Sweetwater Plateau. This plateau is a high, broad surface of low relief and is underlain mostly by beds of Miocene age that dip gently southward. Inliers of Precambrian granite protruding generally 500–1,500 feet above the level of the plateau are the Granite Mountains (also called the Sweetwater Rocks). These inliers form the core of the east-trending Sweetwater uplift.

Until late 1953, when uranium was discovered a few miles to the east, the only regularly inhabited places in the quadrangle were the Puddle Springs Ranch and the George Homestead. Since that time, several small temporary mining camps and a uranium mill (fig. 2) have been established. Moneta, a small settlement on U.S. highway 20, is about 25 miles north of the quadrangle; Jeffrey City, established at Split Rock Post Office to be near the first uranium mill (1956) in central Wyoming, is 25 miles to the south on U.S. Highway 287.

This quadrangle is one of five 7½-minute quadrangles which contain the uranium deposits of the Gas Hills uranium district (fig. 3). In July 1954, the U.S. Geological Survey began a study of these uranium deposits on behalf of the Division of Raw Materials of the U.S. Atomic Energy Commission (AEC). Howard D. Zeller, party chief, the author, and Harold Hyden were assisted in the field by John McDowell, Richard Koogle, and Roy A. MacDiarmid during 1954–56. The Puddle Springs quadrangle is part of the area mapped by the author of the present report. Koogle assisted with the mapping in 1954, and MacDiarmid in 1955. During 1956–58, the author spent about 10 weeks in the region on a stratigraphic study of the Wind River Formation; part of this time was used to modify some of the previous mapping. H. D. Zeller mapped most of the pediment gravels in the southeastern part of the quadrangle.

A preliminary report of the 1954–55 work was published in 1956 (Zeller and others). Several progress reports in the semiannual Trace Elements Investigations Reports of the Geological Survey were published by the Technical Information Service Extension of the Atomic Energy Commission. (See Soister and Conklin, 1959.)

Information on geology of the region was provided by Jack Hadfield of the Atomic Energy Commission (oral commun., 1954), by J. D. Love (1954 and oral commun., 1954), and by Joseph L. Weitz (oral commun., 1954). Weitz also provided advance copies of a map of the region (Van Houten and Weitz, 1956); another guide to the geology was an unpublished map by Thompson and White (1952). Some of the structural symbols in the pre-Tertiary rocks have been copied or modified from these two maps. Eight core holes, three of them in this

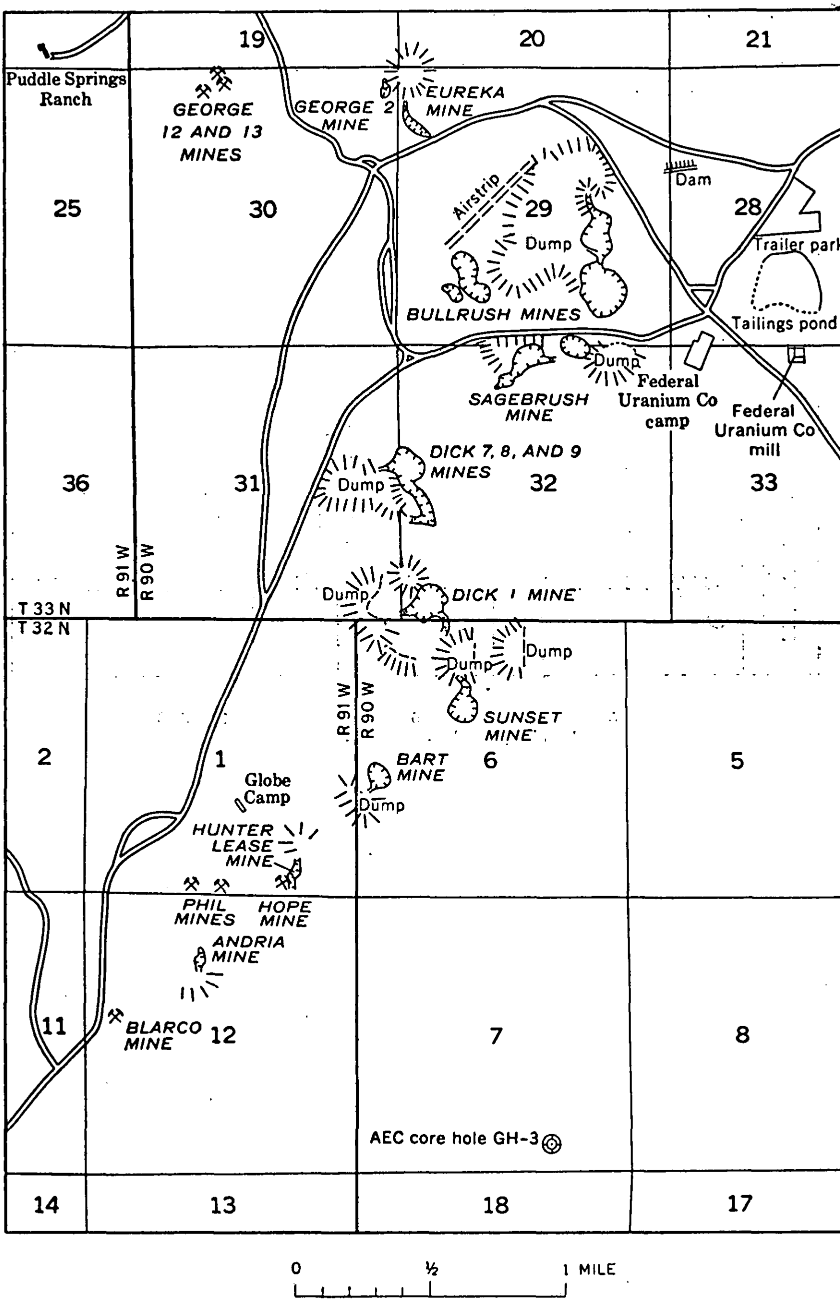

FIGURE 2.—Principal open-pit uranium mines, mill, and other cultural features in the southeastern part of the Puddle Springs quadrangle. Modified from unpublished map by U.S. Atomic Energy Commission, 1960.

244-803—67——2

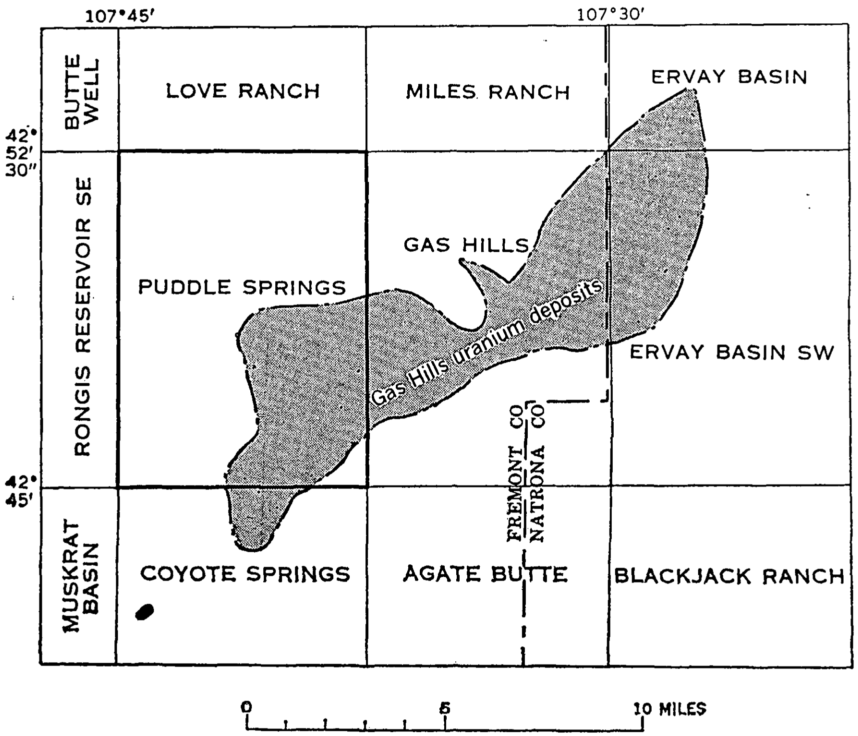

FIGURE 3.—Location of Puddle Springs quadrangle relative to Gas Hills uranium deposits and to other 7½-minute quadrangles.

quadrangle, were drilled by the AEC in 1955 and logged by Bruce Kibbler; logs of these holes proved extremely valuable in solving stratigraphic and structural problems. During 1955, R. M. Hazlewood and John Roller (Black, 1955, 1956a, b) made shallow reflection seismic surveys and were successful in tracing some of the poorly exposed faults and linear features that were detected on aerial photographs. Many helpful suggestions for this report were made by N. M. Denson, D. H. Eargle, E. N. Harshman, J. C. Olson, and H. D. Zeller. Thanks also are extended to Tommy Fackler, of Puddle Springs Ranch, who kindly allowed the author to camp at the ranch.

STRATIGRAPHY

Rocks exposed in the quadrangle (table 1) include the Mowry Shale of Early Cretaceous age, the Frontier Formation and the Cody Shale of Late Cretaceous, the Wind River Formation of early Eocene, the Wagon Bed Formation of middle and late Eocene, pediment gravels of Pleistocene, and alluvium of Recent age. The Thermopolis Shale and Cloverly Formation of Early Cretaceous age and the Morrison and Sundance Formations of Late Jurassic age crop out just south of the quadrangle in the Muskrat Creek inlier (Soister, 1967).

At least 16 oil and gas test holes (table 2) have been drilled. Also, in about 1929 and 1930, the Producers and Refiners Corp. drilled at least six shallow (142–336 ft) diamond-drill test holes in secs. 16 and 21, T. 33 N., R. 91 W. The deeper holes passed through several older

TABLE 1.—*Formations exposed or in the subsurface in the Puddle Springs quadrangle, Wyoming*

System	Series	Stratigraphic unit			Approximate thickness (feet)	Occurrence in quadrangle
Quaternary	Recent	alluvium			68+	Exposed at surface
	Pleistocene	pediment gravels			15	
Tertiary	Eocene, middle and upper	Wagon Bed Formation			400	
	Eocene, middle and upper	Wind River Formation	upper transition zone (120 ft)		[1]825	
	Eocene, lower		Puddle Springs Arkose Member (575 ft)[1]			
				Muskrat Conglomerate Bed		
				Dry Coyote Conglomerate Bed		
			lower fine-grained member (0–130 ft)			
Cretaceous	Upper	Cody Shale			5,000	
		Frontier Formation			730	
	Lower	Mowry Shale			300	
		Thermopolis Shale			275	Penetrated by drill
		Cloverly Formation			95	
Jurassic	Upper	Morrison Formation			230	
		Sundance Formation	"Upper Sundance"		250	
			"Lower Sundance"			
	Lower	Nugget Sandstone			245	
Triassic	Upper	Chugwater Formation	Popo Agie Member (350–400 ft)		1,045	
			Alcova Limestone Member (12 ft)			
	Lower		Red Reak Member (650–750 ft)			
		Dinwoody Formation			65	
Permian		Phosphoria Formation			300–335	
Pennsylvanian		Tensleep Sandstone			275(?)	Possibly present
		Amsden Formation			190(?)	
Mississippian		Madison Limestone			385(?)	
Cambrian	Upper	Gallatin Limestone			<100(?)	
	Middle	Gros Ventre Formation			400(?)	
		Flathead Sandstone			245(?)	
Precambrian		granite, gneiss, schist, and similar rocks				

[1] Composite thickness; maximum thickness of the formation in any one locality is about 600 ft and, of the Puddle Springs Arkose Member, about 500 ft.

TABLE 2.—*Abandoned oil and gas test holes*

[——, absent; (?), present but thickness uncertain]

Map No. pl. 1	Company lease and well	Location			Completion date	Total depth (feet)	Youngest pre-Tertiary formation	Oldest formation reached	Thickness of Wind River Formation (feet)
		Sec.	Township north	Range west					
A	Western States Oil Co., Warren 1.	24	33	91	1920	2, 320	Cody Shale	Frontier Formation.	——
B	Shannon Oil Co., State 1.	16	33	91	1945	4, 585	do	Morrison Formation.	<25
C	Amerada Petroleum Corp., Govt.-Mullen 1.	1	32	91	1951	746	do	Frontier Formation.	158
D	Amerada Petroleum Corp., USA-Mullen 1(A).	31	33	90	1951	833	do	do	197
E	Empire State Oil Co., 2 State.	16	33	91	1952	6, 609	do	Tensleep Sandstone.	——
F	Richfield Oil Corp., 1 Rogers.	7	32	90	1956	2, 867	Thermopolis Shale.	do	460
G	Richfield Oil Corp., 1 Monterey.	1	32	91	1956	3, 700	Frontier Formation.	do	150
H	Richfield Oil Corp., 1–B Monterey.	12	32	91	1956	1, 195	Mowry Shale	Sundance Formation.	268
I	J. G. Dyer, 1 Govt	9	33	91	1957	3, 499	Cody Shale	Mowry Shale	<25
J	Davis Oil Co., 1 Govt.–Grieve Land & Cattle.	34	33	91	1958	2, 461	do	Morrison Formation.	——
K	Humble Oil & Refining Co., 1 Govt.–Vinson.	13	33	91	1960	5, 945	do	Phosphoria Formation.	——

L	Saturn Oil & Gas Co., 1 Govt.-Voth.	25	33	91	1962	4, 810	do	do	(?)
M	Delhi-Taylor Oil Corp., 1-19 Govt.	19	33	90	1962	5, 050	do	do	>190(?)
N	Delhi-Taylor Oil Corp., 1-20 Govt.	20	33	90	1962	150	do	Wind River Formation.	>150(?)
O	True Oil Co., 1 De Lange.	32	33	90	1963	4, 195	do	Phosphoria Formation.	(?)
P	Pan American Petroleum Corp., 1 USA-Cheney.	17	32	91	1963	2, 909	Frontier Formation.	do	

formations and penetrated the upper part of the Tensleep Sandstone of Pennsylvanian age. The only production was from the Shannon Oil Co. State 1 well (table 2, B) on the Glenn anticline; 96,716,000 cu ft of gas was produced from the Frontier sandstone before the well was abandoned in 1947 (Berg and Thompson, 1957, p. 102).

Only the Wind River Formation, host for the uranium deposits, was studied in detail during the investigation for the AEC; a comprehensive report on this formation is in preparation by the author. The pre-Wind River rocks have been studied in adjoining areas by many geologists, and detailed sections were measured a few miles east and west of the quadrangle by H. A. Tourtelot, C. O. Johnson, and J. D. Love (in Love and others, 1947). The Wagon Bed Formation was studied in detail by Van Houten (1950; 1954; 1955; 1964). The following brief description of the stratigraphy of the quadrangle is based on these reports and on lithologic logs by the American Stratigraphic Co. (logs W-751 and CW-1128) of two Richfield Oil Corp. test holes (table 2, F and G).

CAMBRIAN, MISSISSIPPIAN, AND PENNSYLVANIAN ROCKS

Several formations probably lie between the Tensleep Sandstone and Precambrian granitic and metamorphic basement rocks, although pre-Tensleep rocks have not been reached in test holes in this quadrangle (table 1).

Eight miles southwest of the quadrangle, basal beds of the Flathead Sandstone of Middle Cambrian age crop out in contact with Precambrian granitic rocks (Soister, 1966a). These grayish-red-purple to brownish-gray beds consist of granite granule-to-pebble conglomerate and pebbly quartzitic arkosic very coarse grained sandstone. Van Houten and Weitz (1956) indicated a thickness of 245 feet for the Flathead near the head of East Canyon Creek, 9½ miles east of the quadrangle, and reported some glauconite in the sandstone.

Other pre-Tensleep formations in the East Canyon Creek area and in the Conant Creek area 14 miles west of this quadrangle were described by Van Houten and Weitz, and thicknesses were given for each of the areas. Approximate thicknesses for this quadrangle have been obtained by interpolation.

The Gros Ventre Formation of Middle Cambrian age, possibly about 400 feet thick, is glauconitic throughout and consists of gray to reddish-brown siltstone and sandstone with flat-pebble limestone conglomerate in the middle part of the formation.

The Gallatin Limestone of Late Cambrian age, probably less than 100 feet thick, is of gray to red sandy flat-pebble limestone conglomerate.

The Madison Limestone of Mississippian age, about 385 feet thick, consists of limestone and partly cherty dolomite. Three miles west of the quadrangle, in sec. 1, T. 33 N., R. 92 W. (Soister, 1966b), a hole that produced some oil and gas penetrated a few feet into the Madison.

The Amsden Formation of Pennsylvanian age, about 190 feet thick, has reddish fine-grained sandstone in the lower part. The upper part probably consists of red to gray partly silty shale and sandstone interbedded with cherty gray limestone and dolomite.

The Tensleep Sandstone of Pennsylvanian age, about 275 feet thick, consists of gray and yellow slightly limonitic fine- to coarse-grained partly calcareous sandstone and some partly cherty dolomite. Only the upper 112 feet of the Tensleep has been penetrated by an oil test hole in the Puddle Springs quadrangle.

PERMIAN ROCKS

PHOSPHORIA FORMATION

The Phosphoria Formation of Permian age, 300–335 feet thick, has been penetrated in several drill holes, and three separate lithologic units were distinguished in the two logs studied. The basal 55–60 feet consists of dolomite, chert, anhydrite, and a small amount of gray to green claystone and shale; a few thin beds of phosphate rock may be present. The middle 125–150 feet consists of red to brown and gray to green gypsiferous shale and siltstone and at the base a thin lenticular sandstone bed. The upper 115–125 feet consists of white, gray, and brown dolomite, white and gray chert, earthy brown algal limestone, and gray to green claystone and shale. Anhydrite, glauconite, and some phosphatic material are also in this part of the formation.

This quadrangle is part of an area in which intertonguing of red beds and carbonates occurs in the Phosphoria Formation. Red beds are absent on the Conant Creek anticline, about 15 miles to the west, but make up a large part of the rocks in the formation at the north end of the Rattlesnake Range 9 miles east.

TRIASSIC ROCKS

DINWOODY FORMATION

The Dinwoody Formation of Early Triassic age averages about 65 feet in thickness and is mainly gray to green shale but contains some siltstone and very fine grained sandstone. It also includes some thin dolomite and (or) dolomitic siltstone and anhydrite beds.

CHUGWATER FORMATION

The Chugwater Formation is about 1,045 feet thick. It has three members, listed in ascending order: the Red Peak Member of Early Triassic age, and the Alcova Limestone and the Popo Agie Members, both of Late Triassic age.

The Red Peak Member, 650–750 feet thick, consists of red, orange, brown, and a few gray beds of fine-grained sandstone, siltstone, and clay; it is partly calcareous and gypsiferous. The upper part of this member and all the overlying strata to the Cody Shale of Late Cretaceous age crop out on the Dutton Basin (Gas Hills) anticline 3–5 miles east of the quadrangle.

The Alcova Limestone Member, consistently about 12 feet thick, is gray hard finely crystalline limestone. It is an excellent marker bed in central Wyoming because of its persistence and because it is the only prominent limestone in this part of the stratigraphic section.

The Popo Agie Member, about 350–400 feet thick, consists of red and minor light-gray sandstone with interbedded claystone, siltstone, and shale that is mostly red but partly green. It has some thin limestone-pellet conglomerate beds.

JURASSIC ROCKS

NUGGET SANDSTONE

The Nugget Sandstone of Early Jurassic age, about 245 feet thick, is light-gray to greenish-gray and pink fine- to coarse-grained sandstone that has a few thin partings of green and reddish-brown shale. It is partly calcareous and moderately hard. About 5 miles east, where it crops out, the formation is thin to medium bedded, and the sandstone contains some tiny pyrite cubes.

SUNDANCE FORMATION

The Sundance Formation of Late Jurassic age, about 250 feet thick, is fairly evenly divided into two parts, the "Lower Sundance" and the "Upper Sundance." The "Lower Sundance" is gray partly glauconitic fine-grained sandstone and green shale interlayered with scattered orange sandstone beds and one or two thin limestone beds. The "Upper Sundance" consists mainly of calcareous gray and green shale; it also includes beds of green highly glauconitic fine-grained sandstone and brown limestone which contain numerous *Belemnites* and *Camptonectes*. The top beds of the "Upper Sundance" crop out 1½ miles south of the southwest corner of the Puddle Springs quadrangle. These beds form the lowest strata of the inlier along Muskrat Creek; the inlier includes the Frontier Formation in the southwest corner of the Puddle Springs quadrangle.

MORRISON FORMATION

The Morrison Formation of Late Jurassic age, about 230 feet thick, consists mainly of claystone and sandstone. In the Muskrat Creek inlier just south of the southwest corner of the quadrangle, the basal bed of the formation is a fine-grained to very fine grained white to light-gray sandstone composed of well-sorted and fairly well rounded quartz grains. The formation consists mostly of partly calcareous green, gray, and red claystone, siltstone, and shale and white to gray sandstone; a thin bed of nodular limestone occurs near the middle. The upper 80 feet is gray and green claystone above a bed of sandstone.

CRETACEOUS ROCKS

CLOVERLY FORMATION

The Cloverly Formation of Early Cretaceous age, about 95 feet thick, is commonly mapped with the underlying Morrison Formation in this part of the Wind River Basin because of uncertainty as to where to place the contact.

The sandstone 80 feet below the top of the Morrison Formation as indicated on well logs may be one of the beds of "quartz-crystal" sandstone (secondary overgrowths on many quartz grains resulting in numerous sparkling facets) and may thus correlate with the base of the Cloverly in nearby surface sections (Love and others, 1947; Van Houten and Weitz, 1956; Burk, 1957, p. 58). On well logs, a pebble conglomerate which contains dark chert and light-gray quartz and quartzite pebbles is chosen by petroleum geologists as the base of the Cloverly and is herein considered to be the lower part of this formation. At the surface, this conglomerate is generally hard and forms a conspicuous ridge. The conglomerate is well exposed on a prominent ridge 1¼ miles south of the southwest corner of this quadrangle.

The middle part of the formation consists of gray to green and a few red claystone or shale beds that have a thin limestone bed or limestone nodules in the center. The upper part of the formation is hard light-gray fine- to coarse-grained sandstone; this sandstone includes "quartz-crystal" sandstone at least 12 feet thick at the top. The formation grades abruptly into the overlying Thermopolis Shale.

THERMOPOLIS SHALE

The Thermopolis Shale of Early Cretaceous age, about 275 feet thick, is mostly soft dark shale. There are fairly good exposures of the formation less than a mile south of the quadrangle, on both sides of Muskrat Creek. Sandstone near the lower contact contains brown

244-803—67——3

carbonaceous material but is otherwise similar to the underlying sandstone of the Cloverly Formation. The lower two-thirds of the formation consists of dark-gray to black and some brown shale interbedded with gray fine-grained sandstone and siltstone. The Muddy Sandstone Member, which is less than 10 feet thick, is about 100 feet below the top of the formation; it consists of fine-grained silty brown sandstone. The upper one-third of the formation is dark-gray shale containing some thin bentonite beds. Where it crops out, the formation commonly underlies a valley between ridges of the Cloverly and Mowry Formations; the Muddy Sandstone Member forms a very low and discontinuous ridge in the valley.

MOWRY SHALE

The Mowry Shale of Early Cretaceous age, about 300 feet thick, is almost entirely hard brittle siliceous gray marine shale that weathers to white or light silvery gray; it contains numerous fish scales. There are good exposures at Coyote Springs at the south-central edge of the quadrangle, and excellent exposures just south of the southwestern part. Thin bentonite beds occur throughout the formation, especially near the top. The Mowry forms a conspicuous ridge which generally supports almost no vegetation except scattered conifer trees. Where it has been immediately overlain by the Wind River Formation, the color of the Mowry is commonly tinged pink or red because of coatings of red clay or of iron oxide on the shale fragments.

FRONTIER FORMATION

The Frontier Formation of Late Cretaceous age, about 730 feet thick, consists mainly of dark-gray to black and brown marine shale that contains thick sandstone beds. The sandstone has many dark grains and is generally calcareous and hard. The shale has numerous gypsum crystals (selenite) and some ferruginous concretions. The lower part of the formation has beds of white to light-gray bentonite, and the base is commonly placed below the lowest thick bentonite bed in dark shale. The contact of the formation with the overlying Cody Shale is covered by the Wind River Formation in this quadrangle; it is generally placed at the top of a thick interval of sandstone that contains thin beds of dark shale, and below a thick interval of predominantly shale beds.

CODY SHALE

The Cody Shale, of Late Cretaceous age, has a total thickness of about 5,000 feet and is the youngest pre-Tertiary formation in the quadrangle; it is mainly soft marine shale. The Cody consists of dark- to light-gray shale interlayered with thin gray to light-brown hard and soft sandstone and siltstone and some calcareous concretionary beds. Sandstone and concretionary beds are more numerous in the upper half of the formation, where they form low ridges. Fossils of Niobrara and Eagle age have been reported in the Cody Shale of this region. The Cody characteristically forms a gently undulating plain. It is the formation underlying the Wind River Formation throughout most of the quadrangle.

EOCENE ROCKS

WIND RIVER FORMATION

The Wind River Formation, of early Eocene age, contains the uranium deposits of the district and was the subject of virtually all the stratigraphic study during work on the uranium deposits. Original thickness of the formation at the north edge of the quadrangle was probably about 1,000 feet. The thickness at the south edge of the quadrangle where the entire formation is still present, however, is about 600 feet. An AEC core hole (GH–3) in the S½SE¼ sec. 7, T. 32 N., R. 90 W., penetrated 582 feet of the formation and part of the underlying Thermopolis Shale. Composite thickness of the formation from the vicinity of Puddle Springs to the contact with the overlying Wagon Bed Formation in the southeast corner of the quadrangle is 826 feet. The formation thins southward by overlap on the north flank of the Sweetwater uplift, part of the core of which is the Granite Mountains that are about 8 miles south of the quadrangle. Sediments composing the formation were deposited on a mature erosion surface which had a relief of several hundred feet in this quadrangle.

The formation includes (1) a lower fine-grained member, (2) the coarse Puddle Springs Arkose Member, constituting most of the formation, and (3) an upper transition zone. The contact of the lower member and the Puddle Springs has been mapped. Exposures are too poor to allow detailed mapping of the contact of the Puddle Springs and the upper transition zone.

LOWER FINE-GRAINED MEMBER

The lower fine-grained member is about 120–130 feet thick near Puddle Springs but thins southward in the quadrangle to 0. A thickness of 122 feet was found at AEC core hole GH–1 in the Bullrush mine area (E½SW¼ sec. 29, T. 33 N., R. 90 W.). The member consists mainly of grayish-green siltstone and light-gray very fine to fine-grained quartzose sandstone. It includes greenish to olive and thin red beds of claystone, and brown to black carbonaceous claystone and shale which locally contain very thin layers of subbituminous coal. In many places, a thin irregular bed of conglomerate or gravel at or very near the base is composed of white siliceous shale chips from the Mowry Shale and dark chert pebbles and siliceous sandstone and pebble conglomerate fragments as much as a foot in diameter from the Cloverly Formation; the coarse particles are in a quartzose sand matrix. At and near the contact with the overlying arkose member, thin hard coarse-grained arkosic calcareous sandstone beds are common.

PUDDLE SPRINGS ARKOSE MEMBER

The Puddle Springs Arkose Member has a composite thickness of 576 feet in the southeastern part of the quadrangle. In AEC core hole GH–1, the lower 436 feet of the member was penetrated. In AEC core hole GH–3, the entire member, 477 feet thick, was penetrated. From GH–1 to GH–3 a thinning of 221 feet occurs, of which 99 feet is the basal part of this member and 122 feet is the entire lower fine-grained member.

The Puddle Springs Arkose Member consists predominantly of coarse conglomeratic arkosic sandstone interbedded with granite granule-to-boulder conglomerate, fine-grained sandstone, siltstone and claystone, and a few beds of carbonaceous shale. Calcareous sandstone concretions are common in slightly calcareous to noncalcareous arkosic sandstone. Locally, beds or irregular masses of the coarse arkosic rocks are cemented by calcite. The sandstone and conglomerate are generally yellow to gray with local limonitic coloring on the outcrop and near the surface but bluish gray or greenish gray near and below the water table; siltstone and claystone beds are generally light greenish gray to olive green. The member contains uranium deposits from which many thousands of tons of uranium ore has been mined.

The top of the Puddle Springs Arkose Member is placed at the base of the lowest of several 5- to 20-foot-thick tuffaceous and bentonitic sandy mudstone beds which are interbedded with coarse-grained arkosic sandstone beds; the zone of interbedding, called the upper transition zone, is described on page C17.

DRY COYOTE CONGLOMERATE BED

Two granite cobble-and-boulder conglomerate beds of the Puddle Springs Arkose Member were mapped in this quadrangle. The lower one, termed the Dry Coyote Conglomerate Bed, is generally about 10–30 feet thick; however, it is only 5 feet thick at its northern eroded edge east of Puddle Springs but thickens to 53 feet in AEC core hole GH–3 in the southeastern part of the quadrangle. It lies about 320 feet above the base of the member at the northern outcrop; at the south-central edge of the quadrangle, however, it lies on the Mowry Shale, owing to southward overlap on the erosion surface below the

Wind River Formation (see p. C15). The conglomerate pinches out to the east in the SE¼ sec. 33, T. 33 N., R. 90 W., less than half a mile east of the quadrangle.

The Dry Coyote Bed consists mainly of cobbles and boulders of Precambrian granite as much as 3 feet in diameter in a coarse arkosic sand matrix; rubble from the Mowry Shale is common where that formation has been overlapped. Thin sandstone lenses are common and, in a few places, conglomeratic sandstone makes up most of the interval generally occupied by the conglomerate. Carbonaceous material is common in the upper part and immediately overlies the conglomerate in places, particularly just north of Dry Coyote Creek. East of Coyote Creek, uranium minerals are common in the sand matrix and as the coating of some roundstones.

The Dry Coyote Conglomerate Bed is an excellent marker bed for stratigraphic work in the southeastern part of the quadrangle because of its persistence, relatively uniform thickness over a few square miles, and resistance to erosion. Most uranium deposits lie from 150 feet below to 50 feet above this bed, and this association makes it a very useful marker bed in uranium exploration. The conglomerate was apparently deposited on a piedmont alluvial fan just beyond the mouth of one or more major canyons which lie southeast of the quadrangle; however, the conglomerate in the southwestern part of the quadrangle and possibly correlative lenses farther west may have had a more southern source.

MUSKRAT CONGLOMERATE BED

The Muskrat Conglomerate Bed, about 20 feet thick, lies 100 feet above the Dry Coyote. It consists mainly of boulders of Precambrian granitic and metamorphic rocks; the boulders are generally 1–2 feet in diameter, but some are as much as 10 feet across. The matrix is commonly argillaceous and includes some mud balls as much as 3 feet in diameter, and these features indicate the possibility of a mudflow-type origin for this conglomerate. The conglomerate is not present east of Coyote Creek but crops out just west of Coyote Creek and extends westward at least 9 miles; the roundstones composing the bed were carried northward through more than one canyon along the mountain front. Uranium deposits are not known to occur in or to be associated with this conglomerate bed.

UPPER TRANSITION ZONE

The upper 120 feet of the Wind River Formation in this quadrangle consists of interbedded arkose and tuffaceous and bentonitic mudstone. Calcareous cement is absent, and colors are drab yellowish gray, light olive, and gray. The arkose is similar to that in the Puddle Springs

Arkose Member, and the mudstone is similar to beds of the overlying Wagon Bed Formation. Because of the similarities to underlying and overlying strata, this part of the formation is known as the upper transition zone of the Wind River Formation. This zone varies in thickness in the south-central part of the Wind River Basin because of the lenticularity of the bentonitic mudstone beds. Marker beds just above the top provide an excellent mappable upper formational contact.

WAGON BED FORMATION

The Wagon Bed Formation of middle and late Eocene age is about 400 feet thick. It has been studied in detail by Van Houten (1954; 1955; 1957; 1964). The contact with the underlying Wind River Formation is placed at the base of a 26-foot sandy bentonitic mudstone bed which contains a cliff-forming marker bed; this marker bed is 1–3 feet thick and lies 8 feet above the base of the mudstone. A more persistent cliff-forming marker bed 10 feet thick, of sandy mudstone to argillaceous sandstone, overlies the 26-foot basal unit.

The formation consists of bentonitic, tuffaceous, and arkosic mudstone, sandstone, and conglomerate. Arkosic material decreases upward in these rocks, and volcanic material derived from the Rattlesnake Range a few miles to the east increases (Van Houten, 1957, p. 85). Colors are mainly drab yellowish gray and light green to olive.

The Wagon Bed Formation makes up the lower slopes of the high escarpment of the Beaver Divide. Just beyond the southeast corner of the quadrangle, this formation is overlain by the White River Formation of Oligocene age. Conglomerate and tuffaceous sandstone of Miocene age cap the Beaver Divide; these beds were included in the Split Rock Formation of Love (1961), but at least the upper part has since been included in the Arikaree Formation by N. M. Denson (oral commun., 1964).

QUATERNARY DEPOSITS

PEDIMENT GRAVELS

Surfaces sloping northward into the basin from the foot of the Beaver Divide escarpment, at gradients of about 80–200 feet per mile, are veneered by locally derived gravels. These gravels consist mainly of granitic pebbles and cobbles and are set in a coarse arkosic sand matrix; some roundstones of volcanic rocks (middle or late Eocene) from the Rattlesnake Range, to the southeast, occur in the east-central and northern parts of the quadrangle. In places, these gravels are deeply stained or are cemented by iron and manganese oxide. Thickness of the gravels is generally less than 15 feet and in many places may be only a foot or two. In places, distinction between these gravels and the Wind River Formation, source of most of the material, is difficult to make. Because of their physiographic position, commonly about 100 feet above the major streams, and their general northward slope in contrast to the southward dip of the Tertiary rocks, the gravels are interpreted as of Pleistocene age.

ALLUVIUM

The exposed part of the alluvial fill in the modern stream valleys is of Recent age, but alluvium in the deepest part of the major valleys may be of latest Pleistocene age. Thickness of the alluvium in a water well in the Coyote Creek area in the S½SE¼ sec. 26, T. 33 N., R. 91 W., is 68 feet; thickness along Muskrat Creek is probably greater. The alluvium consists of poorly sorted gravel, sand, silt, and clay. Source of most of the alluvium is believed to be the Wind River Formation, because the finer grained sediments comprising most of the other formations have probably been deposited farther downstream, where Muskrat Creek has a lower gradient.

STRUCTURE

PRE-TERTIARY ROCKS

The Puddle Springs quadrangle is on the south-central flank of the Wind River Basin (fig. 1). The axis of the basin lies about 30 miles to the north near the foot of the Owl Creek Mountains and trends east-west, but farther east it curves southeastward. Pre-Tertiary rocks in this quadrangle dip northward about 5°–12° from the north flank of the Sweetwater uplift. The Granite Mountains, about 8 miles south, form the core of this part of the uplift.

The regional dip to the north is modified by northwest-plunging folds (fig. 4). The folds in the southern part of the Wind River Basin commonly have a sinuous axis, and many are anastomosing. An anticlinal axis located by oil and uranium company drilling in the southeastern part of the quadrangle, herein designated the Coyote anticline, is in line with the Glenn anticline and may be a continuation of it.

Many of these structural features are asymmetric with their steep sides on the west, and some of them are underlain by east-dipping high-angle reverse faults (Berg and Thompson, 1957, p. 102). Consequently, the axial surface of most or all of these folds probably dips eastward or northeastward, as shown by Jenkins (1957, p. 140) for the Big Sand Draw oil field a few miles west of the quadrangle. As illustrated in figure 4, the axis of most of these folds at depth probably lies east of its position at the surface. Vertical beds in the

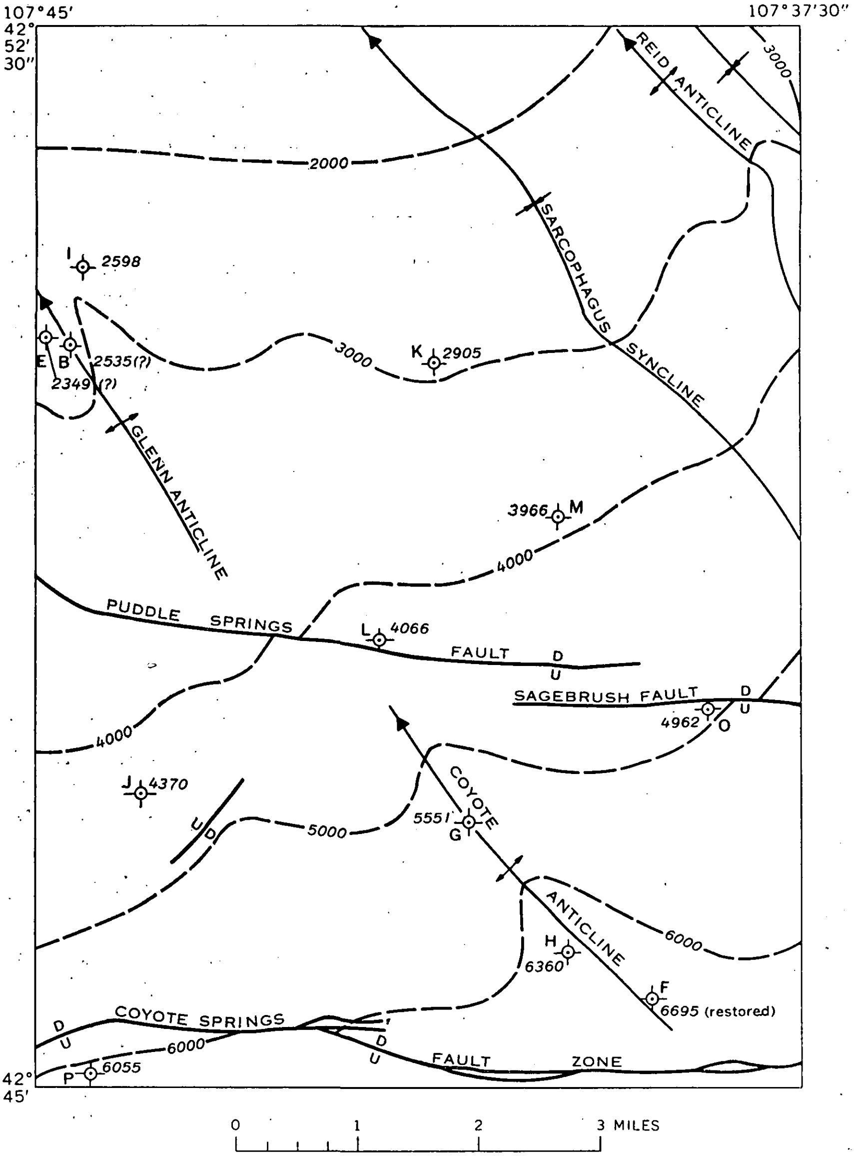

FIGURE 4.—Structure map showing probable eastward dip of axial planes of folds. Axial traces shown are from geologic map. Structure contours on top of Mowry Shale show approximate offset in axial planes in the subsurface. Numbers by well symbols indicate elevation, in feet, of top of Mowry; letters are keyed to table 2. Datum is mean sea level.

Cody Shale on both sides of Muskrat Creek indicate a possible high-angle reverse fault along the crest of the Glenn anticline. A high-angle reverse fault probably lies just east of the northeastern part of the quadrangle along the west flank of the Dutton Basin (Gas Hills) anticline.

Northeast-trending structural features in the pre-Tertiary rocks are not conspicuous in the quadrangle, but the fault in sec. 4, T. 32 N., R. 91 W., was cited by Berg and Thompson (1957, p. 102) as evidence of such a trend.

The age of the folds and associated faults is said to be Laramide—from Late Cretaceous into early Eocene (Berg and Thompson, 1957, p. 102). In the Puddle Springs quadrangle the folding was completed and folds were deeply eroded before deposition of the Wind River Formation.

TERTIARY ROCKS

Structure of the Tertiary rocks of the quadrangle is principally homoclinal; the beds dip generally 1°–5° southward. In the northern part of the quadrangle, and immediately north, beds of the Wind River Formation are almost horizontal, and a few miles farther north they dip gently northward toward the axis of the basin. This reversal of dip has produced a broad east-trending anticline in the formation (J. L. Weitz, oral commun., 1954).

A few miles east of the quadrangle, eastward-trending normal faults of Wind River age have been noted (Zeller, 1957, p. 157), but no evidence was seen to indicate that any of the faults in the Puddle Springs quadrangle were definitely of the same age.

Several post-Miocene (probably post-middle Pliocene, according to Love, 1960, p. 211) east-trending and north-dipping normal faults, downthrown to the north, cut the pre-Tertiary and Tertiary rocks in the quadrangle. They are difficult to map because of poor exposures; many have been mapped on the basis of scanty field evidence combined with lineaments visible on aerial photographs. The larger faults and some smaller ones have been confirmed by the geophysical work of R. M. Hazlewood and John Roller (oral commun., 1955), who also found some which could not be detected on the surface (Black, 1955; 1956a, b).

Displacement on these faults ranges from less than 5 feet to more than 200 feet, and the dip of the fault planes at the surace ranges from 52° to perhaps 90°. In some places, step faults constitute parts of fault zones, and the individual faults are generally downthrown to the north. These eastward-trending faults are undoubtedly of post-Miocene age, because they are in the same system of faults as those of the North Granite Mountains fault zone which displaces Miocene rocks less than 3 miles south of the quadrangle. This system of faults and the southward dip in the Tertiary rocks are features of the tectonic activity which resulted in subsidence of the Sweetwater uplift, probably in Pliocene time (Love, 1961, p. 1). The Gas Hills uranium district lies in the subsidiary basins produced by combined pre-Wind River erosion and this tectonic activity.

A normal fault just south of Puddle Springs, here named the Puddle Springs fault, is one of the largest in the quadrangle. It was detected during mapping in 1954 in sec. 25, T. 33 N., R. 91 W. The fault was projected westward about 2 miles because of the difference in elevation of the base of the Wind River Formation north and south of Coyote Creek; it is believed to terminate in the small fault west of Muskrat Creek. An auger hole drilled in 1955 just north of the fault trace in E½E½SE¼ sec. 25 stopped in the Wind River Formation at 80 feet; the fault has probably at least 200 feet of displacement here. R. M. Hazlewood (oral commun., 1955) reported that geophysical evidence indicates that this fault "horsetails" into about five small faults and ends just west of the road in S½ sec. 30, T. 33 N., R. 90 W. Small faults, however, were noted along the same trend in and near the Bullrush mine immediately to the east. The relatively straight trace of the Puddle Springs fault indicates that it may be almost vertical.

Most of the faults in secs. 29, 30, 31, and 32, T. 33 N., R. 90 W., are based on the author's interpretation of evidence that the Dry Coyote Conglomerate Bed is the only cobble conglomerate at least 5 feet thick here. The Sagebrush fault, here named for the Sagebrush uranium claims, was detected as a linear feature on aerial photographs and was confirmed by the geophysical work of Hazlewood and Roller (Black, 1955, 1956a, b). About 100 feet of displacement is indicated in the northwest corner of sec. 32 on the basis of the mapping of the Dry Coyote Bed. An 8½-foot-thick cobble conglomerate bed at 110 feet in AEC core hole GH–1 in the E½SW¼ sec. 29 is believed to be the Dry Coyote Conglomerate Bed, and thus a throw of possibly 200 feet or more is indicated in the NE¼NW¼ sec. 32.

A complex fault zone, herein called the Coyote Springs fault zone, trends eastward along the south edge of the quadrangle. In poor exposures just east of Coyote Creek, the Dry Coyote Conglomerate Bed immediately overlies or is only a few feet above the Mowry Shale; the relations indicate small fault blocks stepped down to the north with about 200 feet of total displacement. Part of a north-dipping fault plane was dug out but not enough to measure the dip accurately. At the quadrangle's west edge, a few feet of exposure in a gully showed a dip for the fault of 52° N.

URANIUM DEPOSITS

OCCURRENCE

This quadrangle comprises most of the western part of the Gas Hills uranium district (fig. 3). All known economic uranium deposits are confined to beds of the Puddle Springs Arkose Member of the Wind River Formation in the southeastern part of the quadrangle (pl. 1). Original reserves of uranium ore with uranium content averaging about 0.25 percent probably total at least 1 million tons in the quadrangle (H. D. Zeller, oral commun., 1962). Mining and milling of ore from several mines has been in progress since 1955.

Almost all the known ore deposits in the quadrangle occur in the interval from about 150 feet stratigraphically below to about 50 feet above the Dry Coyote Conglomerate Bed. Many small deposits of uranium minerals also lie in or immediately above or below the conglomerate. This common association of uranium with the Dry Coyote Bed causes a somewhat linear north-northeast-trending belt which roughly coincides with the outcrop of the conglomerate (Soister, 1958).

Uranium minerals occur in arkosic sandstone, conglomerate, siltstone, and carbonaceous shale. Uranium minerals, especially phosphuranylite, and uraniferous minerals, particularly opal or allophane, coat and permeate roundstones in conglomerate beds. The ore deposits generally are blanketlike parts of arkosic sandstone or siltstone that contain interstitial uranium minerals. Superjacent and subjacent parts of the same beds commonly have only sparsely disseminated uranium minerals.

Authigenic minerals in or associated with uranium deposits in this quadrangle or in the Lucky Mc mine area 2 miles east are listed in table 3. The list has been compiled from several sources of information (Love, 1954; Grutt and others, 1954; Coleman, 1954, 1957; Gruner and others, 1956; J. W. Adams, written commun., 1955; W. F. Outerbridge, written commun., 1955).

The largest ore deposits in the Gas Hills uranium district are at or near the ground-water table and are only partly oxidized. Unoxidized uranium deposits in the greenish- to bluish-gray arkose contain coffinite and uraninite as the main ore minerals (Coleman, 1957) in association with pyrite, calcite, and gypsum. Molybdenum minerals (ilsemannite and umohoite) are present in the Lucky Mc mines and in other mines outside the quadrangle, but the author knows of none in this quadrangle. At the time of the field work, however, very few pits were deep enough to expose much of the unoxidized ore.

TABLE 3.—*Authigenic minerals composing and associated with uranium deposits' Puddle Springs quadrangle and vicinity*

[References used for chemical compositions: 1—Altschuler, Clarke, and Young (1958); 2—Frondel (1958); 3—Larsen and Berman (1934); 4—Palache, Berman, and Frondel (1946); 5—Palache, Berman, and Frondel (1951)]

Mineral	Chemical composition	Reference
Allophane	$Al_2O_3,SiO_2 \cdot nH_2O$	3
Autunite	$Ca(UO_2)_2(PO_4)_2 \cdot 10\text{–}12H_2O$	2
Barite	$BaSO_4$	-------
Bassetite	$Fe(UO_2)_2(PO_4)_2 \cdot 8H_2O$	2
Becquerelite[1]	$7UO_3 \cdot 11H_2O$	2
Calcite	$CaCO_3$	-------
Carbonate fluorapatite	$Ca_{10}(PO_4,CO_3)_6F_{2\text{-}3}$	1
Coffinite	$U(SiO_4)_{1-x}(OH)_{4x}$	2
Goethite	$HFeO_2$	4
Gypsum	$CaSO_4 \cdot 2H_2O$	5
Ianthinite	$2UO_2 \cdot 7H_2O$	2
Ilsemannite	$Mo_3O_8 \cdot nH_2O$?	4
Jarosite	$KFe_3(SO_4)_2(OH)_6$	5
Jordisite	MoS_2?	4
Liebigite	$Ca_2(UO_2)(CO_3)_3 \cdot 10H_2O$	2
Manganese oxides	-------	-------
Meta-autunite	$Ca(UO_2)_2(PO_4)_2 \cdot 2\frac{1}{2}\text{–}6\frac{1}{2}H_2O$	2
Metatorbernite	$Cu(UO_2)_2(PO_4)_2 \cdot 8H_2O$	2
Metauranocircite[2]	$Ba(UO_2)_2(PO_4)_2 \cdot 8H_2O$	2
Metazeunerite	$Cu(UO_2)_2(AsO_4)_2 \cdot 8H_2O$	2
Opal	$SiO_2 \cdot nH_2O$	-------
Pharmacosiderite	$Fe_3(AsO_4)_2(OH)_3 \cdot 5H_2O$	5
Phosphuranylite	$Ca(UO_2)_4(PO_4)_2(OH)_4 \cdot 7H_2O$	2
Pyrite	FeS_2	-------
Rutherfordine	$(UO_2)(CO_3)$	2
Sabugalite	$HAl(UO_2)_4(PO_4)_4 \cdot 16H_2O$	2
Selenium (native)	Se	-------
Schoepite	$4UO_3 \cdot 9H_2O$ or $2UO_3 \cdot 5H_2O$	2
Scorodite	$Fe(AsO_4) \cdot 2H_2O$	5
Sklodowskite	$Mg(UO_2)_2(SiO_3)_2(OH)_2 \cdot 5H_2O$	2
Soddyite	$(UO_2)_5(SiO_4)_2(OH)_2 \cdot 5H_2O$	2
Symplesite	$Fe_3(AsO_4)_2 \cdot 8H_2O$	5
Torbernite	$Cu(UO_2)_2(PO_4)_2 \cdot 12H_2O$	2
Tyuyamunite	$Ca(UO_2)_2(VO_4)_2 \cdot 5\text{–}8\frac{1}{2}H_2O$	2
Umohoite[1]	$(UO_2)(MoO_4) \cdot 4H_2O$	2
Uraninite	UO_2	2
Uranophane	$Ca(UO_2)_2(SiO_3)_2(OH)_2 \cdot 5H_2O$	2
Uranospinite	$Ca(UO_2)_2(AsO_4)_4 \cdot 10H_2O$	2
Unknown uranium phosphate	-------	-------
Unknown uranium silicate	-------	-------
Other unknown uranium minerals.	-------	-------

[1] Exact formula not known but close to one given.
[2] Original name, uranocircite.

Most minerals listed were found in deposits in the oxidized zone, where the coarse-grained host rocks are mostly grayish yellow. The main ore minerals in the oxidized zone are uranium phosphates, silicates, and hydrous oxides (Zeller, 1957, p. 157). Meta-autunite, phosphuranylite, an unnamed yellow uranium phosphate, and uranophane are the principal minerals in the oxidized zone, and they are commonly associated with black to brown carbonized wood or carbonaceous shale and with manganese, limonite, calcite, and gypsum. Vanadium minerals are rare. Coleman (1957, p. 511) reported that the Gas Hills uranium deposits were found to be significantly enriched in molybdenum, uranium, selenium, arsenic, sulfur, zirconium, and phosphate. Native selenium occurs in deposits just east of the quadrangle but was not found here although some samples had a high selenium content; for example, a sample of sandstone from the Hope (formerly Upetco) mine (SE¼SE¼ sec. 1, T. 32 N., R. 91 W.) had 0.36 percent selenium.

URANIUM CONTENT OF WATER

The important role of natural water in sandstone-type deposits (Wyant and others, 1952, p. 29) has been known for several years. Programs of collecting and analyzing samples of natural waters for uranium content have been carried on since before 1952, according to Fix (1956, p. 667). Water sampling is a very useful prospecting method in the basins of Wyoming (Troyer and others, 1954, p. 17; Denson and others, 1956; Murphy, 1956; Zeller, 1957, p. 156). Anomalously high amounts of uranium have been found in many samples of water from the Wind River Basin (Love, 1954, p. 10; Zeller and others, 1954, 1956; Murphy, 1956).

Analyses of samples collected in the quadrangle in 1954 and 1955 are shown in table 4; most water samples from all Tertiary formations in this region have a high uranium content, but those from the Wind River Formation and from alluvium derived from this formation, particularly near deposits, generally have the highest content. At least one water sample from the Puddle Springs Arkose Member (at Coyote Springs, just south of the quadrangle) had a relatively high arsenic content, and several of the elements mentioned by Coleman (1957, p. 511) may still be moving with ground water in the district.

Water collected from reservoirs for cattle (samples 2 and 12, table 4) has much less uranium than water from the alluvium of Coyote and Muskrat Creeks (samples 6, 9, 10, 13), even though the Coyote and the Muskrat Creek samples were collected farther from uranium deposits. The alluvium along these two creeks is composed largely of arkosic materials from the Puddle Springs Arkose Member and probably contains some fragments of ore. The difference in uranium content is, no doubt, due to the amount of contact the water has had with uranium-bearing sediments. Water in the reservoirs is derived mostly from rapid surface runoff of precipitation. The water in the creeks travels much of its distance below the surface and has consequently been in contact with the alluvium much longer than the water in the reservoirs. Highly uraniferous water from alluvium of Recent age is another indication that much of the uranium is easily soluble and is moving during the present hydrologic cycle.

TABLE 4.—*Uranium content of water, Puddle Springs quadrangle*

[Samples collected during summer 1954. Samples collected in polyethylene bottles; uranium content and pH measured in laboratory a few weeks after sample collection. Twp, Puddle Springs Arkose Member of Wind River Formation; Twl, lower fine-grained member of Wind River Formation; Kc, Cody Shale]

Sample	Location				Source of sample	Geology of source	Uranium content (parts per billion)	pH
	Section		Township north	Range west				
1	NE¼SW¼	1	32	91	Drill hole, 110 ft deep.	Coarse arkosic sediments of ore zone, Twp.	320	7.6
2	C-N½N½	1	32	91	Stock reservoir	Alluvium from Twp.	7	7.2
3	NE¼NW¼	5	32	91	Small spring	Twl over Kc	19	7.9
4	NE¼NE¼	13	32	91	Small pond in prospect pit.	Coarse arkose above principal ore zone, Twp.	18	8.2
5	NW¼NE¼	28	33	90	Spring (Willow Springs).	Alluvium from Twp.	19	(?)
6	NE¼SE¼	3	33	91	Stock well, depth unknown.	Thick alluvium, mostly from Twp.	120	7.8
7	NW¼NE¼	25	33	91	Pond of seep (Puddle Springs).	Thin alluvium over basal Twp near uranium deposits.	570	7.3
8	NW¼NE¼	25	33	91	do	Thin alluvium over basal Twp near uranium deposits (rain on day before sampling).	19	8.1
9	C-S½SE¼	26	33	91	Stock well	Alluvium 68 ft thick, mostly from Twp.	104	7.7
10	NE¼SW¼	27	33	91	Domestic well	Alluvium 25 ft thick, mostly from Twp.	90	7.7
11	SW¼SW¼	35	33	91	Spring	From basal conglomerate Twl over Kc.	3	7.7
12	SE¼NW¼	36	33	91	Stock reservoir	Alluvium, mostly from Twp.	11	7.2
13	SE¼SE¼	16	33	91	Stream (Muskrat Creek).	Small stream flowing on alluvium, mostly from Twp.	49	7.8

SOURCE OF URANIUM

The factors involved in the origin of uranium deposits include source, migration, and deposition of the uranium. Three possible main sources of the uranium in this district have been suggested by geologists: (1) volcanic ash in younger rocks, (2) arkosic sediments of the Puddle Springs Arkose Member (both 1 and 2 have disseminated primary uranium), and (3) hydrothermal solutions. The granitic terrane from which sediments of the Puddle Springs were derived may also have contributed uranium.

Occurrence of intrusive igneous rocks of middle and late Eocene age (Van Houten, 1955) a few miles southeast of the uranium district has led to the mention of hydrothermal solutions as a possible source for the uranium; however, as Love (1954, p. 9) reported, most workers in the area have discounted this source in favor of one of the two other possible sources named above. As a possible original source of the uranium and (or) some of the other elements such as arsenic, perhaps it should not be discarded completely until further evidence is obtained because the apexes of some of the alluvial fans comprising the coarse Puddle Springs Arkose Member are apparently near some of these intrusive bodies.

Volcanic ash in the White River Formation of Oligocene age, in the tuffaceous sandstone of Miocene age, or in the Moonstone Formation of Pliocene age has been cited as a possible source of the uranium (Love, 1954, p. 9; 1961, p. 33; Zeller, 1957, p. 158; Denson and others, 1956, p. 680). The occurrence of uraniferous chalcedony and other uraniferous sedimentary rocks in the Moonstone Formation south of the Gas Hills uranium district has led Love (1961, p. 33) to advocate the Moonstone as the most probable source of the uranium. Masursky (1962, p. 95) believed that the Miocene rocks are a more likely source of uranium in deposits south of the Granite Mountains than are other post-Wind River rocks because of higher uranium content in water from the Miocene rocks.

Fine-grained tuffaceous sedimentary rocks of the White River Formation are in contact with the Wind River Formation where they fill two north-trending valleys ("channels") at the south edge of the Gas Hills uranium district in the Gas Hills and Coyote Springs quadrangles (Zeller and others, 1956). Love (1954) and N. M. Denson (oral commun., 1963) believed that the "channels" were instrumental in the leaching of the uranium from the tuffaceous sedimentary rocks and its deposition in the subjacent Wind River Formation. Two deposits found recently below the "channel" in the Gas Hills quadrangle (H. D. Zeller, oral commun., 1963) are in the Wind River Formation but probably are several hundred feet below the White River Formation. High radioactivity in AEC core hole GH–6 (S½S½SE¼ sec. 2, T. 32 N., R. 90 W.) at the west edge of this "channel" is about 450 feet below the White River and is in the uranium ore zone. No abnormal radioactivity was reported in AEC core hole GH–7 (NE¼SE¼NW¼ sec. 1, T. 33 N., R. 90 W.), which was drilled in the middle of this "channel" and penetrated 303 feet of the White River Formation and 507 feet of the immediately underlying Wind River Formation. Many deposits of the uranium district occur in areas that were not directly below the "channels." The apparent absence of deposits from the Wagon Bed Formation, which underlies the White River except at these "channels," also seems to indicate that the White River Formation is not the source of most of the uranium. Also, the eastern part of the uranium district apparently was inaccessible to water migrating from the White River Formation directly into the Wind River Formation, because the Wagon Bed Formation lies between these two formations in this part of the area.

Derivation of the uranium from the White River Formation or from the Miocene rocks during a period of erosion and retreat of the Beaver Divide escarpment southward to its present position may be a possibility. This derivation could perhaps be accomplished by the leaching of uranium by surface, vadose, and ground water which could issue from springs and then flow at the surface until it entered the ground-water reservoir in the Wind River Formation. This process would have allowed the first deposits to be formed during late Pliocene or Pleistocene time—this age is not incompatible with the age determinations made so far (p. C30). Under this theory, it would be more difficult to explain the absence of deposits from the lower fine-grained member of the Wind River Formation, which has carbonaceous beds, sandstone, and thin conglomerate that should be suitable for uranium deposition. Also, this method of deriving the uranium would not require that "channel" sediments of the White River Formation be in contact with the Wind River Formation, although the "channels" are the primary support for the theory of leaching of uranium from ash of the White River and deposition in subjacent beds of the Wind River.

Analyses of water samples indicate that some uranium has been and is now being leached from tuffaceous rocks of the post-Wind River formations. These rocks may be the source of uranium in small deposits outside the district and of anomalous radioactivity and some uranium and associated elements within the district.

The coarse and highly permeable arkosic sediments of the Puddle Springs Arkose Member constituted the most available source of most of the uranium, especially if most of the original uranium in the granitic rocks had been in intergranular films between the quartz and feldspar grains. No direct data are available to indicate mode of occurrence of the uranium in the granite. Probably most of it is in intergranular films in the Gas Hills area, as shown for other granites by Piggot (1929), Hurley (1950), Brown, Blake, Chodos, Kowalkowski, McKinney, Neuerburg, Silver, and Uchujama (1953), Jahns (1953), and Phair and Gottfried (1958, p. 289).

Masursky (1962, p. 95) reported a uranium content of 0.002–0.003 percent in a granite sample from the Granite Mountains. Hurley (1950, p. 2–4) reported that granite samples that were crushed and then leached by dilute hydrochloric acid lost most of their uranium and (or) thorium, probably because of the easily leachable films of uranium. Phair and Gottfried (1958, p. 287) said that 90 percent of the uranium in samples of granite from the Boulder Creek batholith of Colorado "can be removed by leaching in 1-4 HCl for 24 hours." E. N. Harshman (oral commun., 1964) reported that in an experiment some of the uranium in granite samples from the east end of the Granite Mountains was leached overnight by ordinary water.

The coarse sediments of the Puddle Springs Arkose Member of the Wind River Formation were rapidly deposited and buried and were thus protected from extensive weathering and consequent loss of most of the primary uranium until late Tertiary or early Quaternary time. Loss of some of the uranium by weathering of sediments and migration of uranium during deposition of the sediments in early Eocene time may account for a few small uranium occurrences toward the center of the basin, such as the Hiland deposit (Rich, 1962, p. 518); however, these occurrences may just as easily have been caused by Pleistocene migration. Concentration of the Gas Hills deposits in subsidiary basins caused partly by post-Miocene faulting and the almost total absence of uranium deposits farther north in the basin suggest that these deposits are of post-Miocene age and thus are not due to release of uranium in early Eocene time during weathering of the granitic terrane of the ancestral Granite Mountains.

During late Pliocene(?), Pleistocene, and Recent time, several cubic miles of arkosic rocks of the Puddle Springs Arkose Member was removed by erosion in the vicinity of the deposits and in the updip area immediately to the north. During the breakdown and removal of these rocks, much of the original uranium in the arkose could have become available for solution by vadose and ground water and for migration with the ground water downward and southward. Localization of the deposits in or below the Puddle Springs Arkose Member and the apparent absence of large uranium deposits from younger rocks in and near this district are evidence that strengthens the possibility that the arkosic sediments of the Puddle Springs Arkose Member were the original source of most of the uranium in these deposits. Middle and upper Eocene rocks about 30 miles north of the quadrangle have unusually high amounts of selenium (Beath and others, 1946, p. 9), and equivalent rocks formerly overlying the Gas Hills uranium district may have been the source of the selenium.

MIGRATION AND DEPOSITION OF URANIUM

The field evidence which most strongly suggests that natural water has been and is at present the fluid for transporting the uranium and other elements to the present deposits is the occurrence of some large deposits at and near the ground-water table (Zeller and Soister, 1955). High uranium content in water near the deposits (table 4) indicates continuing movement of the uranium. Radiochemical age determinations by J. N. Rosholt, Jr., on two ore samples collected 2–3 miles east of the quadrangle were only 11,000 and 170,000 years (Zeller, 1957, p. 158). From geochemical, radiochemical, and field evidence, Coleman (1957, p. 512) concluded that migration and deposition of uranium is still going on, and the author's field observations support this view. In all probability, solution, migration via vadose and ground water, and redeposition of uranium during the late Pliocene(?), Pleistocene, and Recent time, somewhat as suggested by Gruner (1956) in his multiple migration-accretion hypothesis, account for the uranium deposits of the Gas Hills district.

Deposition of uranium from solutions has commonly been attributed to physical barriers, such as fault and bedding contacts between finer and coarser rocks, that impede ground-water flow and to precipitating agents such as natural gas, hydrogen sulfide, carbonaceous material, calcite, and waters of varying pH, eH, and other characteristics.

The possibility that natural gas is a precipitating agent for uranium in the Gas Hills district (H. D. Zeller, P. E. Soister, and H. J. Hyden, written commun., Sept. 1955) has frequently been mentioned because of the well-known gas seeps for which the Gas Hills received their name. Gruner (1954, p. 4) proposed "that all uranium ores [of the sandstone-type deposits on the Colorado Plateau] as originally deposited in the sediments were reduced by organic matter and associated sulfide, perhaps H_2S." Grutt (1957, p. 5) believed that the uranium in the Gas Hills deposits may have been deposited by the action of hydrogen sulfide in natural gas (principally from the Frontier Formation) on moving uraniferous ground water. Jensen (1958, p. 599) showed that "hydrogen sulfide gas, derived from anaerobic bacteria, provided a reducing environment in which sulfide and uranium oxide minerals [of sandstone-type uranium deposits in general] may have been precipitated from the ore-bearing solutions." Hostetler and Garrels (1962, p. 158) stated that the reducing environments in which sandstone-type uranium deposits were formed "may have been pockets of carbonaceous material and (or) H_2S or even H_2 which may have been locally produced by the reaction of H_2S with Fe_2O_3; gaseous hydrogen will precipitate uraninite and montroseite from very dilute solutions."

Cheney (1964) indicated that the hydrogen sulfide was probably produced by bacteria which used carbonaceous material and petroliferous residues in the Wind River Formation as energy sources; however, petroliferous sandstone in scattered localities, including beds in the lower part of the formation a short distance northwest of the large Lucky Mc mines in sec. 22, T. 33 N., R. 90 W. (Zeller and others, 1956), is not mineralized. Cheney (1964, p. 169) stated that the "sulfur isotopic data do not support Grutt's hypothesis (1957) that uranium mineralization was caused by hydrogen sulfide of petroliferous origin." Cheney pointed out also that hydrogen sulfide is absent from gas from the Frontier Formation. The Tensleep and Phosphoria Formations, which do contain hydrogen sulfide in gas, are about 2,200 feet below the Wind River Formation at the south end of the mineralized area in this quadrangle and 3,500 feet below it at the north end. Oil and gas tests into these formations in this area have so far proved unsuccessful. If hydrogen sulfide from natural gas were the precipitating agent for uranium in the district, some deposits should occur in the basal conglomerate and sandstone of the lower fine-grained member of the Wind River, and most deposits should be strung out above the truncated edges of the gas-bearing formations or along faults that cut such formations. None of these conditions are met.

Grutt (1957, p. 5) and Jansen (1958, p. 612) stated that plant carbonaceous material is virtually absent from the Wind River Formation. A persistent carbonaceous shale and coal zone (Soister, 1958, p. 118–119 and fig. 23), however, lies at the base of the ore zone in the central part of the Gas Hills district, underlying at least half the known ore reserves of the entire district. Carbonaceous material is present as beds and lenses of carbonaceous shale scattered throughout the formation in other parts of the district. It seems reasonable to believe that such carbonaceous material would provide an adequate source for hydrogen sulfide. Hydrogen sulfide derived from the carbonaceous material and dissolved in ground water could bring about sufficient reducing conditions to cause precipitation of uranium. Precipitation of uranium directly by carbonaceous material is evidenced by carbonized logs and other carbonized plant material impregnated with and partially replaced by uranium minerals.

Some calcareous sandstone concretions not lying near carbonaceous material have anomalous amounts of uranium, and some uranium deposits have large calcareous concretionary sandstone bodies. Calcite, however, apparently is not a major precipitant of uranium in the deposits.

Downward-seeping vadose water and circulating ground water can enter ground-water environments of lower pH and eH in the Puddle Springs Arkose Member because of the carbonaceous, ferruginous, and calcareous materials in various parts of the member, beds of fine-grained rocks that contain interstitial water and (or) support perched water tables, and ground-water barriers formed by faults or the unconformity at the base of the formation. Mixing of waters of different pH and eH may be sufficient to cause deposition of uranium without the immediate presence of carbonaceous material.

One of the most important uranium-localizing factors for the entire Gas Hills district is the coarseness of the Wind River Formation here in contrast with the formation's finer texture to the east and west. The very high porosity and permeability of the Puddle Springs Arkose Member has resulted in its acting as a large ground-water aquifer and reservoir. The subsidiary basins produced by pre-Wind River erosion combined with late Tertiary faulting (p. C21) have provided ideal sites for ground-water reservoirs. The structure in the district is such that much of the water that seeps down through the thick coarse-grained arkose enters the ground water in this member, and the ground water circulates very slowly within the member.

From the physical standpoint, it seems possible that most of the uranium was deposited when uranium-bearing downward-seeping vadose water and laterally percolating ground water came in contact with bodies of relatively stationary water below or at the water table (or in the capillary fringe) that contained effective precipitating agents, such as hydrogen sulfide derived from the carbonaceous material common in the rocks.

The author believes that uranium has been leached from films that originally coated grains of the granitic sediments of the Puddle Springs Arkose Member during the weathering and erosion of these sediments in Quaternary time. The leaching took place in an oxidizing environment above the regional water table by vadose water which then carried the uranium downward toward the water table. Vadose water reaching the water table lost its uranium by precipitation if the environment was sufficiently reducing. Otherwise, the uranium was added to the slowly circulating ground water and later precipitated when the uranium-bearing water entered a suitable reducing environment somewhere within the body of ground water in the Puddle Springs Arkose Member. Large amounts of vadose water undoubtedly were available during the wet glacial intervals of Pleistocene time, when at least some, and perhaps most, of the present deposits were formed, as indicated by Rosholt's age determinations (p. C30).

The uranium deposits probably are geologically quite temporary in that uranium is being constantly carried away from some deposits and added to others near, at, or below the regional water table or perched water tables. As the surface is slowly lowered by erosion, the water table is lowered; the zone of large unoxidized deposits is consequently lowered and smaller oxidized deposits are left as remnants of former large unoxidized deposits. The oxidized deposits above the water table provide additional sources of uranium for younger deposits forming at or below the water table.

EXPLORATION TARGETS

The most favorable places to look for additional uranium deposits are south of the present deposits, in the Wind River Formation. Depth to the principal ore zone, however, increases to the south where the formation is overlain by younger rocks. For example, in AEC core hole GH–3 near the southeast corner of the quadrangle (fig. 2, pl. 1) "abnormal radioactivity" reported at 510 feet is at the same stratigraphic level as the ore zone in the Dick 9 open-pit mine. The area southeast of the present mines (fig. 2) is the most favorable for discovery of new deposits in this quadrangle.

Uranium deposits theoretically could occur in some aquifers of the northward-dipping pre-Tertiary formations below the Wind River Formation. Uraniferous waters could pass from the Puddle Springs Arkose Member of the Wind River Formation into the subjacent aquifer, where the latter is overlapped, and could migrate downdip in the aquifer to a favorable site of deposition. A small deposit of meta-autunite in basal sandstone of the Morrision Formation 2 miles east of the quadrangle near the Lucky Mc mine (Zeller and others, 1956) is probably the oxidized remnant of such a deposit that formed very close to where the Morrison was overlapped by the Wind River Formation. Possible sites of such uranium deposits in or near this quadrangle include sandstone beds of the Frontier Formation in secs. 1 and 12, T. 32 N., R. 91 W., and of the Cloverly Formation south of the Coyote Springs fault zone near or east of Coyote Creek.

REFERENCES CITED

Altschuler, Z. S., Clarke, R. S., Jr., and Young, E. J., 1958, Geochemistry of uranium in apatite and phosphorite: U.S. Geol. Survey Prof. Paper 314–D, p. 45–90.

Beath, O. A., Hagner, A. F., and Gilbert, C. S., 1946, Some rocks and soils of high selenium content: Wyoming Geol. Survey Bull. 36, 23 p.

Berg, R. R., and Thompson, R. M., 1957, Geology of the Conant Creek anticline and adjacent areas, *in* Wyoming Geol. Assoc. Guidebook 12th Ann. Field Conf., Southwest Wind River Basin, Lander 1957: p. 101–104.

Black, R. A., 1955, Seismic studies (Gas Hills area, Fremont County, Wyoming), *in* Uranium in sandstone-type deposits outside the Colorado Plateau, Wind River Basin: U.S. Geol. Survey TEI–590, p. 168–170, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

——— 1956a, Geophysical studies (Gas Hills area, Fremont and Natrona Counties, Wyoming), *in* Uranium in sandstone-type deposits outside the Colorado Plateau, Wind River Basin: U.S. Geol. Survey TEI–620, p. 185–186, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

——— 1956b, Geophysical investigations (Gas Hills area, Fremont and Natrona Counties, Wyoming), *in* Geologic mapping, central region: U.S. Geol. Survey TEI–640, p. 116–119, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Brown, Harrison, Blake, W. J., Chodos, A. A., Kowalkowski, Richard, McKinney, C. R., Neuerburg, G. J., Silver, L. T., and Uchujama, Aiji, 1953, Leaching studies of interstitial material in igneous rocks [abs.]: Geol. Soc. America Bull., v. 64, no. 12, pt. 2, p. 1400–1401.

Burk, C. A., 1957, Stratigraphic summary of the nonmarine Upper Jurassic and Lower Cretaceous strata of Wyoming, *in* Wyoming Geol. Assoc. Guidebook, 12th Ann. Field Conf., Southwest Wind River Basin, Lander 1957: p. 55–62.

Cheney, E. S., 1964, Stable isotopic geology of the Gas Hills uranium district, Wyoming: Yale Univ. unpub. Ph. D. dissert.

Coleman, R. G., 1954, Mineralogical and geological investigations of the uranium deposits of the Wind River district, Wyoming: U.S. Atomic Energy Comm. RME–4056, 19 p., issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

——— 1957, Mineralogy and geochemistry of uranium deposits in the Gas Hills district, Wyoming: U.S. Geol. Survey TEI–690, p. 508–512, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Denson, N. M., Zeller, H. D., and Stephens, J. G., 1956, Water sampling as a guide in the search for uranium deposits and its use in evaluating widespread volcanic units as potential source beds for uranium, *in* Page, L. R., Stocking, H. E., and Smith, H. B., compilers, Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 673–680.

Fix, P. F., 1956, Hydrogeochemical exploration for uranium, *in* Page, L. R., Stocking, H. E. and Smith, H. B., compilers, Contributions to the geology of uranium and thorium by the United States Geological Survey and Atomic Energy Commission for the United Nations International Conference on Peaceful Uses of Atomic Energy, Geneva, Switzerland, 1955: U.S. Geol. Survey Prof. Paper 300, p. 667–671.

Frondel, Clifford, 1958, Systematic mineralogy of uranium and thorium: U.S. Geol. Survey Bull. 1064, 400 p.

Gruner, J. W., 1954, Experimental studies of color changes from red to gray in silts and shales as applicable to uranium ore districts, p. 5–14, *in* Gruner, J. W., Rosenzweig, Abraham, and Smith, D. K., Jr., Annual report for April 1, 1953, to March 31, 1954: U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

——— 1956, Concentration of uranium in sediments by multiple migration-accretion: Econ. Geology, v. 51, no. 6, p. 495–520.

Gruner, J. W., Smith, D. K., Jr., and Knox, J. A., 1956, Mineral determinations in uranium deposits and prospects in Wyoming, northwestern Colorado, and western South and North Dakota: U.S. Atomic Energy Comm. RME–3137, pt. 2, 24 p. issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Grutt, E. W., Jr., 1957, Environment of some Wyoming uranium deposits: Nuclear Eng. Sci. Conf., 2d, Philadelphia, Pa., March 11–14, 1957: Am. Soc. Mech. Engineers Paper 57–NESC–69, p. 313–323.

Grutt, E. W., Jr., Hadfield, J. P., Jr., and Smith, E. W., 1954, Preliminary report on uranium deposits in the Wind River Basin, Wyoming: U.S. Atomic Energy Comm. RME–1056, 58 p., issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Hostetler, P. B., and Garrels, R. M., 1962, Transportation and precipitation of uranium and vanadium at low temperatures, with special reference to sandstone-type uranium deposits: Econ. Geology, v. 57, no. 2, p. 137–167.

Hurley, P.M., 1950, Distribution of radioactivity in granites and possible relation to helium age measurements: Geol. Soc. America Bull., v. 61, no. 1, p. 1–8.

Jahns, R. H., 1953, Distribution of rare elements within granites and granitic pegmatites [abs.]: Geol. Soc. America Bull., v. 64, no. 12, p. 1440.

Jenkins, C. E., 1957, Big Sand Draw field, Fremont County, Wyoming, *in* Wyoming Geol. Assoc. Guidebook 12th Ann. Field Conf., Southwest Wind River Basin, Lander 1957: p. 137–142.

Jensen, M. L., 1958, Sulfur isotopes and the origin of sandstone-type uranium deposits [Colorado Plateau and Wyoming.]: Econ. Geology, v. 53, no. 5, p. 598–616.

Larsen, E. S., and Berman, Harry, 1934, The microscopic determination of the non-opaque minerals [2d ed.]: U.S. Geol. Survey Bull. 848, 266 p.

Love, J. D., 1954, Preliminary report on uranium in the Gas Hills area, Fremont and Natrona Counties, Wyoming: U.S. Geol. Survey Circ. 352, 11 p.

——— 1960, Cenozoic sedimentation and crustal movement in Wyoming (Bradley Volume): Am. Jour. Sci., v. 258–A, p. 204–214.

——— 1961, Split Rock Formation (Miocene) and Moonstone Formation (Pliocene) in central Wyoming: U.S. Geol. Survey Bull. 1121–I, 39 p.

Love, J. D., Tourtelot, H. A., Johnson, C. O., Thompson, R. M., Sharkey, H. H. R., and Zapp, A. D., 1947, Stratigraphic sections of Mesozoic rocks in central Wyoming: Wyoming Geol. Survey Bull. 38, 59 p.

Masursky, Harold, 1962, Uranium-bearing coal in the eastern part of the Red Desert area, Wyoming: U.S. Geol. Survey Bull. 1099–B, 152 p.

Murphy, J. F., 1956, Uranium-bearing water in the Crow Creek and Muskrat Creek areas, Fremont County, Wyoming: Wyoming Geol. Survey Rept. Inv., no. 5, 15 p.

Palache, Charles, Berman, Harry, and Frondel, Clifford, 1946, Elements, sulphides, sulfosalts, oxides, v. 1 *of* The system of mineralogy of James Dwight Dana and Edward Salisbury Dana [7th ed.]: New York, John Wiley & Sons, 834 p.

——— 1951, Halides, nitrates, borates, carbonates, sulfates, phosphates, arsenates, tungstates, and molybdates, v. 2 *of* The system of mineralogy of James Dwight Dana and Edward Salisbury Dana [7th ed.]: New York, John Wiley & Sons, 1124 p.

Phair, George, and Gottfried, David, 1958, Fractionation of uranium in the rocks and accessory minerals of the Boulder Creek batholith, Colorado: U.S. Geol. Survey TEI–740, p. 286–290, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Piggot, C. S., 1929, The radium content of some representative granites of the eastern seaboard of the United States, [pt.] 1 *of* Radium in rocks: Am. Jour. Sci., 5th ser., v. 17, p. 13–34.

Rich, E. I., 1962, Reconnaissance geology of Hiland–Clarkson Hill area, Natrona County, Wyoming: U.S. Geol. Survey Bull. 1107–G, p. 447–540.

Soister, P. E., 1958, Preliminary stratigraphy of Wind River Formation in Gas Hills area, Wyoming, *in* [*chap.*] Geologic mapping, central region: U.S. Geol. Survey TEI–740, p. 112–120, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Soister, P. E., 1966a, Geologic map of the Muskrat Basin quadrangle, Fremont County, Wyoming: U.S. Geol. Survey Misc. Geol. Inv. Map I–482, scale 1:24,000.

——— 1966b, Geologic map of the Rongis Reservoir SE quadrangle, Fremont County, Wyoming: U.S. Geol. Survey Misc. Geol. Inv. Map I–483, scale 1:24,000.

——— 1967, Geologic map of the Coyote Springs quadrangle, Fremont County, Wyoming: U.S. Geol. Survey Misc. Geol. Inv. Map I–481, scale 1:24,000.

Soister, P. E., and Conklin, D. R., 1959, Bibliography of U.S. Geological Survey reports on uranium and thorium, 1942 through May 1958: U.S. Geol. Survey Bull. 1107–A, 167 p.

Thompson, R. M., and White, V. L., 1952, Geology of the Conant Creek–Muskrat Creek area, Fremont County, Wyoming: U.S. Geol. Survey open-file report (map).

Troyer, M. L., McKay, E. J., Soister, P. E., and Wallace, S. R., 1954, Summary of investigations of uranium deposits in the Pumpkin Buttes area, Johnson and Campbell Counties, Wyoming: U.S. Geol. Survey Circ. 338, 17 p.

Van Houten, F. B., 1950, Geology of the western part of the Beaver Divide area, Fremont County, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM–113.

——— 1954, Geology of the Long Creek–Beaver Divide area, Fremont County, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM–140.

——— 1955, Volcanic-rich middle and upper Eocene sedimentary rocks northwest of Rattlesnake Hills, central Wyoming: U.S. Geol. Survey Prof. Paper 274–A, p. 1–14.

——— 1957, Tertiary rocks of southern Wind River Basin area, central Wyoming, *in* Wyoming Geol. Assoc. Guidebook 12th Ann. Field Conf., Southwest Wind River Basin, Lander 1957: p. 79–88.

——— 1964, Tertiary geology of the Beaver Rim area, Fremont and Natrona Counties, Wyoming: U.S. Geol. Survey Bull. 1164, 99 p. [1965].

Van Houten, F. B., and Weitz, J. L., 1956, Geologic map of the eastern Beaver Divide–Gas Hills area, Fremont and Natrona Counties, Wyoming: U.S. Geol. Survey Oil and Gas Inv. Map OM–180.

Wyant, D. G., Beroni, E. P., and Granger, H. C., 1952, Some uranium deposits in sandstones, *in* Selected papers on uranium deposits in the United States: U.S. Geol. Survey Circ. 220, p. 26–29 [1953].

Zeller, H. D., 1957, The Gas Hills uranium district and some probable controls for ore deposition, *in* Wyoming Geol. Assoc. Guidebook 12th Ann. Field Conf. Southwest Wind River Basin, Lander 1957: p. 156–160.

Zeller, H. D. and Soister, P. E., 1955, Gas Hills area, Fremont County, Wind River Basin, Wyoming, *in* Uranium in sandstone-type deposits outside the Colorado Plateau: U.S. Geol. Survey TEI–590, p. 165–168, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

Zeller, H. D., Soister, P. E., and Hyden, H. J., 1954, Gas Hills area, Fremont County, Wyoming, *in* Uranium in sandstone-type deposits: U.S. Geol. Survey TEI–490, p. 122–125, issued by U.S. Atomic Energy Comm. Tech. Inf. Service, Oak Ridge, Tenn.

——— 1956, Preliminary geologic map of the Gas Hills uranium district, Fremont and Natrona Counties, Wyoming: U.S. Geol. Survey Mineral Inv. Field Studies Map MF–83.

○