Selenium in Some Oxidized Sandstone-type Uranium Deposits

GEOLOGICAL SURVEY BULLETIN 1162-C

U. S. DEPARTMENT OF THE INTERIOR

March 3, 1849

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By D. F. DAVIDSON

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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By D. F. Davidson

ABSTRACT

Studies of selenium and other trace metals in samples from some oxidized sandstone-type uranium deposits in New Mexico, Oklahoma, Pennsylvania, South Dakota, Texas, and Wyoming demonstrate that concentrations of as much as 0.1 percent selenium are not uncommon in the immediate vicinity of uranium concentrations. The work also has demonstrated that selenium contents of the uranium ores of these deposits, or of the highly seleniferous material associated with the ores, are not correlatable with the contents of any other constitutents of the ores or concentrations for which analyses have been made, although many of the metals of the deposits were probably derived from the same source, and concentrated together in the deposits.

The lack of relationship of selenium to other constituents of these deposits is undoubtedly a reflection of differential movement and fixation of all constituents during the weathering and oxidation to which the ore deposits have been subjected.

INTRODUCTION

Selenium has long been known to occur in sandstone-type uranium deposits. For example, Hillebrand, Merwin, and Wright (1914, p. 35) reported the discovery of selenium in uranium-vanadium ore samples from the Thompson's district in eastern Utah, the Henry Mountains in Utah, and in samples said to come from Paradox Valley, Montrose County, Colo.

Further investigation of this relationship has been made by the U.S. Geological Survey as a part of a continuing study of the geology and geochemistry of selenium. In this report are gathered new data that have become available as a result of this study; a good deal of older data derived from studies of uranium deposits made by other members of the Geological Survey; and some background geological information of the deposits from which selenium analyses are available.

Only oxidized sandstone-type deposits—and not all of these—are discussed in this report. For example, the Colorado Plateau and the Gas Hills, Wyo., deposits are not considered, for the distribution of trace metals (including selenium) in deposits in these areas is being carefully studied by other workers of the Geological Survey.

Conclusions drawn in this report regarding the relationship of selenium to other constituents of the deposits are only tentative because many factors playing a part in the emplacement and localization of uranium deposits in sandstone, and the selenium which accompanies uranium in many of these deposits, are poorly or not at all understood. Moreover, the relations in oxidized deposits often are dependent upon earlier relations still being studied in the unoxidized counterparts of oxidized deposits.

ANALYTICAL METHODS

The methods of analyses for selenium used to obtain the data used in this report are of two types. Throughout this report these methods will be called the laboratory method and the field method. Both methods employ the well-known distillation of selenium with hydrobromic acid.

The laboratory method is that used for the determination of selenium in foods, and is described in "Official Methods of Analysis of the Association of Official Agricultural Chemists" (Lepper and others, 1952, p. 416–421). In this method selenium is determined by a microtitration. The field method is identical except that for the final step of the laboratory method visual estimation of selenium content as described by Franke, Burris, and Hulton (1936, p. 435) has been substituted. Results provided by the laboratory method are considered to be correct within an error of ±10 percent; those provided by the field method within an error of ±35 percent (H. W. Lakin, oral communication, 1957).

Methods of uranium analysis are now well known, and need not be discussed here (Grimaldi and others, 1954).

All the analytical data presented in this report have come from work done by personnel of the Geological Survey. Uranium and selenium analyses have been made in the Geological Survey's laboratories in Denver, Colo., and Washington, D.C.

OXIDIZED SANDSTONE-TYPE URANIUM DEPOSITS

Oxidized sandstone-type uranium deposits are known in rocks ranging in age from the Paleozoic through Cenozoic Eras, and selenium analyses are available for samples from deposits in Devonian, Pennsylvanian, Permian, Triassic, Cretaceous, Eocene, Miocene, and Pliocene rocks. In this report, deposits are discussed according to the age of the host rocks, the deposits in the oldest rocks being discussed first.

DEPOSITS IN PALEOZOIC ROCKS

Sandstone-type uranium deposits are known in Paleozoic rocks in Pennsylvania, Oklahoma, Texas, and New Mexico. Locations of the deposits discussed here are shown on figure 1. The deposits in eastern Pennsylvania are in formations of Devonian and Pennsylvanian age; those in Oklahoma in rocks of Permian age; and those in New Mexico in rocks of Pennsylvanian and Permian age. Most of these deposits are in fluvial sandstone.

JIM THORPE (MAUCH CHUNK), PA.

The uranium deposits near Jim Thorpe (Mauch Chunk), Pa., (fig. 1) contain vanadium and copper, and occur in coarse graywacke conglomerate near the base of the Pottsville Formation of Pennsylvanian age on the north limb of a syncline, and in graywacke sandstone near the top of the Catskill Formation of Devonian age on the south limb of the same syncline (Klemic and Baker, 1954). The deposits 8 miles north of Jim Thorpe at Penn Haven Junction are in the upper part of the Catskill Formation, probably at about the same stratigraphic horizon as those in the Catskill Formation near Jim Thorpe.

Deposits of uranium minerals are disseminated in lenticular masses a few to several hundred feet across. Uranium minerals in the deposits in the Pottsville Formation are carnotite, tyuyamunite, and uranophane. Carbonaceous material is rare. Selenium has not been recognized in samples from the Pottsville deposits. Uranium minerals in the deposits in the Catskill Formation are autunite, kasolite, uranophane, and uraninite. Carbonaceous material is rare. Clausthalite (PbSe) has been recognized in the deposits at Penn Haven Junction (Klemic and Warman, 1956, p. 315–316). Interstitial uraninite occurs in a zone that includes layered concentrations of heavy minerals (magnetite, allanite(?), zircon, ilmenite(?), leucoxene, tourmaline, apatite, sphene, hornblende, and garnet).

Clausthalite is most abundant in layers rich in uraninite, except for the layer containing the greatest concentration of uraninite. Here clausthalite is scarce, or absent, although uraninite-rich layers above and below contain abundant clausthalite.

The clausthalite in the rock is thought to be epigenetic, for some of the rock is partially desilicified and space between remnants of quartz grains is filled with holocrystalline euhedral chlorite and with clausthalite and calcite.

Selenium analyses for 19 samples and uranium analyses for 9 samples are shown in table 1. It may be noted there is no apparent

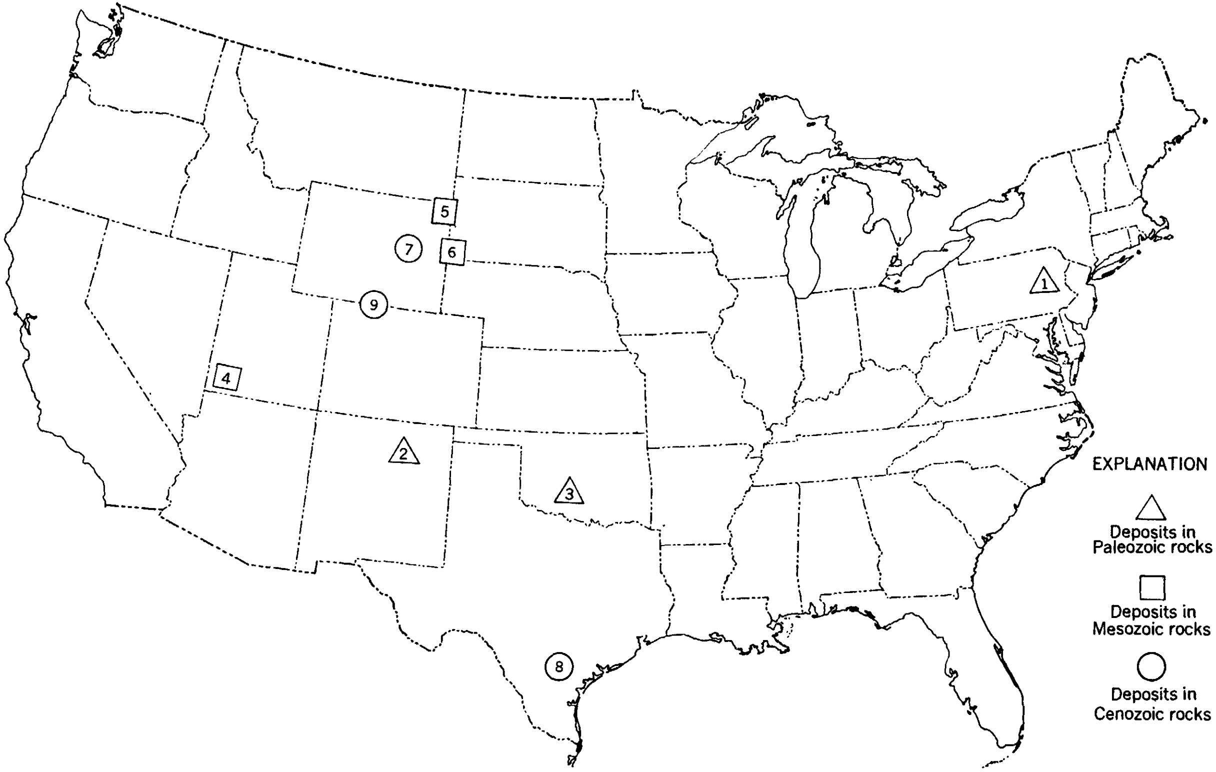

FIGURE 1.—Map of the conterminous United States showing location of discussed uranium deposits. Numbers on map refer to deposits, as follows:

1. Jim Thorpe, Pa.
2. Coyote district, N. Mex.
3. Cement, Okla.
4. Silver Reef district, Utah.
5. Northern Black Hills, Wyo.
6. Southern Black Hills, S. Dak.
7. Powder River Basin, Wyo.
8. Texas Coastal Plains district, Tex.
9. Baggs area, Wyoming and Colo

TABLE 1.—*Selenium and uranium content of some sandstone samples from Carbon, Lycoming, Huntingdon, Schuylkill, Columbia, and Bedford Counties, Pa.*

Sample		Description	U	Se[1]
Field	Laboratory		Parts per million	
Hk-6-53	148823	Chip sample; shale and siltstone, Catskill Formation, Hickory Run, Carbon County.	-------------	[2,5] 5, 5
Hk-6-57	148829	Selected sample; sandstone, Catskill Formation, 4th Run, Carbon County.	-------------	[2,5] 15, 15
Hk-6-58A	148831	do	-------------	[2,5] 82, 85
Mc-Pv-8	150414	Selected sample; sandstone, Mauch Chunk Formation, Mount Pisgah, at Jim Thorpe, Carbon County.	-------------	[3] 400
Pv-20-56	149600	Selected sample; sandstone, Mauch Chunk Formation, Mount Pisgah, at Jim Thorpe, Carbon County.	24, 000	[4] 230
Hk-3-37	115028	Grab sample; sandstone, Catskill Formation, Mauch Chunk Ridge, Carbon County.	[5] 1, 300, 1, 300	[2] 380
Hk-3-44	115035	Grab sample; sandstone, Catskill Formation, Penn Haven Junction, Carbon County.	[5] 5, 600, 5, 600	[2] 200
Hk-3050	115037	do	[5] 300, 300	[2] 660
Hk-3-49	115033	Grab sample; sandstone, Catskill Formation, Butcher Hollow, Carbon County.	[5] 600, 550	[2] 20
Hk-6-109	150408	Selected sample; sandstone, Catskill Formation, near Hecla, Schuylkill County.	-------------	[3] 3
Hk-6-111	150409	Selected sample; sandstone, Mauch Chunk Formation, near Robertsdale, Huntingdon County.	-------------	[3] 3
Hk-6-114	150410	do	-------------	[3] 3
Hk-6-115	150411	do	-------------	[3] 3
Hk-6-116	150412	do	-------------	[3] 3
Hk-6-117	150413	Selected sample; sandstone, Catskill Formation, near Everett, Bedford County.	-------------	[3] 5
Hk-6-80	149596	Selected sample; sandstone, contains copper minerals, Catskill Formation, near Beaver Lake, Lycoming County.	4, 400	[6,5] 40, 40
Hk-6-82	149597	Selected sample; sandstone, contains copper minerals, Catskill Formation, near Sonestown, Lycoming County.	2, 400	[6,5] 10, 10
Hk-6-84	149598	Selected sample; sandstone, Catskill Formation, near Strawbridge, Lycoming County.	1, 000	[6] 4, 3
Hk-6-88	149599	Selected sample; sandstone and siltstone, Catskill Formation, near Glassmere, Columbia County.	4, 000	[6] 3, 3

[1] Analyses by laboratory method.
[2] Analyses by Esma Campbell.
[3] Analyses by Joseph Budinsky.
[4] Analyses by Joseph Budinsky, Esma Campbell, and R. Powell.
[5] Two analyses run.
[6] Analyses by Roosevelt Moore and B. A. McCall.

correlation between selenium and uranium contents of these samples. The selenium contents of these samples are low compared to the contents of selenium of many samples from other districts discussed in this report.

MORA COUNTY, N. MEX.

Small commercial-grade sandstone-type uranium deposits occur in the lower 2,000 feet of the Sangre de Cristo Formation of Pennsylvanian and Permian age in the Coyote district, Mora County, N. Mex. Location of the deposits is shown on figure 1. Associated copper deposits are also uraniferous, but uranium grade and reserves are too low to permit recovery of the uranium.

The uranium deposits are small closely spaced pockets apparently localized by sedimentary structures within one or more fluvial arkosic sandstone beds (Tschanz, Fuller, and Laub, 1958). The uranium deposits are more abundant where carbonized wood, clay galls, and rock fragments are abundant.

Minerals present in the deposits include malachite, chalcopyrite, various vanadium minerals, metatyuyamunite, and microscopic grains of an unidentified black uraniferous substance. The proportion of copper to uranium and vanadium is variable, and any one of these metals may be the most abundant in a given deposit.

In general, the uraniferous sandstones of the Coyote district have a higher content of copper, lead, rare earths, and other minor constituents than uranium ores from the Morrison Formation and Shinarump Member of the Chinle Formation of the Colorado Plateau. Lead and rare earths are concentrated in the sandstone, and with uranium in the heavy-mineral fraction. A few analyses suggest that selenium is higher in concentration in highly uraniferous sandstone as is shown by the data in table 2. Selenium is probably present as iron selenite (Byers and others, 1938), but may be in selenide form or in pyrite or chalcopyrite.

TABLE 2.—*Selenium and uranium content of some sandstone samples from the Coyote district, Mora County, N. Mex.*

[Name of analyst not known to the writer. Selenium analyses by laboratory method]

Sample		Description	Se	U
Field	Laboratory		Parts per million	
G-360	55-3220	Calcareous, arkosic	50	------
334	?	do	9	240
355	?	Micaceous, with metatyuyamunite	50	8,500
351	?	Calcareous, arkosic	3	360

OKLAHOMA AND TEXAS

According to McKay (1957, p. 425–427), in northern Texas and southern Oklahoma, sandstone-type uranium deposits have been found in two stratigraphic zones of Permian age; the upper half of the Wichita Group in the Red River area; and in the Rush Springs Sandstone of the Whitehorse Group in the Anadarko Basin. No selenium analyses of samples from the Red River area are known to the writer and these deposits will not be discussed further.

In the Anadarko Basin, carnotite and tyuyamunite occur in or near fractures in the Rush Springs Sandstone on the Cement anticline at Cement, Okla. (fig. 1). The Rush Springs Sandstone is a thick, festoon-bedded, red, feldspathic, well-sorted sandstone. A selenium analysis is available for only one sample from the Cement anticline deposit; this and other analyses for the sample are given below.

Selenium is present in only a small amount and nothing is known of its relationship to other constituents of the uranium ore sample, or of the form in which it occurs.

Chemical analyses, in parts per million, of a sample from the Cement anticline deposit, Caddo County, Okla.

[$CaCO_3$, Zn, and V_2O_5, analysis by J. S. Wahlberg; U, analysis by H. H. Lipp; P_2O_5, analysis by J. P Schuch; As, analysis by J. E. Wilson; Se, laboratory-method analysis by G. T. Burrow]

Sample		Description	$CaCO_3$	U	P_2O_5	Zn	V_2O_5	As	Se
Field	Laboratory								
Lot 11----	252352-------	Mill pulp, Lister Mills, School land claim.	57,500	22,000	500	34	10,700	78	8

DEPOSITS IN MESOZOIC ROCKS

Small, widely separated, oxidized uranium deposits are known to occur in Triassic rocks in Pennsylvania, New Jersey, Texas, and southern Utah; in Jurassic rocks in Wyoming, and New Mexico; and in Cretaceous rocks in Arizona. Larger oxidized uranium deposits occur in Triassic rocks in Arizona, in Jurassic rocks in Colorado and Utah, and in sandstone of Cretaceous age in the Black Hills of South Dakota and Wyoming.

Some selenium data are available from the deposits of the Black Hills of South Dakota and Wyoming, and southern Utah. No data are available from the deposits of Texas, Wyoming, New Mexico, or Arizona, and these deposits will not be discussed.

SILVER REEF DISTRICT, UTAH

Uranium ore in the Silver Reef district occurs in thinly bedded, crossbedded shales and sandstones within the fluvial Tecumseh Sandstone (Proctor, 1953) in the Silver Reef Sandstone Member (Proctor, 1950) of the Triassic Chinle Formation. Location of the district is shown on figure 1.

According to Stugard (1951), uranium ore from the district contains several times as much vanadium oxide as uranium, some copper, and traces of silver. Ore-bearing beds are lenticular and are localized near the base, in the center, and at the top of Proctor's Tecumseh Sandstone.

Uranium minerals in ores of the district commonly occur as coatings on fracture surfaces and on plant fossils.

Analyses of 10 samples from the district are listed in table 3.

The silver deposits of the Silver Reef district cannot be observed today and have not been studied. Apparently the silver ore recovered in the shallow workings of the district was largely cerargyrite. In deeper mines, Butler and others (1920, p. 592) report

> that below water level both the silver and copper are present mainly as sulphides, with a little native silver. Newberry,[1] however, states that the average of four analyses of silver ores showed 0.23 percent of selenium and 0.26 percent of silver,

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[1] Newberry, J. S., 1881, The Silver Reef sandstones: Eng. Mining Jour., v. 31, p. 5.

which would suggest that part of the silver at least may be combined in some form with selenium.

According to Stugard, the absence of major silver workings in the vicinity of the richest uranium-vanadium prospects implies a lack of association between the uranium-vanadium minerals and economic silver deposits.

The uranium, copper, and vanadium minerals found in the Silver Reef district are epigenetic. This implies deposition from solutions passing through the sandstones. It is possible that during deposition of the sandstones the metals were fixed by carbonaceous material and were later redeposited in their present position. The probable origin of the metals in the solutions has not been determined.

The presence of native silver and silver sulfides below the water table (Butler and others, 1920, p. 592) suggests the possible presence

TABLE 3.—*Chemical analyses of 11 samples from the Silver Reef district, Washington County, Utah*

[Sample data from Stugard (1951)]

Location and description	U	V_2O_5	Se	Ag
	Parts per million			Ounces per ton
Buckeye Reef				
Silver Point claim:				
Grab sample from uraniferous Tecumseh Sandstone of Proctor (1953) from dumps of 2 shafts 300 feet from Doyler shaft	3,800	11,500	44	5.52
Grab sample from Tecumseh Sandstone of Proctor (1953) containing "pseudoautunite" (sic) from east tip of Pumpkin Point near Prospect pit 5	2,000	29,800	128	2.56
Channel sample, 1.8 feet long, of basal Tecumseh Sandstone of Proctor (1953) in Prospect pit 5 on southeast slope of Pumpkin Point	4,300	18,600	4	5.36
Channel sample, 5 feet long, of a 0.2- to 0.4-foot layer of organic shale in Tecumseh Sandstone of Proctor (1953), Prospect pit 4	260	48,000	Not analyzed	Not analyzed
Chloride Chief claim:				
Composite sample from Tecumseh Sandstone of Proctor (1953) (producing lens) in Willis pit 1	3,000	10,000	.7	3.50
Fine material, same location	4,200	46,800	226	13.36
Tecumseh Hill: Grab sample from Tecumseh Sandstone of Proctor (1953) from dump	410	20,900	18	2.03
East Reef				
Duffin mine:				
Composite grab sample from dump material (Tecumseh Sandstone of Proctor, 1953)	200	500	5	1.23
Selected sample of uranium ore	6,100	18,100	34	33.78
White Reef				
Cobb mine: "Soapstone" or sheared clay from clay-pebble layer 100 feet inside mine. Leeds(?) Sandstone	30	400	66	2.48
Leeds mine: Grab sample from Tecumseh Sandstone of Proctor (1953) showing copper carbonates, from mine entrance	50	300	5	11.20

of subjacent igneous intrusive rocks, but no supporting evidence such as sericitized or argillized rock has been found.

Proctor [2] supports a syngenetic origin for the metals in the Silver Reef district:

> It is believed that the metals in the Silver Reef sandstone were primary constituents of original volcanic tuffs in the Chinle formation. These metals were dissolved and/or mechanically transported by streams which were eroding the tuffaceous sediments. They were deposited with the sandstones and shales of the Silver Reef area. Further concentration of the metals of the Silver Reef sandstone was (1) by solution in circulating ground waters and (2) by precipitation because of contact with entombed plant debris and associated bacteria.

Selenium contents of the samples listed in table 3 are low and selenium in the deposits shows no marked correlation with any other element for which analyses are available. The form in which selenium occurs is not known.

BLACK HILLS IN SOUTH DAKOTA AND WYOMING

The uranium deposits of the Black Hills in South Dakota and Wyoming, occur in nonmarine quartzose sandstones of the Inyan Kara Group of Early Cretaceous age. The group, 500 to 600 feet thick, comprises, in ascending order, the Lakota Formation, consisting of three members, the Chilson, Minnewaste, and Fuson; and the Fall River Formation. The formations are composed of sandstone, mudstone, and interbedded sandstone and siltstone.

Robinson and Gott (1958) have published a useful summary of the setting of the uranium deposits and of the general features of the Black Hills. Locations of areas of deposits discussed are shown on figure 2.

Most of the uranium deposits of the Black Hills are of the oxidized type. The important ore minerals of these deposits are carnotite and tyuyamunite, but other minerals have been recognized, among them corvusite, rauvite, and autunite. Uraninite is the principal ore mineral at a few of the mines.

Deposits carrying rauvite, corvusite, uraninite, and pyrite are considered by the writer to be less oxidized than deposits carrying carnotite and limonite and commonly occur in thin sandstone interbedded with highly carbonaceous mudstones. Deposits carrying carnotite and tyuyamunite commonly occur in the thicker sandstones, and are considered to be highly oxidized.

Ore in both highly oxidized and less oxidized ore bodies forms both conformable tabular masses and irregular pod-shaped bodies that transgress textural boundaries and structures in the host rocks. As is usual in sandstone-type uranium deposits, the ore minerals occur

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[2] Proctor, P. D., 1949, Geology of the Harrisburg (Silver Reef) district, Washington County, Utah: Indiana Univ. unpublished doctoral dissertation, 167 p.

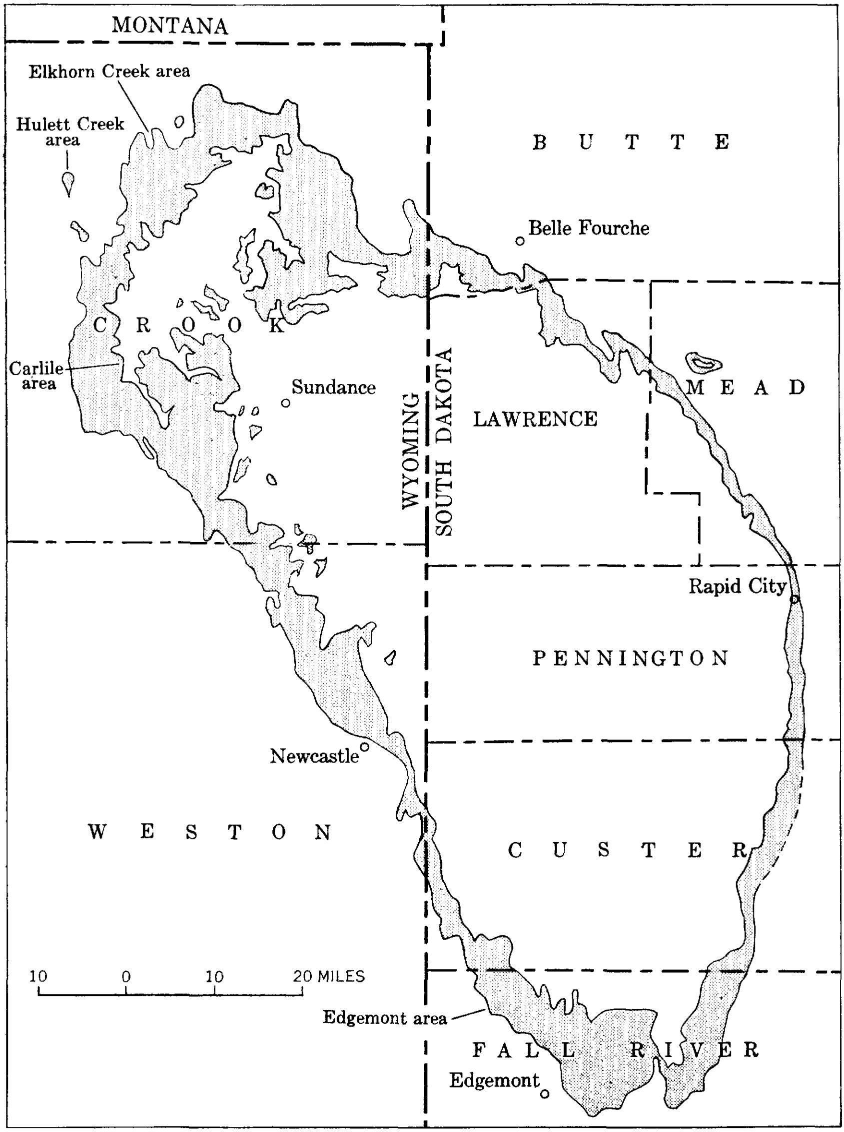

FIGURE 2.—Map showing area of outcrop of Inyan Kara Group, and Morrison and Unkpapa Formations of Jurassic age, and the locations of the principal uranium mining areas of the Black Hills in Wyoming and South Dakota. From Robinson and Gott (1958).

as coatings on sand grains and in joints as interstitial fillings in the sandstones, and as fracture fillings.

NORTHERN BLACK HILLS AND CARLILE MINE

Tables 4 through 11 present selenium and other analyses of samples from uranium deposits of the Northern Black Hills (fig. 1). A number of the samples were collected by C. S. Robinson and A. F. Trites of the Geological Survey.

TABLE 4.—*Chemical analyses of miscellaneous samples from uranium deposits of the Northern Black Hills, Crook County, Wyo.*

[Analyses by C. G. Angelo, J. P. Schuch, H. H. Lipp, G. T. Burrow, Claude Huffman, H. E. Crowe, C. E. Thompson, W. R. Weston and W. J. Breed. Se analyses by laboratory and field method]

Sample		Description	Se	As	U	V_2O_5	Mo
Field	Laboratory		Parts per million				
		Carlile mine					
T-Se-65	55-5609	Sandstone, red-stained	7	30	300	--------	4
T-Se-66	55-5610	Carbonaceous material, uraniferous	300	200	2, 500	--------	8
T-Se-67	55-5611	do	400	300	6, 000	--------	8
T-Se-68	55-5612	Sandstone, above ore zone	3	10	400	--------	4
T-Se-69	55-5613	Sandstone, uraniferous	7	10	12, 000	--------	<4
T-Se-69B	55-5615	Sandstone, with carnotite, 700 ft. west of Carlile mine.	10	------	--------	--------	----
T-Se-69C	55-5616	Sandstone	700	------	--------	--------	----
T-Se-69D	55-5617	do	70	------	--------	--------	----
		Busfield mine					
T-Se-45	55-5590	Sandstone above ore horizon	3	60	300	--------	----
T-Se-46	55-5591	Material from uranium-mineralized joint.	3	60	3, 500	--------	4
T-Se-47	55-5592	Yellow minerals in, and coating, carbonaceous siltstone.	1	50	6, 000	--------	4
T-Se-48	55-5593	Black "coffinite" ore	50	60	16, 000	--------	4
T-Se-50	55-5594	Sandstone overlying ore horizon	3	10	800	--------	4
T-Se-50B	55-5595	Sandstone, uraniferous	5	------	--------	--------	----
D-56-8	253580	Sandstone, oxidized zone	0. 5	<5	30	<500	----
D-56-9	253581	Sandstone, unoxidized zone	4	55	6, 900	1, 000	----
D-56-10	253582	Sandstone, unoxidized-oxidized contact	3	<5	370	500	----
		Vickers mine					
D-56-23	253583	Sandstone	0. 5	5	20	<500	----
D-56-24	253584	do	15	95	210	<500	----
D-56-25	253585	do	0. 5	100	990	<500	----
D-56-26	253586	do	5	120	6, 700	500	----
D-56-27	253587	do	<. 5	5	60	<500	----
D-56-28	253588	do	3	110	3, 000	<500	----
D-56-29	253589	do	20	150	8, 400	5, 400	----
		Jubilee mine					
T-Se-41	55-5578	Siltstone overlying uraniferous sandstone.	1	60	2, 500	--------	----
T-Se-42	55-5579	Sandstone beneath uraniferous sandstone.	1	100	2, 000	--------	4
T-Se-43	55-5580	Sandstone, ore-bearing, carbonaceous	20	160	6, 000	--------	4
T-Se-44	55-5581	Gray nodules cut by limonite-coated fractures.	1	40	3, 500	--------	4
		Hulett Creek mine					
T-Se-52	55-5597	Sandstone, limonitic from lower ore zone	700	80	80	--------	4
T-Se-53	55-5598	Shale, carbonaceous	70	80	2, 500	--------	8
T-Se-54	55-5599	Sandstone, limonitic	10	80	300	--------	4
T-Se-55	55-5600	Sandstone, limonitic	50	40	2, 000	--------	4
T-Se-56	55-5601	Shale, gray	300	40	400	--------	<2
T-Se-57	55-5602	Sandstone, yellow, cross-bedded	300	10	40	--------	16
T-Se-58	55-5603	Sandstone, yellow, orange, and gray	7	20	40	--------	4
T-Se-59	55-5604	Sandstone, limonitic	7	60	1, 500	--------	4

TABLE 4.—*Chemical analyses of miscellaneous samples from uranium deposits of the Northern Black Hills, Crook County, Wyo.*—Continued

Sample		Description	Se	As	U	V_2O_5	Mo
Field	Laboratory		Parts per million				
		Other localities					
T-Se-59B	55-5605	Sandstone, radioactive, Homestake pit 1, New Haven.	20	--------	--------	--------	----
T-Se-59C	55-5606	Sandstone, radioactive, Homestake pit 2, New Haven.	7	--------	--------	--------	----
T-Se-59D	55-5607	Sandstone, radioactive, carbonaceous, Homestake pit 3, New Haven.	10	--------	--------	--------	----
T-Se-59E	55-5608	Shale seam, carbonaceous, limonitic. Minerals Development Co. mine, New Haven.	3	--------	--------	--------	----
T-Se-50C	55-5596	Sandstone, radioactive, clay galls, carbonaceous, Boyles mine, New Haven.	<1	--------	--------	--------	----
T-Se-70	55-5614	Red grit, Shannon Oil Co. deposit	5	40	40	--------	4

TABLE 5.—*Chemical and radiometric analyses of samples from Homestake Mining Co. pits 1 to 5, Hulett Creek area, Crook County, Wyo.*

Pit 1

[Laboratory-method analyses by D. L. Schafer, C. G. Angelo, E. J. Fennelly, J. S. Wahlberg, D. L. Skinner, Wayne Mountjoy, I. C. Frost, G. T. Burrow, and J. P. Schuch]

Sample		Description	eU	U	V_2O_5	Se	As
Field	Laboratory		Percent			Parts per million	
79CR56	252409	Sandstone, brown, carbonaceous; contains yellow uranium mineral.	1.4	2.11	0.15	900	120
80CR56	252410	Sandstone, gray, calcareous, carbonaceous; contains yellow uranium mineral.	.19	.34	.25	10	14
81CR56	252411	Sandstone, gray, carbonaceous, iron-stained; contains yellow uranium mineral.	.22	.40	.30	50	32
82CR56	252412	Sandstone, gray, iron-stained; contains yellow uranium mineral.	.20	.38	.24	3	16

Pit 2

[Laboratory-method analyses by D. L. Schafer, C. G. Angelo, E. J. Fennelly, J. S. Wahlberg, D. L. Skinner, Wayne Mountjoy, I. C. Frost, G. T. Burrow, and J. P. Schuch]

Sample		Description	eU	U	V_2O_5	Fe as Fe_2O_3	MnO	CaO	MgO	Se	As
Field	Laboratory		Percent							Parts per million	
105CR56	252438	Channel sample; sandstone, brown, carbonaceous, iron-stained.	0.18	0.15	0.1	2.70	0.032	2.7	0.1	5	130
106CR56	252415	Grab sample, sandstone, gray, carbonaceous; contains yellow uranium mineral.	.19	.097	.1	--------	------	------	------	100	130
107CR56	252417	Grab sample; sandstone, gray; contains carbonate, iron-stained; contains yellow uranium mineral.	.48	.89	.1	--------	------	------	------	20	14

TABLE 5.—*Chemical and radiometric analyses of samples from Homestake Mining Co. pits 1 to 5, Hulett Creek area, Crook County, Wyo.*—Continued

Pit 3

[From some laboratory-method analyses by C. G. Angelo, D. L. Schafer, E. J. Fennelly, J. S. Wahlberg, D. L. Skinner, I. J. Frost, Wayne Mountjoy, G. T. Burrow, and J. P. Schuch]

Sample		Description	eU	U	V_2O_5	Se	As
Field	Laboratory		Percent			Parts per million	
110CR56	252416	Sandstone, gray, carbonaceous, iron-stained; contains yellow uranium mineral.	0.19	0.11	0.1	15	460

Pit 4

Analyses by C. G. Angelo, D. L. Schafer, E. J. Fennelly, J. S. Wahlberg, G. T. Burrow, and J. P. Schuch, Selenium analyses by laboratory method]

Sample		Description	eU	U	V_2O_5	Se	As
Field	Laboratory		Percent			Parts per million	
114CR56	252420	Sandstone, gray, carbonaceous	0.56	0.30	0.1	275	930
115CR56	252421	do	.18	.20	.1	25	200
116CR56	252422	do	.15	.087	.1	50	115

Pit 5

[Analyses by C. G. Angelo, H. H. Lipp, E. J. Fennelly, J. S. Wahlberg, D. L. Skinner, Wayne Mountjoy, J. P. Schuch, and G. T. Burrow. Selenium analyses by laboratory method]

Sample		Description	eU	U	V_2O_5	Total Fe as Fe_2O_3	MnO	CaO	MgO	Se	As
Field	Laboratory		Percent							Parts per million	
86CR57	252423	0.3-foot channel sample; claystone, gray.	0.21	0.25	0.1	2.36	0.015	0.1	0.3	1	58
87CR57	252424	1.8-foot channel sample; sandstone, brown, carbonaceous, iron-stained.	.51	.13	.1	3.54	.212	3.6	.1	8	204
88CR57	252425	0.4-foot channel sample; claystone, gray.	.10	.043	.1	2.65	.019	.1	.1	4	78
89CR57	252426	3.8-foot channel sample; sandstone, brown, carbonaceous, iron-stained.	.029	.010	.1	2.57	.016	.6	.1	200	58
90CR57	252427	1.2-foot channel sample; sandstone, gray to black; pyrite; and black uranium mineral.	.28	.45	.1	2.20	.016	.2	.1	40	58
91CR57	252428	2.2-foot channel sample; sandstone and siltstone, gray, pyritiferous.	.12	.25	.1	3.28	.014	.2	.3	4	40
92CR57	252429	Grab sample; sandstone (carbonate-cemented concretion).	.15	.16	.1	6.45	.720	5.2	.2	3	22
93CR57	252430	1.6-foot channel sample; sandstone, brown to gray, carbonaceous, iron-stained.	.23	.034	.1	3.75	.016	1.2	.1	10	196
94CR57	252431	Channel sample; sandstone, gray to black, carbonaceous; pyrite; black uranium minerals.	2.1	1.56	.1	4.75	.013	.2	.1	100	875
97CR57	252432	Grab sample; sandstone, brown, carbonaceous, iron-stained.	.10	.016	.1	1.65	.376	3.5	.1	2	76
98CR57	252433	Channel sample; sandstone, gray, carbonaceous.	.17	.18	.1	.69	.464	4.8	.3	1	30
99CR57	252434	Channel sample; sandstone, gray, carbonaceous, pyrite.	.11	.12	.1	1.15	.029	1.3	.1	3	70
100CR57	252435	Channel sample; sandstone, brown, carbonaceous.	.016	.008	.1	1.75	.006	1.2	.1	300	58
103CR57	252436	Channel sample; sandstone, gray, pyrite.	.14	.14	.1	11.80	.039	4.9	.2	125	275
104CR57	252437	Channel sample; sandstone, gray, carbonaceous.	.16	.18	.1	1.07	.023	2.4	.1	8	58

TABLE 6.—*Chemical and semiquantitative spectrographic analyses of channel samples from Homestake Mining Co. pit 7, Hulett Creek area, Crook County, Wyo.*

[Laboratory-method analyses of selenium by G. T. Burrow. Spectrographic analyses by P. J. Dunton. M indicates major constituent; Tr. indicates trace. Looked for but not found: Na, K, P, Ag, As, Au, Be, Bi, Cd, Ce, Co, Cs, Dy, Er, Eu, Ga, Gd, Ge, Hf, Hg, Ho, In, Ir, In, Ir, La, Li, Lu, Mo, Nb, Ni, Os, Pb, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sc, Sm, Sn, Ta, Tb, Te, Th, Tl, Tm, W.]

Sample		Description	Chemical analyses (parts per million)	Semiquantitative spectrographic analyses (percent)		
Field	Laboratory		Se	Si	Al	Fe
D-96-57	256810	Sandstone, fine-grained, buff	200	M	0.7	0.7
97-57	256811	Sandstone, fine-grained, buff to brownish-gray.	800	M	1.5	1.5
98-57	256812	Sandstone, fine-grained, yellowish-brown	380	M	.7	.7
99-57	256813	do	100	M	.7	.3
100-57	256814	Sandstone, fine-grained, micaceous, brownish-gray.	220	M	1.5	.7
101-57	256815	Sandstone, fine-grained, yellowish-white to brownish-gray.	120	M	1.5	.3
102-57	256816	Sandstone, fine- to medium-grained, yellowish-brown.	80	M	.7	.15
103-57	256817	do	130	M	1.5	.7
104-57	256818	Sandstone, fine- to medium-grained, gray	80	M	.7	.3

Sample		Semiquantitative spectrographic analyses (percent)—Continued							
Field	Laboratory	Mg	Ca	Ti	Mn	B	Ba	Co	Cr
D-96-57	256810	0.015	0.03	0.15	0.003	---------	0.015	0.0007	0.00015
97-57	256811	.03	.03	.3	.007	.007	.015	.0007	.0007
98-57	256812	.03	.03	.15	.003	.003	.015	.0007	.0003
99-57	256813	.015	.03	.15	.003	.007	.015	---------	.00015
100-57	256814	.03	.03	.3	.003	.003	.015	.003	.0003
101-57	256815	.03	.03	.15	.003	.007	.015	---------	.00015
102-57	256816	.015	.015	.15	.003	---------	.007	---------	.00015
103-57	256817	.03	.03	.15	.003	.007	.015	---------	.0003
104-57	256818	.015	.03	.15	.003	.003	.015	---------	.00015

Sample		Semiquantitative spectrographic analyses (percent)—Continued							
Field	Laboratory	Cu	Ni	Sr	U	V	Y	Zr	La
D-96-57	256810	0.0007	0.0007	Tr.	---------	0.007	---------	0.015	---------
97-57	256811	.0015	.0007	0.0007	0.07	.03	0.0015	.03	0.007
98-57	256812	.0015	.0015	.0007	---------	.007	---------	.015	---------
99-57	256813	.0007	---------	Tr.	---------	.003	---------	.03	---------
100-57	256814	.0015	---------	.00015	---------	.03	.0015	.07	---------
101-57	256815	.0007	---------	.00015	---------	.03	---------	.03	---------
102-57	256816	.0007	---------	Tr.	---------	.003	---------	.015	---------
103-57	256817	.0007	---------	.00015	---------	.03	.0015	.015	---------
104-57	256818	.0007	---------	.00015	.07	.03	---------	.03	---------

Table 7.—*Chemical and semiquantitative spectrographic analyses of samples of a thin-bedded silty locally carbonaceous sandstone unit of the lower part of the Fall River Formation, Hulett Creek, Crook County, Wyo.*

[Laboratory-method analyses of selenium by G. T. Burrow. Spectrographic analyses by P. J. Dunton. M indicates major constituent. Looked for but not found: P, Ag, As, Au, Be, Bi, Cd, Ce, Dy, Er, Eu. Gd, Ge, Hf, Hg, Ho, In, Ir, La, Li, Lu, Nd, Os, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sc, Sm, Sn, Ta, Tb, Te, Th, Tl, Tm, W, Yb, Zn]

Sample		Description	Chemical analyses (parts per million)	Semiquantitative spectrographic analyses (percent)		
Field	Laboratory		Se	Si	Al	Fe
D-94-57	256808	0.5-foot channel sample; sandstone, fine-grained, brown.	50	M	1.5	1.5
93-57	256807	0.7-foot channel sample; interbedded sandstone and siltstone, light yellowish-gray to dark grayish-brown; abundant carbonaceous material.	100	M	3	.7
92-57	256806	0.5-foot channel sample; sandstone, fine-grained, brownish-gray.	80	M	3	.3
91-57	256805	1-foot channel sample; sandstone, fine-grained, tan.	280	M	1.5	.7
90-57	256804	0.5-foot channel sample; sandstone, fine-grained, tan.	120	M	1.5	.3
95-57	256809	Grab sample; thick pink efflorescent salt coating from sample D-92-57.	200	M	1.5	1.5

Sample		Semiquantitative spectrographic analyses (percent)									
Field	Laboratory	Mg	Ca	Na	K	Ti	Mn	B	Ba	Co	Cr
D-94-57	256808	0.03	0.07	0.15	--------	0.15	0.007	0.003	0.015	0.0003	0.0003
93-57	256807	.15	.15	.15	0.7	.3	.015	.007	.015	.0015	.0015
92-57	256806	.03	.03	.07	--------	.3	.007	.007	.015	.0003	.0007
91-57	256805	.07	.15	.15	--------	.3	.015	.007	.015	.0007	.0015
90-57	256804	.03	.03	.15	--------	.3	.007	.007	.015	--------	.0007
95-57	256809	.3	.3	.3	--------	.15	.07	.003	.015	.003	.0015

Sample		Semiquantitative spectrographic analyses (percent)									
Field	Laboratory	Cu	Ga	Mo	Ni	Sr	V	Y	Zr	Pb	U
D-94-57	256808	0.003	--------	--------	0.0007	0.003	0.007	0.0015	0.015	--------	------
93-57	256807	.0015	0.00015	--------	.0015	.0015	.007	.0015	.03	--------	------
92-57	256806	.003	--------	--------	.0007	.003	.007	.0015	.03	--------	------
91-57	256805	.0015	--------	--------	.0015	.003	.007	.0015	.015	--------	------
90-57	256804	.0007	--------	0.0015	--------	.0015	.003	.0015	.03	--------	------
95-57	256809	.015	--------	--------	.007	.003	.015	.0015	.015	0.0015	0.07

Two samples, one from Homestake Pit 1 (table 5, field sample 79CR56), and one from Homestake Pit 7 (table 6, field sample D-97-57), contain markedly more selenium than any other samples. These two samples are iron-stained, locally carbonaceous, fine-grained sandstone and contain, respectively, 900 and 800 ppm selenium.

In general, selenium content of most of the samples from the Northern Black Hills is low, and no relation between selenium contents and contents of any other metals appears to exist, although the sample from Homestake Pit 7 (table 6, field sample D-97-57) containing 800 ppm selenium is also the most manganiferous, and one of the most cupriferous of the samples from this pit. Selenium is probably present in these deposits as iron selenite (Byers and others, 1938) associated with limonite or hematite. Elemental selenium probably occurs locally, although none was recognized in the field.

Figure 3 shows the relation of the nine samples whose analyses are reported in table 6. No correlation exists between selenium content of samples and the location, or physical characteristic of the host rock.

Six carefully selected samples from a natural exposure of part of the uranium ore-bearing horizon of the Fall River Formation were analyzed chemically and spectrographically. The analyses are

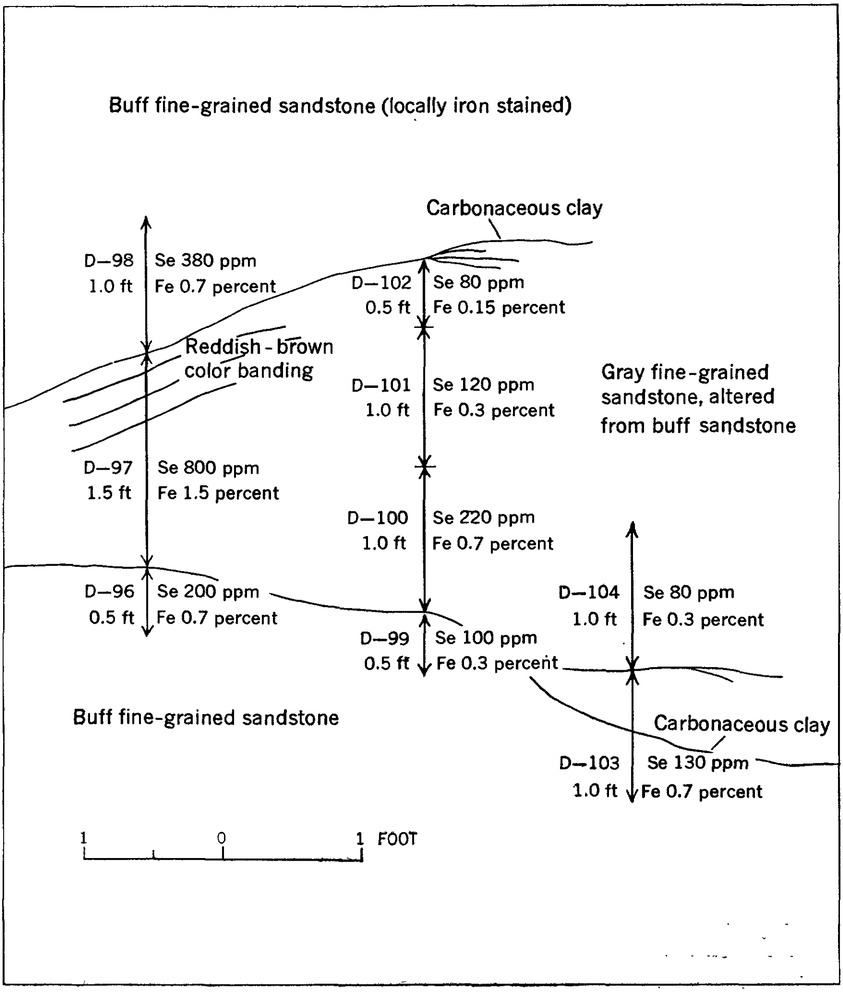

FIGURE 3.—Sketch showing relation of samples from Homestake Mining Co. pit 7, Hulett Creek, Crook County, Wyo. (See table 6.) Footage figures refer to length of sampled interval.

presented in table 11. Comparison of analyses shows no convincing correlation between selenium content of the samples and content of any other element, although rather hazy correlations may exist between selenium and calcium, manganese and chromium. Of particular interest in the group is the sample (field sample D-95-57) made up largely of efflorescent salts, for it contains 200 ppm selenium and 700 ppm uranium. These metal contents suggest that selenium and uranium are moving together in ground water, and perhaps in fairly high concentrations.

The uranium deposit at the Carlile mine (fig. 2) in the Carlile area, Crook County, Wyo., is a concentration of carnotite and tyuyamunite in sandstones of the Lakota Formation (Bergendahl, Davis, and Izett, 1961). Causes for localization of the uranium minerals are probably sedimentary structures, and differences of permeability in the host rock.

Bergendahl, Davis, and Izett (1961) state that the mineralogy of the Carlile deposit, and the lithologic features of the sandstone host rock suggest that uranium and vanadium were transported in the high-valent states by carbonate or sulfate solutions, were extracted from solution by organic material and were reduced to low-valent states to form an assemblage of oxides and silicates. These primary minerals were oxidized in place and the present carnotite-tyuyamunite assemblage was formed.

In general, radioactivity analyses of samples correspond very closely with the chemical analyses for uranium; thus it is probable that only minor solution and migration of uranium has occurred since the present suite of oxidized minerals was formed. This is of interest because the five samples seem to show a gross positive relationship between selenium content, and uranium, arsenic, and zinc content.

Following are selenium and other analyses for five samples from the Carlile uranium deposit:

Analyses of selected samples from the Carlile mine

[Analyses by C. G. Angelo, J. P. Schuch, Claude Huffman, J. S. Wahlberg, and G. T. Burrow. Selenium analyses by laboratory method]

Sample		U	P_2O_5	As	Zn	Se
Field	Laboratory	Percent		Parts per million		
B-13	252315	1.95	0.07	225	94	590
B-11	252314	.76	.16	110	15	470
B-27	252316	.44	.05	85	9	730
B-37	252318	.13	.10	40	6	200
B-29	252317	.006	.05	5	1	75

The selenium in these samples probably is in the selenite state, associated with iron in limonite and hematite. This type of occurrence in the Gas Hills in Wyoming has been discussed by Lakin and Trites (1958). Some selenium possibly is present in elemental form, but it was not recognized in the field.

SOUTHERN BLACK HILLS—GOULD MINE

The Gould mine in the Edgemont area (fig. 2) has been well described by Cuppels (1962) and much of the descriptive material following has been taken from his report.

The Gould mine is in one of the largest oxidized uranium deposits of the Black Hills. The deposit consists of concentrations of hydrated vanadates of uranium distributed irregularly through a zone 1 to 15 feet thick near the middle of a thick sandstone of the Lakota Formation. Cuppels states that the distribution of uranium has been controlled by fractures and differential permeability of the host rock. He believes that the deposit is the product of a redistribution of the components of an earlier unoxidized ore body.

Selenium and other analyses of 63 samples collected at the Gould mine by Cuppels, and other geologists are presented in table 8.

No meaningful relation between selenium content of samples and any other measured constituent is shown. Some reasons for this lack of correlation, and the generally low selenium content of the Gould deposit, are discussed later in this report.

The form in which the small amount of selenium present occurs is not known.

TABLE 8.—*Chemical analyses of samples of uraniferous sandstone, Gould mine, Fall River County, S. Dak.*

[Analyses by Maryse Delevaux, H. E. Crowe, R. R. Beins, R. P. Cox, J. P. Schuch, J. S. Wahlberg, E. C Mallory, Jr., J. E. Wilson, G. T. Burrow, W. D. Goss, W. R. Weston, C. G. Angelo, Mary Finch G. Edgington, A. Sweeney, and P. Moore. Selenium analyses by laboratory method]

Sample		Description	As	Se	Zn	U	V_2O_5	Total Fe as Fe_2O_3
Field	Laboratory		Parts per million					
F37484	227423	Channel sample; sandstone	500	20	20	200	--------	--------
F37485	227424	do	200	5	20	12,600	--------	--------
F37486	227425	do	250	1	20	600	--------	--------
F37487	227426	do	350	20	20	2,500	--------	--------
F37494	227186	do	700	7	20	800	--------	--------
F37495	227187	do	1,600	20	20	700	--------	--------
F37500	227188	do	300	10	20	1,400	--------	--------
F37754	227375	do	50	3	20	1,700	--------	--------
F37759	227379	do	300	7	20	2,800	--------	--------
F37765	227382	do	50	1	20	1,700	--------	--------
F37766	227383	do	100	10	20	2,600	--------	--------
F37769	227385	do	200	7	20	1,000	--------	--------
F37770	227386	do	100	1	20	1,400	--------	--------
F37775	227389	do	50	5	20	1,900	--------	--------
F37776	227390	do	100	1	20	800	--------	--------
F37495	238715	do	250	10	20	13,000	--------	--------
F37496	238716	Channel sample; sandstone, friable.	350	10	20	16,000	--------	--------
F37497	238717	Channel sample; sandstone, iron-stained.	600	10	20	9,000	--------	--------
F37498	238718	do	600	7	20	8,000	--------	--------
F37499	238719	Channel sample; sandstone, iron-stained, friable.	600	10	20	21,000	--------	--------

TABLE 8.—*Chemical analyses of samples of uraniferous sandstone, Gould mine, Fall River County, S. Dak.*—Continued

Sample		Description	As	Se	Zn	U	V_2O_5	Total Fe as Fe_2O_3
Field	Laboratory		Parts per million					
F37760	238720	Channel sample; sandstone, iron-stained.	300	3	20	22,000	------	------
F37761	238721	do	300	3	20	12,000	------	------
F37762	238722	do	70	1	20	6,000	------	------
F37203	225377	Channel sample; sandstone	250	5	20	2,000	------	------
F37205	225379	do	100	7	20	600	------	------
F37207	225381	do	150	5	20	300	------	------
F37210	225384	do	350	3	20	12,600	------	------
F37211	225385	do	250	1	20	1,800	------	------
F37237	225845	do	300	20	20	1,500	------	------
F37239	225847	do	100	2	20	2,000	------	------
BB-92-54	240465	Channel sample; sandstone, iron-stained; yellow uranium minerals.	76	10	------	950	1,600	21,000
BB-93-54	240466	Channel sample; sandstone, iron-stained.	290	12	------	640	3,900	34,700
BB-94-54	240467	do	54	15	------	40	<1,000	27,100
BB-95-54	240468	Channel sample; sandstone, white.	59	5	------	70	<1,000	24,900
BB-96-54	240469	Channel sample; sandstone, iron-stained; yellow uranium minerals.	164	8	------	2,300	1,900	27,400
BB-97-54	240410	Channel sample; sandstone, iron-stained.	323	12	------	110	3,300	34,000
BB-98-54	240471	Channel sample; sandstone, contains clay galls.	129	20	------	520	2,100	19,900
BB-99-54	240472	Channel sample; sandstone, iron-stained.	235	15	------	80	1,400	36,000
BB-100-54	240473	Channel sample; sandstone, bleached.	130	10	------	50	<1,000	19,300
BB-101-54	240474	Channel sample; sandstone, iron-stained.	196	15	------	200	2,100	35,700
1 NPC-55	140900	Sandstone, iron-stained; yellow uranium mineral.	390	8	------	6,700	------	------
2NNPC-55	140901	do	340	10	------	1,700	------	------
3 NPC-55	140902	Sandstone, iron-stained	510	7	------	110	------	------
4 NPC-55	140903	Sandstone	210	20	------	2,700	------	------
5 NPC-55	140904	Sandstone; yellow uranium mineral.	170	7	------	1,700	------	------
6 NPC-55	140905	do	490	40	------	1,300	------	------
7 NPC-55	140906	Sandstone, iron-stained	450	20	------	60	------	------
8 NPC-55	140907	Claystone, silty, white to light gray.	410	50	------	50	------	------
10 NPC-55.	140908	Sandstone, laminae of clay and silt.	240	8	------	4,600	------	------
11 NPC-55.	140909	Sandstone, iron-stained; yellow uranium mineral.	230	9	------	2,500	------	------
12 NPC-55.	140910	Sandstone, iron-stained	210	<3	------	4,000	------	------
13 NPC-55.	140911	Sandstone	80	4	------	1,300	------	------
14 NPC-55.	140912	do	110	<3	------	5,500	------	------
15 NPC-55.	140913	do	70	<3	------	2,700	------	------
16 NPC-55.	140914	do	40	<3	------	2,800	------	------
17 NPC-55.	140915	Clay, yellow-stained	170	100	------	70	------	------
18 NPC-55.	140916	Sandstone, iron-stained; yellow uranium mineral.	690	10	------	14,000	------	------
19 NPC-55.	140917	Sandstone	900	10	------	2,100	------	------
20 NPC-55.	140918	Conglomerate, clay, and sandstone.	100	<3	------	880	------	------
21 NPC-55.	140919	Sandstone, iron-stained	580	30	------	120	------	------
22 NPC-55.	140920	Sandstone, iron-stained; yellow uranium mineral.	390	<3	------	22,000	------	------
23 NPC-55.	140921	Sandstone	100	<3	------	4,200	------	------
24 NPC-55.	140922	Conglomerate, clay, and sandstone, iron-stained.	470	<3	------	5,200	------	------

DEPOSITS IN CENOZOIC ROCKS

According to Finch (1956) uranium occurs in Cenozoic rocks in the Wyoming basins, and the northern Great Plains region; in the Gulf Coastal Plain in Texas; in the Nevada basins; and in California lake beds. In the Wyoming basins and the northern Great Plains region, uranium and uranium-vanadium deposits occur mainly in sandstone (commonly tuffaceous and muddy) and arkose formations that range from Paleocene to Pliocene in age. In the Texas Coastal Plain region, oxidized uranium deposits with minor amounts of vanadium and copper occur in tuff and sandstone formations of Eocene and perhaps Oligocene age. In Nevada and California, uranium deposits occur in tuffaceous sandstones of the Miocene and Pliocene lake beds.

Selenium analyses are available from some deposits of the Wyoming basins and the Texas Coastal Plain; consequently, these deposits are discussed in this report.

NORTHERN POWDER RIVER BASIN

According to Sharp, McKeown, McKay, and White (1956) ore deposits in the Pumpkin Buttes, or northern area, of the Powder River Basin of Wyoming (fig. 1), occur in the Eocene Wasatch Formation, which is about 1,500 feet thick and is composed of claystone, siltstone, lignite, carbonaceous shale, sparse limestone beds, and sandstone.

The deposits occur in sandstone in an elliptical area of about 300 square miles, with Pumpkin Buttes in the center. Within the area about 1,000 feet of the Wasatch Formation is exposed. Sandstone lenses containing ore are in the lower half of the exposed section.

Chief uranium minerals are uranophane, metatyuyamunite, carnotite, and uraninite. Paramontroseite is associated with secondary uranium minerals in several deposits.

Occurrences of uranium are classified by their habits and mineralogic associations. Three main types of occurrences are recognized: uranium minerals disseminated in porous sandstone, or concentrated around calcite-enriched sandstone; oxidized uranium minerals closely associated with manganese oxide concretions; and uraninite concretions occurring with pyrite.

In general, disseminated uranium minerals are found in buff sandstone lenses especially at or near the contact of buff sandstone with red sandstone. The uranium minerals occur chiefly as interstitial fillings, replacing calcite, or filling cracks in calcite. Field testing has shown that these deposits are not very seleniferous.

The nodular ores consist of secondary uranium minerals associated with concretionary nodules of black iron-rich manganese oxide, which cements and replaces sandstones. The nodules are found within red sandstones and seem to have no consistent areal or stratigraphic pattern of distribution within individual sandstone lenses. Field testing indicates that the selenium content of these deposits is low.

Uraninite that cements sands into rounded concretionary nodules is found in places at two of the larger mines of the area, although most of the ore at these deposits is oxidized. The uraninite is commonly associated with pyrite. The pyrite occurs either as the core of a rounded mass of uraninite or as a small rounded mass at the edge or within the mass of uraninite. All uraninite concretions are surrounded by a thick layer of oxidized uranium minerals. Uraninite rims sand grains and fills interstices.

The pyrite-uraninite deposits contain high concentrations of selenium. Table 9 lists analyses of five samples from the deposits of this type. Crystalline elemental selenium occurs locally in these deposits and probably also occurs as a substitute for sulfur in pyrite.

The uranium deposits of the northern Powder River Basin are thought to have been formed by the redistribution and concentration of the original uranium, vanadium, iron, and manganese contents of the sandstone lenses.

TABLE 9.—*Selenium analyses of samples from the northern Powder River Basin, Campbell County, Wyo.*

[Chemical analyses (laboratory method) by G. T. Burrow]

Sample		Description	Locality	Selenium (parts per million)
Field	Laboratory			
D-85-57	256799	Grab sample; black and yellow pyritiferous uraniferous sandstone.	Blowout mine	1,900
86-57	256800	Grab sample; red crystalline coating on yellow uraniferous sandstone.	do	430
87-57	256801	Grab sample; red sandstone	do	900
88-57	256802	Grab sample; yellow uraniferous sandstone.	Jeanette mine	1,000
89-57	256803	Grab sample; yellow and red uraniferous sandstone.	do	1,100

SOUTHERN POWDER RIVER BASIN

The uranium deposits of the southern Powder River Basin (fig. 1) are similar to those of the Pumpkin Buttes area to the north, and, according to Sharp and White (1955), are in a zone of randomly spaced red, or partly red, sandstone lenses that extend northward to the Pumpkin Buttes area along the center of the exposed Wasatch Formation.

Uranium deposits tend to be located at the color contact between red sandstone and gray-buff sandstone. Sharp and White (1955) state that along this contact concretions of uranium minerals tend to concentrate in a zone peripheral to calcite; that coalified wood fragments are abundant in the deposits; and that yellow uranium minerals are abundant on these fragments in some places. Carnotite and tyuyamunite are the ore minerals. Uranophane is sometimes found and where present generally occurs with manganese oxide nodules. Manganese oxides enclose or are mixed with uranium minerals and are found in red sandstone.

Field testing seems to demonstrate that deposits consisting largely of uranophane associated with manganese oxide nodules are low in

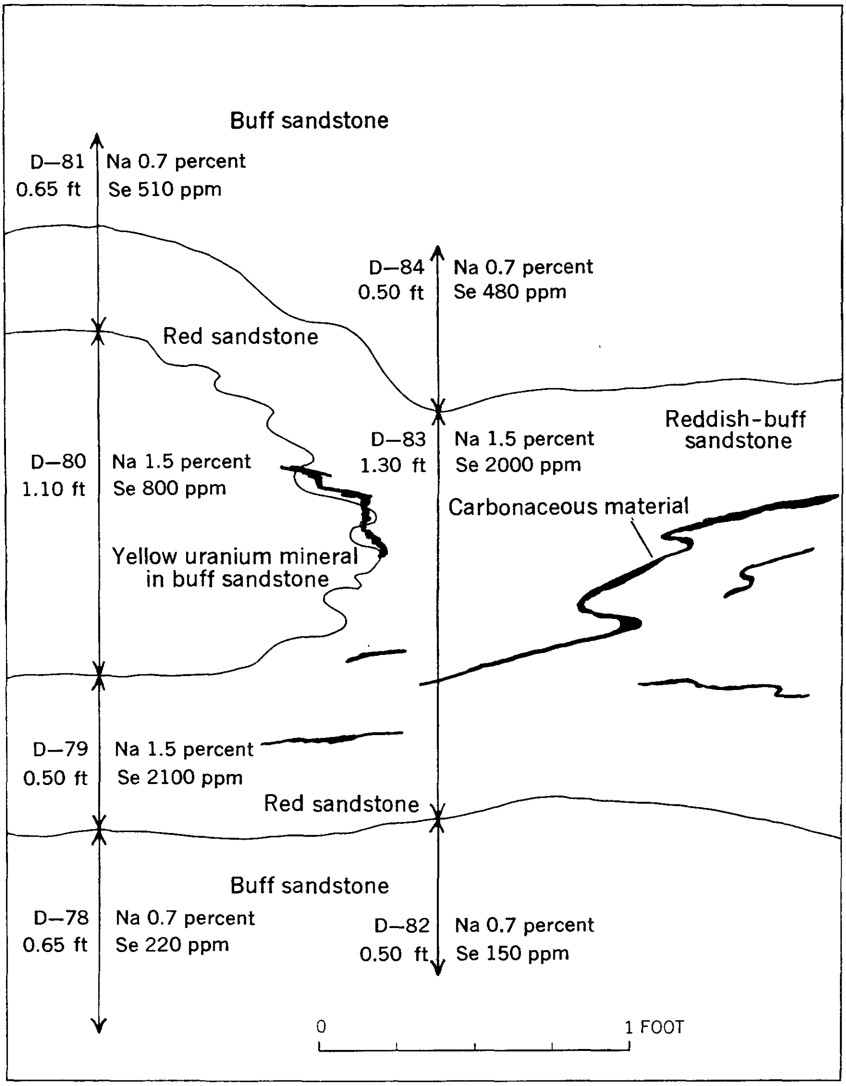

FIGURE 4.—Sketch showing relation of channel samples from Sodak Mining Co. Pit, Converse County, Wyo. (See table 10.) Footage figures refer to length of sampled interval.

selenium content. However those deposits consisting largely of carnotite or tyuyamunite are often locally highly seleniferous. Table 10 presents the analyses of samples from a carnotite-type deposit mined by the Sodak Mining Co. Figure 4 shows the relation of the samples.

Selenium is present in elemental form, and is associated with iron in limonite, and with hematite(?), where the selenium is probably mostly in the selenite state (Byers and others, 1938).

TABLE 10.—*Chemical and semiquantitative spectrographic analyses of channel samples from a uranium mining pit of the Sodak Mining Co., Converse County, Wyo.*

[Laboratory-method analyses of selenium by G. T. Burrow. Spectrographic analyses by P. J. Dunton. M indicates major constituent. Looked for but not found: P, Ag, As, Au, B, Bi, Cd, Ce, Dy, Er, Eu, Gd, Ge, Hf, Hg, Ho, In, Ir, La, Li, Lu, Mo, Nb, Nd, Os, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sc, Sn, Sm, Ta, Tb, Te, Th, Tl, Tm, W, Yb, Zn]

Sample		Description	Chemical analyses (parts per million)	Semiquantitative spectrographic analyses (percent)	
Field	Laboratory		Se	Si	Al
D-78-57	256792	Sandstone, medium- to coarse-grained, clayey, pinkish-gray.	220	M	7
79-57	256793	Sandstone, medium- to coarse-grained, slightly clayey, brownish-gray.	2100	M	7
80-57	256794	Sandstone, medium- to coarse-grained, slightly clayey, yellow and yellowish-gray; some carbonaceous material.	800	M	7
81-57	256795	Sandstone, medium- to coarse-grained, slightly clayey, reddish-gray.	510	M	7
82-57	256796	Sample; sandstone, medium- to coarse-grained, moderately clayey, yellowish-gray.	150	M	7
83-57	256797	Sandstone, coarse- to medium-grained, moderately clayey, brownish-red.	2000	M	7
84-57	256798	Sandstone, fine- to medium-grained, slightly clayey, light brownish-gray.	480	M	7

Sample		Semiquantitative spectrographic analyses (percent)									
Field	Laboratory	Fe	Mg	Ca	Na	K	Ti	Mn	Ba	Be	Co
D-78-57	256792	0.7	0.3	0.3	0.7	3	0.07	0.015	0.07	--------	0.0003
79-57	256793	.3	.3	.3	1.5	3	.07	.015	.07	0.00015	.0015
80-57	256794	.7	.3	.7	1.5	3	.07	.015	.07	.00015	.003
81-57	256795	.3	.3	.3	.7	3	.07	.007	.03	.00015	.0007
82-57	256796	.3	.3	.3	.7	3	.07	.007	.03	--------	-------
83-57	256797	.3	.3	.3	1.5	3	.07	.015	.07	.00015	.0015
84-57	256798	.3	.3	.3	.7	3	.07	.007	.03	--------	.0003

Sample		Semiquantitative spectrographic analyses (percent)									
Field	Laboratory	Cr	Cu	Ga	Ni	Pb	Sr	U	V	Y	Zr
D-78-57	256792	0.0003	0.0007	0.0003	0.0007	0.0015	0.007	0.07	0.015	0.0015	0.015
79-57	256793	.0003	.0003	.0003	.0003	.003	.007	.7	.07	.0015	.015
80-57	256794	.0007	.0007	.0003	.0003	.007	.015	3	.15	.003	.015
81-57	256795	.0003	.0003	.00015	.0003	.003	.007	.3	.03	.0015	.007
82-57	256796	.0003	.0003	.00015	.0007	.0015	.003	-------	.015	-------	.015
83-57	256797	.0003	.0003	.00015	.0007	.003	.007	.3	.07	.0015	.015
84-57	256798	.0003	.0003	.00015	.0007	.0015	.003	-------	.015	-------	.007

The data seem to show a highly seleniferous halo around the most uraniferous rock. Distribution of sodium seems to parallel distribution of selenium but there are no clear-cut correlations between selenium content of samples and the contents of any other elements for which analyses are available.

Table 11 shows the analyses of 4 samples of a "concretion" from a mining pit in the southern Powder River Basin. The banding of the selenium concentration is very obvious, and there is a suggestion that selenium is forming a halo around the most uraniferous material. In this concretion there appears to be a correlation between selenium and sodium, and selenium and chromium, but there were so few samples analyzed that this relation may not be a real one.

TABLE 11.—*Chemical and semiquantitative spectrographic analyses of four samples of a concretion from an abandoned uranium mining pit, Converse County, Wyo.*

[Laboratory-method analyses of selenium by G. T. Burrow. Spectrographic analyses by P. J. Dunton. M indicates major constituent. Looked for but not found: P, Ag, As, Au, B, Bi, Cd, Ce, Dy, Er, Eu, Gd, Ge, Hf, Hg, Ho, In, Ir, La, Li, Lu, Mo, Nb, Nd, Os, Pd, Pr, Pt, Re, Rh, Ru, Sb, Sc, Sn, Sm, Ta, Tb, Te, Th, Tl, Tm, W, Yb, Zn]

Sample		Description	Chemical analyses (parts per million)	Semiquantitative spectrographic analyses (percent)	
Field	Laboratory		Se	Si	Al
D-71-57	256786	Chip sample; sandstone, medium- to coarse-grained, light-brown to reddish-brown, slightly clayey. Inner core of concretion.	380	M	M
72-57	256787	Chip sample; sandstone, medium- to coarse-grained, reddish-gray, moderately clayey. First layer surrounding core of concretion.	2100	M	7
73-57	256788	Chip sample; sandstone, medium- to coarse-grained, yellowish-white, moderately clayey, has bleached appearance. Second layer surrounding core of concretion.	240	M	7
74-57	256789	Chip sample; sandstone, medium- to coarse-grained, reddish-gray with slight whitish mottling, moderately clayey. Outer layer of concretion.	4500	M	7

Sample		Semiquantitative spectrographic analyses (percent)									
Field	Laboratory	Fe	Mg	Ca	Na	K	Ti	Mn	Ba	Be	Co
D-71-57	256786	0.7	0.3	0.7	1.5	3	0.003	0.007	0.00015	0.00015	0.0007
72-57	256787	.3	.3	.3	.7	3	.03	.03	.07	.00015	.0007
73-57	256788	.3	.3	.15	1.5	3	.03	.007	.07	---------	.0003
74-57	256789	.3	.3	.15	.7	3	.03	.007	.07	---------	.0003

Sample		Semiquantitative spectrographic analyses (percent)									
Field	Laboratory	Cr	Cu	Ga	Ni	Pb	Sr	U	V	Y	Zr
D-71-57	256786	0.0003	0.0007	0.0007	0.0007	0.03	0.015	0.15	0.07	0.0015	0.015
72-57	256787	.00015	.0003	.0007	.0007	.007	.007	.3	.07	.0015	.007
73-57	256788	.0003	.00015	.0007	.0007	.003	.007	------	.03	-------	.007
74-57	256789	.00015	.0003	.0007	.0007	.003	.007	------	.03	.0015	.007

TEXAS COASTAL PLAINS—KARNES COUNTY

Finch (1956) states that uranium deposits in Tertiary rocks occur in tuff and tuffaceous sandstone formations of late Eocene or early Lligocene age in southeastern Texas and in a limy sandstone unit of Pliocene age in western Texas. The small deposits in western Texas, which contain less vanadium than uranium, consist of metatyuyamunite in vugs in limy sandstone.

Large oxidized uranium deposits containing minor vanadium and copper occur in southern Texas in the flat-lying Jackson Group of Eocene age and possibly in overlying beds of Oligocene age. The ore-bearing beds consist of poorly bedded, mostly unconsolidated, marine, brackish-water, nearshore deposits and of continental beds of light-colored tuff, sand, and sandy clay.

Yellow and green uranium minerals. probably uranium phosphate and silicate minerals, occur along fractures, bedding planes, and disseminated in the rock. Large amounts of arsenic and molybdenum are reported to occur with the uranium. The most uraniferous rock appears to be associated with hydrated iron oxides, bentonite, and rocks that are characterized by mixed and irregular bedding. Carbonaceous material is rare and commonly shows no spatial relation to the ore. The deposits range in size from bodies a few feet across to those that contain many thousands of tons of ore.

According to Eargle and Snyder (1957), uranium minerals or radioactive rocks have been found in tuffaceous sand, silt, or bentonitic clay in at least 7 different stratigraphic positions ranging in age from late Eocene to Pliocene. The known radioactive minerals occur in the Goliad Sand of Pliocene age, the Oakville Sandstone of Miocene age, and the Catahoula Tuff of Miocene(?) age in Duval County; in the Oakville Sandstone and the upper 500 feet of the Jackson Group in Karnes County; and in the Catahoula Tuff in Gonzales County (general location of the deposits in Karnes County is shown on fig. 1).

In Karnes County uranium minerals have been found only rarely deeper than 30 feet below the surface chiefly filling interstices between, and replacing, the grains of a sandstone that lies above impervious clay. Some of the clay also contains uranium minerals, generally as a coating along joint and bedding planes. The richest concentrations of uranium, however, are found in sand that has a clayey matrix. Some of the sand beds contain clay pebbles and small fragments of carbonaceous material.

Although detailed mineralogic studies have not been made, the following uranium minerals have been identified: Autunite, carnotite, tyuyamunite, uranophane, schroeckingerite, and schoepite. Other epigenetic minerals such as pyrite, hematite, sphalerite, and ilsemannite are associated with the uranium minerals at one prospect. Detrital minerals of the ore-bearing sandstones include many derived from igneous rock sources.

A. D. Weeks (1956) noted pyrite and marcasite in drill cores from two prospects; Coleman and Delevaux (1957) reported sulfides from drill core containing as much as 240 ppm selenium.

In the walls of pits at one prospect, uranium minerals are found chiefly near the base of the channel-filling sandstones, closely associated with dark streaks of manganese dioxide and disseminated through the clayey material beneath the sands, particularly along joint and bedding planes. The deposits probably are in either the basal beds of the sands and clays of the Dubose Member of the Whitsett Formation or in the upper part of the Stones Switch Sandstone Member of the Whitsett Formation.

Eargle and Snyder (1957) believe that the source of the uranium was in the tuffaceous sediments and that the uranium leached from the tuffaceous sediments was concentrated by evaporation or by interaction with clays and carbonaceous or other materials where ground waters were concentrated in stratigraphic or structural (fault) traps or channels.

Table 12 presents selenium and uranium analyses of 16 samples from the Texas Coastal Plains region. Selenium content of the sam-

TABLE 12.—*Selenium and uranium analyses of samples from the Coastal Plains region, Karnes County, Tex.*

Sample		Locality	Description	Se	U
Field	Laboratory			Parts per million	
T-Se-131		Korzekwa property	Sandstone, uraniferous	[1] 50	[2] 720,000
F-47221	256845	Bargmann tract	do	[1] .5	[2] 460
F-47220	256846	do	Sandstone	[1] .5	[2] 150
F-47225	256847	do	Sandstone, uraniferous	[1] 4	[2] 1,300
F-47217	256848	do	do	[1] 20	[2] 1,100
F-47249	256851	Lyssy-Nistroy tract	do	[1] 2	[2] 280
F-47236	256861	Peyton-Jandt tract	Sandstone	[1] <.5	[2] <10
F-47238	256869	Pavelek property	do	[1] .5	[2] 10
167	56-38	Lyssy property	Sandstone, uraniferous, yellow	[3] 70	[4] 1,300
166	56-37	do	Sandstone, uraniferous, black	[3] 7	[4] 1,400
164	56-35	do	Soil, sandy, yellow	[3] <1	--------
501	56-42	Korzekwa property	Sandstone, uraniferous, yellow	[3] <1	[4] 51,300
561	56-43	Lyssy property	do	[3] 3	[4] 43,600
F-32419	225877	Karnes County	do	[5] 13	[6] 98,200
F-32421	225878	do	do	[5] 8	[6] 72,200
T-Se-81	55-4779	Jaffe lease	Sandstone, uraniferous	[7] <1	--------

[1] Laboratory-method analyses by G. T. Burrow.

[2] Analyses by E. J. Fennelly.

[3] Field-method analyses by H. E. Crowe.

[4] Analyst not known.

[5] Analyses by C. G. Angelo and J. S. Wahlberg.

[6] Analyses by C. G. Angelo, J. S. Wahlberg, R. F. Dufour, and Wayne Mountjoy.

[7] Field-method analyses by H. E. Crowe, J. E. Swick, and R. R. Beins.

ples is low and there appears to be no relation between the selenium and uranium content of the samples.

BAGGS AREA, WYOMING AND COLORADO

The uranium deposits of the Baggs area (figure 1) are in the Miocene(?) Browns Park Formation, and are much like those already described in Tertiary rocks in other areas—for example, those in the southern Powder River Basin.

Prichard (1956) reports that uranium, selenium, molybdenum, and arsenic occur together at the top of the unoxidized, and in the lower 3 feet of the oxidized, zone in the uranium deposits of the Poison Buttes claim group. Secondary uranium minerals are present higher in the oxidized zone, but selenium, molybdenum, and arsenic are present in only very small amounts, or are entirely absent. Data in table 13 illustrate the relation of the metals to the top of the unoxidized zone. There seems to the writer to be little doubt that a zone of secondary enrichment exists in these deposits approximately at the contact of the oxidized and unoxidized zone. Presumably, selenium has been leached from rocks higher in the section, moved downward, and redeposited near this contact.

TABLE 13.—*Chemical analyses of selected elements in samples of mineralized sandstone from the Poison Buttes claim group, Wyo.*

[Field-method analyses by H. E. Crowe, R. W. Weston, C. E. Thompson, J. T. Slayback, C. G. Angelo, Mary Finch, G. T. Burrow, and J. P. Schuch]

Sample		Se	As	Mo	U	Position of sample in relation to top of unoxidized zone
Field	Laboratory	Parts per million				
T-Se-109	55-5649	50	50	40	400	40 feet above.
T-Se-96	55-5636	30	100	400	400	23 feet above.
T-Se-99	55-5639	30	200	400	800	8 feet above.
T-Se-101	55-5641	2,000	800	2,000	2,000	3 feet above.
T-Se-106	55-5646	2,000	1,600	>2,000	3,500	2 feet above.
T-Se-104	55-5644	3,000	400	600	2,500	Top 1 foot of unoxidized zone.

This secondary enrichment results in a gross positive correlation between selenium and uranium, arsenic and molybdenum in samples from this district.

Some elemental selenium is present in these deposits, but much of the selenium of the enriched zone is probably substituting for sulfur in sulfide minerals. It is possible that some selenide minerals occur, but to this date, none have been recognized.

Table 14 presents analyses of 12 other samples from the area. These analyses suggest that in the Poison Basin area as a whole there is no detailed and systematic variation of selenium content with the content of any other element for which analyses are available.

TABLE 14.—*Chemical analyses of some samples from the Poison Basin area, Carbon County, Wyo.*

[Laboratory-method analyses by C. G. Angelo, Mary Finch, G. T. Burrow, and J. P. Schuch]

Sample		Description and locality	As	Zn	Se	Mo	U
Field	Laboratory		Parts per million				
PW4-26	225093	Channel sample; sandstone, calcareous; sec. 32, T. 13 N., R. 92 W.	40	50	1	40	110
27	225095	Channel sample; sandstone, calcareous, sec. 4, T. 12 N., R. 92 W.	20	100	9	20	200
27a	225096	Channel sample; sandstone; sec. 4, T. 12 N., R. 92 W.	50	70	60	10	1,700
27d	225098	Channel sample; sandstone, calcareous; sec. 4, T. 12 N., R. 92 W.	20	80	100	20	500
28	225099	do	40	20	3	>800	80
28a	225100	Grab sample; sandstone, carbonaceous, calcareous; sec. 4, T. 12 N., R. 92 W.	60	20	4	>800	30
30	225101	Channel sample; sandstone; sec. 4, T. 12 N., R. 92 W.	10	20	9	40	30
31	225102	Channel sample; sandstone; sec. 35, T. 13 N., R. 93 W.	20	50	9	60	80
31a	225103	do	20	30	20	60	110
31b	225104	do	20	50	8	60	220
33	225105	Grab sample; sandstone, silicified (?); sec. 1, T 12 N., R. 93 W.	20	30	7	20	30
34	225106	Channel sample; sandstone; sec. 31, T. 13 N., R. 92 W.	20	30	9	100	30

DISCUSSION

Selenium, generally considered to be a rare and dispersed element with a low crustal abundance (0.09 ppm, Goldschmidt, 1954) has been shown by the data presented in this report to be greatly enriched in some oxidized sandstone-type uranium deposits. The data also demonstrate the erratic distribution of selenium in many deposits of this type and also that it is difficult to correlate selenium content with the content of any other analyzed constituent of these deposits.

However, three patterns of selenium distribution, probably caused by oxidation subsequent to original deposition of uranium and selenium, can be recognized.

1. The first pattern is exemplified by the Carlile uranium deposit of the northern Black Hills which shows a correlation between selenium and uranium contents, and between selenium and some other measured constituents of the deposit. Bergendahl, Davis, and Izett (1961) have stated that this deposit consists of secondary uranium minerals that are thought to have formed by oxidation in place of primary uranium oxide and silicate minerals.
2. The deposit at the Gould mine in the southern Black Hills, on the other hand, is said to be the product of movement and redistribution of the components of an earlier unoxidized uranium deposit (Cuppels, 1962). The present uranium deposit is an example of pattern two; selenium contents are low, and there seems to be no demonstrable relation of selenium content to the content of any other measured constituent of the ore body. It

must be pointed out at this juncture that both the Carlile and Gould deposits are at this time entirely in the zone of oxidation.

3. Prichard's data (1956), from the Poison Buttes claims near Baggs, Wyo., present a picture of pattern three: supergene enrichment of selenium, arsenic, molybdenum, and uranium at the top of the present unoxidized zone. At this deposit it seems almost certain that the metals were deposited in what is now the oxidized zone, were mobilized during oxidation, moved downward a short distance, and redeposited under reducing conditions. Great concentrations of these metals occurred as a result of this process.

The chemical reasons for the somewhat different behavior of selenium and uranium in each of these deposits have been summed up ably by Lakin and Trites (1958), and Garrels and Christ (1959). A statement of the findings of these workers as they relate to the distribution of selenium and uranium in the deposits described here may not be out of place.

In all three deposits, selenium was probably originally present in selenide form, or substituting for part of the sulfur of sulfide minerals. Such occurrence of selenium has been shown by Coleman and Delevaux (1957) to be common in sandstone-type uranium deposits of the western United States. Uranium was most likely present in silicate or oxide minerals.

Oxidation, without too much circulation of ground or meteoric water through an oxidizing ore body, will break down selenide and sulfide minerals to elemental selenium, selenites, and eventually to selenates and sulfates. Elemental selenium and selenites are rather insoluble and will stay in place even under severe leaching conditions, but sulfate salts are more soluble and are in large part removed by leaching. Uranium oxide and silicate minerals will, under such conditions, and in the presence of vanadium, oxidize to carnotite and tyuyamunite—stable vanadate minerals—and are likely to stay in place. The Carlile deposit shows such a pattern of metal distribution.

Presumably at the Gould deposit oxidation began in the same way as at the Carlile deposit, but at the Gould deposit sufficient water was present to permit leaching and removal of some constituents of the deposit relative to other constituents. Selenium in the selenate state is leachable and probably was rapidly removed. Cuppels (1962, p. 82) notes that uranium seems to have been moved only short distances, for radioactivity determination of uranium daughter products, and chemical analyses for uranium indicate that the bulk of the Gould deposit is in equilibrium. There is an excess of vanadium at this deposit indicating that more than enough vanadium was present at the start of the oxidation process to retain uranium in the deposit by rapidly tying it up in the vanadate minerals carnotite, tyuyamunite, and metatyuyamunite.

At the Poison Buttes claims near Baggs, Wyo., a rather different sequence of events seems to have taken place. The reduced uranium minerals, and selenium-containing minerals of the original deposit presumably were oxidized in the presence of a moderate amount of water and both uranium and selenium were mobilized.

As noted before, selenium in the selenate state is leachable in water, and is here presumed to have migrated downward. Uranium freed by oxidation from the reduced ore minerals probably joined with sulfur freed from oxidizing sulfide minerals to form water-soluble uranyl sulfate salts, and in the absence of sufficient vanadium to form insoluble vanadates, it too moved downward. The metals thus were carried to the boundary between the zone of oxidation and the reduced zone, probably the water table, and were there reprecipitated forming the enriched deposit that is the present ore deposit.

Regarding the ultimate source of the selenium in seleniferous sandstone-type uranium deposits, there can be no more certainty than for the uranium in the deposits, because it seems almost certain that the selenium and uranium were concentrated in the deposits at the same time. As anyone who has kept up with geologic literature describing or discussing the origin of sandstone-type uranium deposits is aware, there are nearly as many hypotheses of origin of such deposits as there are deposits; some argue that the deposits are hydrothermal, others that they have accumulated by concentration of uranium contained in the host rock when the host rocks were deposited. Still others suggest that the deposits have been formed by uranium which was deposited in other nearby rocks, particularly tuffs, leached from these source beds and deposited in the present host rocks.

Any or all of these arguments can be called upon to explain the presence of selenium in these uranium deposits, for certain parallels in behavior and distribution between the two metals have been recognized. Garrels (1957) for example has suggested that alkaline solutions have probably been the transporters of the uranium now found in sandstone-type deposits. Lakin (oral communication, 1958) states that it is his opinion that alkaline solutions are probably better carriers of selenium than neutral or slightly acid solutions.

The fact that selenium is transported by hydrothermal solutions is well shown by a study (Davidson, 1960) of a number of selenium-bearing silver and antimony deposits. It may also be concluded that selenium and uranium may be carried together in hydrothermal solutions because selenium minerals are known to occur in pitchblende deposits (S. C. Robinson, 1950).

The suggestion made by Denson (1955), Eargle and Snyder (1957), and others that the uranium in at least some sandstone-type deposits is derived from tuffs or rocks containing volcanic ash and detritus is of interest to the writer, because he (Davidson and Powers, 1959) has demonstrated that some volcanic ash, and some rocks made up of volcanic ash contain selenium.

Selenium and uranium probably occurred together in most sandstone-type deposits as they were first constituted, for selenium occurs with uranium in every "black-ore" deposit sampled by the writer in connection with selenium work.

It should be noted that nearly all the deposits discussed in this paper are in a sense really gossans, and that in order to understand the origin of these deposits it is necessary to understand something of the origin of the preexisting deposits from which they formed.

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