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URANIUM RESOURCES IN THE SILVER REEF (HARRISBURG) DISTRICT, WASHINGTON COUNTY, UTAH

by

Frederick Stugard, Jr.

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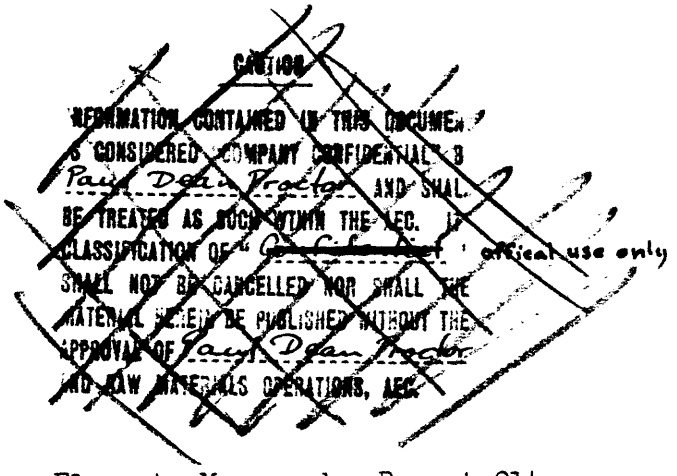

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URANIUM RESOURCES IN THE SILVER REEF (HARRISBURG) DISTRICT, WASHINGTON COUNTY, UTAH

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ABSTRACT

The Silver Reef district is near Leeds, about 16 miles north of St. George, Utah. The major structural feature of the district is the Virgin anticline, a fold extending southwestward toward St. George. The anticline has been breached by erosion, and sandstone hogbacks or "reefs" are carved from the Shinarump conglomerate and sandstone members of the Chinle formation, both of Triassic age. Thirteen occurrences of uranium-vanadium minerals, all within the Tecumseh sandstone, which is the upper part of the Silver Reef sandstone member of the Chinle formation, have been examined over an area about 1.75 miles wide and 3 miles long.

Two shipments of uranium-vanadium ore have been produced from the Chloride Chief and Silver Point claims. Samples from the deposits contain as much as 0.94 percent U_3O_8. The ore contains several times as much vanadium oxide as uranium, some copper, and traces of silver. It occurs in thinly bedded cross-bedded shales and sandstones within the fluviatile Tecumseh sandstone member of the Chinle formation. The ore beds are lenticular and are localized

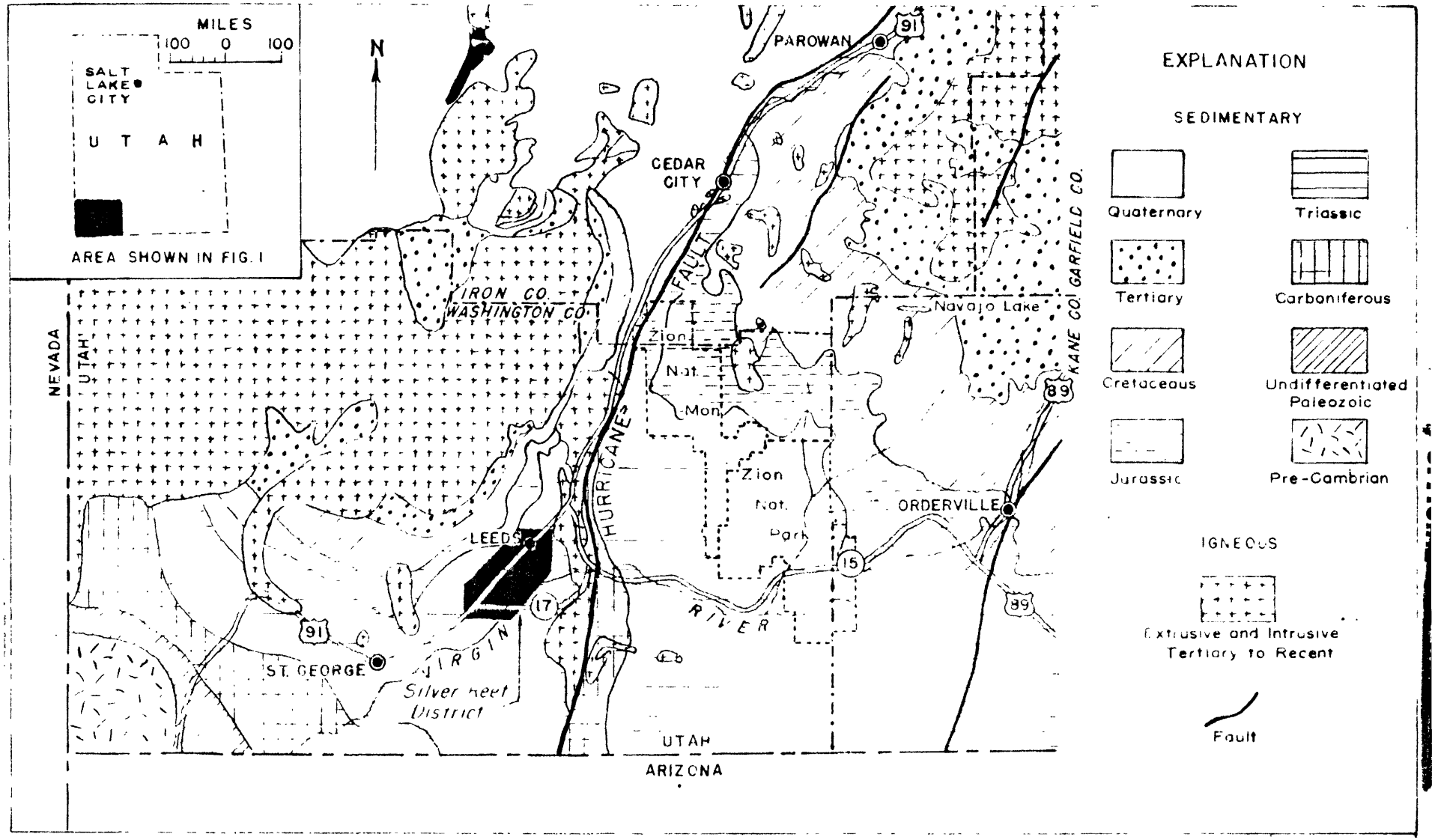
near the base, center, and top of this sandstone member. The uranium-vanadium ore contains several yellow and green minerals not yet identified; the occurrences are similar to, but not associated with, the cerargyrite ore that made the district famous from 1879 to 1909.

INTRODUCTION

About 7,200,000 ounces of silver, valued at $7,800,000, were produced from the Silver Reef district between 1875 and 1909. The ore mineral was cerargyrite, (silver chloride, "horn silver") that impregnated sandstone beds or "reefs". The presence of uranium minerals in the silver workings was first recorded in 1881.

Discovery of silver ore in 1873 resulted in the formation of the Harrisburg mining district in June 1874. The name Silver Reef was soon applied to the new district. Among the Parrusit Indians there grew, within a few years, a mining camp of 1,500 men who sought the wealth so near the surface and brought a new word into the language - "chlorider".

The Silver Reef mining district includes part of T. 41 S., Rs. 13 and 14 W., Salt Lake meridian, near the town of Leeds, Utah. Leeds (fig. 1) is about 16 miles north of St. George and about 50 miles south of Cedar City, the nearest rail head. The district is about 163 miles by road from Marysvale, the nearest purchasing depot for uranium ore.



AFTER: BUTLER ET AL., U.S.G.S. PROF. PAPER 111

SCALE
10 5 0 10 20 MILES

FIGURE 1.-- INDEX MAP OF SOUTHWESTERN UTAH

The owner of most of the formerly large silver-producing properties in the district is Mr. Alex. W. Colbath of Leeds, Utah. The names of lessees, operators, and other owners of properties are given below in the descriptions of individual deposits.

The period of greatest silver production was from 1877 to 1888. Proctor (1949) lists 29 mines once operating in an area of 2 square miles. The mineralogy of the silver deposits attracted early attention to the district because it was the only place in the United States where cerargyrite, AgCl, had been found in sandstones.

The uranium production from the district to December 1950 was 8.68 tons of rocks containing 0.67 percent U_3O_8 (0.56 percent U) and 3.77 percent V_2O_5. This shipment was made by F. M. Willis to the Atomic Energy Commission purchasing depot at Monticello, Utah, on April 4, 1950. About 10 tons of ore of similar grade was ready for shipment in December 1950.

All known mineral deposits in the Silver Reef district are on the limbs of the Virgin anticline or subsidiary folds; most of them are where the Triassic sequence of rocks is repeated by faulting on the Leeds anticline (pl. 1). The sandstone beds in this sequence crop out in hogbacks that are referred to in this report as White Reef, Buckeye Reef, and Butte Reef (pl. 2). The same rocks on the east limb of the virgin anticline are referred to as East Reef.

Previous geologic reports on the area include two reports made during silver-mining operations (Rothwell, 1880; Rolker, 1881) _/,

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_/ Names and dates in parentheses refer to bibliography at end of report.

an account by Butler and Heikes (Butler et al, 1920), and a study by Proctor (1949). A complete bibliography of previous contributory articles is given by Proctor (1949, pp. 163-167). More recently, reconnaissance reports have been made on the uranium potentialities of the district by various writers (Smith, 1946; Towle and Anderson, 1950; Everhart, 1950; Stugard, 1950).

A preliminary examination of the Silver Reef district was made in August 1950 as part of the U. S. Geological Survey's program for evaluation of uranium resources of the Marysvale region (Wyant et al, 1950). In December 1950, 12 days were spent in a more detailed study of the deposits in order to obtain additional data. Radiometric traverses were made and spot readings taken with a Geiger-Mueller counter (Beckman MX-5 gamma-beta rate meter) at various points on the east and west limbs of the anticline and in those old mines still accessible. A photographic enlargement, with a scale of 1 inch equals 150 feet, of the Tecumseh Hill-Pumpkin Point area of Proctor's geologic map, was used as the base for preparation of figure 2; to this, details of uranium prospects were added, using pace, tape, and Gurley compass. The writer took 17 samples in the district for analysis.

Mr. Paul Dean Proctor, of the U. S. Geological Survey and Indiana University, accompanied the writer in the field in August and kindly permitted the use of much of his unpublished material in this report. Special acknowledgment is made to Mr. F. M. Willis

and Mr. F. L. Morgan for making available all analyses furnished them by the Bureau of Mines and other laboratories. Mr. A. J. Gude III assisted in the preparation of the maps for reproduction.

Mine workings

The locations of the larger mines are shown on plates 1 and 2 and on figure 2. Most of the old silver mines that were operated between 1879 and 1909 were inaccessible in 1950. The small prospect pits (fig. 2) that have been opened for uranium since Proctor's geologic mapping have been plotted on figure 2.

Uranium workings

More than 150 uranium claims have been located in the district and on nearby parts of the Virgin anticline. Four claims have been prospected by pits: the Chloride Chief, Silver Point, Lucky Strike No. 2, and Leeds uranium mine.

The Chloride Chief and Silver Point claims are on the eastern end of Buckeye Reef at Pumpkin Point. On these two claims are two prospect pits, the Willis pits No. 1 and No. 5, that have produced uranium ore.

A small open cut has been made at the entrances to two old silver adits on the Lucky Strike No. 2 claim (sample location 33, pl. 1).

Two new pits, among a group of small old silver prospect pits, have been made at the Leeds uranium mine.

Old silver mines

Most of the silver mines are on White Reef, and on Tecumseh Hill, which is part of Buckeye Reef (pl. 2). The deeper workings were flooded, following irrigation of nearby orchard lands and the only extensive mine workings accessible in December 1950 were those of the Cobb mine (inclined shaft) on the west side of White Reef (pl. 2).

The A. S. & R. shaft (line A-A', pl. 2), sunk in 1929, is the most important development on White Reef. This shaft is 600 feet deep and connects all the major workings of the reef. In 1929 the water was pumped from the entire reef and all deposits in the interconnected workings were assayed. No ore was produced. This shaft, like all others in the district, is inaccessible today because of the unsafe timbering.

Tecumseh Hill on Buckeye Reef is covered by scores of shallow workings where supergene cerargyrite was found. Three small shafts were sunk near the eastern end of Buckeye Reef; of these, the Doyle shaft is of interest for the uranium-vanadium minerals in its dump. Butte Reef does not contain any important deposits. The East Reef contains the Vanderbilt and Duffin mines (pl. 1) and numerous small workings, most of which can still be entered for examination.

GEOLOGY

The Silver Reef district is about 5 miles west of the Hurricane fault (fig. 1) that separates the Markagunt plateau on the east from the Basin and Range province (Fennerman, 1930) on the west. The Permian to Jurassic sequence of sedimentary rocks, capped by lavas, is found in both the Markagunt plateau and the Silver Reef district; the rocks on the Silver Reef side of the Hurricane fault have been downthrown.

The center of the Silver Reef district is on the west limb of the Virgin anticline, a fold extending southwestward toward St. George. The anticline has been breached by erosion, and hogbacks or "reefs" have been carved from conglomerate of the Shinarump formation and the sandstone members of the Chinle formation, both of Triassic age. The central part of the anticline is occupied by a lowland developed on the less resistant Moenkopi formation, also of Triassic age.

Stratigraphy

The rocks exposed in the Silver Reef district (pl. 1) are, from youngest to oldest, basalt (Quaternary), Navajo sandstone (Jurassic), Chinle formation (Triassic), Shinarump formation (Triassic), and Moenkopi formation (Triassic). All observed uranium-vanadium mineral occurrences are within the Chinle formation.

Quaternary basalt flows and small cinder cones overlap part of the east limb of the Virgin anticline.

The Navajo sandstone of Jurassic age crops out in the red cliffs west of the Virgin anticline and at one time extended over the entire district. The 1,000 feet of dark-red sandstone, in high, precipitous bluffs, is underlain by about 1,000 feet of red shales, interbedded with layers of light-red sandstone.

The Chinle formation in the Silver Reef district has been divided by Proctor (1949) into six members, which are, from youngest to oldest, the Duffin sandstone, the Tecumseh sandstone, the Leeds sandstone, the Trail Hill sandstone, the Fire Clay bentonitic shale, and the Hartley shale and sandstone. These members are shown on plate 2 and figure 2, but are grouped in pairs on plate 1. In earlier reports, the Tecumseh and Leeds sandstones were collectively called the "Silver Reef sandstone", and are so indicated on plate 1./

/ The Triassic Chinle formation in which the mines and prospects are found is divided on plate 1 by Proctor into uppermost Chinle (Trcu), Silver Reef sandstone (Trsr), and remaining Chinle formation (Trcl).

The Duffin sandstone is a buff and red sandstone. The Tecumseh sandstone is a medium-grained micaceous, thin- to thick-bedded buff and lavender sandstone about 60 feet thick. Its terrestrial origin is indicated by fluvial cross-bedding, by lensing of shale beds within the member, by clay galls or "pebbles", and by fossil reeds and rushes. The Leeds sandstone is a cross-bedded buff sandstone

containing scattered fossil reeds and rushes and concretionary nodules of iron oxide 0.5 to 2 inches across; pyrite was reported by Proctor (1949, p. 25). The Leeds sandstone is at least 40 feet thick on Paulmar Hill and Pumpkin Point. The Duffin, Tecumseh, and Leeds sandstones are distinguishable with difficulty in some places; the distinction is best made on Tecumseh Hill and Pumpkin Point by observing the partings between these sandstone members.

The Trail Hill sandstone is a silty red sandstone, approximately 240 feet thick, with a 3- to 6-foot buff layer about 20 feet from the top. This sandstone forms the steep slopes below the cliffs of Tecumseh and Leeds sandstones.

The Fire Clay bentonitic shale forms rounded, slumped masses of mauve to pink, shaley clay near the base of the steep slope formed by the more resistant Trail Hill sandstone.

The Hartley shale and sandstone is brownish red and weathers into arable soil of the same color. There are no good exposures of this member near Paulmar or Tecumseh Hills.

Structure

The Virgin anticline (pl. 1) is a symmetrical fold whose limbs dip 18°-36° away from a near-vertical axial plane, the trace of which strikes about N. 30° E. The anticline plunges gently beneath alluvium and lava flows to the north-northeast. The anticlinal structure involves the Triassic Chinle, Shinarump, Moenkopi, and

older formations. The reefs on the anticlinal limbs extend southwestward at least 14 miles, from the village of Leeds almost to St. George.

The reefs are all formed by the Tecumseh, Leeds, and Trail Hill sandstones. The reef-forming sandstones in White Reef (A. S. & R. shaft, Cobb mine, Leeds mines) are repeated on the other side of a thrust fault, first mapped by Proctor, as Buckeye Reef (Tecumseh Hill and Doyle shaft). Another repetition of the sandstones in Butte Reef is caused by bending and normal faulting.

On the northwest side of the Virgin anticline, subsidiary structures, the Leeds anticline and syncline (pl. 1), have not been affected by faulting. The Leeds anticline forms Tecumseh Hill (pl. 2).

At Pumpkin Point, the local dips of the Tecumseh and Leeds sandstones vary widely, so that there probably are faults across the Point, although these have not been located.

ORE DEPOSITS

Uranium ores from the Silver Reef district consist of uranium minerals as coatings on fracture surfaces and plant fossils in moderately hard terrestrial sandstones. The ratio of vanadium to uranium is as much as 10 to 1; copper may be as abundant as vanadium. The calcium carbonate content commonly is below 2 percent. The ore commonly contains several ounces of silver per ton.

Table 1.--Analyses obtained by operators of uranium prospects in the Silver Reef district, Washington County, Utah

Date	Agency making analyses	Sample number (fig. 2)	Sample data	U_3O_8 (percent)	V_2O_5 (percent)	$CaCO_3$ (percent)	Ag (oz./ton)	Cu (percent)
Nov. 25,'49	American Smelting & Refining Co. ore purchasing agent for Atomic Energy Commission.	1	Chloride Chief claim, Pumpkin Point, Willis prospect pit No. 1. Tecumseh member of Chinle formation.	0.91	2.51	0.7		
Dec. 14,'49		2	do.	0.94	4.30	1.0		
Mar. 23,'50		3	do.	1.19	4.26	1.0		
Apr. 26,'50	U.S. Vanadium Corp., Rifle, Colo.	4	do. High grade ore pile.	0.59	3.75			
		5	do. Low grade ore pile.	0.16	2.21			
		6	Chloride Chief claim. Prospect pit No. 3.	0.29	1.86			
		7	Chloride Chief claim. Dump, prospect pit No. 1.	0.10	0.57			

Table 1. -- Analyses obtained by operators of uranium prospects in the Silver Reef district, Washington County, Utah. (continued)

Date	Agency making analyses	Sample number (fig.2)	Sample data	U_3O_8 (percent)	V_2O_5 (percent)	$CaCO_3$ (percent)	Ag (oz./ton)	Cu (percent)
Apr.26,'50	U.S. Vanadium Corp., Rifle, Colo.	8	Silver Point claim. Pit No.5	0.13	0.75			
		9	Silver Point claim. Prospect pit No. 5 at east end.	0.61	3.90			
June 5,'50	Smith-Emery Co., 920 Sautee St., Los Angeles 15, Calif., 323221.	10	Chinle formation, Pumpkin Point	1.40			10.56	
Dec. 8,'50	J. Earl Smith, Uranium Specialist, Moab, Utah.	11	Silver Point claim. Composite grab samples along 600 feet of Leeds and Tecumseh sandstones, south side Pumpkin Point.	0.74	3.34	1.9		0.13
		12	Silver Point claim. Eastern most prospect pit, Tecumseh sand stone, Pumpkin Point. Channel across 1.5 feet.	0.81	2.14	1.12		0.34

Table 1.--Analyses obtained by operators of uranium prospects in the Silver Reef district, Washington County, Utah 1/.--Continued.

Date	Agency making analyses	Sample number (fig. 2)	Sample data	U_3O_8 (percent)	V_2O_5 (percent)	$CaCO_3$ (percent)	Ag (oz./ton)	Cu (percent)
Dec.8,'50	J. Earl Smith, Uranium Specialist, Moab, Utah.	13	Chloride Chief claim. Prospect pit by power lines on Pumpkin Point. Grab sample with caliche.	0.39	2.43	2.1		0.49
		14	Chloride Chief claim. Prospect pit nearest acess road, Pumpkin Point. Tecumseh sandstone.	0.45	3.26	2.3		0.37

Figures supplied by Mr. F. M. Willis and Mr. F. L. Morgan.

Table 2.--Analyses reported by the Atomic Energy Commission from Silver Reef district, Washington County, Utah.

Sample number (pl. 1, fig. 2)	Field number	Sample data	Equivalent U_3O_8 (percent)	U_3O_8 (percent)	V_2O_5 (percent)	Cu (percent)	Ag (oz./ton)
15	F-9031	Duffin mine, East Reef. Selected specimen from ore bins.	0.4				
16	F-9032	Rough Rider No. 2 claim, East Reef. Selected specimens of highest grade material.	0.5	0.6		1.51	
17	F-9033	Tecumseh mine, Buckeye Reef. Selected specimens.	0.05				
18	F-9034	Tecumseh mine, Buckeye Reef. Grab sample.	0.02	0.005		0.77	
19	F-9035	Tecumseh mine, Buckeye Reef. Selected specimens.	0.125		0.51	0.38	3.6
20	F-9029	Chloride Chief claim, Willis prospect pit No. 1. Grab sample.	0.135			0.26	2.94

Table 3.--Analyses of samples taken by the Geological Survey from Silver Reef district, Washington, Utah.

Sample number (pl. 1, pl. 2, fig. 2)	Field Number	Sample data	Equivalent uranium (percent)	Uranium (percent)	V_2O_5 (percent)	Se (p.p.m.)	Cu (percent)	Ag (oz./ton)
21	SR-1	Buckeye Reef, Silver Point claim. Grab sample of uraniferous Tecumseh sandstone from Doyle Shaft dump.	0.13	0.12				
22	SR-2	do.	0.089	0.11				
23	FS 24-45	Buckeye Reef, Silver Point claim. Grab sample of most uraniferous Tecumseh sandstone from dumps of 2 shafts 300 ft. east of Doyle shaft.	0.24	0.38	1.15	44.0		5.52
24	FS 30-52	Buckeye Reef, Silver Point claim. Grab sample Tecumseh sandstone with "pseudo-autunite", east tip Pumpkin Point. Near prospect pit No. 5.	0.15	0.20	2.98	128.0	7.15	2.58
25	FS 25-46	Buckeye Reef, Silver Point claim. Channel across 1.8 feet of basal Tecumseh sandstone in prospect pit No. 5 on southeast slope Pumpkin Point.	0.42	0.43	1.86	4.0		5.36

Table 3.--Analyses of samples taken by the Geological Survey from Silver Reef district, Washington County, Utah.--Continued.

Sample number (pl. 1, pl. 2, fig. 2)	Field number	Sample data	Equivalent uranium (percent)	Uranium (percent)	V_2O_5 (percent)	Se (p.p.m.)	Cu (percent)	Ag (oz./ton)
26	FS 24-74	Buckeye Reef, Silver Point claim. Channel along 5 feet 0.2 to 0.4-foot layer of organic shale in Tecumseh sandstone prospect pit No. 4	0.026	0.026	4.80		3.58	
27	FS 24-75	Same location as FS 24-74. Vertical channel across 2.5 feet silty red sandstone, 1 ft. buff sandstone, 0.4 feet organic debris (sample FS-24-74), 1.1 feet white sandstone	0.006	0.003	0.98		0.75	
28	FS 23-43	Buckeye Reef, Chloride Chief claim. Composite grab sample from Tecumseh sandstone (producing lens) in Willis pit No. 1.	0.25	0.30	1.01	<0.7		3.50
29	FS 23-44	Same location as FS 23-43. Fine material.	0.42	0.42	4.68	226.0		13.36
30	FS 22-41	Buckeye Reef. Tecumseh Hill. Grab sample from dump. Tecumseh sandstone.	0.049	0.041	2.09	18.0		2.03

Table 3.--Analyses of samples taken by the Geological Survey from Silver Reef district, Washington County, Utah.--Continued

Sample number (pl. 1, pl. 2, fig. 2)	Field number	Sample data	Equivalent uranium (percent)	Uranium (percent)	V_2O_5 (percent)	Se (p.p.m.)	Cu (percent)	Ag (oz./ton)
31	FS 42-72	North side Butte Reef "Leeds uranium mine." Channel across 3 feet Tecumseh sandstone, west end of cut.	0.024	0.039	0.10		0.27	
32	FS 42-73	Same location as FS 42-72. Composite grab sample of mined ore.	0.18	0.23	2.39		1.28	
33	FS 41-71	East Reef. Lucky Strike No. 2 claim. Channel sample across 1.9 feet uppermost Tecumseh sandstone.	0.16	0.19	1.03		1.47	
34	FS 26-48	East Reef. Duffin mine. Average of dump material. Composite grab sample. Tecumseh sandstone.	0.017	0.02	0.05	5.0		1.23
35	FS 26-47	Same location as FS 26-48. Selected sample.	0.42	0.61	1.81	34.0		33.78
36	FS 27-49	White Reef. Cobb mine. "Soapstone" or sheared clay from clay pebble layer 100 feet inside mine. Leeds (?) sandstone.	0.004	0.003	0.04	66.0		2.48

Table 3.--Analyses of samples taken by the Geological Survey from Silver Reef district, Washington County, Utah.--Continued.

Sample number (pl. 1, pl. 2, fig. 2)	Field number	Sample data	Equivalent uranium (percent)	Uranium (percent)	V_2O_5 (percent)	Se (p.p.m.)	Cu (percent)	Ag (oz./ton)
37	FS 28-50	White Reef, Leeds mine. Grab sample from mine entrance. Tecumseh sandstone showing copper carbonates.	0.005	0.005	0.03	5.0		11.20
38	FS 40-70	Christy tailing dump. White Reef, Tecumseh Hill. Composite of 25 grab samples.	0.009	0.010	0.07		0.25	
39	FS 29-51	Shinarump conglomerate from ridge east of Leeds.	0.001	0.001				

The ore is in cross-bedded lenses as much as 6 feet thick, and 10 to 50 feet long, within the Tecumseh member of the Triassic Chinle formation.

Distribution

Uranium-vanadium minerals have been observed in the Silver Reef district at three places on Tecumseh Hill, on the dumps of the Doyle shaft and two small shafts 300 feet to the east, in five prospect pits on Pumpkin Point, at Lucky Strike No. 2 claim (sample 33, pl. 1), and on the East Reef at the Duffin mine and Rough Rider claim (sample 16, pl. 1). Each of these occurrences is represented by analyses in tables 1, 2 and 3. Proctor (1949, pp, 100, 101, 161) also reported small showings in lavender sandstone 200 feet northeast of the Toquerville mine (not shown on pl. 1) on East Reef, on the nose of the Virgin anticline, and at several places about 1,000 feet east of the Virgin anticline. Each exposure described by Proctor is only a few inches in thickness and a few feet in length.

The two richest deposits are in an upper ore zone mined at Willis pits No. 1 and No. 2 (fig. 2) on Pumpkin Point, and in a 1.8-foot thick lower ore zone about 15 feet stratigraphically lower (pit No. 5, fig. 2). The upper ore zone is almost tangential to the top of the hill and may have been eroded in part, leaving abnormally radioactive float at several places near the end of Pumpkin Point.

An organic layer 0.2 foot thick containing uranium-vanadium minerals exposed in pit No. 4 (fig. 2) is believed to be part of the lower ore zone exposed in pit No. 5.

The Tecumseh Hill exposure of uranium-vanadium minerals noted on figure 2 is referred to in this report as the basal ore zone.

The upper, lower, and basal ore zones are respectively near the top, middle, and base of the Tecumseh sandstone (cross section, fig. 2).

Some uranium-vanadium minerals were seen on the dump of the small shaft about 300 feet east of the Doyle shaft (pl. 2). This small shaft is said to have been about 60 feet deep before it was filled with debris. It is believed that the uranium deposit exposed in this small shaft may represent an extension of the upper and lower ore zones exposed on Pumpkin Point.

In addition to the basal ore zone exposure on Tecumseh Hill, there are two dumps showing uranium-vanadium minerals (fig. 2). The zone from which these minerals came is not known, but may well be one of the three ore zones already identified, because the grade (samples 17, 18, 19 and 30, tables 2 and 3) of rock samples from these dumps is comparable to the ore samples in situ. A wider distribution of uranium-vanadium minerals than is visible on Tecumseh Hill is evidenced by the presence in a composite grab sample of the Christy tailing dump of 0.01 percent uranium (sample 38, table 3).

Lucky Strike No. 2 claim (sample location 33, pl. 1) is the site of three old silver prospect adits, at two of which organic lenses containing uranium-vanadium minerals are exposed. These lenses are in the lower part of the Tecumseh sandstone. The larger of the two lenses is 1.9 feet thick in the center, 15 feet long and 0.1 foot thick at the edge; it is made up half of plant remains and clay, and half of sandstone. The grade of one channel sample is 0.19 percent uranium (sample 33, table 3). The entire claim is on a fault sliver and step faults of divergent attitudes occur every 10 to 50 feet, so that extensions of ore zones would not be of practicably minable size.

Samples were taken from the dump of the Duffin mine (samples 15, 34 and 35, tables 2 and 3). No uranium-vanadium minerals were seen in place and the quantity of uranium present is believed to be extremely small, although high-grade samples can be found on the property.

The Vanderbilt mine (pl. 1) and Rough Rider claim (sample location 16, pl. 1), like the East Reef mineral locations mentioned by Proctor (1949), contain uranium-vanadium minerals only in small and scattered exposures. These mineral sample localities are believed to be in the Tecumseh sandstone.

Mineralogy

Uranium-vanadium minerals appear to be confined to the closely cross-bedded and more permeable beds, especially those containing carbonized plant stems and platy argillaceous rock.

Carnotite-type uranium-vanadium minerals have at least three modes of occurrence in the Silver Reef district. Bright-yellow coatings on small fracture surfaces and on plant remains are present in all observed deposits. Dark yellowish-green coatings on sand grains, fracture surfaces, and bedding surfaces occur in the three minor deposits on Tecumseh Hill, in all the pits on Pumpkin Point, and at the "Leeds uranium mine". Powder X-ray pattern and semi-quantitative spectrographic analyses make it probable that the principal ore mineral is volborthite $Cu_2 (VO_4) (OH)$.

A moderate greenish-yellow coating on detrital muscovite flakes in the Tecumseh sandstone on the eastern tip of Pumpkin Point looks much like autunite, but preliminary laboratory work indicates that probably two or more minerals are present.

J. W. Adams, of the Geological Survey, found that this mineral coating contains copper and vanadium. Uranium undoubtedly is present in the sample, but the mineral will not give a fluorescent bead with NaF flux, probably because of some quenching effect. The absence of fluorescence, and the presence of copper and vanadium, indicate that the mineral probably is not autunite. An analysis of a sample containing this mineral or minerals is given as sample 24 in table 3. The copper content, 7 percent, is notable.

According to Proctor (1949, pp. 100, 101, 161), autunite occurs in very minor quantities at the Duffin mine, the Toquerville mine, and the other localities on East Reef mentioned under Distribution. Autunite was first mentioned by Rolker (1881, p. 26)

as occurring "around the Gad shaft"; the Gad shaft was a small working in the Tecumseh Hill area (pl. 2) now covered by debris from a multitude of small mining operations. On the basis of preliminary mineral study, it now appears probable that all the reported autunite actually is a pseudo-autunite coating on mica flakes composed of a mixture of uranium minerals as described above, but this can only be established by further work.

Samples from various parts of the Silver Reef district contained a little selenium (table 2), but no selenium minerals were observed (Cf. also Proctor, 1949, pp. 114, 115).

Study of the mineralogy of the several uranium-vanadium occurrences at Silver Reef is in progress; field identification was not possible.

The silver deposits cannot be observed today and their mineralogy was not studied. The silver ore recovered in the shallow workings was largely cerargyrite. Butler et al (1920, p. 592) reports "that below water level both the silver and copper are present mainly as sulphides, with a little native silver. Newberry, however, states that the average of four analyses of silver ores showed 0.23 per cent of selenium and 0.26 per cent of silver, which would suggest that part of the silver at least may be combined in some form with selenium. The abundance of hydrous iron oxides in the oxidized ores indicates some iron in the unoxidized ores." Difficulty in treating some silver ores from the Tecumseh mine (pl. 2) was ascribed (Butler et al, 1920, p. 591) tentatively to the presence of "phosphate of uranium."

Absence of major silver workings in the vicinity of the richest uranium-vanadium prospects on Pumpkin Point implies a lack of association between uranium-vanadium minerals and economic silver deposits. Samples 10 (table 1), 19 (table 2), 23, 24, 28, 29, 30, 34, 35, 36, and 37 (table 3), however, contained all three metals, although no silver minerals were observed.

Size and grade

Many of the outcrops, mine dumps, and mine workings in the Silver Reef district were traversed in August 1950 with a Geiger-Mueller counter _/ and the significant results are recorded in table 4. In November 1950, numerous radiometric traverses were made _/, using a 2 by 20 inch probe for greater sensitivity. These traverses across Tecumseh Hill, Pumpkin Point, and Paulmar Hill showed that the background is almost uniform throughout the area. Abnormal readings were obtained only at those dumps containing visible uranium-vanadium minerals. The exceptionally close agreement between "equivalent uranium" and uranium analyses (table 3) indicates that the uranium minerals are in equilibrium and that Geiger-Mueller counter readings give a good indication of uranium content.

_/ Model 2610, Nuclear Instrument and Chemical Corporation, Chicago.

_/ Atomic Energy Commission Model SGS-18A Geiger-Mueller counter, made by El-Tronics, Inc., Philadelphia, Penna.

Table 4.--Radiometric observations, Silver Reef district, Washington County, Utah _/.

Location	Reading (gamma)	Meter scale	Reading (gamma-beta)	Meter scale
Tecumseh Hill (surface)				
Least active rock (background count).	1	0.2	1	0.2
Dump rock with yellow coating.	3	0.2	3	0.2
Most active part of dumps.	3	2.0	7	2.0
Pit on northern part of hill, 6 to 12 inch bed of sandstone with visible uranium-vanadium minerals. "Basal ore zone."	8	2.0	11	2.0
East extension Buckeye Reef				
Willis pit No. 1, Tecumseh sandstone. "Upper ore zone."	5	2.0	13	2.0
Ore pile at Willis pit No. 1. "Upper ore zone."	6	2.0	13	2.0
Pile of "fines," Willis pit No. 1. "Upper ore zone."	9	2.0	17	2.0
Dumps at two shafts 300 feet east of Doyle shaft.	2.5	0.2	4	0.2
Prospect pit No. 5 on southeast slope of Pumpkin Point. "Lower ore zone."	5	2.0	9	2.0
East Reef, Duffin mine				
Least radioactive rock (background count).	1	0.2	1	0.2

Table 4.--Radiometric observations, Silver Reef district, Washington County, Utah _/.--Continued.

Location	Reading (gamma)	Meter scale	Reading (gamma-beta)	Meter scale
East Reef, Duffin mine (continued)				
Specimen pile with visible carnotite.	15	0.2	6	2.0
Rock in ore bin.	5	0.2	6	0.2
Fire clay Hill				
Bentonitic shale outcrops.	1	0.2	1	0.2
Adit in east side White Reef, east of Cobb mine.	1	0.2	1	0.2
Shinarump conglomerate.	1	0.2	1	0.2
Portal of Leeds No. 2 mine, White Reef.	Background only.			
Two small adits northwest from the Vanderbilt mine, East Reef.	do.			
Three small adits nearest the Virgin River on East Reef.	do.			

_/ Meter readings were obtained with an uncalibrated unstandardized Model 2610 Geiger-Mueller counter, made by Nuclear Instrument and Chemical Corporation, Chicago.

The largest uranium ore deposits known in the Silver Reef district are in the Tecumseh sandstone on Pumpkin Point. Two uraniferous zones, the upper and lower ore zones, are exposed. The largest individual deposit, in the lower ore zone, is more than 1.8 feet thick (lower contact concealed) and 16 feet long - with discontinuous exposures over 55 feet total. A single exposure 430 feet to the west is believed to be part of the same ore zone. Samples 28 and 29 (table 3), from the lower ore zone contained respectively 0.3 percent uranium, 1.01 percent vanadium oxide, and 3.5 ounces per ton of silver; and 0.42 percent uranium, 4.68 percent vanadium oxide, and 13.36 ounces per ton of silver. Sample 2 (table 1) is reported to contain 0.94 percent uranium and 4.30 percent vanadium oxide. Sample 26 (table 3) from the single exposure 430 feet to the west, representing a bed 0.2 foot thick across 5 feet, contained 0.026 percent uranium, 4.80 percent vanadium oxide, and 3.58 percent copper.

The upper ore zone is in part eroded, but is exposed as a lens 0.1 to 6 feet thick and 50 feet long. In cross section it consists of two lenses, each about 6 feet in maximum thickness and 25 feet long. Samples 1, 2, 3, 4, 5, 7, 20, 28, and 29 (tables 1, 2, and 3) from this exposure - Willis pit No. 1 - have from 0.14 to 0.8 percent uranium, from 0.5 to 4.30 percent vanadium oxide and from 0.13 to 7.15 percent copper.

Origin

The only uranium, copper, and vanadium minerals found in the Silver Reef district are of secondary origin. This implies deposition from solutions passing through the sandstone. It is possible that during deposition of the sandstone 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.

Uranium, copper, and vanadium minerals are found in the Silver Reef district which extends about 1.75 miles east-west and 3 miles north-south. They occur in thinly bedded cross-bedded shales and sandstones, within the fluviatile Tecumseh sandstone. The ore beds are both discontinuous and lenticular, and show a stratigraphic localization. The ore beds show no localization by the anticlinal structure. The only exposed igneous rocks within many miles are Quaternary basalts; the Fire Clay bentonitic shale is believed to represent Triassic tuffs deposited earlier than ore-bearing members of the Chinle formation.

The presence of native silver and silver sulfides (Butler et al, 1920, p. 592) below the water table suggests the possible presence of subjacent igneous intrusives, but no supporting evidence - such as sericitized or argillized rock - of ultimate igneous origin has been found. It is difficult to conceive of other than magmatic waters carrying sufficient quantities of copper, vanadium, uranium,

silver, and selenium to deposit the minerals now found. However, the question of ultimate origin cannot be decided on the basis of evidence at hand.

Proctor (1949, p. 11) 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 concentrations 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."

This hypothesis would suggest the Triassic stream channels as the loci of ore mineral deposition and for that reason Proctor's geologic map (pl. 2) indicates directions of the Triassic stream flow (inferred from the truncated foreset beds of sandstones) at various localities.

A summary of other theories of origin of the silver ores is given by Butler et al (1920, pp. 155-156). Much of the early theorizing on origin of the silver ores was based on the mistaken premise that the locally abundant boulders of igneous rock in the district were derived from nearby intrusive rocks.

The general association of silver with selenium but disassociation of silver with copper must be accounted for in an adequate theory of origin. Such an explanation could be implemented by future geologic study of: (1) surface and underground water samples;

(2) samples of volcanic rocks of the region; (3) detailed mineralogy of ores of each metal; and (4) other uranium-vanadium-copper-silver deposits.

SUGGESTIONS FOR PROSPECTING

Continued prospecting of the known ore zones within the Tecumseh sandstone should include trenching outward from each exposure of uranium-vanadium minerals to prove the continuity of the favorable zones for ore lenses on Pumpkin Point and Tecumseh Hill. Blasting might be needed on the Tecumseh Hill exposure. From Willis pit No. 1, trenching should extend all the way down the north slope of the hill. Bulldozing from pit No. 5 should extend along the ledge to beyond pit No. 4, on the south side. Trenches that contour the north side of the hill would also be advisable. Selection of high-grade material uncovered in the trenching might make prospecting self supporting.

If the ore zones found are sufficiently continuous to make the zones minable, vertical drill holes to the east of the fault exposed on the east side of Tecumseh Hill, and also near the Doyle shaft, might explore continuations of these deposits. Such drill holes should be about 125 feet deep, and would probe the ore-bearing zones under the alluvial flats.

It would be advisable to prospect, visually and with a Geiger-Mueller counter, the East Reef in its less accessible parts all the

way southwestward toward St. George, although the present exposures of uranium-vanadium minerals as far south as Duffin mine appear to be mineral occurrences only.

To look for new claims, prospectors would do well to look for continuations of the Tecumseh and Leeds sandstones (Silver Reef sandstone) on the east side of the Hurricane fault, southwest of Zion National Monument. Outcrops of the Chinle formation, which includes the Silver Reef sandstone, are about 2 miles wide (Gregory and Williams, 1948, p. 21) at the mouth of Timber Creek.

In addition to new physical exploration, two possible sources of low-cost information on White Reef are:

(1) A study of the Majors Drilling Company diamond-drill cores, from holes near the Hartman shaft drilled in 1946 for Mr. John Clawson, Mr. John Earhorn, and Mr. (?) Holmes of Bingham, Utah (all otherwise employed at that time by Kennecott Copper Corporation). If these cores are still in existence, they might be examined and tested with a Geiger-Mueller counter.

(2) A study of samples taken by The American Smelting and Refining Company in 1929, when the A. S. and R. shaft was sunk on the White Reef southwest of the ghost town of Silver Reef and the interconnecting workings of the entire reef were pumped dry. If any "splits" of these samples still are held by the company, they could be assayed for uranium and vanadium, and copper if not known.

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