# Contributions to the Geology of Uranium 1953–54

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# CONTENTS

The letters in parentheses preceding the titles are those used to designate the separate chapters

# Uranophane at Silver Cliff Mine Lusk, Wyoming

GEOLOGICAL SURVEY BULLETIN 1009-A

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# A CONTRIBUTION TO THE GEOLOGY OF URANIUM

## URANOPHANE AT SILVER CLIFF MINE, LUSK, WYOMING

By VERL R. WILMARTH and D. H. JOHNSON

### ABSTRACT

The uranium deposit at the Silver Cliff mine near Lusk, Wyo., consists primarily of uranophane which occurs as fracture fillings and small replacement pockets in faulted and fractured calcareous sandstone of Cambrian(?) age. The country rock in the vicinity of the mine is schist of pre-Cambrian age intruded by pegmatite dikes and is unconformably overlain by almost horizontal sandstone of Cambrian(?) age.

The mine is on the southern end of the Lusk Dome, a local structure probably related to the Hartville uplift. In the immediate vicinity of the mine, the dome is cut by the Silver Cliff fault, a north-trending high-angle reverse fault about 1,200 feet in length with a stratigraphic throw of 70 feet. Uranophane, metatorbernite, pitchblende, calcite, native silver, native copper, chalcocite, azurite, malachite, chrysocolla, and cuprite have been deposited in fractured sandstone.

The fault was probably mineralized throughout its length, but because of erosion, the mineralized zone is discontinuous. The principal ore body is about 800 feet long. The width and depth of the mineralized zone are not accurately known but are at least 20 feet and 60 feet respectively.

The uranium content of material sampled in the mine ranges from 0.001 to 0.23 percent uranium, whereas dump samples range from 0.076 to 3.39 percent uranium.

### INTRODUCTION

The ore deposit of the Silver Cliff mine near Lusk (population 2,000), in south-central Niobrara County, Wyo., was studied by the U. S. Geological Survey on behalf of the Division of Raw Materials of the U. S. Atomic Energy Commission. The purpose of this study was to determine the mode of occurrence, extent, and reserves of uranium in the deposit.

The Silver Cliff mine is near the top of Silver Cliff Hill, a prominent topographic feature that rises nearly 300 feet above the surrounding plains. The mine is half a mile west of Lusk, in sec. 7, T. 32 N., R. 63 W., 6th principal meridian (fig. 1).

### GEOLOGICAL INVESTIGATIONS

The copper deposits at the Silver Cliff mine were first described by Ball (1906, p. 104). The uranium deposit at the Silver Cliff mine was first described by Lind and Davis (1919, p. 441–443). In 1926, Larsen, Hess, and Schaller (1926, p. 155–164) described the mineralogy of the ores at the Silver Cliff mine. They identified pitchblende in the calcite veins and found uranophane to be the predominant secondary uranium mineral. Dietz (1929, p. 17–20) briefly described

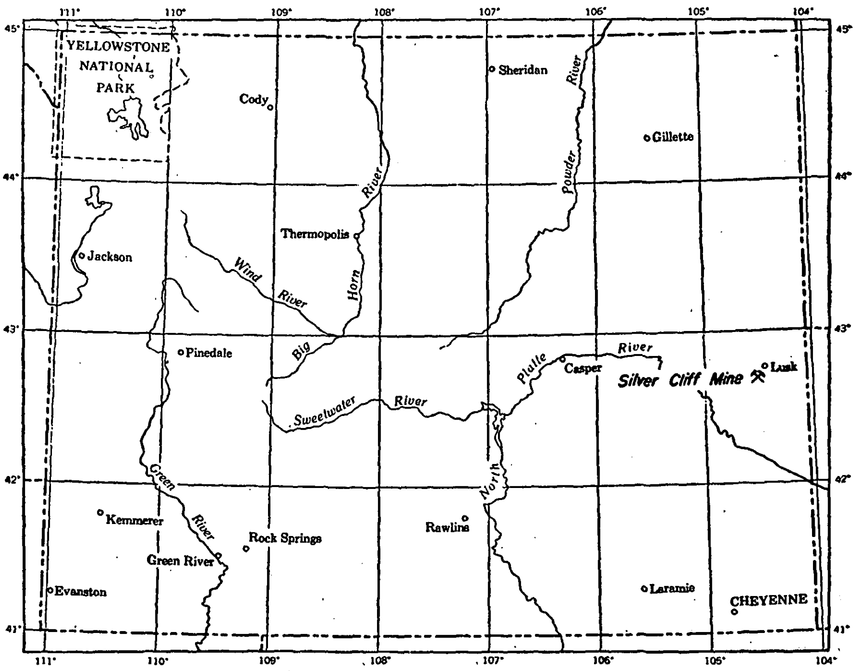



FIGURE 1.—Index map of Wyoming showing location of Silver Cliff mine.

the deposit and gave the value of the production from the mine as $33,857.48 in uranium ore. In 1944, West [1] examined and sampled the underground workings of the mine for the Union Mines Development Corporation. In 1946, Slaughter and Nelson [2] briefly visited the mine and in 1949, it was examined by Wyant.[3] In 1949, a reconnaissance geologic map of the area was made by Denson and Botinelly (1949). In August 1950, the writers mapped the surface and accessible mine workings on a scale of 1 inch to 40 feet. The accessible mine workings and dumps were examined with a Geiger counter and an ultraviolet light, and all roads in the vicinity of the mine were traversed in a car equipped with instruments to detect abnormal radioactivity.

## HISTORY AND PRODUCTION [4]

In the winter of 1879, a Mr. McHenry discovered the deposit and located the claim, which he named the Rochelle silver mine. In February 1880, the Great Wyoming Mining and Milling Company was organized to operate the property. On the basis of samples that

[1] West, J. F., 1944, Examination of the Silver Cliff mine, Lusk district, Hartville uplift area, Wyoming: Union Mines Development Corporation Rept. 48-1, p. 1-11.
[2] Slaughter, A. L., and Nelson, J. T., 1946, Trace elements reconnaissance in South Dakota and Wyoming, Preliminary Report: U. S. Geol. Survey Trace Elements Inv. Rept. 21, p. 20-22.
[3] Wyant, D. G., 1949, Uranophane deposit, Lusk, Wyo: U. S. Geol. Survey memorandum.
[4] The Lusk Herald, Lusk, Wyo., v. 50, no. 2, May 28, 1936.

contained as much as $6,000 per ton in gold and silver, this company built a 400-ton mill which was operated only intermittently because the grade of the ore was lower than anticipated. Between 1880 and 1884, a 285-foot shaft was sunk from the top of Silver Cliff Hill and a 1,200-foot adit was driven to the bottom of the shaft from the north side of Silver Cliff Hill. A winze from the 1,200-foot adit was abandoned because of excess water. According to Mrs. Jamesetta Hale of Lusk, Wyo. (oral communication) the vertical shaft was caved in 1884, and the mine abandoned. The mill was dismantled in 1886. In 1918, E. D. Lorimer set up a small mill and began milling material from the mine dumps for radium ore, and between 1918 and 1922, six carloads of ore that contained about 3 percent uranium oxide were shipped to the Radium Company of Denver, Colo. These operations at the mine ceased in 1922.

## MINE WORKINGS

The workings of the Silver Cliff mine (pl. 1) consist of four large pits, a 285-foot vertical shaft, five levels having a total of about 1,600 feet of drifts, and a small stope. The largest pit (pit 1) is on the north side of Silver Cliff Hill and the other three (pits 2, 3, 4) are on the south side (pl. 1). Much of the uranium ore was produced from these pits. The underground workings, which approximately parallel the Silver Cliff fault, consist of five levels: The 5,100, 5,190, 5,243, 5,228, and 5,220 (pl. 1). A vertical shaft, just north of pit 2, is reported to be 285 feet deep; it is now caved about 30 feet below the surface. An adit, the 5,100 level, was driven from the south bank of Niobrara Creek reportedly for 1,200 feet and connects near the bottom of the 285-foot shaft. The adit is accessible for 400 feet and was driven S. 20° E. in an altered shear zone in schist of pre-Cambrian age. Silver and copper ores were produced from these workings.

## GEOLOGY

The rocks of Silver Cliff Hill (pl. 1) consist of southeast-dipping calcareous sandstone of Cambrian(?) age that unconformably overlies metamorphic rocks of pre-Cambrian age. On the hills south and east of the mapped area, the Guernsey formation, of Devonian and Mississippian age, unconformably overlies the sandstone.

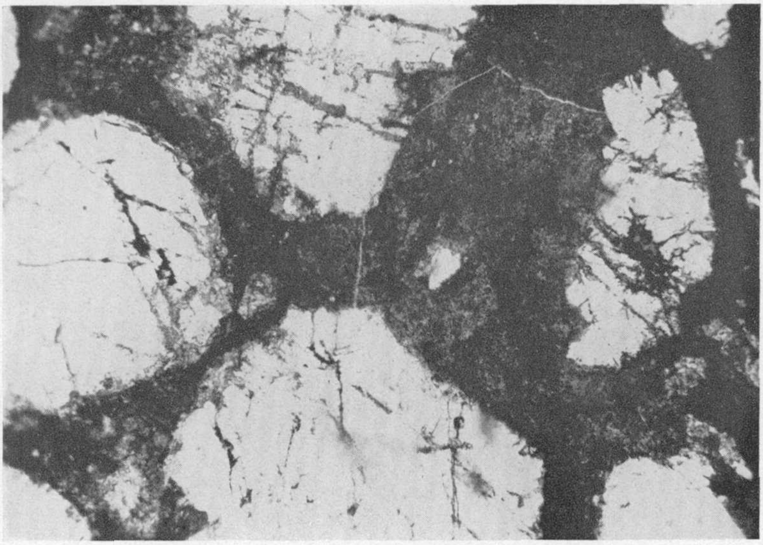
### ROCK UNITS

Pre-Cambrian rocks are exposed on the flanks of Silver Cliff Hill and in the saddle between it and the hill to the south. These rocks consist of highly metamorphosed rocks that have been injected by pegmatite dikes, and include quartzite, mica schist, actinolite schist, granite-gneiss, and a carbonate vein. The quartzite is dark gray, fine grained, and locally contains some mica flakes. The mica schist ranges in texture from a fine-grained quartz-muscovite-biotite schist to a coarse-grained rock that contains abundant large flakes of biotite and muscovite. A 2- to 3-foot band of actinolite schist occurs in the footwall of the Silver Cliff (main) fault in pit 1 (pl. 1). The granite-gneiss is dark gray, coarse grained, and composed of feldspar, mica, quartz, and hornblende. A dark-brown, 8-foot-wide siliceous carbonate vein is exposed in a prospect pit south of the main mine workings (pl. 1). The vein strikes N. 25° E. and dips steeply southeast.

The pegmatite dikes conform to the foliation of the metamorphic rocks, and range in width from a few inches to 10 feet and in length from several feet to 180 feet in length. Several of the larger pegmatites are shown on the map (pl. 1). By visual estimate, the pegmatite composition is perthite (60 percent), quartz (20 percent), muscovite (15 percent), and black tourmaline and andraditic garnet (5 percent).

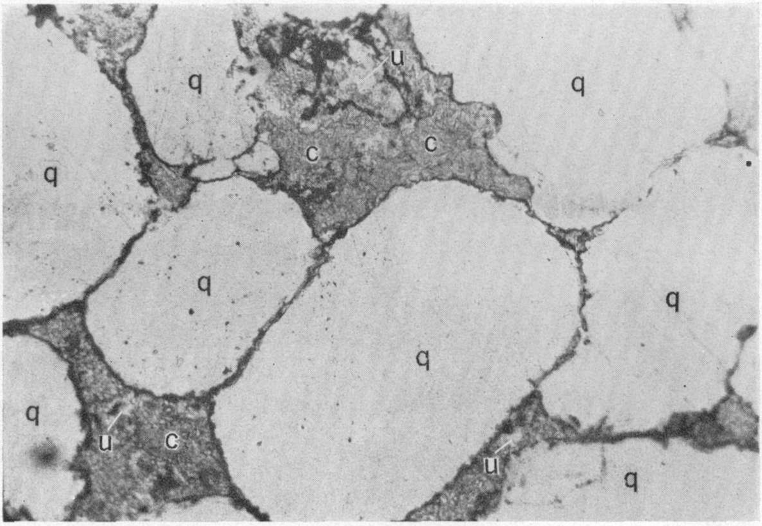
The calcareous sandstone of Cambrian(?) age is described by Denson and Botinelly (1949) as a hard coarse-grained reddish-brown conglomeratic sandstone ranging in thickness from a feather edge to 60 feet. This calcareous sandstone has been tentatively correlated with the basal Cambrian sandstone and quartzite in the Laramie Mountains to the west and with the basal sandstone of the Deadwood formation in the Black Hills to the north. In the vicinity of the Silver Cliff mine, this calcareous sandstone caps Silver Cliff Hill and several buttes to the north and south, and forms clifflike walls as much as 20 feet high above the contact with the pre-Cambrian rocks. The calcareous sandstone consists of well-rounded quartz grains and feldspar fragments cemented by calcite. The quartz grains average 0.5 mm in diameter, but in places, particularly near the base, quartz pebbles as much as 2 inches in diameter are abundant. Adjacent to the fault, the calcite cement has been partly removed, forming a sugary-textured sandstone. Crossbedding is well developed locally in the sandstone, which ranges in color from light reddish brown through buff to dark brown. About 15 feet above the contact between the metamorphic rocks and the sandstone of Cambrian age, a 6-foot bed of dense, fine-grained, dark-brown sandstone forms an excellent marker bed. The original thickness of the calcareous sandstone in this area is not known, because erosion has removed the upper part, but a thickness of about 80 feet remains on Silver Cliff Hill (pl. 1).

Petrographic study of the calcareous sandstone brings out clearly the granular texture of the rock. Quartz grains constitute from 80 to 85 percent of the rock and range from 0.03 millimeter to 1 millimeter in diameter. They are well rounded to subangular, and most grains



*A*. PHOTOMICROGRAPH OF URANIUM-BEARING SANDSTONE.

Highly fractured quartz pebbles replaced by chalcocite (black) and a mixture of uranophane, malachite, and azurite (light gray). × 400.




*B*. PHOTOMICROGRAPH OF TYPICAL URANOPHANE-BEARING SANDSTONE.

Rounded quartz pebbles (*q*) with the interstitial crystalline uranophane (*u*), calcite (*c*), and limonte (black). × 400.

have many minute inclusions of a reddish-brown opaque material, probably hematite. The quartz grains show undulatory extinction and a few have been replaced by calcite and limonite along fractures. Feldspar grains, ranging from 0.2 millimeter to 0.6 millimeter in diameter, constitute 2 to 5 percent of the rock. They are altered and generally contain narrow veinlets of limonite along cleavage planes. Malachite, uranophane, and azurite have replaced some feldspar grains. Calcite and limonite, the principal cementing materials, constitute as much as 10 percent of the rock.

## STRUCTURE

The pre-Cambrian metamorphic rocks that crop out in the mapped area (pl. 1) have been severely deformed. They are characterized by a well-developed foliation that strikes N. 15°–20° E. and dips 65°–85° E. The calcareous sandstone overlies the pre-Cambrian rocks with a marked angular unconformity, strikes N. 59°–62° E and dips 4° SE. The relative positions of these rocks are shown in plate 1. The pre-Cambrian and Cambrian(?) rocks are part of the eroded core of the Lusk dome, the most northerly of three similar domelike structures along the eastern margin of the Hartville uplift.

A high-angle reverse fault, designated by the writers as the Silver Cliff fault, cuts the south end of the Lusk dome; the uranium deposit of the Silver Cliff mine occurs along the fault. This fault has an average strike of N. 15° E., dips 53°–68° E., and can be traced on the surface from the north side of Silver Cliff Hill southward for about 1,200 feet. Movement along the fault has placed pre-Cambrian rocks over calcareous sandstone of Cambrian(?) age; the stratigraphic throw is about 70 feet. In the underground workings, gouge, in places as much as 10 feet thick, marks the fault. In the sandstone adjacent to pit 1, a normal fault strikes N. 10° E., dips 54° E. and has a vertical displacement of 2 feet. This fault, subsidiary to the Silver Cliff fault, apparently had no control on the deposition of the uranium.

Two sets of joints are conspicuous in the sandstone except near the Silver Cliff fault where it is extensively fractured. The more conspicuous of the joint sets strikes N. 65°–75° W. and dips 55°–65° N. The other set strikes N. 30°–40° E. and dips 75°–85° E.

## ORE DEPOSITS

Silver and copper ore was produced from the Silver Cliff mine before its exploitation for uranium in 1919. The silver, copper, and uranium minerals occur as fracture fillings in calcite veins and as irregular replacement bodies in either the fault zone, or the highly fractured calcareous sandstone of Cambrian(?) age in the footwall of the Silver Cliff fault. Four uranium minerals—pitchblende, gummite, uranophane, and metatorbernite—have been identified from the Silver Cliff mine. They are intimately associated with native copper, native silver, chalcocite, malachite, azurite, cuprite, and chrysocolla, in a gangue of calcite, limonite and clinozoisite. Previous mining operations for uranium were restricted to the sandstone deposits. In several prospect pits the pre-Cambrian metamorphic rocks contain secondary copper minerals but no radioactive material.

## URANIUM OCCURRENCE IN FAULT ZONE

Uranophane is the only uranium mineral found in the fault zone, and is associated with secondary copper minerals, native silver, limonite, and calcite. In the upper mine workings the fault zone is as much as 6 feet wide and contains uranophane and the associated minerals as fracture fillings and as small replacement bodies along the fractures. In the 5,100 level, the fault zone is as much as 10 feet wide and contains abundant pyrite adjacent to the fault on the hanging wall side. The 10 samples of fault zone material (table 1) contained from 0.001 to 0.12 percent uranium and minor quantities of copper and silver. The uranium is sporadically distributed throughout the fault zone as is shown by these samples. Only one sample (W–17) from the fault zone contained more than 0.1 percent uranium and it was taken from a surface outcrop. The samples collected from the fault zone in the mine workings indicated no commercial quantities of uranium, this suggests that perhaps sample W–17 was enriched by weathering. However, the Silver Cliff fault zone, above the zone of oxidation, probably does not contain commercial quantities of uranium, although mineable quantities of primary uranium minerals may exist in the fault zone at depth.

## URANIUM OCCURRENCE IN SANDSTONE

The uraniferous zone in the sandstone at the Silver Cliff mine lies in the footwall of the Silver Cliff fault. The surface outcrop of this zone extends continuously along the fault from pit 1 on the north side of Silver Cliff Hill, southward for 830 feet and discontinuously for another 240 feet to the southernmost prospect pit on the fault (pl. 1). The southern limit is not accurately known; no abnormal radioactivity, however, could be detected southward along the surface outcrop of the fault, nor were uranium minerals observed south of this point. Inasmuch as there appears to be a radioactive zone outside the mapped area on the southward extension of the Silver Cliff fault, examination of surface outcrops may discover uraniferous material south of the mapped area. The known vertical dimension of the uraniferous zone in the sandstone extends about 60 feet from the surface to the lowest mine working, and probably the zone extends downward another 20

TABLE 1.—*Sample analyses, Silver Cliff mine, Niobrara County, Wyo.*

[Analyses by Trace Elements Section Denver Laboratory]

| Sample No. | Type of material | Equivalent uranium [1] (percent) | Uranium (percent) | Copper (percent) | Silver (ounces per ton) |
|---|---|---|---|---|---|
| W-6 | 6-foot channel in sandstone | 0.003 | 0.001 | -------- | -------- |
| W-7 | 6-foot vertical channel in sandstone | .004 | .001 | -------- | -------- |
| W-8 | 6-foot channel in sandstone perpendicular to fault | .005 | .001 | -------- | -------- |
| W-9 | 3.5-foot channel across face of adit in sandstone | .006 | .004 | -------- | -------- |
| W-10 | 6-foot channel across fault zone | .000 | .001 | -------- | -------- |
| W-11 | 6-foot vertical channel in sandstone | .001 | .001 | -------- | -------- |
| W-12 | 6-foot channel across face of adit in sandstone | .001 | .001 | -------- | -------- |
| W-13 | 6-foot vertical channel in sandstone | .029 | .033 | -------- | -------- |
| W-14 | 6-foot vertical channel in sandstone | .017 | .029 | -------- | -------- |
| W-15 | 4-foot channel in sandstone | .004 | .004 | -------- | -------- |
| W-16 | 4-foot vertical channel in sandstone | .12 | .10 | -------- | -------- |
| W-17 | 4-foot channel in fault zone | .11 | .12 | -------- | 0.28 |
| W-18 | 4-foot channel in fault zone | .014 | .009 | -------- | -------- |
| W-19 | 6-foot channel across face of pit in sandstone | .002 | .001 | -------- | -------- |
| W-20 | 6-foot vertical channel in sandstone | .001 | .001 | -------- | -------- |
| W-21 | 6-foot vertical channel up faced adit in sandstone | .002 | .003 | -------- | -------- |
| W-22 | 4-foot vertical channel in sandstone | .023 | .020 | -------- | -------- |
| W-23 | 5-foot vertical channel in sandstone | .005 | .004 | -------- | -------- |
| W-24 | 6-foot channel in sandstone | .008 | .008 | -------- | -------- |
| W-25 | 6-foot vertical channel in sandstone | .001 | .001 | -------- | -------- |
| W-26 | Composite dump sample | .020 | .020 | -------- | -------- |
| W-51 | 5-foot channel across hematite-stained fault zone | .006 | .003 | 0.37 | .98 |
| W-52 | Chip sample of radioactive sandstone | .56 | .61 | 10.88 | 15.04 |
| W-53 | Chip sample of radioactive sandstone | 1.38 | 1.48 | 2.60 | 1.23 |
| W-54 | Chip sample of radioactive sandstone | 1.59 | 1.41 | 1.97 | .16 |
| W-55 | 6-foot channel across back of drift in fault zone | .007 | .004 | .27 | .92 |
| W-56 | Grab sample of biotite-muscovite schist | .004 | .001 | .02 | .98 |
| W-57 | 5-foot channel across fault zone | .015 | .008 | .16 | 1.06 |
| W-58 | 5-foot channel across fault zone | .004 | .002 | .21 | 1.00 |
| W-59 | Grab of hematite sandstone near fault zone | .006 | .002 | .03 | .98 |
| W-61 | 3-foot channel across actinolite layer in fault zone | .006 | .002 | .03 | .97 |
| W-63 | Grab sample from dump of old Silver Cliffe mine | .014 | .002 | <.02 | .94 |
| W-64 | 5-foot channel across carbonate vein | .001 | .001 | <.02 | .96 |
| W-65 | Selected dump material | 3.80 | 3.39 | 2.85 | 1.41 |
| W-66 | Selected dump material | .90 | 1.03 | 2.05 | .72 |
| W-69 | Grab sample of pegmatite | .004 | .001 | <.02 | .97 |
| W-70 | Representative sample from uranophane-bearing sandstone from dump. | .080 | .095 | -------- | -------- |
| W-71 | Typical sample of uranophane-bearing sandstone | .17 | .19 | -------- | -------- |
| W-72 | Grab sample of hematite stained schist | .012 | .007 | -------- | -------- |
| W-73 | 3-foot channel across fault zone | .006 | .002 | -------- | -------- |
| W-74 | 3-foot channel across fault zone | .003 | .002 | -------- | -------- |

[1] Equivalent uranium is based on measurement of radioactivity wherein it is assumed that all of the radioactivity of a sample arises from uranium and its disintegration products, and that none of the radioactivity arizes from the thorium series or from potassium; it is assumed, furthermore, that the uranium is in radioactive equilibrium with all of its disintegration products wherein each radioactive product in the series is disintegrating at exactly the same rate at which it is being formed.

feet to the contact of the sandstone with the pre-Cambrian metamorphic rocks (pl. 1). Near the south end of the mapped area, erosion has removed the sandstone. Thus the thickness of the uranium-bearing rock ranges from less than an inch to about 80 feet.

The width of the uranium-bearing zone in the sandstone on the footwall of the Silver Cliff fault is not known accurately. In the mine workings, uranium minerals are detectable in the sandstone for as much as 25 feet away from the fault; on the surface, however, no uranium minerals were found nor could abnormal radioactivity be detected in the sandstone near the fault.

Uranium occurs in two types of sandstone. The less abundant but more radioactive type is a heavy, compact, brown to black sandstone that contains pitchblende, gummite, uranophane, chalcocite, secondary copper minerals, native silver, and limonite. This brown to black sandstone was found only in small pockets, as much as 3 feet across, along the east side of the stope (pl. 1). Thin sections (pl. 2*A*) studies of this sandstone show that all the quartz grains have been corroded and many are replaced by copper and uranium minerals. The uranium content of this ore ranges from 0.61 to 1.48 percent. Appreciable quantities of copper and silver were found in sample W–52, from the stope (pl. 1). This brown to black type grades into the more common type of uraniferous sandstone. This type is light-buff to rust-brown sandstone which, in contrast to the other type does not contain large quantities of copper and silver minerals. Uranophane is the most abundant uranium mineral, and characteristically occurs interstitial to the quartz grains, (pl. 2*B*), as thin coatings on fracture surfaces, and as small replacement bodies in the sandstone. Minor quantities of metatorbernite, azurite, and malachite are associated with the uranophane. Many of the fractures are filled with calcite, and locally, where these fractures are incompletely filled, the uranophane forms radiating crystal aggregates. The uranium content of the sandstone ranges from 0.001 to 3.39 percent, and is dependent upon the spacing of the fractures and replacement bodies.

### DEPOSITION AND DISTRIBUTION OF URANIUM MINERALS

The deposition of the uranium ore, thus far mined in the sandstone was controlled principally by the fractures that resulted from movement along the Silver Cliff fault. The brittle sandstone was readily fractured during faulting and these open fractures apparently acted as channels for the movement of the ore solutions. The relatively soft and plastic gouge along the Silver Cliff fault probably dammed the ore solutions, restricting them to the footwall and thus prevented the deposition of uranium minerals in the pre-Cambrian quartzite on the hanging wall.

The distribution of uranium in the sandstone is irregular. In any set of fractures, some surfaces are coated with uranophane and the others are completely barren. Assays of samples (table 1 and pl. 1) indicate considerable variation in the distribution of the uranium minerals.

## MINERALOGY

Uranophane, the most abundant uranium mineral at the Silver Cliff mine, occurs in the sandstone as lemon-yellow to pale-green coatings as much as one-sixteenth inch thick on fracture surfaces and in irregular replacement bodies as much as 2 inches across, and is estimated to constitute as much as 2 percent of the rock. In thin section veinlets of uranophane as much as 0.02 mm in width fill fractures in quartz grains and in calcite veins. Locally uranophane has impregnated and replaced the calcite of the veins and the cementing material. In fracture fillings and coatings uranophane is massive or in small radiate or stellate clusters; whereas in replacements it is restricted to radiating aggregates. Uranophane has been analyzed by Mary Thompson of the U. S. Geological Survey and contained 65.24 percent uranium oxide, 8.53 percent calcium oxide, 12.66 percent silica, and 13.02 percent water. The optical properties of the uranophane are: optically negative, with slight varying optical angle, $2V^{Li}(32°–42°)$, $2V^{Na}(37°–45°)$ and strong dispersion. The indices of refraction measured by the immersion method are: $\alpha(1.642)$, $\beta(1.665)$, and $\gamma(1.672)$.

Pitchblende and gummite, both uranium oxides, were identified by Schaller (Larsen, Hess, and Schaller, 1926 p. 161–162) in the ore from the Silver Cliff mine. Pitchblende has been identified by S. J. Garde of the U. S. Geological Survey in ore specimens collected by the writers from the dump material. The pitchblende occurs as small specks in the calcite veins and as a replacement in the calcite cement. Some of the pitchblende in the calcite veins is surrounded by crystalline uranophane. In a polished section of black sandstone collected from the stope, a narrow irregular veinlet of pitchblende(?) parallels a chalcocite vein that cuts across the quartz grains. The pitchblende(?) has been partially replaced by uranophane and secondary copper minerals. A deep-red to orange isotropic mineral, tentatively identified as gummite, is associated with several small masses of uranophane. Small quantities of metatorbernite, a pale-green hydrous copper uranium phosphate, previously reported by Wyant,[5] were found on the mine dump, but the mineral was not found in the mine. The metatorbernite is associated with secondary copper minerals and coats fracture surfaces in the sandstone. The primary ore minerals, other than pitchblende, are chalcocite and native silver in a gangue of calcite and minor clinozoisite. Chalcocite, the only copper sulfide noted, occurs as fracture fillings and as small replacement masses in the sandstone. The alteration products of the chalcocite are native copper, azurite. malachite, cuprite, and chrysocolla. These secondary copper minerals coat fracture surfaces in the sandstone, fill fractures in the fault zone, and locally replace the calcite cement. Most of the prospect pits in the metamorphic rocks show secondary copper minerals. Small quantities of native silver were found as thin coatings on fracture surfaces of a specimen of dark-brown radioactive sandstone from the stope. Analysis of ore samples (table 1) shows that silver is a common constituent of the ore.

Calcite is the gangue mineral in the veins and is the most abundant cementing material in the sandstone. The calcite cement occurs in

[5] Wyant, D. G., op. cit. p. 1.

white to gray, rounded fragments that range from 0.03 to 0.07 millimeter in diameter. Most of the calcite cement contains many minute grains of limonite. The white to light-gray vein calcite is coarse grained and forms subhedral crystals as much as 0.4 millimeter in length and 0.03 millimeter in width. Several of the larger calcite veins contain euhedral calcite crystals perpendicular to the vein walls and finer grained calcite filling the center of the vein. Clinozoisite was found in one thin section. It is a clear, gray mineral that forms radiating aggregates in rounded spaces formerly occupied by quartz grains. Much bright-green fluorescence was noted in places, but these invariably showed low radioactivity, whereas the most radioactive areas were only slightly fluorescent. The fluorescent material is probably hyalite that contains enough uranium to produce fluorescence.

## RADIOACTIVITY SURVEYS ON SILVER CLIFF FAULT AND IN ADJACENT AREAS

The accessible mine workings, prospect pits, and surface areas adjacent to the Silver Cliff fault were examined with a Geiger counter. All the mine dumps along the fault showed an abnormal amount of radioactivity. The highest readings in the mine workings were obtained from a black sandstone adjacent to the fault on the east side of the stope (pl. 1). Pitchblende was tentatively identified in specimens of sandstone from this area. Abnormal radioactivity was noted in the sandstone on the footwall of the Silver Cliff fault, but the pre-Cambrian quartzite on the hanging wall of the fault showed no abnormal radioactivity. Surface examination with a Geiger counter indicated no abnormal radioactivity in the sandstone in the footwall of the Silver Cliff fault, suggesting the possible leaching of uranium minerals by ground waters or the sporadic distribution of uranium minerals. At several places in the fault gouge zone, however, abnormal radioactivity was noted, and on close examination secondary uranium minerals were found.

## GRADE

Although the grade of the ore shipped in 1919 from the Silver Cliff mine was reported to be 3 percent uranium (Dietz, 1929, p. 17–20), the average grade of rock left in the mine is much less. Samples assayed 0.001 percent to 1.48 percent uranium. The erratic distribution of uranium minerals along fractures and in replacement bodies in the sandstone would make bulk or open pit mining necessary, and the average grade of the material mined would depend upon the spacing of the fractures, and the number and size of replacement bodies.

The richest sample (W-53) collected in the underground workings was taken from the east side of the stope (pl. 1), and contained 1.48 percent uranium. This sample was from an area of about 3 square feet of dark-brown to black sandstone. The richest sample (W-65) collected from the dump material contained 3.39 percent uranium. Of the 38 samples (table 1) collected by the writers, 8 contained more than 0.1 percent uranium, 4 contained from 0.02 to 0.1 percent uranium, and the rest contained less than 0.02 percent uranium. West[6] reports assays ranging from 0.02 to 0.23 percent uranium for 25 chip samples in the underground workings, and from 0.31 to 4.65 percent uranium from selected samples of dump material. Slaughter and Nelson[7] report the uranium content of two grab samples of dump material as 0.076 percent and 0.090 percent.

## ORIGIN

Two theories on the origin of the uranium deposit at the Silver Cliff mine have been proposed. (Larson, Hess and Schaller, 1926, p. 156) states that the uranium minerals in part fill fractures and in part replace the sandstone. He believes that the solutions which deposited minerals followed cracks and spread from these into sandstone. Hess, also states that the original uranium minerals were dispersed among the quartz grains, and so mixed with other minerals that pure material has not been found. West,[8] suggested that the primary uranium minerals in the sandstone were formed at the time of or after the formation of carbonate veins in the fault fissures. Secondary uranium minerals were formed by oxidation of the primary mineral.

The writers believe the sequence of geologic events in the vicinity of the Silver Cliff mine to be reverse faulting, minor faulting and fracturing of the sandstone and deposition of the ore. Calcite, chalcocite, and pitchblende, the primary minerals were deposited in the fault zone and in the fractured sandstone on the footwall of the fault. The paragenesis of these minerals, has not been definitely established; probably they are contemporaneous or have overlapping periods of deposition. During supergene alteration, the primary copper minerals were converted to cuprite, and the pitchblende was altered to gummite, uranophane, and metatorbernite. The deposits of uraniferous sandstone probably are the result of alteration of the primary minerals in place, whereas those in the light buff sandstone result from solution and redeposition of the uranium by descending ground waters to form a commercial secondary uranium deposit.

[6] Op. cit. p. 9-11.
[7] Slaughter, A. L., and Nelson, J. T., op. cit. p. 22.
[8] West, J. F., op. cit.

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