Geology - Mineralogy

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URANOPHANE AT THE SILVER CLIFF MINE
NEAR LUSK, NIOBRARA COUNTY, WYOMING*

By

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Trace Elements Investigations Report 158

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URANOPHANE AT THE SILVER CLIFF MINE
NEAR LUSK, NIOBRARA COUNTY, WYOMING

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By Verl R. Wilmarth and D. H. Johnson

ABSTRACT

In 1950, the U. S. Geological Survey studied a uranium deposit, previously exploited, at the Silver Cliff mine near Lusk, Wyo. The deposit consists primarily of uranophane that occurs as fracture fillings and small replacement pockets in faulted and fractured quartzite of Cambrian (?) age. The country rock in the vicinity of the mine is schist of pre-Cambrian age intruded by pegmatite dikes and unconformably overlain by flat-lying Cambrian (?) quartzite.

The mine is at the southern end of the Lusk Dome, a local structure probably related to the Hartville uplift. In the immediate vicinity of the mine, this dome is cut by the Silver Cliff fault, which is a north-trending high-angle reverse fault approximately 1,200 feet in length with a stratigraphic throw of 70 feet. The fractured quartzite has been the locus for the deposition of uranophane, metatorbernite, pitchblende, calcite, native silver, native copper, chalcocite, azurite, malachite, chrysocolla, and cuprite.

The fault was probably mineralized throughout its length, but owing to erosion the mineralized zone is now 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.

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INTRODUCTION

The Silver Cliff mine near Lusk, in south-central Niobrara County, Wyo., was studied in August 1950 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.

Location and accessibility

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). Lusk, a town of about 2,000 population, is on U. S. Highway 85 and U. S. Highway 20 and on the main line of the Chicago and Northwestern Railroad.

The mine is about 1,500 feet south of a graded road that parallels the railroad tracks leading west from Lusk.

Geologic investigations

The copper deposits at the Silver Cliff mine were described by Ball (1906, p. 104) in 1906. The uranium deposit at the Silver Cliff mine was first described by Lind and Davis (1919, pp. 441-443). In 1926, Larsen, Hess, and Schaller (1926, pp. 155-164), described the mineralogy of the ores at the Silver Cliff mine. They identified pitchblende in the calcite veins and uranophane as the predominant secondary uranium mineral. Dietz (1929, pp. 17-20), briefly described the deposit and gave the value of the production from the mine as \$33,857.48 in uranium ore. In 1944, West (1944) examined and sampled the underground workings of the mine for the Union Mines Development Corporation. In 1946, Slaughter and Nelson (1946) briefly visited the mine and in 1949, it was examined by Wyant (1949). In 1949, a reconnaissance geologic map of the area was made by Denson and Botinelly (1949). They show the following formations in the vicinity of the Silver Cliff mine: metamorphic rocks of pre-Cambrian age, quartzite of Cambrian (?) age, and the Guernsey formation of Mississippian and Devonian age.

In August 1950, the writers mapped the surface and accessible mine workings on a scale of 1 inch to

FIGURE 1.- INDEX MAP OF WYOMING

40 feet. Radiometric and ultra-violet light traverses were made of the accessible mine workings and dumps, and radiometric car traverses were made of all roads in the vicinity of the mine.

History and production _/

_/ Lusk Herald, Lusk, Wyo., vol. 50, no. 2, May 28, 1936.

In the winter of 1879, a Mr. McHenry discovered and located the deposit, which he called 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 contained as much as \$6,000 per ton in gold and silver, this company built a 400-ton mill which was operated only intermittently as 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. J. Hale (oral communication) the vertical shaft was caved in 1884, and the mine abandoned. The mill was dismantled in 1886.

In 1918, E. D. Lorimer commenced milling the mine dumps for radium ore and between 1918 and 1922, 6 carloads of ore that contained about 3 percent uranium oxide were shipped to the Radium Company of Denver, Colo. Mining and milling operations at the mine ceased in 1922.

Mine workings

The workings of the Silver Cliff mine (partly in the area shown on figs. 2 and 3) consist of four large pits, a 285-foot vertical shaft, four levels aggregating about 1,600 feet of drift, 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 (fig. 2). Much of the uranium ore was produced from these pits.

The underground workings, which approximately parallel the Silver Cliff fault, consist of four levels: the 5,190, 5,243, 5,228, and 5,220 (fig. 3). A vertical shaft, just north of Pit 2, is reported to be 285 feet deep; it is now caved below about 30 feet. An adit was driven from the south bank of Niobrara Creek (northwest of the mapped area) reportedly for 1,200 feet and is said to connect with 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 pre-Cambrian

schist. Silver and copper ores were produced from these workings.

GEOLOGY

Rock units

The rocks of Silver Cliff Hill (fig. 2) consist of southeast-dipping quartzite 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 Mississippian and Devonian age, unconformably overlies the Cambrian (?) quartzite.

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 high-grade metamorphic rocks that have been injected by granitic 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 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 wide band of actinolite schist occurs on the footwall of the Silver Cliff (main) fault in Pit 1 (fig. 2). 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 (fig. 2). The vein strikes N. 25° E. and dips steeply southeast.

The pegmatite dikes, conformable to the foliation of the metamorphic rocks, range from a few inches to 10 feet in width and from several feet to 180 feet in length. Several of the larger pegmatites are shown on the map (fig. 2). 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 Cambrian (?) quartzite as described by Denson and Botinelly (1949) is a "hard, coarse-grained, reddish-brown conglomeratic quartzite ranging in thickness from a feather edge to about 60 feet. The quartzite 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, the quartzite caps Silver Cliff Hill and several buttes to the north and south, and forms cliff-like walls as much as 20 feet high at the contact with the pre-Cambrian rocks. The quartzite

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 up to 2 inches in diameter are abundant. Adjacent to the fault, the calcite cement has been partially removed, forming a sugary-textured sandstone. Cross bedding is well developed locally. The quartzite ranges from light reddish brown through buff to dark brown. About 15 feet above the metamorphic rock-quartzite contact, a 6-foot bed of dense, fine-grained, dark-brown quartzite forms an excellent marker bed. The full thickness of the quartzite formation in this area is not known, as erosion has removed the upper portion, but approximately 80 feet of quartzite remain on Silver Cliff Hill (fig. 4).

Petrographic study of the quartzite 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 mm to 1 mm in diameter. They are well-rounded to subangular, and most grains have numerous 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 mm to 0.6 mm 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.

In the recent alluvium exposed in the valleys adjacent to the mapped area, several boulders of limestone were found, but limestone does not crop out in the mapped area.

Structure

The pre-Cambrian metamorphic rocks that crop out in the mapped area (fig. 2) have been severely deformed. They are characterized by a well-developed foliation that strikes N. 15° - 20° E. and dips 65° - 85° E. The quartzite of Cambrian (?) age, which overlies the pre-Cambrian rocks with a marked angular unconformity, strikes N. 50° E. and dips 4° SE. The relative positions of these rocks are shown on figure 4. The pre-Cambrian and Cambrian (?) rocks are part of the core of the Lusk dome, the most northerly of three similar dome-like structures that are 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 strikes 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 Cambrian (?) quartzite; the stratigraphic throw is about 70 feet. In the underground workings, gouge, in places as much as 6 feet thick, marks the fault.

In the Cambrian (?) quartzite 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 effect on the deposition of the uranium.

The Cambrian (?) quartzite near the Silver Cliff fault has been fractured so extensively that no joint pattern can be recognized; elsewhere, two joint sets are conspicuous. The more prominent of these 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 were produced from the Silver Cliff mine prior to 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 Silver Cliff fault zone, or the highly fractured Cambrian (?) quartzite in the footwall of the Silver Cliff fault. Several prospect pits in the pre-Cambrian metamorphic rocks contain secondary copper minerals but no radioactive material was found. 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.

Uranium deposit

Uranium occurs in two types of deposits at the Silver Cliff mine: in the gouge of Silver Cliff fault zone and in the Cambrian (?) quartzite on the footwall of the Silver Cliff fault. Previous mining operations for uranium were restricted to the quartzite deposit.

Uranium occurrence in fault zone

Uranophane, the only uranium mineral found in the fault zone, is associated with secondary copper

minerals, limonite, and calcite. The uranophane and accompanying minerals fill fractures, and partially replace narrow calcite veins in the fault gouge. The eight samples of fault zone material (table 1) contained from 0.001 to 0.12 percent uranium. Minor quantities of copper and silver are also present. Analyses of samples indicate that the uranium is erratically distributed throughout the fault zone. Only one sample (W-17) from the fault zone contained more than 0.1 percent uranium and this was taken from a surface outcrop. Analyses of samples collected from the fault zone in the mine workings indicated no commercial quantities of uranium, suggesting that perhaps sample W-17 was enriched by weathering. The Silver Cliff fault zone, above the zone of oxidation, probably does not contain commercial quantities of uranium; however, the solutions from which the uranium was deposited probably migrated up along the fault zone and if so primary uranium minerals may occur at depth.

Uranium occurrence in quartzite

The uraniferous zone in the quartzite 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 intermittently for another 240 feet to the southern most prospect pit on the fault (fig. 2). 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 projection of the Silver Cliff fault, examination of surface outcrops may prove uranium mineralization south of the mapped area.

The downward extent of the Cambrian (?) quartzite is limited by the underlying pre-Cambrian metamorphic rocks. The known vertical dimension of the uraniferous zone in the Cambrian (?) quartzite extends from the surface to the lowest mine working, about 60 feet, and it is believed the zone extends downward another 20 feet (fig. 4). Near the south end of the mapped area, erosion has removed the quartzite. Thus the thickness of the uranium-bearing quartzite ranges from less than 1 inch to about 80 feet.

The width of the uranium-bearing zone in the Cambrian (?) quartzite on the footwall of the Silver Cliff fault is not known accurately. In the mine workings, uranium minerals are detectable in the quartzite for as much as 25 feet away from the fault; on the surface, however, no uranium minerals were found nor could

Table 1. -- Sample analyses, Silver Cliff mine, Niobrara County, Wyoming --/

Sample number	Material	Equivalent uranium (percent)	Uranium (percent)	Copper (percent)	Silver (oz. per ton)
W-6	6-foot chip channel in quartzite	0.003	0.001	Not determined	Not determined
W-7	6-foot vertical channel in quartzite	0.004	0.001	do	do
W-8	6-foot channel in quartzite perpendicular to fault	0.005	0.001	do	do
W-9	3.5-foot channel across face of adit in quartzite	0.006	0.004	do	do
W-10	6-foot channel across fault zone	0.000	0.001	do	do
W-11	6-foot vertical channel in quartzite	0.001	0.001	do	do
W-12	6-foot channel across face of adit in quartzite	0.001	0.001	do	do
W-13	6-foot vertical channel in quartzite	0.029	0.033	do	do
W-14	6-foot vertical channel in quartzite	0.017	0.029	do	do
W-15	4-foot channel in quartzite	0.004	0.004	do	do
W-16	4-foot vertical channel in quartzite	0.12	0.10	do	do
W-17	4-foot channel in fault zone	0.11	0.12	do	do
W-18	4-foot channel in fault zone	0.014	0.009	do	do
W-19	6-foot chip channel across face of pit in quartzite	0.002	0.001	do	do
W-20	6-foot vertical channel in quartzite	0.001	0.001	do	do
W-21	6-foot vertical channel up faced adit in quartzite	0.002	0.003	do	do
W-22	4-foot vertical channel in quartzite	0.023	0.020	do	do
W-23	5-foot vertical channel in quartzite	0.005	0.004	do	do
W-24	6-foot channel in quartzite	0.008	0.008	do	do
W-25	6-foot vertical channel in quartzite	0.001	0.001	do	do
W-26	Composite dump sample	0.020	0.020	do	do
W-51	5-foot channel across hematite stained fault zone	0.006	0.003	0.37	0.98
W-52	Chip sample of radioactive quartzite	0.56	0.61	10.88	15.04
W-53	Chip sample of radioactive quartzite	1.38	1.48	2.60	1.23
W-54	Chip sample of radioactive quartzite	1.59	1.41	1.97	0.16
W-55	6-foot channel across back of drift in fault zone	0.007	0.004	0.27	0.92
W-56	Grab sample of biotite-muscovite schist	0.004	0.001	0.02	0.98
W-57	5-foot channel across fault zone	0.015	0.008	0.16	1.06
W-58	5-foot channel across fault zone	0.004	0.002	0.21	1.00
W-59	Grab of hematite quartzite near fault zone	0.006	0.002	0.03	0.98
W-61	3-foot channel across actinolite layer in fault zone	0.006	0.002	0.03	0.97
W-63	Grab sample from dump of old Silver Cliff Mine	0.014	0.002	< 0.02	0.94
W-64	5-foot channel across carbonate vein	0.001	0.001	< 0.02	0.96
W-65	Selected dump material	3.80	3.39	2.84	1.41
W-66	Selected dump material	0.90	1.03	2.05	0.72
W-69	Grab sample of pegmatite	0.004	0.001	< 0.02	0.97
W-70	Representative sample from uranophane-bearing quartzite from dump	0.080	0.095	Not determined	Not determined
W-71	Typical sample of uranophane-bearing quartzite	0.17	0.19	do	do

--/ Analyses by Trace Elements Section Denver Laboratory

abnormal radioactivity be detected in the quartzite away from the fault.

Uranium occurs in the quartzite in two phases: The less abundant but more radioactive phase is in a heavy, compact, brown to black quartzite that contains pitchblende, gummite, uranophane, chalcocite, secondary copper minerals, native silver, and limonite. This brown to black quartzite was found only in small pockets as much as 3 feet across along the east side of the stope (fig. 2). Thin sections studies of this phase of the quartzite 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 (fig. 2). This brown to black phase grades into the more characteristic and abundant type of uraniferous quartzite.

The typical phase is light buff to rust brown quartzite which in contrast to the other phase, does not contain large quantities of copper and silver minerals. Uranophane is the most abundant uranium mineral, and characteristically occurs along fracture surfaces and as small replacement bodies in the quartzite. 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 quartzite ranges from 0.001 to 3.39 percent, and is dependent upon the spacing of the fractures and replacement bodies.

Localization and distribution of uranium minerals

The localization of the uranium ore thus far mined in the Cambrian (?) quartzite is controlled principally by the pre-ore fractures that resulted from movement along the Silver Cliff fault. The brittle quartzite was readily fractured during faulting and these open fractures appeared to have acted as channelways for the movement of the ore solutions. The relatively soft and plastic gouge along the Silver Cliff fault probably prevented deposition of uranium minerals in the quartzite on the hanging wall.

The distribution of uranium in the uraniferous quartzite is quite irregular. In each set of fractures, some surfaces are coated with uranophane and the others are completely barren. Assays of samples (table 1 and figures 2 and 3) indicate considerable variation in the distribution of the uranium minerals.

Mineralogy

Uranophane, the most abundant uranium mineral at the Silver Cliff mine, has been analyzed by Mary Thompson of the U. S. Geological Survey and found to contain 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, $P < V$. The indices of refraction measured by the immersion method are: α (1.642), β (1.665), and γ (1.672).

The uranophane occurs as lemon-yellow to pale-green coatings up to 1/16 inch thick on fracture surfaces and in irregular replacement bodies, as much as 2 inches across, in the Cambrian (?) quartzite. 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 of the intergranular cementing material. The habit of the uranophane is quite variable. As fracture fillings and coatings, the uranophane is massive or occurs as small radiate or stellate clusters. As replacement material, the uranophane occurs as radiating aggregates as much as 0.12 mm in diameter. It is estimated that uranophane constitutes as much as 2 percent of the quartzite.

Pitchblende and gummite, both uranium oxides, were identified by Schaller (1926, pp. 161-162) in the ore from the Silver Cliff mine. The writers tentatively identified as pitchblende small specks of a black, opaque mineral that occurs in the calcite veins and as a replacement in the calcite cement. In a polished section of black quartzite 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 (1949), 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 quartzite.

Calcite is the gangue mineral in the veins and is the most abundant cementing material. The calcite cement occurs in white to gray, rounded fragments that range from 0.03 to 0.07 mm in diameter. Most of the calcite cement contains numerous minute grains of limonite. The white to light-gray vein calcite is

coarse grained and forms subhedral crystals as much as 0.4 mm in length and 0.03 mm in width. Several of the larger calcite veins contain euhedral calcite crystals perpendicular to the vein walls with a finer-grained calcite filling the center of the vein.

Chalcocite, the only copper sulfide noted, occurs as fracture fillings and as small replacement masses in the quartzite. The alteration products of the chalcocite are native copper, azurite, malachite, cuprite, and chrysocolla. These secondary copper minerals coat fracture surfaces in the quartzite, 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 quartzite from the stope. Analysis of ore samples (table 1) shows that silver is a common constituent of the ore.

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.

An ultraviolet light traverse of underground workings showed no relationship between fluorescence and radioactivity. 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.

Radiometric surveys on Silver Cliff fault and in adjacent areas

A radiometric survey was made of the accessible mine workings, prospect pits, and of surface areas adjacent to the Silver Cliff fault. All the mine dumps along the fault showed abnormal radioactivity. The highest readings in the mine workings were obtained from a black quartzite adjacent to the fault on the east side of the stope (fig. 3). Pitchblende was tentatively identified in specimens of quartzite from this area. Abnormal radioactivity was noted in the quartzite on the footwall of the Silver Cliff fault, but the quartzite on the hanging wall of the fault showed no abnormal radioactivity.

Surface examination with a Geiger counter indicated no abnormal radioactivity in the quartzite in the footwall of the Silver Cliff fault, suggesting the possible leaching of uranium minerals by ground waters or

the erratic 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.

Two areas north of the Silver Cliff mine were tested radiometrically for possible occurrence of uranium.

(1) At the north end of the Lusk Dome, 8 miles north of Lusk, reverse faulting has resulted in geologic conditions similar to those at the Silver Cliff mine. The radiometric traverse made of this area indicated radioactivity only slightly above background. One composite grab sample of quartzite from near the fault, contained 0.001 percent uranium. (2) A small area 5 miles north and 1 mile east of Lusk contains exposures of Cambrian (?) quartzite and pre-Cambrian metamorphic rocks. No abnormal radioactivity was found during the radiometric reconnaissance survey of this area. The absence of abnormal radioactivity in these areas, however, does not preclude the possible occurrence of uranium minerals at depth.

The area in the immediate vicinity of the Silver Cliff mine was tested by a series of carborne radiometric traverses along whatever roads were accessible. Abnormal radioactivity of about 3 times background was noted for a distance of 200 feet on U. S. Highway 20, 1.1 miles west of its junction with U. S. Highway 85. The radioactive zone is on the projected strike of the Silver Cliff fault exposed in the Silver Cliff mine. Detailed radiometric traverses of an area for 100 feet away from the road showed no abnormal radioactivity. Although the cause of the radioactivity was not determined, two possible explanations are: (1) the radioactivity is from road metal carried to site; (2) the radioactivity is the near surface expression of uranium minerals along the Silver Cliff fault, or adjacent fault structures. The first suggestion is believed unlikely since the area is flat and has no evidence of road fill. It is possible that the source of radioactivity is similar to that at the Silver Cliff mine; only subsurface exploration would provide positive information.

Grade

Although the grade of the ore shipped in 1919 from the Silver Cliff mine was reported to be 3 percent uranium (Dietz, 1929, pp. 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 quartzite 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 from the east side of the stope (fig. 3), and contained 1.48 percent uranium. This sample was from an area of about 3 square feet of dark brown to black quartzite. 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 eight contained more than 0.1 percent uranium, four contained from 0.02 to 0.1 percent uranium, and the remainder contained less than 0.02 percent uranium. West (1944, pp. 9-11), 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 (1944, p. 22) report the uranium content of two grab samples of dump material as 0.076 percent and 0.090 percent.

Origin

According to Hess (1926, p. 156), the uranium deposits at the Silver Cliff mine in part fill fractures and in part replace the quartzite. He believes that the solutions from which the minerals were deposited followed cracks and spread from the cracks into the quartzite. Hess (1926, p. 156) states that the original uranium mineral or minerals were scattered between the sand grains, and mixed with other minerals so that pure material has not been found.

West (1944), suggested that the primary uranium minerals in the quartzite were introduced along with or after the formation of carbonate veins in the fault fissures. Secondary uranium minerals were deposited as oxidation of the primary mineral progressed.

The present writers believe that the deposit is hydrothermal in origin. Briefly, the sequence of events following the deposition of the quartzite is thought to be (1) reverse faulting, (2) minor faulting and fracturing of the quartzite, and (3) deposition of the ore. Calcite, chalcocite, and pitchblende, the primary minerals, were deposited in fractures and in replacement bodies in the quartzite. The paragenesis of these minerals has not been definitely established; probably they are contemporaneous or have overlapping periods of deposition. Uranophane, gummite, metatorbernite, native silver, native copper, azurite, malachite, and chrysocolla are all products of oxidation and replace the primary minerals.

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ABSTRACT

Total indicated and inferred uranium reserves are 39,600 tons that average 0.036 percent uranium and contain 28,100 pounds of uranium; of this tonnage, 7,000 is indicated in the dump and the remainder is inferred in place in the mine.

Areal reconnaissance might disclose additional uranium deposits in this region, particularly in the Rawhide Butte area, 20 miles south of Lusk. Rehabilitation of the vertical shaft and the 1,200-foot adit are recommended.

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URANIUM RESERVES

The uranium reserves (table 2) at the Silver Cliff mine are classed as indicated ore--comprising the mined ore in dumps, and inferred ore--comprising unmined ore. The principal uranium mineral is uranophane which occurs as thin coatings on fracture surfaces and as small pockets in quartzite, and as tiny veinlets in fault gouge.

The indicated ore consists of uranium-bearing rock that was discarded during former mining. The average grade of this material is estimated to be 0.020 percent uranium. The dumps contain about 7,000 tons of this indicated ore containing 2,800 pounds of uranium.

One small pillar of unmined ore, just east of the stope, is well enough exposed to be classed as indicated ore but is so small that it is better included with the inferred ore.

Two blocks of inferred ore are considered:(1) the ore in the quartzite on the downthrown side of the fault, and (2) the ore in the fault gouge.

The largest block of inferred ore is in the quartzite on the downthrown side of the fault. Radiometric examination of the quartzite in the mine and on surface outcrops, and chemical analysis of the samples taken, indicate that the uranium-bearing part of the quartzite extends southward along the fault from the northernmost metamorphic rock-quartzite contact continuously for 835 feet and then intermittently for an additional 240 feet. The southern limit of the uranium-bearing quartzite is not accurately known, but no abnormal radioactivity could be detected along the outcrop of the fault for more than 25 feet south of the southernmost pit. For calculating reserves the total length of the uraniferous quartzite zone was taken as 1,075 feet.

The width of the uraniferous quartzite zone is extremely variable. Ore has been mined underground as far as 25 feet from the fault, but the pits in the quartzite along the fault indicate that the average width is probably about 15 feet. Reserves were calculated for an average width of 15 feet. The uranium-bearing quartzite is assumed to extend from the surface downward to its contact with the pre-Cambrian rocks. Its thickness ranges from a feather edge to nearly 80 feet. The average thickness used in computing reserves is 31 feet.

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The grade of ore in the quartzite was determined by weighting the assay of each sample by the length of the sample and averaging the weighted assays from several parts of the deposit. Analyses of 21 chip and channel samples of uraniferous quartzite ranged from 0.001 to 1.48 percent uranium; the weighted average is 0.045 percent uranium. This average may be in error by as much as 25 percent because of the erratic distribution of the uranium minerals along fractures in the quartzite.

The uraniferous quartzite, 1,075 feet by 15 feet by 31 feet, contains 38,500 tons of ore, allowing 13 cubic feet per ton. Subtracting 12,300 tons of ore previously mined gives 26,200 tons of inferred ore, with an average grade of 0.045 percent uranium, in the mine. This ore contains 23,500 pounds of uranium.

The inferred reserves in the gouge of the Silver Cliff fault zone are calculated on the assumptions that the gouge is uranium-bearing throughout the length of the fault and that the grade is represented by the weighted average of the eight samples taken. The fault gouge zone has an average width of 5 feet, an average vertical dimension of 31 feet, and a minimum length of 835 feet. The samples from this zone contained from 0.001 to 0.12 percent uranium with a weighted average of 0.014 percent uranium. Allowing 20 cubic feet per ton, the inferred reserves in the fault gouge are 6,400 tons of ore containing 1,800 pounds of uranium.

Table 2. --Reserves of the Silver Cliff mine, Niobrara County, Wyoming

Material	Indicated			Inferred		
	Tons	Uranium (percent)	Uranium (pounds)	Tons	Uranium (percent)	Uranium (pounds)
Quartzite	None			26,200	0.045	23,500
Fault gouge	None			6,400	0.014	1,800
Dump material	7,000	0.020	2,800	None		
Totals and averages	7,000	0.020	2,800	32,600	0.039	25,300

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PROPOSAL FOR PHYSICAL EXPLORATION

Physical exploration of the uranium deposit at the Silver Cliff mine is warranted primarily to obtain geologic information that might aid in prospecting other geologically similar deposits; secondly to determine the dimensions and grade of the uranium-bearing quartzite; and thirdly to explore the fault zone in the underground workings. The most effective method to explore this property is by rehabilitation of the 1,200-foot adit and the 285-foot vertical shaft. The owners have applied for a D. M. E. A. loan and the rehabilitation of the adit and shaft should be undertaken by them. The Survey plans to map and sample any parts of the adit and shaft that are exposed during this rehabilitation. Recommendations for further exploration, i. e. core drilling will depend on the information obtained from the above developments.

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FIGURE 2.- GEOLOGIC MAP OF THE SILVER CLIFF MINE, NIOBRARA COUNTY, WYOMING

FIGURE 3.- GEOLOGIC MAP OF UNDERGROUND WORKINGS, SILVER CLIFF MINE, NIOBRARA COUNTY, WYOMING

FIGURE 4.- GEOLOGIC SECTIONS OF THE SILVER CLIFF MINE, NIOBRARA COUNTY, WYOMING