UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
AFFILIATED WITH
THE COLLEGE OF MINES AND MINERAL INDUSTRIES
UNIVERSITY OF UTAH
SALT LAKE CITY, UTAH

GEOLOGY OF THE SILVER REEF (HARRISBURG) MINING DISTRICT

WASHINGTON COUNTY UTAH

By
PAUL DEAN PROCTOR

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UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

The Utah Geological and Mineralogical Survey was authorized by act of the Utah State Legislature in 1931; however, no funds were made available for its establishment until 1941 when the State Government was reorganized and the Utah Geological and Mineralogical Survey was placed within the new State Departement of Publicity and Industrial Development where the Survey functioned until July 1, 1949. Effective as of that date, the Survey was transferred by law to the College of Mines and Mineral Industries, University of Utah.

The *Utah Code Annotated 1943, Vol. 2, Title 34,* as amended by *chapter 46 Laws of Utah 1949,* provides that the Utah Geological and Mineralogical Survey "shall have for its objects":

1. "The collection and distribution of reliable information regarding the mineral resources of the State.

2. "The survey of the geological formations of the State with special reference to their economic contents, values and uses, such as: the ores of the various metals, coal, oil-shale, hydro-carbons, oil, gas, industrial clays, cement materials, mineral waters and other surface and underground water supplies, mineral fertilizers, asphalt, bitumen, structural materials, road-making materials, their kind and availability; and the promotion of the marketing of the mineral products of the State.

3. "The investigation of the kind, amount, and availability of the various mineral substances contained in State lands, with a view of the most effective and profitable administration of such lands for the State.

4. "The consideration of such other scientific and economic problems as, in the judgment of the Board of Regents, should come within the field of the Survey.

5. "Cooperation with Utah state bureaus dealing with related subjects, with the United States Geological Survey and with the United States Bureau of Mines, in their respective functions including field investigations, and the preparation, publication, and distribution of reports and bulletins embodying the results of the work of the Survey.

6. "The preparation, publication, distribution and sale of maps, reports and bulletins embodying the results of the work of the Survey. The collection and establishment of exhibits of the mineral resources of Utah.

7. "Any income from the sale of maps and reports or from gifts or from other sources for the Survey shall be turned over to the State Treasurer and credited by him to a fund to be known as the Survey Fund to be used under the direction of the Director of the Survey for publication of maps, bulletins or other reports of investigation of the Geological and Mineralogical Survey."

The Utah Geological and Mineralogical Survey has published maps, circulars, and bulletins as well as articles in popular and scientific magazines. For a partial list of such publications see the inside back cover of this publication and the preceding pages. For other information concerning the geological and mineralogical resources of Utah address:

ARTHUR L. CRAWFORD, *Director*

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

College of Mines and Mineral Industries

University of Utah

Salt Lake City, Utah

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FOREWORD

With the establishment of the Utah Geological and Mineralogical Survey, it was at once evident that neither funds, personnel, nor facilities were available to begin a full-fledged Geological and Mineralogical Survey of the State on an independent basis. However, the law under which it was founded authorized the Survey to cooperate with any and all existing agencies whose activities might contribute to its program. As a consequence, immediate steps were taken to enlist the support of agencies and individuals who might be interested in this type of cooperation. Obviously, the research of graduate students doing thesis work on problems in Utah offered the most immediate promise for fruitful participation.

The author of this Bulletin was one of the first such graduate students to enter into a contract with the Survey to carry out specific research of mutual interest. Paul Dean Proctor, then a candidate for the Ph.D. degree at Indiana University, was granted a limited subsidy for certain specified purposes with a view to enriching the content of his manuscript for the production of a bulletin meeting Survey standards. His area for study had already been selected by Proctor in consultation with Dr. Charles F. Deiss, Chairman of the Department of Geology, Indiana University, and with Dr. Eugene Callaghan, Professor of Economic Geology at that institution.

Because of its historic significance in orogenesis and because of its strategic position at the boundary line of the Colorado Plateau with the Basin and Range Province as these provinces are exhibited in Southern Utah, the Silver Reef district was given priority by the Survey as a subject of study. While it was undertaken primarily as a means of throwing additional light, by the application of modern means of research, on the historic problem of the formation of economic deposits of silver in sandstone the presence of small amounts of uranium, vanadium and selenium in the mineral assemblage making up the Silver Reef ore bodies was an intriguing aspect of the subject, and the fact that the Silver Reef district was situated on what was believed to be a possible oil structure furnished an additional reason for giving preference to this investigation.

The contract with Proctor was written while the Utah Geological and Mineralogical Survey was yet a subsection of the Raw Materials Division of the Utah State Department of Publicity and Industrial Development.

The final publication of the work has been delayed for a number of reasons, chief of which was the discontinuance of the U.P.I.D., the transfer of the Utah Geological and Mineralogical Survey to the College of Mines and Mineral Industries, University of Utah (with a decreased appropriation) and the consequent curtailment in funds and personnel to process this and other research papers resulting from these cooperative contracts. In the meantime, Proctor completed his requirements and was awarded his doctorate degree from Indiana University. His work was received with such approval that he was made Associate Professor of Geology at Indiana University where he remained until the Fall Quarter of 1952, when he returned to the Brigham Young University as a permanent member on the geological faculty of that institution.

The problem of the genesis of the Silver Reef ore bodies is one which has received the close attention of students of economic geology throughout the world. These ore bodies constitute the only occurrence of its size of silver in sandstone unconnected in any demonstrable way with an igneous source. It will be noted from the following Bulletin that Dr. Proctor comes to the conclusion, after weighing all the evidence from his own and from previous investigations, that the silver was derived from particles originally disseminated in volcanic ash. He thinks that these were in turn concentrated by solution and reprecipitated by organic matter along stream channels of the Buckeye Reef member of the Chinle formation. However, to some of those familiar with the wide-spread occurrence of the Chinle bentonitic members assumed to have come from volcanic ash, it may be difficult to visualize the mechanism by which the silver is assumed to have been concentrated into an economic deposit in the Silver Reef area while not receiving similar concentration in any of the many areas to the east of the Silver Reef district where these same Chinle beds are well exposed.

Another circumstance which may have greater significance than is obvious from Proctor's treatment is the apparent correlation between the structure of the area and the Silver Reef ore deposits. It appears that the economic deposits form a U-shaped outline around the nose of the Leeds anticline. This would seem to suggest that the folding preceded the emplacement of the minerals so as to have influenced their mechanism of accumulation. One wonders if there may not have been some connection between the great andesitic accumulations in Pine Valley Mountain to the north and the hydrothermal solutions which conceivably traveled southward and upward on the Leeds anticline becoming colder in their long transit through the porous sandstones, which acted as conduits, until they no longer could retain in solution their metallic burden.

No doubt Dr. Proctor has considered and discounted in his own mind these seeming impediments to his theory. This painstaking review of the literature and of the contributions Proctor has made from his own studies will be welcomed by researchers in this field. In spite of all the work that has been done on the Silver Reef mineral occurrence, it still remains as one of the enigmas of mineral genesis.

Arthur L. Crawford, Director
Utah Geological and Mineralogical Survey

GEOLOGY OF THE SILVER REEF

(HARRISBURG) MINING DISTRICT
WASHINGTON COUNTY
UTAH

BY

Paul Dean Proctor*

ABSTRACT

The Silver Reef mining area in southwestern Utah contains the only known occurrence in the United States of commercial bodies of silver ore with minor copper-uranium-vanadium minerals in sandstone. The ore bodies are restricted to the Silver Reef sandstone member of the upper Triassic Chinle formation and occur on the limbs and nose of a major anticline and a subsidiary anticline and syncline. A newly recognized north-trending normal fault and a thrust fault with a minimum eastward displacement of 1500 feet repeat the ore horizon three times. No constant relationship exists between the mineralization and the folds or faults.

Silver, copper, and minor gold values in a bentonite 300 feet below the ore-bearing horizon, minerals of these metals and lense-like bentonitic shales in the Silver Reef sandstone, and other known occurrences of notable metal content in volcanic tuffs suggest a new theory of origin for these unusual deposits. It is concluded that the metals were primary constituents of original volcanic tuffs in Triassic time; that these metals were dissolved and/or mechanically transported by streams eroding the tuffaceous sediments; that they were later deposited with the sandstone and shales of the Silver Reef area; that further concentration of the metals in the Silver Reef sandstone was by (1) solution in circulating ground water, and (2) precipitation through contact with entombed plant debris and associated bacteria in more permeable buried Triassic stream channels. Folding, erosion, and exposure of the ore horizon is assumed to have resulted in secondary enrichment of the ore deposits by meteoric waters.

*Formerly Associate Professor of Geology, Indiana University, now Associate Professor of Geology, Brigham Young University.

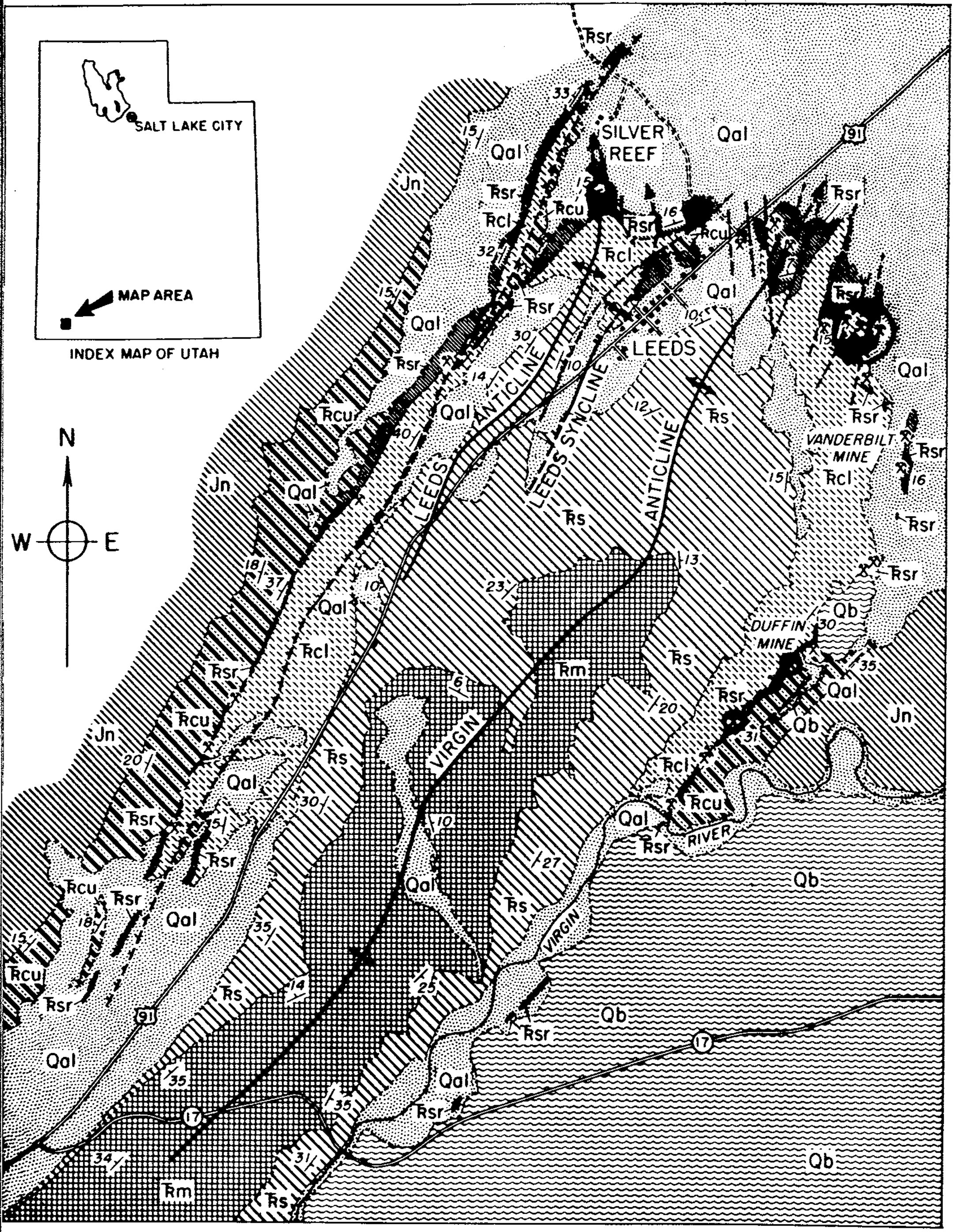
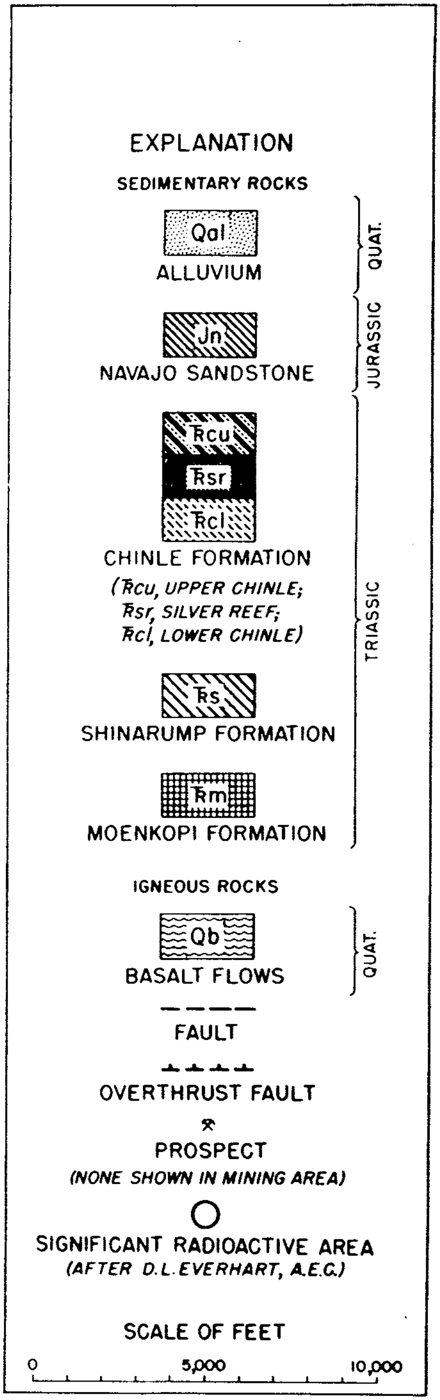


Plate I. GEOLOGIC MAP OF HARRISBURG (SILVER REEF) DISTRICT, WASHINGTON COUNTY, UTAH



LEGEND FOR Plate I.

<u>INTRODUCTION</u>

The Silver Reef area in southwestern Utah merits greater attention than it has received for it contains the only known occurrence of commercial bodies of silver ore in sandstone in the United States. It yielded almost $8,000,000 in silver during a decade that included the late 1870's and early 1880's from some 29 mines distributed through an area of two square miles. Furthermore, minerals containing copper, vanadium, and uranium are associated with the silver minerals so that a proper study of the Silver Reef deposits may furnish comparative data that should be of value in understanding deposits of these metals elsewhere in the sedimentary rocks of the Colorado Plateau. It is believed that the metals in the Silver Reef sandstone were primary constituents of original volcanic tuffs in the Chinle formation. These metals were dissolved and/or mechanically transported by streams which were eroding the tuffaceous sediments. They were deposited with the sandstones and shales of the Silver Reef area. Further concentration of the metals in 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. A new interpretation of structural features should encourage additional prospecting in the Silver Reef area, not only for metals but, interestingly enough, for petroleum.

PREVIOUS WORK

As much of the known ore has been extracted and many of the underground workings are no longer accessible, the recorded observations of earlier workers are particularly valuable in interpreting features of the district. Rolker in 1881 described several of the mines and his careful observations on the Buckeye Reef are very helpful for the later study since most of the mines on this reef are now inaccessible. Rothwell, as editor of the Engineering and Mining Journal in 1880, summed up his observations on the district. Professor J. S. Newberry recorded data on the district and offered a theory on the origin of the silver deposits in 1880. Later, Butler (pp. 582-594, 1920)[1] in his review of the ore deposits of Utah summarized the work of former writers and added his own observations. Several brief private reports to the different companies which have operated in the district were written by Ball (1920), Crane (1920), Wroth (1920), Elgin and Wilson (1946), Stugard (1951) and others. Both Dobbin (pp. 121-144, 1939) and Gardner (pp. 241-260, 1941) geologically mapped the surrounding area in some detail.

FIELD WORK

The writer began work in the district in the fall of 1947 and completed the field work during weekends, half of December and two months of 1948. The known productive area of the district was surveyed on a scale of 200 feet to the inch and all of the accessible workings were inspected and some were geologically mapped. The mine areas on the East Reef were also surveyed on the same scale. A background geologic map of the mining district on a scale of one inch equals one-half mile was completed on copies of U. S. Soil Conservation photos of the area. The final map was compiled on a controlled mosaic of two inches equals one mile.

An underground map of most of the known workings was compiled from old maps of the area. It is regretted that other maps of now inaccessible workings were not made available to make the compilation more complete. However, the map does give a fair representation of the mines and their extent.

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1. (   ) refers to reference in bibliography at end of report.

ACKNOWLEDGMENTS

No study of any mining district can be rep sentative of the district without the wholehear cooperation of the mine owners and men who h worked there. To those men who gave freely their time and information I extend my than Space permits only the mention of a few. Mr. W. Colbath, former owner of the property, was m kind in granting permission to study the distr and in supplying underground maps of the Thomps Cobb area and the Doyle shaft workings. His d cussion of the other mines in the area was m enlightening. Mr. E. W. Newman, geologist for A. S. & R. Company and his associates dese special thanks for the valuable information suppl on the work completed by their company in 19 and for the copies of all the underground worki they sampled and surveyed on the Buckeye Re Mr. James Ehrhorn, Superintendent of the U. Mine at Bingham, Utah was very kind in furnish the diamond drill cores of five holes drilled the district in 1946 and in supplying copies reconnaissance reports made by his enginee Others who have been very helpful are Mr. Fr Hartley and Messrs. Oscar, Willard, and Bob McMu of Leeds, Utah.

To my part-time assistants Tom Gwynn, Johns, Herman Heath, Bob White, and my wife Mar I extend my sincere thanks. Finally, without aid of a small field expense grant from the Department of Publicity and Industrial Developm Raw Materials Division through Arthur L. Crawf Commissioner, and the generous fellowship and pense account of the Shell Oil Company at Ind University for the 1948-49 academic year, much the data now presented could not have been obtai

The study was done under the very help guidance of Dr. Eugene Callaghan, former Professo Economic Geology, Indiana University, and to the writer extends his deepest appreciation thanks for his invaluable help. Credit is acknowledged to W. H. Moran for his drafting and to George Ringer and Dr. C. F. Deiss for t constant support.

LOCATION

The Harrisburg (Silver Reef) district is in Washington County in southwestern Utah. Leeds, a farming community, population 200, is just north of the center of the district. The nearest railroad is a branch line at Cedar City, Utah, 34 miles to the north and 2300 feet higher. U.S. Highway 91 lies one mile east of the former productive mines of the district.

The region is semi-arid, and the winters are mild, but the summers are hot. Rainfall at Anderson's Ranch, two miles north of Leeds, averaged 12.69 inches per year over a 27 year period. Table 1 lists the monthly average for the same period.

Table 1.* Monthly Rainfall Average - 27 Year Period
Anderson's Ranch, 2 miles North of Leeds, Utah

Month	Average	Month	Average
January	1.74	July	0.73
February	1.94	August	0.92
March	1.31	September	0.59
April	1.04	October	1.02
May	0.65	November	0.77
June	0.31	December	1.67
Annual Average - same period			12.69 inches.

*U.S. Department of Commerce, Weather Bureau, G. K. Greening, Meteorologist.

Water is scarce, and the main source is Quail Creek, which drains a portion of the Pine Valley Mountains to the west. The stream supplies the mines and the town of Leeds with water for both culinary and irrigation purposes. A few small perennial springs a few hundred feet west of Leeds are utilized for irrigation and cattle. The only other stream in the district is the Virgin River in the southeast part of the area which lies 300-400 feet lower than Silver Reef. The water is used for irrigation at Washington and St. George to the south. The Stormont Mill, now dismantled, once milled ore on the river near its intersection with the East Reef. Of the estimated 15 miles of underground workings in the area, probably 50% are flooded with water. In case of drought most of this water could be recovered by rehabilitating the A.S.&R. Co. shaft and pumping from the 460 level.

Timber is scanty or absent near the mines, but fair growths of cedar, juniper, and pine suitable for mine use cover the less precipitous slopes of the Pine Valley Mountains six miles to the west. There is a sparse growth of desert type plants, mainly sage brush and varieties of cactus near the mines. Where water is available for irrigation purposes farming is extensively practiced in the small flat valleys. Some cattle are raised in the area, but these are secondary in importance to fruit growing.

SURFACE FEATURES

Relief in the area of the mines is not more than 1000 feet. The old town of Silver Reef, now represented by only two habitable buildings and numerous old rock foundations and stone walls, lies on a boulder-strewn terrace at approximately 4000 feet elevation. The mines themselves are on the face and dip slope of ridges of ledge-making sandstone and range in elevation from less than 3600 feet to 4000 feet.[2] To the west resistant,

2. Mine elevations were established on an assumed datum of 4000 feet for U.S. Mineral Monument #1. Since all former underground maps are on this datum, the writer's survey also utilizes these elevations.

red sandstone cliffs rise almost a thousand feet above the Silver Reef Area. Farther west igneous rocks of the Pine Valley Mountains form precipitous slopes which rise to altitudes of over 10,000 feet. East of the district the imposing Hurricane Cliff separates the downfaulted St. George Basin from the main Colorado Plateau Province. Farther to the east and north a stairway of ledges rises to the Zion Canyon National Park Monument area and beyond to the Colob Plateau to more than 10,000 feet in elevation.

Leeds lies in a synclinal valley cut in soft shales between resistant sandstone ledges. Northeastward-dipping hogbacks of grit and conglomerate flank a breached anticline which extends 18 miles to the southwest. The soft shales in the core of this anticline have been intricately eroded into a badlands type of topography. Vegetation is practically absent here and the local name "Purgatory" has been appropriately applied.

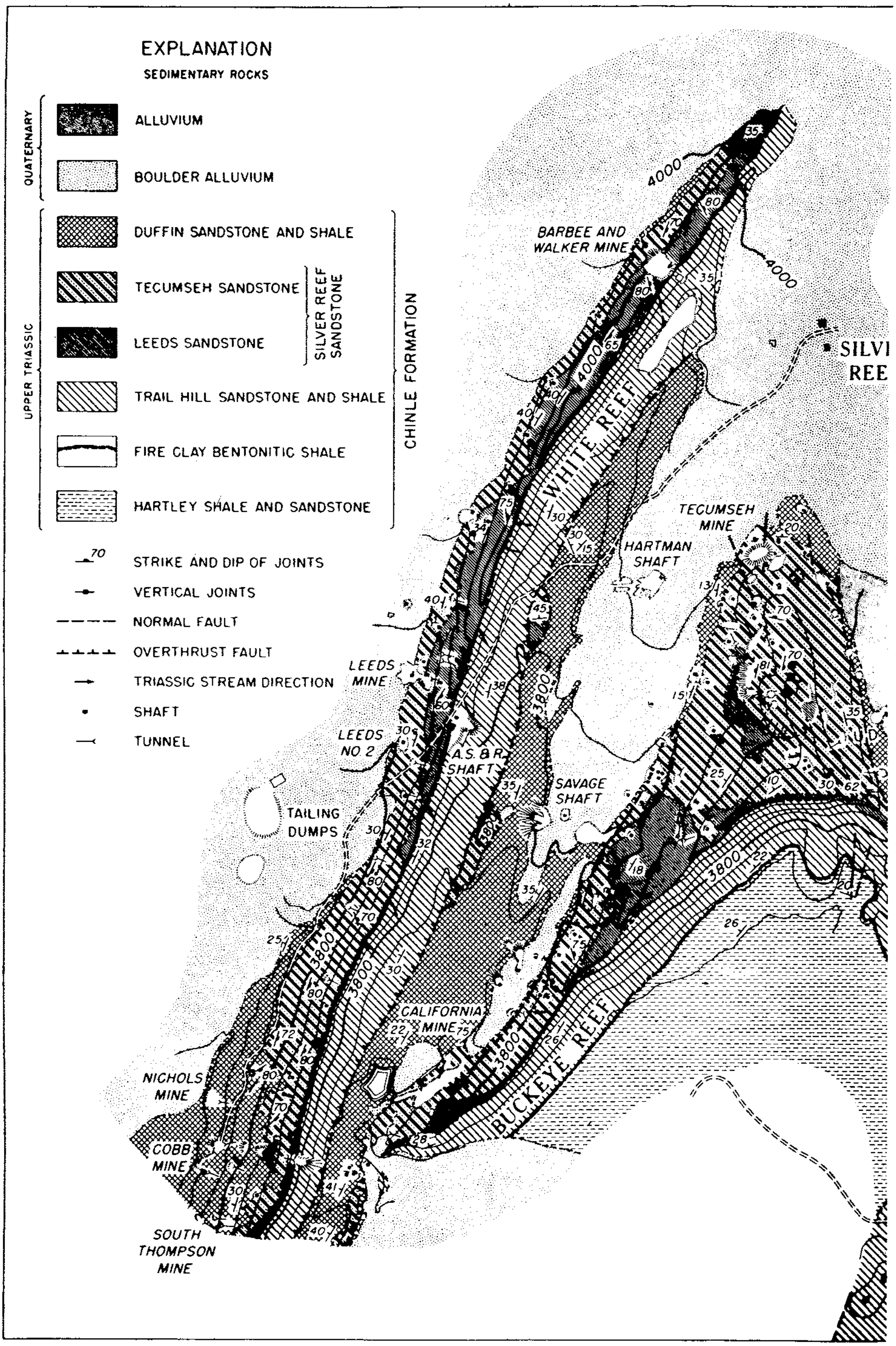


Plate II GEOLOGIC MAP OF SILVER REEF MINING AREA, WASHINGTON COUNTY, UTAH

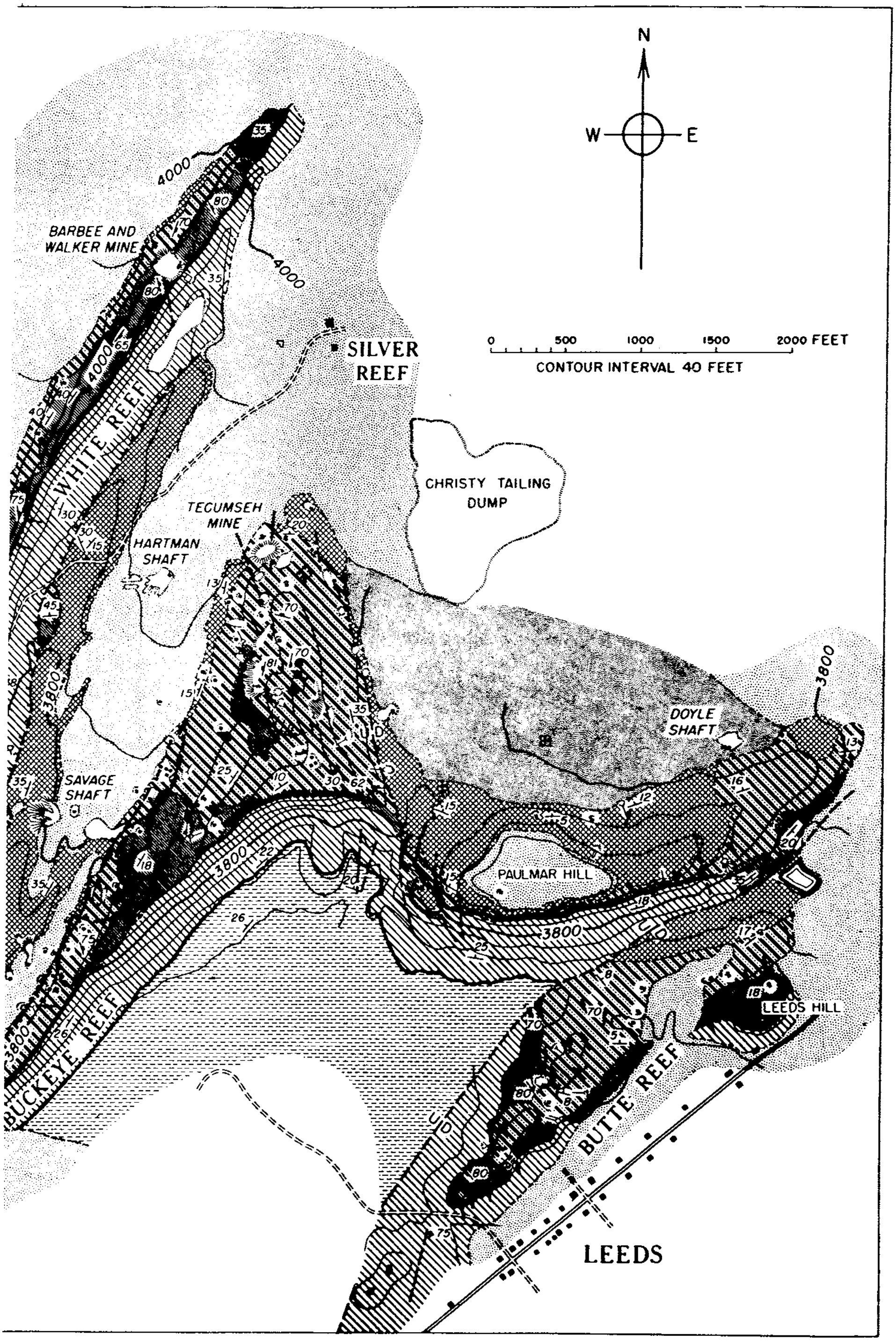


Plate II. GEOLOGIC MAP OF SILVER REEF MINING AREA, WASHINGTON COUNTY, UTAH

GEOLOGIC SETTING

SEDIMENTARY ROCKS

The sedimentary rocks of the Silver Reef area range in age from Lower Triassic to Jurassic and are typical of the stratigraphic sequence in southwestern Utah and Colorado Plateau. The rocks closely resemble those so well known to visitors of nearby Zion National Park. Sandstones, shales, siltstones, and mudstones are the important lithologic types. With the exception of the Virgin limestone member in the lower part of the Moenkopi formation which contains marine fossils, all the rocks are believed to have been deposited under non-marine conditions. The only fossils thus far found near Silver Reef above the Virgin limestone are fragments of trees, rushes, and reeds. Within the part of the Silver Reef area that was mapped, the lower Triassic Moenkopi and the upper Triassic Shinarump and Chinle are the formations with which this study is concerned. More detailed description is devoted to the Chinle than the other formations in the following pages because it contains the silver-bearing horizon.

Moenkopi Formation

With the exception of the basal portion, most of the Moenkopi formation is very well exposed in the Silver Reef area. Reeside and Bassler (pp. 59-62, 1922) described a section near the Harrisburg dome including the unmapped Virgin limestone member two miles south of the area covered by this report. In addition, Huntington and Goldthwait (pp. 101-59, 1904), Butler (pp. 583-594, 1920), Gardner (pp. 241-260, 1941), and Gregory and Williams (pp. 224-228, 1947) have all described or named the rocks in the surrounding country, though the rock names of Huntington and Goldthwait have been superseded by more recent correlations. Reeside and Bassler (p.55, 1922) subdivided the Moenkopi into the Rock Canyon conglomerate, Virgin limestone, and Shnabkaib members in ascending order.

Only the Shnabkaib member is included in the mapped area. Further subdivision seemed unwarranted.

The Moenkopi is exposed only in the breached anticline in the area called Purgatory just north of the Harrisburg-Hurricane road for over a distance of four and a half miles. The sandstones, soft shales, mudstones, and minor gypsum beds have been eroded and an intricate drainage pattern has been developed that provides good exposures. From a vantage point overlooking Purgatory basin the brightly colored Moenkopi section appears as a series of colored bands wrapping around the nose of the anticline. Grays, whites, and pinks predominate near the base of the section exposed, whereas red and maroon color the upper part. A section of 376 feet of Moenkopi (Shnabkaib member) was measured just north of the Harrisburg-Hurricane road.

Lithologically the member exposed may be divided into four distinctive units: (1) an underlying series of white to light red gypsiferous shales and mudstones with minor sandstone (not measured); (2) 54 feet of variegated brick-red shales with minor interbedded yellowish, micaceous shales; (3) 60 feet of creamish yellow, highly cross-bedded, somewhat iron stained friable sandstone; and (4) 262 feet of brick-red to brownish red shales, sandy shales, sandstone and mudstones.

The measured section is as follows:

<u>Section of exposed Moenkopi formation in Purgatory Basin, North of Harrisburg-Hurricane road, Washington County, Utah.</u>

... Shinarump
24' Platy fine-bedded red shales, mudstones. Reed impressions.
3' Cross-bedded, micaceous sandy mudstone.
4' Platy, fine-grained argillaceous sandstone, hard, ripple-marked.
7' Fine-grained argillaceous brick-red sandstone.
20' Red fine-grained red massive sandstone.
10' Micaceous, thin-bedded, sandy mudstone.
5' Fine-grained muddy brick-red sandstone.

105' Soil weathering, brick-red shales and mudstones. Gypsum layers present. Base green-gray micaceous sandstone, upper part mainly brick red mudstone, thin gypsum layers parallel to bedding. Upper one-fourth red and minor gray micaceous shales and some sandstones.

50' Brick-red shales and mudstone, upper portion quite micaceous sandy shale. Lower one-third ripple marked. Easily eroded member.

60' Yellow, highly cross-bedded, iron stained griable sandstone. May be quite argillaceous. Contact fluting and pitting characteristic. Good ledge maker.

54' Variegated brick-red, micaceous sandstone and shales. Minor interbedded yellow micaceous shales. Red predominant color. Weak member.

... Gypsiferous gray to pinkish and red shale and mudstones. Easily eroded member. (Not measured.)

Shinarump Conglomerate

The Shinarump conglomerate is doubtless one of the most interesting formations in the southwestern United States. This formation ranges in areal extent from northwestern New Mexico (Sears, J., p. 10, 1925) and across southern Utah (Baker, p. 37, 1933; Gregory, H. B. & Moore, R. C., p. 52, 1931) and northern Arizona (Longwell, et. al., pp. 9-11, 1925) into southeastern (Longwell, C. R., p. 52, 1928) and southern Nevada (Hewett, D. F., p. 34, 1931). In almost every published description the lithology is the same, the thickness seldom exceeds 100 feet, and its primary structures are similar. The source of the Shinarump and its mode of deposition constitute one of the intriguing problems of the Colorado Plateau and the region to the west (Stokes, p. 1383, 1948).

The resistant Shinarump formation lies between a series of deep red sandstones and shales where its brown to grayish-brown and buff colors are in marked contrast to the enclosing rocks. It is essentially 115 feet of coarse-grained sandstone with abundant interbedded pebble conglomerates. Pebbles in the conglomerates rarely exceed an inch in diameter and consist chiefly of quartz and quartzite, though chert and lesser limestone pebbles do occur. Reeside and Bassler (p. 73, 1922) reported igneous rock pebbles in the section they measured near Virgin City, though no such pebbles were observed in the Silver Reef area. Rapid lensing of the interbedded pebble conglomerates and some of the sandstones is characteristic of the formation. An abundance of fragments of fossil wood and impressions of rushes and reeds may be locally present near the top of the formation. Stream cross-bedding and channels are abundant. Local unconformities or filling of former stream channels were observed in the underlying Moenkopi formation. A fluviatile origin is suggested.

The Shinarump forms bold ledges that include the southwestward-trending ridge south and west of the Leeds cemetery and the nose and prominent encircling hogback enclosing Purgatory Basin. Joints are prominently exposed in the beds. From the Silver Reef area the Shinarump crops out for many miles south along U. S. Highway 91, towards St. George, Utah.

Shinarump Conglomerate Section North of the Harrisburg-Hurricane Road

... Chinle Formation.

15' Massive, reddish, coarse-grained sandstone.
16' Yellow to light red, platy, cross-bedded sandstone.
15' Moderate brown, coarse-grained sandstone. Yellow streaks parallel to bedding. Fossil wood.
35' 20' grayish yellow to dark yellowish-orange grit, pitted and fluted weathered surface. 15' grit and sand, small lenses of conglomerate. Buff, smooth weathering.

34' Grit and pebble conglomerate, stream cross-bedding prominent. Pebbles to 1" diameter, mainly quartz and quartzite.

115' Total

... Moenkopi Formation.

Chinle Formation

A new structural interpretation in the Silver Reef area has forced a change in the stratigraphic section originally described by Ball (1920), Crane (1920), Rolker (pp. 22-24, 1881) and that noted by Butler (pp. 586-7, 1920) for the Silver Reef area. A detailed description of the Chinle formation seems warranted as it contains the economically important Silver Reef sandstone. However, the scale permits showing only three members of the Chinle formation on the geologic map (Plate I), but subdivision into seven members is necessary for careful stratigraphic and structural work in the mine area.

Within the Silver Reef area the Chinle formation consists of about 1100 feet of alternating sandstones and shales with the exception of two small beds of cherty limestone near the old Silver Reef cemetery. On the basis of color and lithology the formation is subdivided into a lower member consisting predominantly of dark red shales and minor interbedded red sandstones 265 feet thick overlying the Shinarump formation, a prominent 5-15 foot bed of white arkosic sandstone, 10-15 feet of purplish to bluish-gray bentonitic shales with included banded chert, 310 feet of deep red to brick red sandstone and shales with an included one foot bed of white silicified limestone, 65 feet of buff weathering to white sandstone overlain by 35 feet of lavender to purple sandstone together known as the Silver Reef sandstone (Reeside and Bassler, p. 62, 1922) and finally the upper Chinle which consists of more than 400 feet of red shales and sandstones with some white, friable sandstone beds which locally are 10 feet or more in thickness.

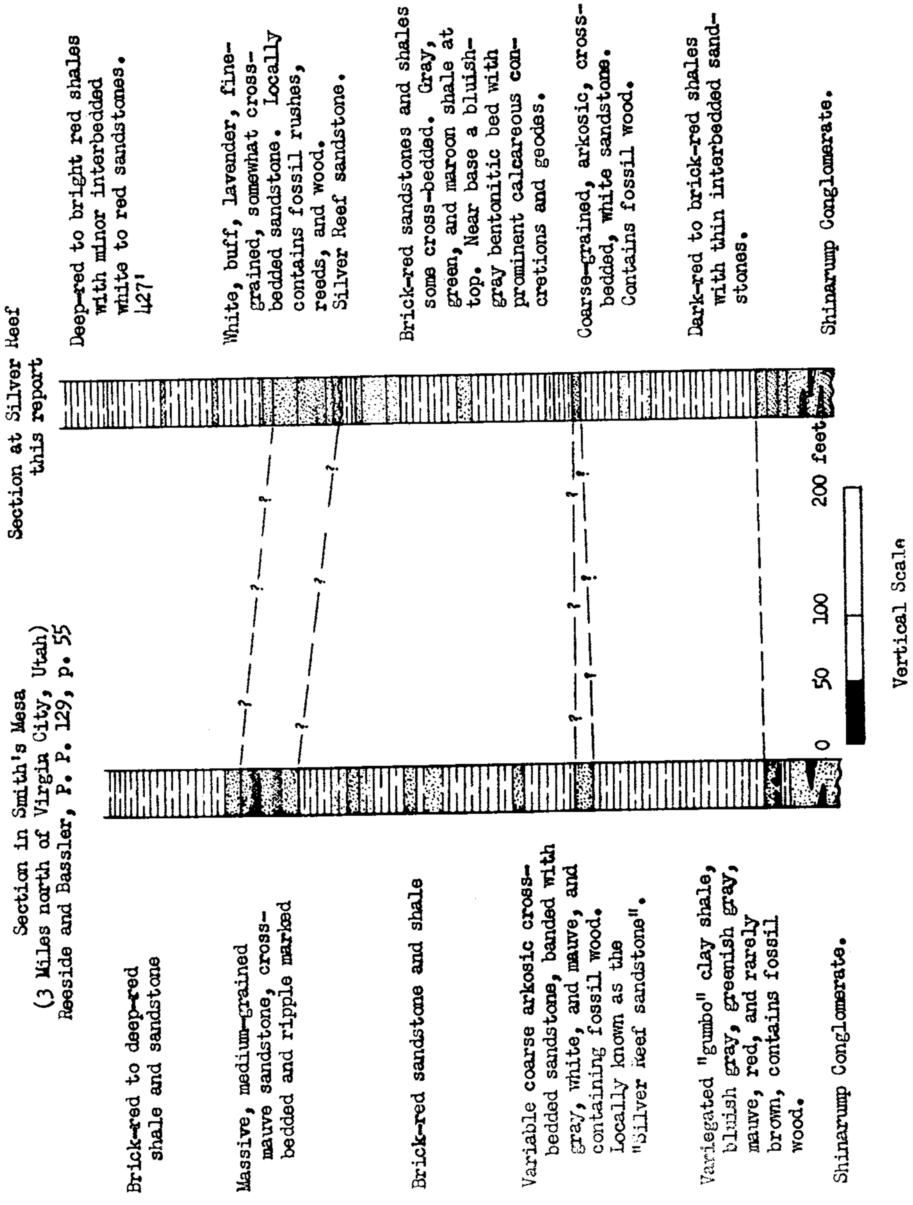


Figure 1. Measured sections of Chinle formation.

The Chinle formation is exposed throughout the Silver Reef area and particularly on the East limb of the Virgin anticline where much of the Quaternary alluvium has been stripped away. Typically, the Chinle forms gentle slopes with the exception of the more resistant sandstone members within the formation which crop out as bold cliffs. From Leeds west to the high red sandstone cliffs all the rocks exposed are Chinle except for a line of Shinarump outcrops just west and south of the town. The gently rolling surface west of Highway 91 near Harrisburg and south toward St. George shows the characteristic weathering of the formation. Within this section the prominent Silver Reef sandstone stands out as a ridge above the soft shales. North and east of Leeds much of the Chinle is covered by Quaternary alluvium and wind blown sand.

Lower Chinle Member

The lower Chinle member is mainly a series of brown to red sandstones and shales with some gypsum and possibly minor salt which occurs between the Shinarump formation and the Silver Reef sandstone member of the Chinle formation. The member is 620 feet thick, easily weathered, and forms the strike valleys both east and west of Leeds. For clarity of description and mapping purposes the member is further subdivided and described under the following: Hartley shales and sandstones, Fire Clay Hill bentonitic shales, and Trail Hill sandstone. These names are applied to local areas only and should not be considered applicable to beds of any great areal extent within the lower Chinle member.

Hartley shales and sandstones.

These are named for the exposures measured northwest of the Leeds Cemetery where 280 feet of predominantly deep red shales and lesser fine-grained sandstone beds mainly only a few inches in thickness overlie the Shinarump formation. The beds readily weather and subsequent valleys have been eroded in them wherever they are exposed, as shown particularly west of Leeds and south along the strike. Good exposures of this section are difficult to find. Toward the top of the section small slumped areas in the red shales are indicative of salt which has been dissolved away. Minor gypsum also occurs in this section.

A prominent cliff-forming bed of arkosic sandstone at the top of the Hartley beds is 5-15 feet thick and weathers light brown to white. It is well exposed at the foot of the Buckeye Reef near Tecumseh Hill and southward. On the East Reef the arkosic sandstone crops out along the back slope of the Shinarump hogback where many petrified trees and some coal-like material occur in it. Two silicified trees over 20 feet in length and two and one-half feet in diameter were found in the sandstone south of Leeds. Remains of old tree trunks, now completely silicified occur in this bed on the East Reef north of the Duffin Mine. Locally the sandstone fills channels in the underlying shales but in general the strike and dip are the same as those of the underlying beds. The arkosic sandstone has been incorrectly correlated with the sandstone just west of Leeds by Ball (1920), who refers to it as the "Butte Reef sandstone."

Fire Clay Hill bentonitic shales

The best exposures of the Fire Clay Hill bentonitic shales of the lower Chinle are on the East Reef 1000 feet north of the Duffin Mine where the shales conformably overly the arkosic sandstone and are gray to purplish. A distinctive fluffy soil indicative of bentonite, with gentle to steep scarps, characterizes the weathered outcrop of these gray to purplish beds. The thickness changes a little from the East Reef to the West Reefs, but the average is 10-13 feet. Towards the base, calcareous concretions and geodes as much as six inches in diameter occur sporadically, and in places are associated with concretions of iron-oxide and distinctive copper-bearing concretions up to five inches in diameter. Assays of the copper concretions show considerable copper, some silver, and a fair showing of gold as given below:

Table 2. Assay Report on Concretions From Fire Clay Hill Bentonitic Shales

Chalcocite Concretions		Calcareous Concretions	
Copper	30.90%	Copper	0.15%
Silver	1.85 ozs./ton	Silver	0.20 ozs./ton
Gold	0.14 ozs./ton	Gold	None
Iron	8.30%	Iron	0.50%
Insoluble	41.60%	Insoluble	6.40%

An agate bed banded with red, orange, green, yellow, and white occurs at the base of the shales. It ranges in thickness from a fraction of an inch to almost a foot and is remarkably persistent on the Buckeye Reef to a point near its junction with the White Reef. The agate bed also crops out below the White Reef for a distance of several miles to the south. The best exposures are at the base of Fire Clay Hill south of the old town of Silver Reef. On the East Reef the same beds of shale are present, but the agate bed may or may not be at the base. At one place the agate bed was observed to cut across the bedding at a slight angle. In places near the top, round chert pebbles weather out of the shales. The striking color, concretions, geodes, nodules, and other associated features make the Fire Clay Hill bentonitic shales an excellent key horizon for mapping purposes. The shales are present below the Buckeye, White and East Reefs, and their apparent absence under the Butte Reef is explained by alluvium which covers the probable outcrop.

Owing to the unusual character of these beds and the sporadic distribution of gold, silver, and copper in concretions a detailed study of several samples was made. It was noted particularly that in water the shaly materials quickly absorbed water and expanded to four or more times their original volume. This property is indicative of bentonite and doubtless explains the fluffy soil on the outcrops. Assays for gold, silver, and copper were run on several samples cut across the beds. Two types of material were collected: (1) well oxidized, expanded, fluffy variety and (2) fresh, shale-like material. Results of the assays are listed below:

Table 3. Assay Report on Fire Clay Hill Bentonitic Shales, Silver Reef, Utah.

Gold	Silver	Copper	Description
none	none	none	Oxidized, reddish to brown expanded sediment.
none	none	none	Partly expanded blue-gray sediment East Reef.
none	trace	none	Somewhat expanded clay. North of U.S. M.M. #2.
none	trace	none	South of Harrisburg, clay quarry, fluffy, gray to purple, expanded clay.
none	0.10 ozs./ ton	none	Fresh shale-like material, south of Fire Clay Hill 400 feet.
none	0.10 ozs./ ton	0.34%	Fine, powdery, fresh shale-like material, north of U.S. M.M. #2.

Several x-ray patterns were taken of the bentonitic shales and compared with a standard pattern from the Black Hills bentonite. Thermal analyses were also run on several of the samples. Dr. C. J. Vitaliano (personal communication, 1949) estimates that the samples contained up to 60% or more of bentonite.

Trail Hill sandstone

Brownish-red to brick-red shales and interbedded fine- to medium-grained sandstones crop out above the Fire Clay Hill bentonitic shales. Lenses of pebble conglomerates as much as one foot thick, cross bedding, and minor ripple marks, characterize parts of the Trail Hill sandstones. The sandstones are friable, brick-red, and average 310 feet in thickness. Locally a bleaching of the red sandstone, probably by meteoric waters which have reduced the ferric iron cement to the ferrous and then dissolved it away, has resulted in red and white mottling or white banding which crosses the bedding and parallels local joints.

A distinctive white to grayish-white siliceous limestone from six inches to 1.5 feet in thickness occurs at the top of the ledge sandstone. This bed forms an easily recognizable white band in the red sandstone and is traced readily for several miles. Best exposures are near the Leeds-Thompson mine area on the White Reef and on the face of the Buckeye Reef east of the Savage mine. The bed also crops out on the East Reef just below the Duffin mine.

A red, medium-grained, friable sandstone with minor interbedded brick-red shales crops out above the siliceous limestone. The sandstone forms ledges that show ripple marks and prominent cross bedding. The brick-red sandstones grade into a fine to medium-grained sandstone with interbedded purplish shales.

Green to gray shales, locally grading to bluish green, occur above the pink to red sandstones. The shales readily weather and would form gentle slopes, but their position between two resistant sandstones causes them to form rather steep slopes, though gentler than those of either of the sandstones above or below. The thickness of the shales is fairly constant at 25 feet. Eastward toward the Butte Reef and underlying it, the color changes to a deep maroon above and green below. On the East Reef the color of the shales is mainly gray.

An unusual bed of jasper 2-6 inches thick, strongly resembling petrified wood, occurs eight feet below the upper contact of the shale. Microscopic study shows that fine-grained quartz has replaced the shale. The bed seldom crops out, but the distinctive red wavy banded float demonstrates its presence over wide areas.

Silver Reef Sandstone Member

Owing to its distinctive appearance and position near the center of the measured section, the Silver Reef sandstone is arbitrarily selected as the member dividing the upper Chinle from the lower Chinle in the area described in this report. The Silver Reef sandstone contained all the known commercial quantities of silver which were mined in the past in the Harrisburg (Silver Reef) Mining district. Copper carbonates and uranium-vanadium mineral showings also are mainly restricted to this member of the Chinle.

Reeside and Bassler (p. 62, 1922) noted the Silver Reef sandstone in a section measured on Smith's mesa, three miles north of Virgin City, Utah, and 12 miles east of Silver Reef:

"In our area only one section of the Chinle formation was measured, though the formation is a prominent member of the stratigraphic series. This section (no. 13, p. 73) is near Virgin City and aggregates 995 feet in thickness. No limestones were observed. The basal member consists of 260 feet of variegated, bluish-gray, greenish-gray, mauve, red, and rarely brown "gumbo" clay shale and contains fossil wood. Upon this rests 25 feet of variable coarse arkosic-cross bedded sandstone banded with gray, white, and mauve containing fossil wood. This sandstone is overlain by 420 feet of brick-red shale and sandstone, forming a slope. Next comes a massive medium-grained cross-bedded ripple-marked, cliff-forming mauve sandstone 90 feet thick. Above this sandstone lies about 200 feet of brick-red to deep-red shale and sandstone.

The banded gray, white, and mauve sandstone is locally known as the "Silver Reef" sandstone, as it is said to be the zone which in the Silver Reef, near Leeds, Utah, contains the fossil logs impregnated with silver minerals that in the eighties supported several flourishing mining enterprises."

The position of the Silver Reef sandstone is only 260 feet above the base of the Chinle formation according to these authors, yet in the Silver Reef area the correlative sandstone is 620 feet above the base. It will be noted that their "arkosic sandstone," or supposed Silver Reef sandstone, lies about the same distance above the base of the Chinle as that measured by the writer for the arkosic bed in the Hartley shales and sandstones which also contain prominent fossil logs. The Silver Reef sandstone in the Silver Reef area is at approximately the same horizon as the "mauve cross-bedded, ripple-marked sandstone" of Reeside and Bassler. The strong possibility exists that the Silver Reef sandstone has changed in color and lithology somewhat to the east and that the same error has been made by them as by Ball (1920), Crane (1920), and Butler (p. 587, 1920) in correlating the sandstone of the Butte (Silver Reef sandstone) Reef with the arkosic bed (see figure 1).

For convenience of description and also for mapping purposes the Silver Reef sandstone has been subdivided into the Leeds sandstone, named for the exposures near the Leeds mine, which includes mainly white to buff, fine- to medium-grained sandstone beds with interbedded shales; and an overlying lavender, fine- to medium-grained sandstone called the Tecumseh sandstone for the exposures on Tecumseh Hill.

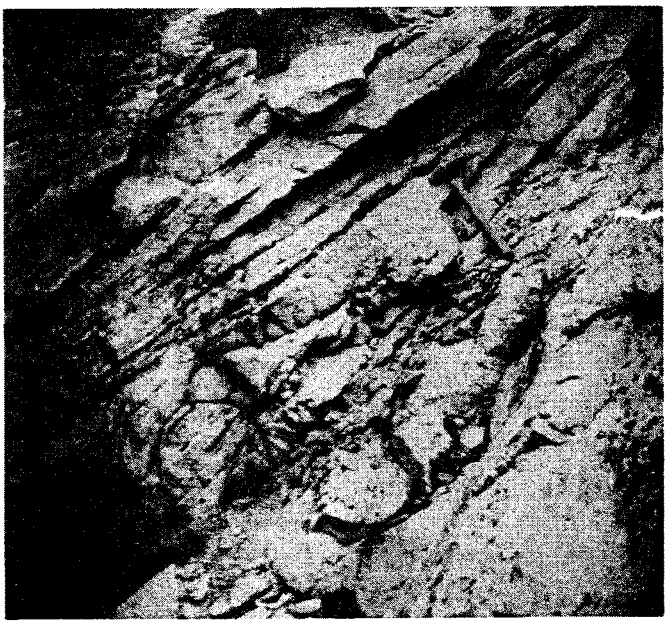
Leeds Sandstone

The Leeds sandstone locally is unconformable on the underlying shales. The thickness varies from place to place, but in the main mining area it reaches 60 feet. The sandstone weathers mainly white and buff to brown, and stands out as a prominent ledge maker. It is fine-grained, and a little coarse-grained muscovite mica may locally be prominent on the bedding planes.

Stream cross-bedding is prominent in many places. Locally channels within the sandstone are recognizable. Ripple marks are rare, though a current type was noted near Harrisburg. The sandstone beds within the member range from massive 15-foot beds down to thin, platy sandstones and locally are highly cross-bedded. Lenticular, interbedded, dark gray to green or locally maroon shales may be present. The shales are usually notably slickensided and show a glistening luster on the fresh fracture surface. The slickensided shales, called "soapstones" by the miners, seldom crop out sufficiently to permit mapping but may be more than six feet in thickness. Commonly they thin abruptly along both the strike and the

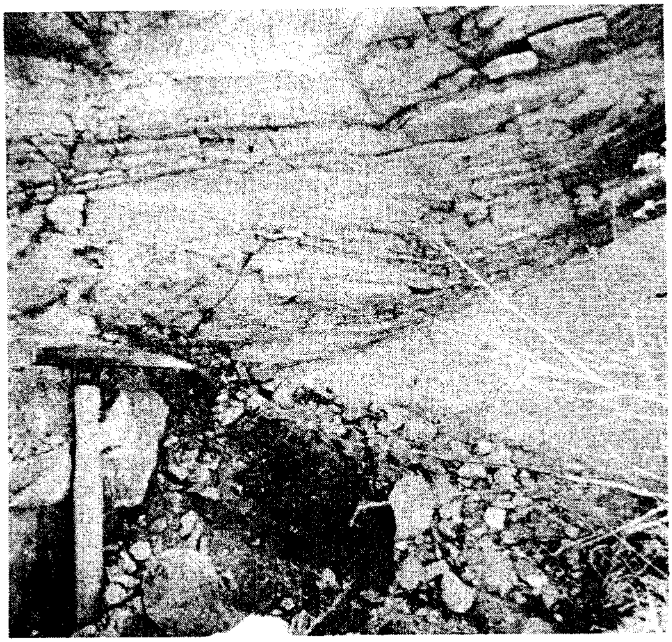
Plate III. TYPES OF CROSS-BEDDING

A. Local delta foreset type of cross-bedding, Butte Reef, near Leeds, Utah.

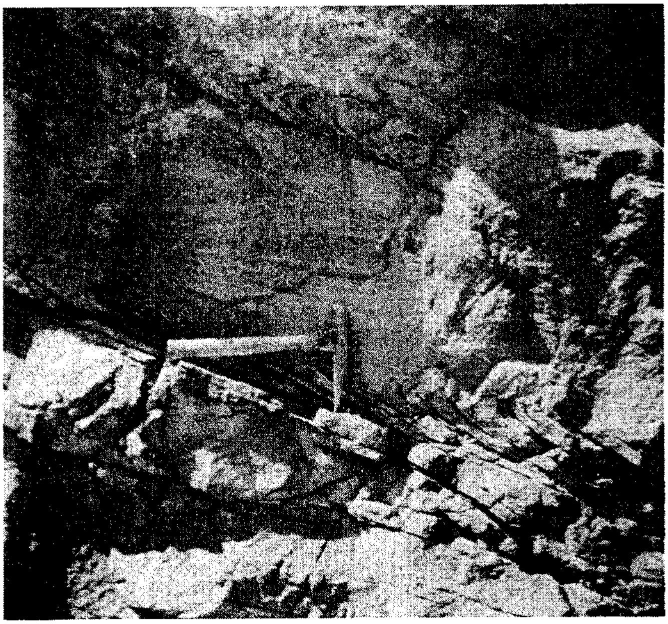


B. Massive channel-fill cross-bedding, White Reef, near Leeds, Utah.

Plate IV. TYPES OF CROSS-BEDDING



A. Thin-bedded channel-fill cross-bedding White Reef, near Leeds, Utah.



B. Flow cross-bedding, south of Savage Shaft, Buckeye Reef, near Leeds, Utah.

dip. The saddle at the A.S. & R. shaft on the White Reef is the result of the weathering of a "soapstone" bed. Where not badly weathered, the beds may show fine cross-laminations.

Sandstones containing clay galls and balls occur both above and below the shales. Locally they may be sufficiently abundant to form clay ball conglomerates. The clay balls are unusual in that they range from as small as one-fourth inch in diameter or less to more than four feet. The beds enclosing the balls are as much as four or more feet in thickness (see Plate VI, A). The Leeds, Cobb, and McNally mines show all gradations of these as do many pits along the face of both the Buckeye and White reefs.

Fossil rushes, reeds, parts of petrified trees, and rarely logs to 30 feet in length are found in the Leeds sandstone. No other types of fossils have been discovered. Locally, the fossil remains may be replaced by silver-chloride, copper carbonate, iron and copper sulfides, and/or uranium-vanadium minerals. Concretionary nodules of iron oxide with some pyrite, and copper sulfide as much as 1 inch or more in diameter also occur in the sandstone.

Tecumseh Sandstone

The Tecumseh sandstone about 35-45 feet thick, in places is unconformable on the Leeds sandstone. It is thin-bedded to massive and commonly lavender colored. Impressions of rushes and reeds occur on the bedding surfaces, but in lesser abundance than in the white and buff sandstones below. Muscovite mica is common on the bedding planes. A buff to yellow sandstone, prominently iron-stained and as much as six feet thick, occurs near the middle of the Tecumseh sandstone on Tecumseh Hill and also along the east face of the White Reef near the Thompson mine.

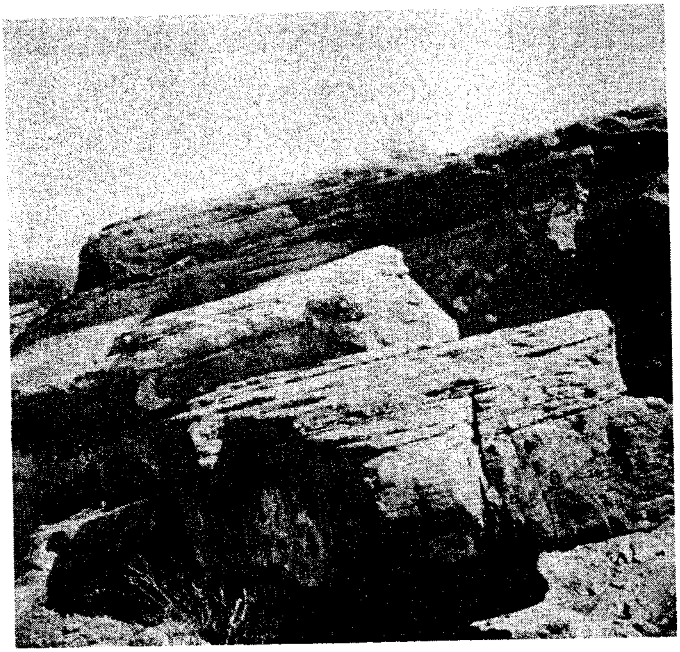
In the main mining area the lavender sandstones reach their greatest thickness on Tecumseh Hill where the average is approximately 35-40 feet. North, near the Barbee mine, the thickness is 30 feet or less. On the East Reef at the Duffin mine a section shows about 50 feet of lavender sandstone. Directly east of Leeds the Leeds sandstone decreases in thickness. The Tecumseh increases and on the nose of the Virgin anticline is the most prominent bed.

Depositional History of Silver Reef Sandstone

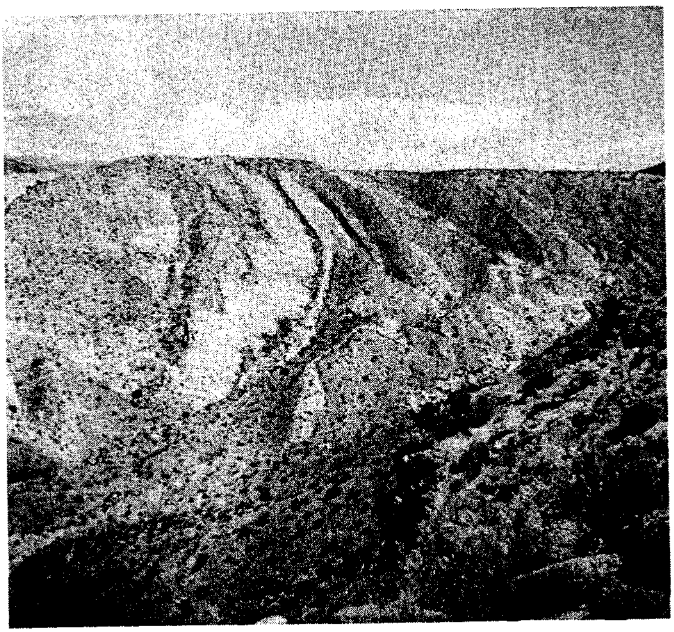
As the locus of ore deposition is within the Silver Reef sandstone, a detailed study of the member and its primary features is essential. The abundance and size of some of the clay balls, the numerous clay galls, sandstone lenses, the less abundant interbedded, lenticular shales, and the prominent cross-bedding are among the most distinctive primary features observed. The fine texture of the sandstone and the local abundance of fossil remains of probable rushes and reeds and parts of trees are also of special note.

A critical question may be asked: Is this sandstone member of the Chinle formation of marine or continental origin? Among geologists of the southwestern United States the origin of the Triassic Chinle "Red Beds" has been a subject of lively discussion and debate. E. B. Branson (pp. 607-630, 1927) suggested a marine origin for much of the upper Triassic of Southern Utah. Reeside in a later article (p. 48, 1929) supported the idea of a continental origin. The consensus of later writers--Gilluly (p. 89. 1929) Gregory and Moore (p. 57, 1931), Baker (p. 40, 1933) et. al.--is that the Chinle beds are of continental origin. As the Silver Reef sandstone lies stratigraphically near the center of the Chinle formation, there is strong inclination to include it with other members and ascribe to it a continental origin. However, more evidence than just position in a continental sequence is needed. Briefly summarized, the lack of marine fossils, the abundance of parts of trees, remains of ancient rushes

Plate V. SEDIMENTARY ROCK TYPES

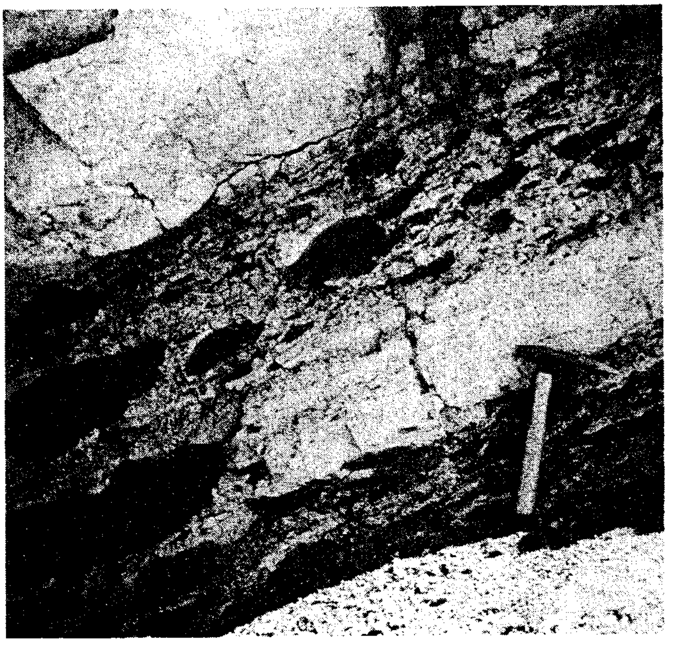


A. Contact of Leeds and Tecumseh sandstone just north of Leeds, Utah.

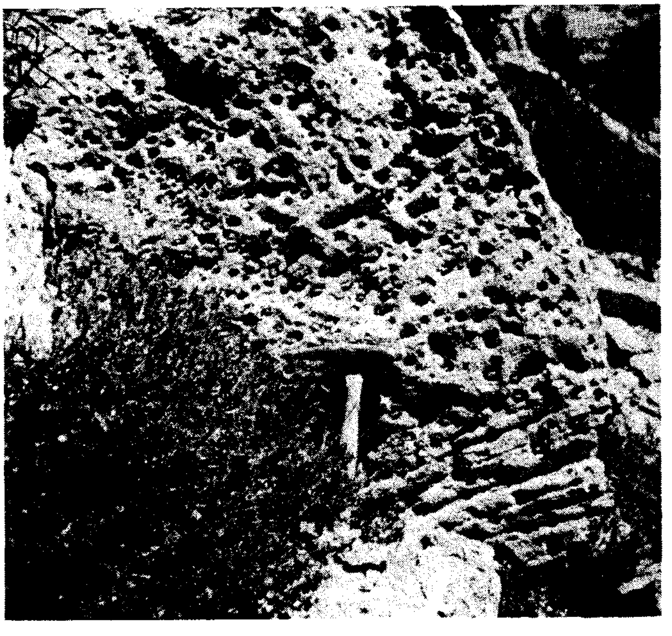


B. Duffin sandstone, south of Duffin mine, East Reef, near Leeds, Utah.

Plate VI. SEDIMENTARY ROCK TYPES



A. Flattened clay balls in Leeds sandstone, White Reef, near Leeds, Utah.



B. Pitted weathering sandstone at base of Buckeye Reef.

and reeds, stream cross-bedding (discussed below), channeling of the underlying shales, clay galls, clay balls, and rapid lensing of individual sandstone and shale beds all strongly suggest a continental origin for the Silver Reef sandstone.

Of the three important transporting agents: wind, water and ice, which may have deposited the sandstone, ice is directly excluded because of the rather perfect sorting of the sediments, stratification, stream channels, etc. Wind and water could have been important in the deposition of the sandstone, but the above features are most typical of fluviatile deposits and the irregular cross-bedding often cited as evidence for eolian origin is lacking. It is concluded that the sandstone member was deposited by streams.

Other questions that arise are: Was there a special direction of flow of the stream or streams, and if so, what direction? Finally, under what environmental conditions was the sandstone deposited? The first question can be answered with a fair degree of certainty; the latter is somewhat speculative.

The abundance of Triassic stream channels in the Silver Reef sandstone in the main mining district and the distinctive types of cross beds associated with them are of special interest. Many writers have described different varieties of cross-bedding in other localities. Probably most familiar to geologists are the summaries of Grabau (pp. 701-704, 1913) and Lahee (pp. 80-88, 1941). Other work on this sedimentary feature has been published by Andree (p. 377, 1915), Knight (pp. 1-82, 1929), Andersen (pp. 21-31, 1931), McKee (pp. 64-81, 1939), Scott (pp. 165-172, 1949), and others. Pettijohn (pp. 132-134, 1949(in his recent book summarizes many of the important types which have been described.

From descriptions in the literature it is obvious that no general agreement has been reached as to the proper name for the different types of stream cross-bedding. Cross lamination, false bedding, current bedding, cross bedding, have all been used to describe this sedimentary feature. According to Fay (p. 193, 1930) cross-bedding is "lamination in sedimentary rocks, confined to single beds and inclined to the general stratification." This is in contrast to Andersen who would restrict the term to a definite type of inclined bedding. Since the term cross-bedding has been used extensively in American literature, the definition of Fay is accepted for this report and modifying adjectives are added to describe the various types.

In the Silver Reef area at least two and possibly three distinctive types of cross-bedding are recognizable: (a) The local delta foreset cross-bedding of McKee (p. 78, 1939); (b) Channel fill cross-bedding; (c) The third type is a modified form of (a) which shows plastic flow of the local delta foreset cross-bedding just after deposition. The term flow cross-bedding is suggested for this variety.

The local delta foreset bedding consists of a series of truncated, gently inclined beds dipping 30 degrees in one direction and showing a rather constant strike where exposed. Outcrops showing this type may be as much as 100 feet or more in length. The angle of dip is greatest near the top, and more gentle downward until finally an almost tangential contact occurs with the underlying beds. The length of the inclined beds may be as much as 10 feet or more. The local delta foreset type is well exposed on the Butte Reef just west of Leeds. Though no complete horizontal section was observed, the cross-bedding apparently disappears along the strike for partly exposed projected beds failed to show the cross-bedding. The cross-bedding probably formed in a standing body of water as foreset beds of a small delta. (Plate III, A) clearly shows the tangential relationship on the underlying bed and apparent truncation of the upper part by the overlying sandstones.

The channel fill cross-bedding (see Plates III, B and IV, A) appears to represent the filling of a former stream channel cut into the underlying sandstone beds. McKee (pp. 78-79, 1939) describes a similar type on the Colorado delta, but his description applies to channels in muds, rather than sandstone. As shown in the figure, the beds in the filled channel may range from a fraction of an inch to more than a foot thick. In one place a massive appearing sandstone more than seven feet in thickness filled one of these channels.

The thinner beds approach parallelism with the walls of the channel, whereas the uppermost channel-fill beds may gradually coalesce with the overlying sandstones. Only the beds between the first and last deposited in the channels may be truncated by the overlying sediments. In many places, however, most of them show truncation by the overlying sandstone beds. The channel-fills range from a few feet to over 300 feet in width. The length of the channels is unknown since only small portions of the channel direction were recognized or exposed. It is important to note that the channel-fill cross-bedding is most apparent in the smaller channels. The larger ones may show such a slight divergence of bedding from the enclosing beds as to be almost unrecognizable. It necessarily follows that the wider the former channel, the closer the beds approach to parallelism with the enclosing beds, though local variations may occur. Another factor to be considered is lithology. If a channel is cut into massive white sandstone and filled with a similar variety of sandstone great difficulty may be experienced in recognizing the former channel. Generally, however, slight color and textural differences in the sandstones distinguish the channels.

In the Leeds mine, a channel-fill sandstone grades laterally into clay balls, and finally into alternating sandstones and shales. The geologic setting suggests a once continuous deposit of alternating clays and sand through which a channel was cut by a stream and later filled by reworked clay and additional sand.

Closely spaced measured sections along both the Buckeye and White reefs in the mining area show an interfingering of lenses or channel-fills of sandstone beds. Both the channel-fill and local-delta foreset types of cross-bedding were observed within these lenses.

The third type of cross-bedding is recognized as a special variety of local-delta foreset bedding upon which another structure has been superimposed following deposition. In this respect it may well be termed a secondary feature, but its almost coincident formation at the time of deposition justifies a description here. Apparently small foreset cross-beds were deposited. Just after deposition subaqueous movement of the sediments took place and the cross-bedding was folded plastically in the direction of dip of the foreset beds. These small folds may have been the result of later beds being deposited near the angle of repose of the sediments. A slight shift in the load by slumping or slight tilting could have resulted in the plastic flow of the water-saturated cross-beds. The folding is almost isoclinal (Plate IV, B). Examples of this type of cross-bedding are shown in the open surface stope 1300 feet south of the Savage shaft.

Stream Directions

The direction of maximum inclination of the local-delta foreset type of cross-bedding was considered to be the direction of the original current depositing the sand. In some localities the strike of the cross-bedding could be determined. The stream direction at these points was taken at 90° to the strike in the direction of inclination of the cross-bedding. In the case of the channel-fill cross-bedding, the trend of the stream channel was determined by the trend of the axis of the channel, but the actual current direction could not be ascertained except where cross-bedding of foreset type was also present.

In general, the direction of inclination of the cross-bedding is fairly uniform in the mining area. As can be readily understood, neither the scale of the map nor the continuity of beds allow control at one horizon within the Silver Reef sandstone. The stream directions shown on the map occur at different stratigraphic positions within the 80 to more than 100 feet of Silver Reef sandstone. The former stream or streams generally flowed N.30° W. Locally, southeast of the Savage Mine, the direction changes to almost east-west and southward. The scarcity of cross-bedding or stream channels in a direction other than the main trend suggests a fairly uniform depositional history for the sandstone. Modifying factors of possible flood plain environment probably existed. Plate II shows a generalized distribution of readings and stream direction in the mining area. While it is realized that some of the interpretations are doubtful because of poor exposures, still the trend is remarkably constant for those shown. It is regretted that most of the large mines in the district are inaccessible and that detailed work on the cross-bedding had to be limited mainly to surface outcrops.

Duffin Sandstone and Shales

Stratigraphically above the Silver Reef sandstone and separated from it by local unconformities is a 427 foot sequence of medium to coarse grained, brick-red sandstones with interbedded purple shales. Cross-bedding is locally prominent. Near the California, Barbee and Walker, and Thompson mines a clay pebble conglomerate as much as one foot in thickness lies just above the upper contact of the Tecumseh sandstone. The clay pebbles are as large as half an inch in diameter, and probably represent the beginning of different conditions of sedimentation.

West of the McNally mine the red sandstone and shales include a thin white sandstone 50 feet above the lower contact. The white sandstone is not continuous and lenses laterally and vertically into the red sandstones above and below it. This same bed may be represented on the Buckeye Reef west of the California Mine by a white, discontinuous sandstone ranging from a few inches to four or more feet in thickness. The bed is badly sheared. The white sandstone strongly resembles the Leeds sandstone in texture and color. This same bed was not observed on the East Reef. Because outcrops are very poor near Silver Reef, a section of Chinle above the Silver Reef sandstone was measured east of the Duffin Mine. It showed the following:

<u>Measured Section of Upper Chinle Formation</u>
<u>500 feet south of Duffin Mine</u>

Thickness	Description
...	Navajo sandstone.
65'	Brick-red, medium-grained sandstones, minor red shales, slope weathering.
12'	Bright-red, medium-grained, ledge-maker sandstone.
75'	Partly covered. Exposed section mainly dark-red shales, some quite sandy. Near base two beds thin gray argillaceous sandstone.
18'	Brick-red shales, slope weathering. Base, pitted, friable, gray, medium-grained sandstone six inches thick.
22'	Top, mottled gray and red sandy shale four inches thick, ledge-former. Six feet below, brick-red, friable sandstone. Base, slope weathering brick-red shales.

60' Series of brick-red shales, slope weathering; near base three beds two to four inches thick of gray calcareous shale.
73' Mainly brick-red shales. Center of unit two inch bed gray shale, red shales below. At base a well-jointed, pitty weathering sandstone 2 1/2' thick.
25' Mainly sandy, brick-red shales with no distinctive beds. At base six inches of white, fine-grained sandstone.
62' Predominantly red shales, some minor sandstone; 2 1/2' pink sandy shale 20 feet above base.
15' Red shales, soil-weathering, 10 feet thick, 5' of pink to red sandstone ledge-maker at base.
... Silver Reef sandstone member.

427' Total

Navajo (Jurassic ?) Sandstone

The limit of areal mapping was arbitrarily taken as the base of the massive, cliff-forming, red Navajo sandstone. A section was not measured, but a generalized section above the Duffin shales and sandstones would show a brick-red, massive sandstone ledge-maker near the base, followed by strongly eolian cross-bedded red and brick-red sandstones. Reeside and Bassler's description (p. 63, 1922) is characteristic of this prominent sandstone:

> In Washington County, Utah, there lies above the Chinle formation a massive cross-bedded sandstone that is locally all red but in most places red in the lower part and white above the red portion making up one-half or more of the unit. The lower part characteristically forms arches, and the upper part weathers to round pinnacles and domes. ... only one measurement of the thick-

ness of the sandstone was attempted, and that with rather unsatisfactory results ...and gave a total thickness of 2100 feet just west of Zion Canyon and 20 miles to the east of Leeds, Utah.

Quaternary Alluvium

Slightly consolidated and unconsolidated alluvium occupies only a small portion of the Silver Reef district but is most prominent in the northern and southwestern parts and along the Virgin River. Part of the alluvial cover remains as flat-topped erosion remnants and terraces below the high ridges of Jurassic rocks, and yet locally lies more than 100 feet above the beds of the present streams. The other part covers the bottoms of the valleys and its surface is only a few feet above the streams and dry washes in the area.

Boulder Alluvium

The material occupying the terraces and erosion remnants is designated the Boulder Alluvium in view of the large boulders of latite (Gardner, p. 243, 1941), limestone, quartzite conglomerate, and brown sandstone it contains along with an interstitial filling of sand and silt. Remnants of this material are as much as 50 feet thick.

Best exposures of the Boulder Alluvium are at the old town of Silver Reef and west between the White Reef and the Navajo sandstone ledges. The alluvium also occurs east of Silver Reef and in the town of Leeds, and to the east and south where it covers part of the Shinarump formation. To the west, south of the California mine, a subsequent valley is filled with the Boulder Alluvium. Outliers occur north of the junction of U. S. Highway 91 and State Highway 17, centering near the mouth of a large canyon in the Navajo sandstones. South of Harrisburg, in Purgatory Basin, similar deposits crop out, and terrace remnants more than 40 feet above the present stream level are clearly visible.

Directly north of Leeds on Paulmar Hill an erosional remnant more than 30 feet thick occurs as a capping 100 feet above, and completely isolated from, other areas of alluvial cover. Similar remnants are near Harrisburg and to the south where several hills are capped by the Boulder Alluvium. Possibly 60 percent of the Boulder Alluvium has been eroded away.

Lower level terrace deposits of Boulder Alluvium cover much of the Upper Triassic sediments southwest of Leeds. These deposits are co-extensive with the alluvium present in Purgatory Basin and that east and south of Leeds. Erosion has also greatly modified these lower level deposits.

The distribution, the 20 foot or more diameter of some of the included boulders, and the location of the deposits gives some idea as to the origin and age of the Boulder Alluvium. The fact that the greatest amount of alluvium is near the mouth of large canyons which cut rocks of similar composition to the included boulders suggests a source in that direction. The complete lack of bedding in some places, and rough form of stratification in other localities, suggests that stream action and possibly another agent were responsible for the deposits.

The major deposits were probably the result of deposition by streams on large alluvial fans that spread and possibly coalesced along the foot of the high cliffs. At times, however, mudflows may have swept down the narrow canyons in the resistant Navajo sandstone and spread laterally over large areas in front of the canyons. Land forms of such deposits cannot now be identified because of the extensive erosion, but the lack of bedding and boulder size suggests such an origin for at least part of the deposits.

Not all of the alluvium was deposited at the same time, as outliers of the higher level Boulder Alluvium suggests a period of at least 100 feet of erosion before lower terrace material was deposited. Even this later valley filling has been modified by erosion. East of Leeds, valleys 60 feet or more in depth have been cut through the lower level deposits and into the underlying shales. Thus a minimum of 160 feet and as much as 340 feet of sediment has been removed since the deposition of the Paulmar Hill upper terrace Boulder Alluvium.

The extent of erosion and the time required to accomplish it and also the need for a greater abundance of water than under the present arid climate suggests that deposition of the alluvium took place some time in the Wisconsin stage of the Pleistocene epoch.

Recent Alluvium

Flat-topped erosion remnants above the intricately weathered Chinle shales are composed of sand and silt with some minor small boulders of latite, quartzite conglomerate, sandstone and limestone. At a lower level, sand and boulders occupy the stream beds. This is especially true along the Virgin River. East of Leeds and north of the Vanderbilt mine more than a square mile of wind blown sand covers eroded Chinle rocks.

The Quaternary alluvium was deposited during at least two periods of time. West of Harrisburg deposition of sands followed the erosion of much of the Boulder Alluvium and tended to fill the valleys which had been cut. Later, erosion swept away part of this and redeposited much of it in the stream valleys. Erosion remnants were left behind as cappings on the Chinle shales.

On the East Reef wind has deposited a few feet of sand over low outcrops of the Chinle formation. This deposition is still going on. The source of the material is the prominent Navajo sandstone and Chinle sandstones surrounding the area.

IGNEOUS ROCKS

Igneous rocks are absent in the main mining area and except for a small volcanic cone and eroded basalt flow near the Duffin Mine, all of the rocks occur south and east of the Virgin River.

Basalt Flows

A small volcanic cone composed of scoriaceous basalt occurs a few hundred feet north of the Duffin Mine. Just to the south of the mine an erosion remnant of a flow of similar composition crops out southward almost to the river. South and east of the Virgin River an extensive area is covered by basaltic flows. Along the southeast margin of the area several small volcanic cones rise above the lava flows.

The volcanic rock near the Duffin Mine is a dense somewhat vesicular basalt. Locally, a pyroclastic composed of fragments of feldspar and dense basaltic material occurs at its base. The volcanic rock lies on the eroded edges of the Chinle formation and covers part of the Silver Reef sandstone north of the mine. South of the river, except for small windows, the flows cover all of the Chinle and the Navajo sandstone.

Though the volcanic cone near the Duffin Mine is only slightly eroded, a stream channel has been cut through more than six feet of a related flow of basalt and 20 feet into the underlying shales and sandstone. To the south the Virgin River has cut a channel through the basalt flows over a distance of three miles along the edge of the Shinarump hogback.

Apparently lava of basaltic composition welled out from the different cones onto a topography not very different from that of the present. In general the lava flows followed southwest drainage lines. The flow south of the Virgin River was stopped in its westward movement by the Shinarump formation hogback and turned to the south for several miles. Gardner (p. 244, 1941) dates corresponding basalts just to the east of the area as Quaternary. There are not sufficient field data in the Silver Reef district to allow a closer dating, though they can be said to have preceded the deposition of some of the lower level Boulder Alluvium for a capping of it occurs on an erosion remnant of basalt south of the Duffin Mine.

STRUCTURAL SETTING OF THE DISTRICT

The Harrisburg (Silver Reef) mining district is unique in its structural setting. To the east the well-known Hurricane fault (Gardner, pp. 241-260, 1941) with stratigraphic displacements ranging to as much as 10,000 feet, separates the block containing the district from the Colorado Plateau proper. Westward is the Basin and Range province whose eastern boundary in this vicinity is taken as the Beaver Dam Mountains and the drainage divide north of the Pine Valley Mountains (Callaghan, 1946). Structurally, the area is transitional between two major provinces. In its degree of folding and minor thrust faulting the area is more closely related to the Basin and Range than to the Plateau province.

Folds

Broad open folds constitute the main structural features in the Leeds area. The most prominent fold, the Virgin anticline, may be traced for more than 18 miles southwestward. Subsidiary folds to the west of the major fold also occur, but both thrust faulting and normal faulting have modified the surface expression of these folds.

Virgin Anticline

The Virgin anticline is a continuation of the structure noted by Gardner (p. 250, 1941) and mapped by Dobbin (p. 136, 1939). This symmetrical fold trends approximately N. 30°-40° E. for a total distance of at least 18 miles from a point south of St. George, Utah, to northeast of Leeds, where it plunges northward under a cover of Quaternary alluvium and basalt south and west of Toquerville. The limbs dip from 18-36 degrees. Three domes were described by Dobbin (pp. 140-144, 1934), the Harrisburg, Washington, and Bloomington. Silver Reef is just north of the Harrisburg Dome, the northernmost of the three.

The highly resistant Shinarump conglomerate forms a hogback ridge around a core of Moenkopi formation and completely surrounds the fold on the north. Near the old town of Harrisburg the west limb of the fold trends N.30° E. and dips 20°-30° W. To the west the dip gradually flattens to 18 degrees. The beds on the east limb north of the Duffin Mine dip 16° E. Local drag on faults may steepen the east dip considerably, however. From the Duffin Mine southward to the Virgin River, where the beds overlying Shinarump conglomerate disappear beneath the River gravels and Quaternary basalt, the beds have a fairly constant strike of N.40° E. and dip of 28° E.

Near the Toquerville and Vanderbilt mines, just north of the Duffin mine, the Silver Reef sandstone trends north and dips 17° E. Northward the east limb of the Virgin anticline flattens and the strike changes sharply to east-west. Here the beds form the north plunging nose of the fold. Within Purgatory Basin the beds dip continuously north from the Harrisburg road northward. Longitudinal faults somewhat modify the beds of the fold above the Shinarump but have little apparent effect on the Shinarump outcrops. The west limb of the Virgin anticline, south and west of Leeds, has been somewhat modified by faulting and partly covered by alluvium.

Subsidiary flexures occur on the northwest flank of the Virgin anticline. The axis of an open syncline trends N.30° E. to north and lies just west of Leeds. A few hundred feet further west, a parallel trending anticline plunges to the north. Both folds gradually coalesce southward with the larger Virgin anticline.

Leeds Anticline

The Leeds anticline is well exposed on Tecumseh Hill just south of the old town of Silver Reef (see Plate I). Erosion has etched out the more resistant Silver Reef sandstone and the fold is expressed topographically. Here the axis trends north and the fold plunges approximately 15 degrees to the north under the Boulder Alluvium near the Tecumseh mine. The west Buckeye Reef forms the west limb of the fold and trends approximately No. 34° E., 20° W. Local variations of strike and dip occur near the Savage, Kinner, and California shafts where the dip increases to 45 degrees in a distance of 100 feet or less. The flexure is near the contact of the Boulder Alluvium and the Silver Reef sandstone. Down dip the beds flatten and it is reported (Newman, E. W., personal communication) that in the A.S.& R. shaft the beds dip gently to the east.

The White Reef west of the Buckeye Reef, strikes N.30°W. from the South Thompson mine area to north of the Barbee and Walker mine where the reef disappears beneath the alluvium. Local variations are of little or no consequence. An exception occurs 600 feet south of the Leeds No. 2 shaft where the dip changes from 35° to 17° W. The structure is completely anomalous to that of surrounding areas and may represent primary depositional slump.

From the Thompson mine to the southern end of the Leeds anticline half a mile north of Harrisburg the trend of the White Reef is constant. The axial trend of the anticline varies from N. 28° E. to N.40° E. South of Harrisburg the White Reef represents part of the west limb of the Virgin anticline.

Drag on a north-trending fault has steepened the east limb of the Leeds anticline, and in fact, may well have formed a part of the fold by dragging the beds down to the east. On Tecumseh Hill the beds strike N.20° W. and dip from 20° to 45 E. South of the Leeds Cemetery the strikes and dips are variable on the east limb. They range from N.30 E. to N. 40 E. and dip as much as 15° E. About a half mile north of Harrisburg the dip is gently to the south. In a few scores of feet it reverses in direction and the Shinarump conglomerate becomes the true west limb of the Virgin anticline.

Leeds Syncline

The Leeds syncline forms the southern part of the Leeds Valley. Here, infolded Chinle shales and sandstones have weathered to the rich sandy loam of the valley floor. The fold begins about a mile south of Leeds and plunges northward from 5°-21°. The axial trend ranges from N. 30° E. to N. 5° W. The limbs of the fold constitute the west limb of the Virgin anticline and the east limb of the Leeds anticline respectively. The fold is open and is as much as 5000 feet in width.

The southern part of the Butte Reef west of Leeds represents an erosional remnant of the Silver Reef sandstone along the axis of the syncline. North of the road crossing the Butte Reef, the axis is offset a few tens of feet to the west by a northeast trending fault. The Leeds syncline continues through the Buckeye Reef northward, but faulting has so disturbed the beds on both the east and west limbs that the original flexure is not readily apparent. North of the reef the fold plunges from 5°-16° northward beneath the Quaternary alluvium.

Joints

A distinctive pattern of strike, oblique, and dip joints occurs in the Leeds and Tecumseh sandstones, but joint patterns in other beds in the area, with the exception of the Shinarump conglomerate and the massive Navajo sandstone, are absent or indistinct. In view of the possibility that some of the ore bodies in the sandstone might have been localized by these structures, several hundred bearings were taken on the different sets. The study indicated that the dominant sets trend a few degrees east and west of north, whereas the strike of the less numerous sets approaches east-west. The dip is nearly vertical, but changes with the different sets. Generally, the most numerous joints are the longest; some of the individual ones extend as much as 300 or 400 feet along the strike. The average length, however, is only a few tens of feet. The best exposures are on the White Reef, Butte Reef, and Buckeye Reef; those on the East Reef are only poorly developed.

White Reef

A distinctive joint pattern is well exposed in the Tecumseh sandstone in the Thompson-Cobb mines area. The sets trending and dipping N.50° E., 70°-80° E., N. 10°-23° W., 60°-70° NE., and N. 5° E., 70°-80° E. are the most prominent. A less prominent set trends N.85° E., and dips 80° S. to vertical. By intersecting the others it cuts the sandstone into blocks. Other less prominent joints vary from these trends. To the north on the White Reef, just west of the A.S.& R. shaft a set trending N. 5°-15° E. and dipping 60°-80° E. is well shown. It is intersected, but not cut, by a set trending N. 80° E. to east-west and dipping 70°- 85° S. which breaks the Leeds sandstone into large rectangular blocks. The other prominent sets exposed to the south do not occur in the latter area. The N.5°-15° E. set continues to the north where a N. 10°-15° W., 70°-75° NE. set becomes prominent. Near the Barbee and Walker mine two oblique faults cut the reef and another joint set trending N. 30° W. and dipping 70°-75° NE. parallels the breaks.

Buckeye Reef

Joints are not numerous south of the Savage shaft on the Buckeye Reef, nor do the few exposures observed show as characteristic a pattern as those on the White Reef. The most prominent sets, however, trend N.5°-10° W. and dip vertically, and N.20°-30° E. and dip 70°-75° E. A less distinctive set trends N.75° W. to east-west and the dip ranges from 75° S. to 75° N.

Joints are much better exposed on Tecumseh Hill in the Tecumseh sandstone. The main set on the west limb of the anticline ranges in trend from N. to N.5° E. and dips 60° E. to 90°. On the east side of the anticline, the joints dip steeply on the west. Two other sets, one trending North, 70°-80° N., and the other N.70° W. to

East and dipping to 90° cut, but do not displace, the north trending joints above. Locally, a shear pattern is superimposed on the joint system.

Butte Reef

Several joint sets are exceptionally well shown on the Butte Reef. The dominant trends are N.45° W. with dips of 75° S. to 90° and N.30°-40° W. with near vertical dips. These joints cut both the Leeds and Tecumseh sandstones and show no change in strike or dip when they cross the contact. A similar pattern is exposed in the Leeds Hill section a short distance north.

East Reef

Few joints are exposed on the East Reef. Gentle slopes may have acted as a protection against scour and etching out of the joints by rainwater. On the nose of the Virgin anticline a few poorly exposed joints trend N.10° E., dipping 65° E. and N.70° W. dipping 90°. Near the Vanderbilt mine two sets, one trending N.5° W. and dipping 80° W. and the other trending N.85° E., and dipping 90° occur in the Duffin and Tecumseh sandstones. Just south of the Duffin mine two sets trend N.10° W., dipping 80° W., and N.80° W. dipping 56° W.

Origin

Several facts are important in considering the origin of the joints:

a. A small thrust fault and adjacent shears near the Gad shaft on the Buckeye Reef are later than the joints and destroy or mask them on the footwall of the fault. The thrust and shearing explains the scarcity of joints in this part of the Buckeye Reef.

b. Small normal faults cutting the White Reef near the Barbee and Walker mine do not correspond in direction with the joint trends though a set of fractures parallel the faults. Though exposures are not the best, the fault and accompanying fractures appear to cut the joint system.

c. The trends of the joints on the three reefs are different. For example, those on the Butte Reef vary considerably from those on Tecumseh Hill, as do also the structures, a synclinal trough versus an anticlinal crest.

d. Restoration of the sandstone to a horizontal surface fails to yield a similar pattern for the sets on the different reefs.

Summarizing, the joints precede both the thrust and normal faults, yet the pattern on the individual reefs do not match when the beds are "restored" to a horizontal position. They are thus restricted in time from the period after the beds were raised from a nearly horizontal position to a time before the normal and thrust faulting occurred. The change in pattern corresponding with a change in structure on the different reefs suggests that the joints were formed at the time of the folding of the rocks, and are the result of the same deformational stresses.

Faults

Though faults are not abundant in the Silver Reef district, the few that do occur are of importance both structurally and economically. Normal faults with stratigraphic displacements ranging to more than 300 feet are localized on the north plunging noses of the folds. Generally the faults parallel the trends of the axes of the folds but locally they may transect them. The faults are almost wholly restricted to the Chinle formation and are especially distinctive where they cut the resistant Silver Reef sandstone member. Drag along the faults is not common, though locally the beds have been dragged from horizontal to almost vertical. Some of the faults show little displacement but a wide shear zone, whereas others with a relatively large displacement show little or no shearing except on the fault itself. Most of the faults are of the pivotal type so that the amount of displacement varies along the strike.

On the nose of the Virgin anticline the major faults cut the Silver Reef sandstone into large, variously tilted blocks. West of Highway 91 the Silver Reef sandstone is displaced several hundred feet on a normal fault. A few hundred feet further west another prominent fault trending north cuts the east limb of the Leeds anticline and drops Duffin sandstone against Tecumseh sandstone. Other smaller longitudinal faults occur on the nose of the fold.

Directly west of the old town of Silver Reef the White Reef section has been overthrust to the east several hundred feet. The thrust fault dips to the west and trends north-northeast, closely following the strike of the bedding for a distance of several miles.

Normal Faults

For the sake of clarity, the normal faults in the district are discussed according to their locations on the White Reef, Butte Reef etc.

White Reef

Small faults with stratigraphic displacements of but a few inches were observed on the White Reef but their limited extent does not permit their being shown on the map. Only two normal oblique faults with displacement large enough to record were noted near the Barbee and Walker Mine area. The southernmost of the two shows an apparent horizontal displacement of 25 feet measured on the strike of the fault. The fault cuts all members of the Trail Hill sandstone and disappears under alluvium to the east. A similar fault 900 feet north shows 40 feet apparent horizontal displacement. Both of the faults trend N.25° W., and dip steeply to the south. Neither could be traced any distance because of the alluvial cover.

Buckeye Reef

The Buckeye Reef is cut by a prominent shear zone near the California Mine which is related to normal fault movement and which trends N.30° E. with vertical dip. Though the stratigraphic displacement with downdrop to the west could not be determined accurately, Colbath (personal communication) on the basis of his underground mapping, suggests a displacement of a few feet. Cumulative movement through the shear zone may represent much more displacement, however. The zone apparently grades into a sharp flexure southward, but northward it is a fault which is partly covered by dumps and sand. A similar shear zone ends against a fault dipping 30°-38° south-southeast 730 feet from the Savage shaft. The shear zone may represent the displaced northern portion of the California fault. The associated broken zone locally is as much as 80 feet in width. To the north it disappears under dumps and sand cover and just east of the Savage shaft may split and gradually die out.

Near the Tecumseh mine, three north-trending faults displace the beds as much as 30 feet in an apparent horizontal displacement along the strike of the fault. The dips of the fault planes were not visible, but vertical shearing occurred parallel to them.

The most prominent faults in the mine area are east of the crest of Tecumseh Hill. Apparent horizontal displacement along the faults is as much as 130 feet. The Trail Hill fault west of the small cemetery brings Duffin sandstone in juxtaposition with Tecumseh sandstone. In general, the faults west of the Trail Hill fault (Plate II) drop blocks down to the east, whereas to the east of it the minor faults drop blocks to the west. Stratigraphic separation is approximately 60 feet, but it may be much more to the north and progressively less to the south. The amount of drag that occurs may modify this figure somewhat. Two small exposures of the fault plane indicate that the dip ranges from 65°E. to vertical. The fault shows progressive increase in displacement down to the east toward the old town of Silver Reef. South of the Silver Reef cemetery wash, however, the upthrown block gradually becomes the downthrown side for 500 feet and then the fault grades into a small flexure and disappears. The reversal in displacement suggests a scissor type of movement on the fault with practically no displacement at the pivotal point. East of the Tecumseh mine, the fault disappears under the alluvium.

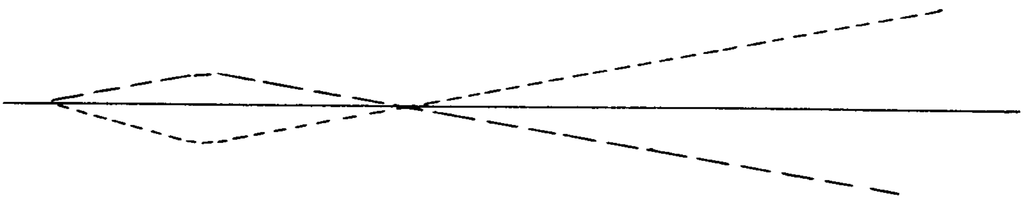


Figure 2. Diagrammatic section along Trail Hill fault.

Figure 2. Diagrammatic section along Trail Hill fault.

- - - - - Represents datum line in foot wall.

—— —— —— Represents same datum line in hanging wall.

———— Represents original position of datum line.

A fault 400 feet east of Fire Clay Hill diverges southward from the Tecumseh fault and within a short distance almost parallels the main break. A series of springs, abundance of vegetation, and missing strata indicate its presence. The displacement is not known, but since the movement involves only the Trail Hill sandstones and shales the displacement is probably less than that of the Trail Hill fault. The fault dies out within 800 feet to the south.

Three other small normal faults diverge north from the east wall of the Trail Hill fault. The movement along these faults has produced crushing and minor brecciation of the sandstone. Recesses have formed along the fault zones where weathering has etched out the less resistant rock. Displacements on the faults are only a few feet and decrease north until they also die out in a short distance by grading into very minor flexures. In the valley 100-300 feet east of Fire Clay Hill two small normal faults displace a sandstone ledge and drop the hanging wall to the east.

A half mile to the east and north the Butte Reef extension is limited by one of the largest normal faults in the Silver Reef area. The fault can be traced at least two miles south from the Leeds Reservoir. The strike ranges from N.25-55°E. In a trench, dug for water along the fault on the west side of the Butte Reef, shear zones trend N.33°E. and dip 70°E. Fractures break off at an acute angle to the southwest from the main fault, and a group of small springs rise along them. North near the Leeds Reservoir prominent drag causes some of the beds to stand vertically, whereas other smaller blocks in the fault zone have been rotated into an overturned position. True stratigraphic displacement on the fault approximates 380 feet.

Virgin Anticline Nose

Because of the lack of mining on the nose of the Virgin anticline, less detail is listed for the faults in this area. As shown on plate I the

Silver Reef sandstone blocks have been rotated in various directions. Stratigraphic displacements range from a few feet on some of the blocks to more than 150 feet. Eastward across the nose of the fold the faults trend from almost north near the highway to N.20° E. on the east side of the nose. To the north the faults are covered by alluvium, while to the south some alluvium and the great similarity of the red shales and sandstones below the Silver Reef sandstone make them extremely difficult to trace.

In many respects the faults on the nose of the fold are similar to others described for fold structures in the Rocky Mountain Province. Irwin (p. 119-125, 1926) summarizes and interprets structural data on many of the oil producing anticlines in this province. He concludes:

> Now certainly, domes and anticlines are loci of maximum disturbance during their growth, and where the strata involved are composed of great thicknesses of shales, alternating with relatively thin competent members, the conditions are ideal for a shaking-down process which results in gravity faulting....
>
> ....the faults on upfolds are, in the main, local features dependent upon the folding for their origin, then it is highly probable that the folding and faulting are essentially contemporaneous.

East Reef

Underground mapping at the Toquerville and Vanderbilt mines on the east limb of the Virgin anticline in the Silver Reef sandstone member indicates several faults. The faults have a fairly constant strike of N. 20°-25°E. and dip 65°-75°E. The hanging wall has been dropped to the east. The amount of displacement could not be determined. Near the Duffin mine and to the south faults are not evident. South and east of the Virgin River alluvium and lava flows almost completely cover the sediments and possible faults.

Thrust Faults

The history of the Silver Reef mining area has been one of controversy concerning the presence or absence of a fault between the White Reef and the Buckeye Reef. In order to fairly approach the solution of the problem a careful stratigraphic and structural study of the rocks between the two reefs was made. In the following paragraphs much of the data collected in this study is briefly summarized.

Detailed work on the stratigraphy of the White and Buckeye Reefs indicates a striking similarity in sequence of rock layers. Summarized below are the important likenesses.

a. Approximately the same thickness of Silver Reef sandstone, varying only in the amount of Tecumseh and Leeds sandstone, occurs on both reefs.

b. A distinctive pitted weathering sandstone as much as eight or more feet thick occurs at the base of each reef (see Plate VI, B).

c. Approximately eight feet below the base of each reef is a characteristic red-banded jasper from one to six inches thick included in 25 feet of greenish to reddish shales.

d. Distinctive brick red sandstone beds 40 feet thick include a white siliceous limestone ledge from 2" to 12" thick. This probably represents the "Pride of the West Ledge" of Rolker (p. 24, 1881). Careful search, however, revealed the ledge under both reefs in contrast to Rolker's original statement.

e. A fluffy weathering, purplish bentonitic shale occurs below the deep-red sandstone and shales of both reefs, though the thickness varies somewhat.

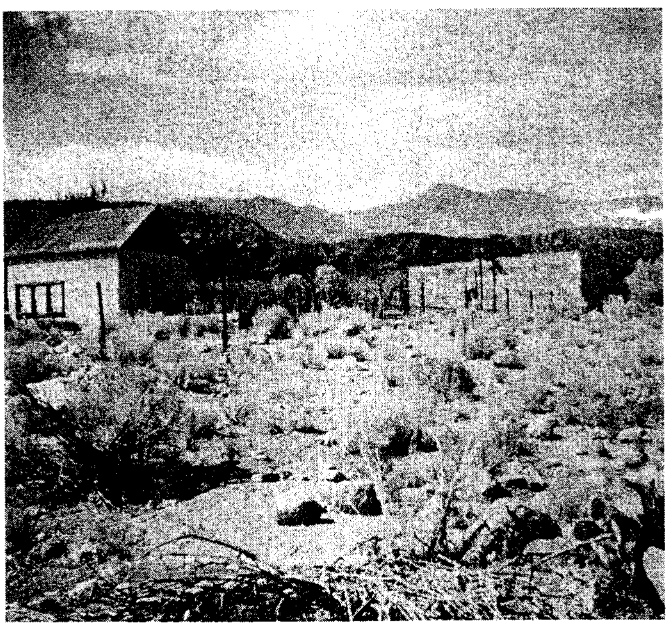
Plate VII. THRUST FAULTS

A. Small overthrust in adit just south of A. S. & R. shaft, near Leeds, Utah.

B. Flat fault in incline, 800 feet south of Savage Shaft, near Leeds, Utah.

Plate VIII. VERTICAL SHEAR ZONE AND RUINS

A. Vertical shear zone south of Savage Shaft, Buckeye Reef, near Leeds, Utah.



B. Remains of town of Silver Reef, Utah. Boulder Alluvium in foreground.

In the detailed mapping of the reefs certain structural features at variance with the general structural pattern were observed. These are summarized below:

a. A small syncline 150 feet wide occurs just north of the A.S.& R. road in the valley. The structure is anomalous in an area of generally consistent strike and dips.

b. On the west side of the valley, south of the A.S.& R. road, two hills which trend parallel to the power line are composed of white to lavender sandstone similar in appearance and composition to the Tecumseh and Leeds sandstones. The north hill is highly sheared and broken. Visible bedding trends at right angles to the prevailing strike of the other sedimentary beds in the valley.

c. The south hill also shows extreme shearing in the sandstone. Leeds (?) sandstone lies over the Tecumseh (?) in a reverse relationship. A shaft on the west side of the hill which should have cut a minimum of 30 feet of sandstone passed completely through the block in a few feet and into the underlying red shales. Near the south end of the hill a shear zone with prominent brecciation dips 25° to the west.

d. Prominent drag folds occur in the red shales to the south of the hill described above. The folds are small, ranging to 40 feet in width and 100 in length. All of the minor folds are overturned to the east. These are unusual for an area where shales and sandstones show no indication of intricate folding.

e. South of the California mine extreme shearing of more massive gray to buff sandstone beds and "cutting out" of different small beds of the red shale and sandstone series occur.

f. The Buckeye Reef completely disappears 4,000 feet south of the California mine and crops out again one and a half miles south of Harrisburg. Springs occur at the point of disappearance of the Buckeye Reef. To the north of the outcrop near Harrisburg small reverse faults are exposed in a large wash.

g. Small overthrust faults occur in the Leeds Mine on the White Reef, in a small adit 400 feet southward on the road from the A.S.& R. shaft, 1,100 feet south of the Savage shaft, 900 feet northeast of the shaft in an incline, and in pits on the east side of Tecumseh Hill. In all cases except one, the overthrust is to the east. The exception is the fault southeast of the Savage shaft which is discussed below.

Considering the above stratigraphic and structural conditions which exist in the area, four possible explanations might be advanced to account for them:

1. There is no fault between the reefs. The repetition of the similar beds is the result of like sedimentation conditions which resulted in almost identical beds of white to red sandstones and shales being deposited. The different structural anomalies probably resulted during the folding of the rocks.

2. A normal fault between the reefs, with a downdrop to the east, has repeated the section.

3. A steep west dipping reverse fault occurs between the reefs. Repetition of the beds is the result of an upthrown west block.

4. A thrust fault of 20°-40° dip to the west exists between the reefs. The west block has been thrust to the east over the Buckeye Reef.

Rolker, Butler, Ball, and others suggested that the similarity in the stratigraphy of the two reefs was the result of similar sedimentation conditions. Rolker (p. 34, 1881) was first to publish his views on the absence of a fault between the reefs:

> I have purposely been explicit in describing the circuits of the reefs, because the theory has been advanced that the Buckeye and Butte Reefs were in turn faulted from the original reef, the White Reef, on its west side and that only one reef existed on the east side of the horseshoe (the anticline). Aside from the fact that the two reefs are seen on the entire circuit, there are other reasons which speak against a one-reef theory. With their sides 300-1500 feet apart, gradually widening until the gap is about 4,000 feet, or more at the head of the curve, it would be a very strange fault if we assumed it to have fallen off the White Reef, in the shape of a horseshoe. But again, underlying the White Reef is the Pride of the West Ledge, siliceous limestone, very plainly marked, and to be seen distinctly at the first glance, all along the White Reef. This marked distinctive bed is absent in the Buckeye Reef. Further, the character of the Buckeye and White Reef ores is as different to the experienced eye as dark blue is from purple and they act differently in the mill.

Butler (p. 587, 1920), in his excellent treatise on the ore deposits of Utah, suggested at least two separate sandstone reefs as indicated by his figure 66, and the description below the illustration. Later, Ball in a rather thorough examination of the district noted "the presence of three distinct main reefs has been definitely proven by this examination." He measured detailed stratigraphic sections and analyzed them.

Crane (1920) in an unpublished report to the directors of the Silver Reef Consolidated Mines Company wrote:

> ...some investigators have been led to suppose that the two reefs represent the faulted segments of a single reef. Close examination has shown that the two reefs are stratigraphically one above the other with no evidence of faulting between their outcrops and that the marked difference in stratigraphic relation from north to south is accounted for by a thinning of the intervening red shales due to differential deposition along the strike.

Just before the sinking of the more than 500 foot vertical shaft for the American Smelting and Refining Company, A. H. Means, in a report to the vice-president of the company, also concluded that no fault existed between the two reefs.

Thus in both published and unpublished reports many geologists, some after detailed work, concluded that the likeness of the beds was the result of sedimentation similarities.

In more recent work in the general area of the old mining district, Dobbin shows (p. 126, 1939) a fault between the White and Buckeye Reefs with a down drop to the east. He mentions strike faulting as being of minor consequence along the northwest flank of the Virgin anticline. Though he does not mention the reefs directly, the faulted sandstone ledgemaker shown on his map west of Leeds undoubtedly represents the Silver Reef sandstone.

Two other possibilities exist: the high angle reverse fault and the low angle thrust possibility. Cursory examination of the aerial photographs of the Leeds area would indicate that either a normal fault or rapidly lensing beds could account for the anomalies. More careful study of the photographs, however, would show that any possible fault between the reefs must be at least 400 feet east of the A.S.& R. shaft since a continuous unfaulted section of Trail Hill sandstone and shale can be traced in the field for a considerable distance along the strike of the White Reef. Yet, underground workings in the Buckeye Reef vertically below such a minimum distance failed to show any displacement of the beds. These same beds of sandstone were still present at the face of the drifts considerably to the west of any possible normal fault dipping to the east. Therefore, any fault, if one be present, must have a westward dip and the movement, of necessity, must be of a reverse type. The shaft which was sunk by the A.S.& R. Company in 1929, cut the Buckeye Reef about 350 feet below the collar. That this could have been another sandstone bed than the Buckeye Reef was considered, but a drift to the east with raises from it to the sandstone above and then a connecting incline into the old Savage Mine stopes left little doubt that the sandstone bed was the Buckeye Reef extension. Since the full section of the Buckeye Reef silver-bearing sandstone is exposed in the shaft, any fault to explain such a condition must have a dip from the minimum west position on the surface to at least the top of the exposure in the shaft. Projection of a line between these two points yields a maximum possible dip of 30°W. Thus, any such fault must be in a low angle thrust category.

Briefly summarized, then, the stratigraphic similarities in the beds, especially the jasper bed, a one foot thick siliceous limestone bed, and purple shales below each reef, and the structural evidence in the form of folds, and more important, in small thrust faults, the presence of springs along the proposed trace, and the lensing of beds against an overlying series, strongly suggest an overthrust fault between the Buckeye and White Reefs. Finally, evidence in the A.S.& R. shaft workings shows that the beds have changed in dip from 30°W. to a few degrees east while the overlying beds at the surface all dip 30°-35°W. The strike of the fault approximates that of the beds and the trace can be followed over a distance of six miles.

Displacement on the fault is difficult to estimate. If it be assumed that the dip of the fault is consistent, the dip-slip displacement may be several thousand feet as the beds and fault are parallel. However, flattening of the dip of the beds of the White Reef by drag may yield a dip-slip displacement of at least 1,300 feet and possibly much more.

The question may well be asked why the fault was not recognized by other investigators in the area. Several fortuitous occurrences make any fault in the area, except those cutting distinctly dissimilar rocks difficult to find. The fault between the two reefs is entirely within soft, easily weathered, deep-red to brick-red shales and minor sandstones. The Duffin, lower Trail Hill sandstone and shales, and Hartley shales and sandstone are almost identical in lithology and color. Also the fact that the shales have been very little deformed in the faulting process, that no fossils except parts of trees are known, and the known rapid lensing of individual beds within the Triassic section could well have caused most investigators to conclude that no fault existed.

<u>Thrust Southeast of Savage Shaft</u>

A thrust fault of small displacement occurs 1,200 feet south of the Savage shaft on the Buckeye

Reef (see plate II). Where the trace of the fault cuts the crest of the Reef observable dip-slip displacement is 50-70 feet. At the fault, the sandstones are somewhat sheared and broken, though just above it, the overriding north block shows practically no shearing. Joints are still prominent in the hanging wall, but the foot wall of Tecumseh sandstone to the south is highly sheared. Joints, though present in this block, are scarce and appear to have been destroyed by the deformation.

The thrust fault can be traced 200 feet down the east face of the Buckeye Reef where it dips approximately 36°N. On the dip slope of the Buckeye Reef the fault is partly covered with dumps, but it is visible in the shafts nearby. An inclined shaft just north of the fault on the Boulder Alluvium contact shows a flat fault cutting steeply dipping Tecumseh beds (see Plate VII, B). This is the last visible evidence of the fault to the north.

Apparent displacement on the fault is to the south, but whether this was the actual direction of movement could not be determined. The small thrust is probably related in time to the main thrust described above.

Age of Faults

From direct field evidence in the district the age of the faults must range between post-Upper Triassic and pre-late Pleistocene (?), since they cut Chinle rocks and are covered by terrace deposits of probable late-Pleistocene age. However, other relationships within the district are suggestive of a more specific age than the possible wide range cited above. Gardner (p. 250, 1941) suggests that folding, which probably included the formation of the Virgin anticline, occurred during the Laramide Revolution in late Cretaceous or early Tertiary time. Since both normal and thrust faults cut the major fold and the subsidiary folds to the west, these faults may be contemporaneous or post-fold in age.

The close spatial relationship of the normal faults on the nose of the Virgin and Leeds anticline suggests a genetic connection to the folding. This is borne out when it is noted that the faults are of small areal extent and apparently are almost limited to the more competent Silver Reef sandstone, shales and thin sandstones. As mentioned above, these types of structure are quite similar to the epi-anticlinal faults described by Irwin (p. 119, 1926) and may represent structural adjustments of a more competent member within a series of shales at the time of the folding.

As none of the larger normal faults extend into the thrust fault zone no age relationship could be established between the two types of faulting. However, some of the smaller thrust faults on the Buckeye Reef are displaced by steeply dipping normal faults. It is possible, of course, that these dislocations could have occurred just following the thrusting or again at a much later time, but either way it indicates that some normal faults occurred after the thrusting. Yet, the prominent shear and small fault extending from the California mine northward is cut off on top by a flat thrust 800 feet south of the Savage shaft. This is indicative of a pre-thrust age. Thus, it appears that two periods of normal faulting occurred in the district. Which age of faulting corresponds with the more numerous faults on the Virgin anticline nose is not known.

The nearest thrust faulting is that described by Dobbin (p. 131, 1939) in which he observed two periods of thrust faulting south of St. George, Utah. One thrust of considerable magnitude occurred in Eocene time. It was later dislocated by normal faults. He also records a post-Miocene (?) thrust 14 miles west of St. George where rocks of early Mississippian age are thrust over Miocene (?) conglomerate. Since both of the thrusts described are many miles southwest of Leeds they cannot be related directly to the small thrust at Silver Reef.

The possibility exists that the small thrust between the White and Buckeye Reefs originated at the time of the formation of the Virgin anticline and its associated smaller folds. Such a thrust may have resulted when the fundamental strength of the rocks was exceeded by the stresses. Yet, during this folding period, the now faulted beds were covered by several thousand feet of Jurassic, Cretaceous and possibly Eocene beds. However, if it be considered that the thrust between the reefs is a result of renewal of stresses on the major fold after erosion had removed much of the Jurassic, Cretaceous, and Tertiary cover, the thrust would seem more likely to occur in the stratigraphic position that it does and would represent the latest expression of faulting in the Silver Reef area.

ECONOMIC GEOLOGY

HISTORY

Though high grade silver float was discovered in 1869 in the Silver Reef area, it was not until 1875 that rich ore was found in place and active mining was started. Even then the "boom" period, so common to western mining camps, did not get under way until 1877 and lasted only until 1888 when company operation ceased. The usual period of mining by lessees followed but ended by 1909. Several re-examinations of the district have been made in later years but there has been almost no production until the recent (1950) uranium ore shipment. As nearly as existing records can be interpreted, the production of the district from 1875 to 1910 is valued at $7,822,900 which is also roughly the amount in ounces of silver mined and shipped. Interesting details of the history and production seem worth recording and are set forth in the following paragraphs.

In 1869, John Kemple, a prospector, found silver float near Harrisburg, Utah, which assayed $17,000 to the ton. The discovery caused considerable excitement in the area, but no discoveries of ore in place were made at that time. H. C. Burchard (p. 268, 1883) noted that in 1871, "the Union district was organized and 16 locations or claims were recorded which, however, were subsequently abandoned." On June 22-23, 1874, the code or laws and constitution of the Harrisburg mining district were written and adopted. The district included an area of 144 square miles with the Harrisburg school as the center point. Orson B. Adams became the first district recorder and during the remainder of 1874 recorded twenty-seven claims.

In April and May of 1875, several prospectors arrived from Salt Lake City, but their work in the district was unsuccessful and they are reported to have left the camp in disgust. It has been claimed that the arrival of William Tecumseh Barbee in July 1875, probably was the greatest stimulus to discovery in the district. He prospected the White Reef north of the present Barbee and Walker mine without success. He left the camp but returned in the fall of 1875, when he carefully prospected the Tecumseh Hill section. According to Mr. Oscar McMullin, (personal communication, Dec., 1948), a former miner in the old camp, the original discovery of rich ore in place was made by Barbee who noted an outcrop of 300-400 ounce silver which had been gouged out by the wheels of Joe and Alex McCleave's wood wagon on the east side of Tecumseh Hill. This find started the first known mining in the district.

By December 8, 1875, ten and one half tons of ore had been shipped to Salt Lake City smelters. According to Rolker (p. 30, 1881), the sorted ore ran $502 per ton. A second shipment 45 days later was valued at $7,000 net. High shipping and smelter rates and other miscellaneous charges at the Salt Lake Smelters made it impossible to ship anything but the very richest of ore. Better rates were obtained in Pioche, Nevada, which was in its declining stage of high-grade silver production, and shipments to that town began in July, 1876. Others than Barbee were mining in the Silver Reef area at this time for Rolker (p. 30, 1881) records that $8,000 was paid to "outsiders." Up to October, 1876, Barbee netted $17,000 from the Salt Lake smelters and $23,000 from Pioche.

It is estimated that only 12 persons made up the population of the camp until November, 1876. Litigation in the Pioche mines, and possibly much unemployment from the end of the "boom" mining there, brought such a rush of miners to Silver Reef that it was termed the "Pioche Stampede." The population of the new town rapidly increased and mining began in earnest.

The first claim to be surveyed for patent was in May, 1877. An interesting sidelight is the comment of the U. S. Deputy mineral surveyor, F. Dickert (p. 11, 1877), who states:

> Stonewall Jackson claim, owned and claimed for patent by Gisborn of Salt Lake City, Utah. Located March 10, 1875. Surveyed for patent May 30 and 31, 1877, after being forcibly ejected on the 19th and 21st of May, 1877 by the parties at present in possession of the ground.[3]

It appears that ownership rights on claims were as highly disputed in this district as in many of the other western mining camps of the period. Mr. Dickert also established United States Mineral Monument No. 1, on Tecumseh Hill, and No. 2 on the volcanic cone on the East Reef, north of the Duffin mine. All later patent survey claims were tied to these monuments.

With the mining of the high grade ores and promise of good profits, several mining and milling companies were organized and control gained of the important claims. The Leeds Company, with four claims restricted to the White Reef and the first mill, was organized in the autumn of 1877.

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[3] Note that the claim was staked before the arrival of W. T. Barbee in the district.

Interestingly enough, the Leeds 5-stamp mill, which was completed in February of 1877, was originally the Magnet Mill from Bullionville, Nevada, which had already processed hundreds of thousands of dollars worth of high grade Pioche silver ore. The Christy Milling and Mining Company was incorporated in the fall of 1877. At approximately the same time the Pioneer 3-stamp mill was placed in operation, but this mill ran only until June, 1879. The following January, the Christy 5-stamp mill was completed just east of the main Silver Reef townsite. By March, 1878, the Barbee and Walker 5-stamp mill was completed and in operation. Fire destroyed this mill June 23, 1879, but it was rebuilt and renewed milling activities February 27, 1880. The last mill of importance in the district was constructed on the banks of the Virgin River approximately one mile south of the Duffin mine on the East Reef. The Stormont Company, owner of the mill, processed its first ore there on July 4, 1878. A summary of the available data on company operation is given in Table 8.

The greater part of the ore mined in the district was run through one of the four major custom mills. All of the plants were designed on the amalgamation principle similar in operation to the Stormont Mill, of which a generalized flow sheet is shown in figure 3. This mill has long since been dismantled.

Original milling costs, according to old reports were $7.57 per ton for the Stormont Company, based on a little less than a years operation. The Leeds Company was able to mill 2,064 tons at $5.74 per ton, though during a four-month period its costs ran as low as $4.57 per ton. Apparently, the 5-mile haul to the Stormont Mill on the Virgin River was an important item in the cost of milling. An average milling cost for the different mills approximated $5.00 per ton.

Tailing losses in the different mills in the district varied somewhat. The Stormont mill

GENERALIZED FLOW SHEET

of former

STORMONT MILL
(period 1878-1888)

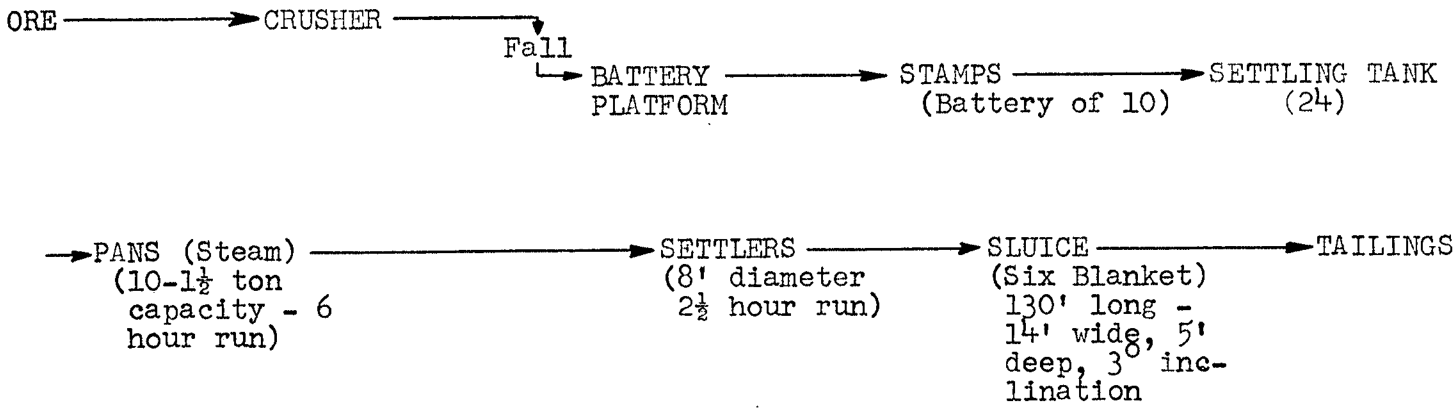


Figure 3 - Flow Sheet

recovered up to 86% of 20.63 ounce ore on 10,000 tons. The Barbee and Walker Mill on a run of 5740 tons of 29.10 ounce ore recovered 79.7% of Assay value. The Leeds Company averaged 79.4% recovery on 12,000 tons of 19.42 ounce ore. The above figures represent recovery during the height of the mining boom. It is possible that tailing losses for the ensuing periods following 1880 may have been less due to improved milling methods. No later records are available, however.

Mining costs ranged from $4.50 to $9.50 per ton depending on the locality of the mine, amount of prospecting or development work, dead work, water, and other factors. Rolker (p.32, 1881) states that the total cost of the ores in 1880, including the bullion charges ranged from $14.00 to $17.00 per ton. These figures are probably a maximum and represent company operation. Lessees were able to mine at a much lower cost per ton. Hartley (personal communication) reports that chloriders mined ore worth $10.00 at a profit in 1890. For a summary of mining and operating costs of the Stormont Company, the reader is referred to the Engineering and Mining Journal of January 24, 1880.

The mining method employed was shrinkage stoping, and minor underhand stoping. Stope walls were supported by stulls and fills of broken rock and low grade ore. Most of the mines, except those with large caved stopes and those filled with water, are still quite accessible at the present time.

As shown by figure 4, the greatest period of mining activity was from 1877 to 1888. Major company operations had ceased by 1888, though considerable mining by "chloriders" followed their cessation. Early in 1892, R. G. McQuarrie and Albert Grant leased the mines and mill of the Christy Company and subleased to the chloriders in the district. Sudden decreases in the price of silver caused losses on formerly profitable ore.

In 1893, Wooley, Lund, and Judd, former merchants of Silver Reef gained control of the Barbee and Walker mine, mill, and other properties. With R. G. McQuarrie as manager, the Barbee and Walker mill was converted into a more economical water driven plant. Pendleton (p. 112, 1930), a former resident of Silver Reef, claims that both the lessee and sub-lessees made a profit. As figure 4 shows, however, the production was negligible compared to former periods.

In 1898, the Brundage Company, of Cleveland, Ohio, acquired the Wooley, Lund, and Judd interests and most of the other important mining properties in the district. However, further declines in the price of silver during the ensuing three years brought mining almost to a standstill. Butler (p. 586, 1920) notes the last silver production as 1909. Apparently, the last mill run was made in 1909 when Heikes (p. 485, Min. Res. of U.S.) reports that the "Free Coinage property" (Brundage Mining and Reduction Company) produced some silver bullion which was recovered in a 5-stamp amalgamation mill.

In 1916, A. W. Colbath attempted a revival of the district. The Silver Reef Consolidated Mines was organized and all the former important claims in the Silver Reef area were brought under the control of this company. Development work was undertaken on the White Reef and also the Buckeye Reef with encouraging results at the Cobb Mine. No production is recorded for the period, however. The remaining mill in the district was dismantled and sold by the company.

During the years 1929-30, the American Smelting and Refining Company undertook considerable sampling of the old mines on the Buckeye Reef. A three compartment 540 foot vertical shaft was sunk at the base of the White Reef southeast of the Leeds mine shaft. Drifts, cross cuts, and raises were made on the 300 and 460 foot levels to connect to the old workings of the Leeds Mine on the White Reef and the old Savage stopes on the Buckeye Reef respectively.

Mr. A. W. Newman, geologist for the American Smelting and Refining Company, writes an interesting sidelight on his part in the development work (Personal Communication, May 7, 1948):

> My main job at the time was to direct this work by plumbing the shaft and doing the necessary surveying to make a connection with the lowest Savage stope so it could be unwatered without killing any men--which is a story in itself as it was like coming up under a lake 200 feet deep.

The connection was made successfully without injury to any of the men. After de-watering of all of the old mines, the company sampled the accessible workings. With the continued fall in the price of silver, this was the last major attempt to open the mines of this unique district. Late in 1946, a private group sampled some of the old dumps and drilled 3 diamond drill holes on the Buckeye Reef and 2 on the White Reef. In 1950, a 8.68 ton shipment of ore averaging 0.56% uranium was made. Considerable prospecting for uranium is underway at the time of this publication.

Production

The former main producing mines of the district are on the White and Buckeye Reefs with less important ones on the East Reef. Beginning at the north end of the White Reef and proceeding south the main producers were the Barbee and Walker, the Leeds, Leeds #2, and the Thompson and Cobb area including the smaller mines McNally, Nichols, Newton, and South Thompson. The Emily Jane property lies south of the South Thompson mine. On the Buckeye Reef (see figure 9) the mines from north on the nose of Tecumseh Hill southward include the Silver Flat, Manhatton, Savage, Buckeye, Kinner, Last Chance, Maggie, California, and Stormont. The East Reef mines are less extensive and produced but a fraction of the total production. These include the Toquerville, Vanderbilt, and Duffin.

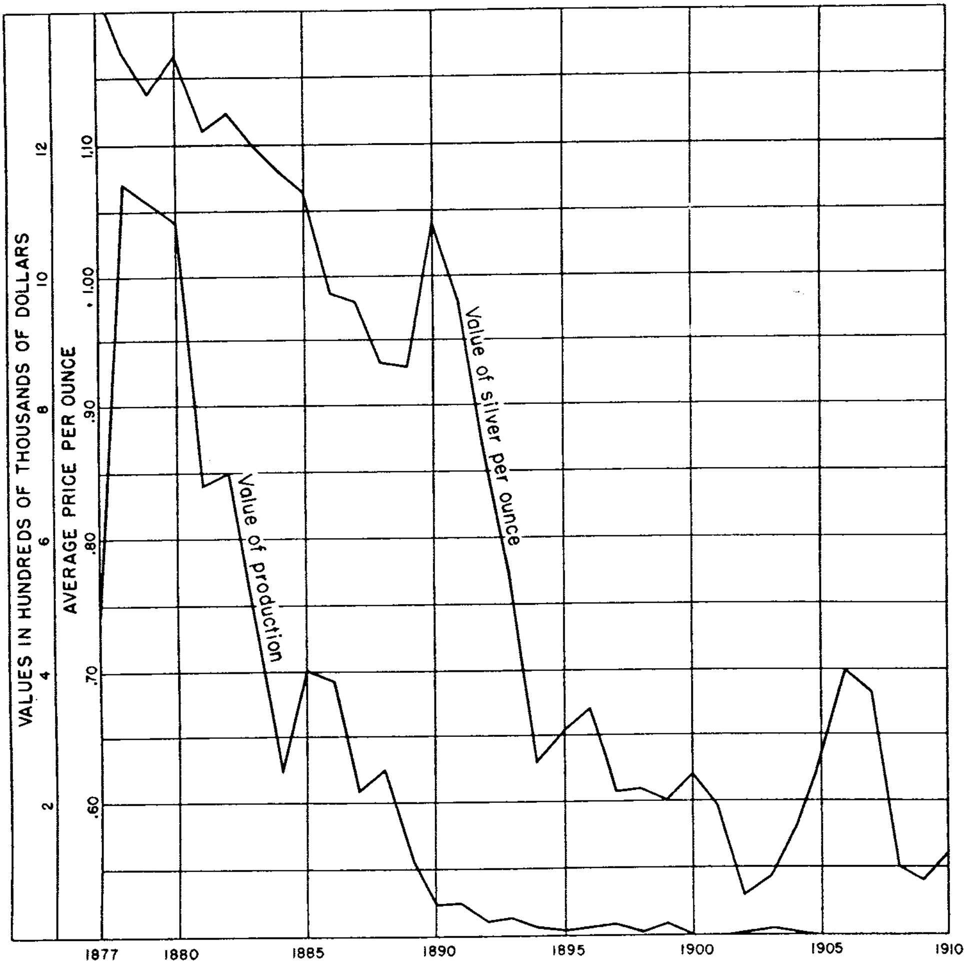


Figure 4. Production chart,
Silver Reef, Utah, 1877-1910.

Various production estimates have been made for the district ranging from $7,987,142, (p. 586, 1920) to over $17,000,000 (Crane, 1920). Butler and Heikes' figures probably are the most accurate. Their generalized data check closely with Wells Fargo Bullion shipments and estimates made by engineers in the district at the time of the mining. They estimate a total production of 7,211,463 ounces of silver.

The writer reviewed all of the Reports of the Director of the Mint from 1881 to 1904 inclusive and arrived at a somewhat lower figure. Errors in recording ounces produced as noted by Wells Fargo Company as shipments, and the total production figure for the year shows a discrepancy in value of at least $318,061. Based on ounces alone, and an average silver price for each year, the writer's total is $7,504,861.14 exclusive of 1875-76 production and $53,994 for 1901-1909. However, using total production figures and adding $48,000 for 1875-76 one arrives at a grand total of $7,823,000,000 for the period of 1875-1910.

The above data have been summarized in figure 4. It is of interest to note that the decrease in value of production of silver ore preceded by 3-5 years the rapid drop in the value of fine silver per ounce. Major production in the district, as the cumulative graph shows, took place in the relatively short period of less than six years. Following this there was an almost continual decrease in production until its cessation in 1909. High milling costs, materials costs, transportation, wages, strikes, decline in the price of silver and lower silver content in the ore have all been cited as contributing causes for the demise of the camp, but the last factor appears to have been the greatest.

Individual production records for the different mines are not available. However, the Barbee and Walker, Leeds, Manhatton, Tecumseh, Savage, Buckeye, Kinner, Last Chance, Maggie, California, Thompson, and McNally were by far the largest producers in the mining district. (See Table 8).

MINERAL DEPOSITS

The major ore deposits of the Harrisburg (Silver Reef) mining district occur on the Buckeye Reef west of Leeds and on the White Reef to the west. Less important deposits occur sporadically on the Butte Reef and the East Reef from U. S. Highway 91 east and south along the Silver Reef sandstone outcrops to the Virgin River. The ore deposits ranged from a few feet in diameter to bodies several hundred feet in length and a hundred feet or more in width. In thickness they varied from thin plates of the ore mineral to mineralized zones as much as 20 feet thick. In plan the deposits were dish-shaped or elongate lenses, others were almost amoeba-like in shape with foot-like projections off the main body. The grade of the ore, as well as the size and shape of bodies, was subject to considerable variations. Zones assaying more than $500 to the ton were mined locally, but the average grade of the district probably did not exceed $20-$25 worth of silver to the ton. Gold was not present except rarely in traces. Cerargyrite constituted more than 90% of the ore minerals. Silver sulfide (argentite?) was reported, but doubtless played a minor part in the total production of the district. Malachite, azurite, and minor vanadium-uranium-bearing minerals also occurred in the district but they were of minor importance and were not mined during the former productive period of the camp.

General Character of the Ore Deposits

The majority of the ore deposits occur in definite stratigraphic zones within the Silver Reef sandstone. Generally, most of the deposits were found at or near the Leeds-Tecumseh sandstone contact though there was considerable variation from it. In a few places silver mineralization cut across stratigraphic boundaries and showed no selectivity for one bed over another.

On the White Reef the known zones were restricted to the Leeds sandstone, whereas on the Buckeye, Butte, and East Reef either the Tecumseh or Leeds sandstone contained the silver deposits. Local accumulations of copper carbonates and minor copper sulfides were almost restricted to the Leeds white sandstone, though rarely malachite and azurite occupy small areas in the overlying Tecumseh sandstone. The uranium-vanadium minerals occurred in very small quantities in the Tecumseh lavender sandstone and in lesser amounts in the Leeds sandstone.

The largest ore bodies mined occurred on the Buckeye Reef. Several of the individual bodies were as much as 400 feet in length and 200 feet in width. Most of the bodies, however, averaged approximately 200-300 feet in length and 100-150 feet in width. In plan variable shapes were the rule, most of them being roughly elongate in plan and lenslike in section. Ore bodies were known to end abruptly along an almost straight line, others showed small "fingers" projecting out from the main mineralized zone. The stope shapes shown in figures 11, 12, and 13 indicate in general the ore assay cut-off position of the ore bodies. The actual mineralized zone might be much different in appearance.

The grade of the ore varied from one locality to another. Some of the richest deposits were mined on Tecumseh Hill where thin plates of silver chloride paralleled the bedding planes. Content of silver in the ore ranged to $500 or more per ton, yet in a few feet such high grade streaks would lens out into almost barren rock. South on the Buckeye Reef in the Kinner and Last Chance mines ore bodies as much as 20 feet in thickness were mined. Here the silver content was more persistent. Similar conditions existed on the White Reef in regards to grade of ore body and size. Even at the present time samples in one of the mines ranges from a few cents in silver to several hundred dollars to the ton, but these, of course, are spotty occurrences. Rolker (p. 26, 1881) estimated the average grade of the ore to 1880 at $20-$25 to the ton. Later Ball (1920) in a private report placed it nearer to $15 in the stopes and believed that the sorting of the ore in the mines brought the value to approximately $20 for the mill ore. For the entire period of production the writer concurs with Ball's estimate.

The mineralogy of the ore was very simple in all of the mines. Silver chloride (cerargyrite) practically constituted the only ore mineral. Malachite and azurite in some places were directly associated with the silver minerals but mainly were found separate. The known uranium-vanadium minerals are scarce, but are also closely associated in stratigraphic position with the silver and copper minerals. Silver sulfide was reported as making up part of the ore at and below the water table during the mining period. It was commonly associated with fossil trees which also contained chalcocite and pyrite.

The intimate association of the major silver mineral with certain lithologic types is notable. With reference to a certain rock type, the ore is classified into four important varieties with a fifth less important one added:

1. Small fossil plant and larger tree replacements by silver chloride in buff to white fine grained sandstone. At depth, the silver sulfide occurs in the tree remains. Iron oxide nodules, pseudomorphic after pyrite, and chalcocite nodules also occurred together with the plant remains.

2. Disseminated specks of silver chloride and thin plates of the same mineral parallel to the bedding planes, with rare native silver.

3. Silver chloride associated with clay gall and clay ball conglomerates.

4. Streaks and small grains of silver chloride in sheared lavender to brownish red sandstone.

5. Horn silver films and occasionally some native silver on slicken-slided surfaces within the shale or "soapstone."

Ore bodies were almost restricted to lenses of lavender, and buff to white sandstone containing abundant plant remains. The lithology of these ore zones rapidly changed from sandstone to clay conglomerate to alternating sandstone and shales. On the strike and dip such a body thinned and disappeared or became too small to mine profitably. Some carbonaceous material extended beyond the silver ore limit. The silver content within the clay gall and clay ball conglomerates behaved in a like manner.

Though commercial silver deposits were restricted to the Silver Reef sandstone member of the Chinle formation, assays indicate that a very minor amount of silver is present in the rocks both above and below it. In fact, within the member itself, it would be difficult to find a sample free of a trace of silver. Gold, commonly an associate of silver in many districts as at least a trace, was not indicated as being present in the ore deposits which were mined during the early period of the camp. However, Nesbitt claims that (p. 464, 1902) though the ores never showed "any gold by assay, in leaching the ore--silver sulfides produced contained a trace of gold." Mr. F. Hartley, former owner of the Cobb mine, also noted (personal communication) that some gold was paid for in a shipment of silver ore from the mine. A. Colbath reports:

> that in 150 samples run for gold the great majority were blanks, in addition a few traces were obtained and a 10 foot

sample from the Warsaw incline on the Buckeye Reef to the east--contained gold $2 (old price), silver eight ounces and copper 0.4% to the ton.

Samples of chalcocite-pyrite concretions collected from the underlying Fire Clay bentonitic shales by the writer assayed up to $4.90 in gold, 1.85 ounces in silver and 30% of copper to the ton.

Since the various ore deposits in the district show such similar habits of occurrence, and since they are so intimately related to the enclosing sandstone beds, an over-all description of the field occurrences seems justified. For ease of description and understanding, they are discussed according to their location on the following reefs:

(1). The White Reef west and south of the old town of Silver Reef.

(2). The Buckeye Reef east and south of the old town and south of its disappearance near the Emily Jane property.

(3). The Butte Reef west of the town of Leeds.

(4). The East Reef on the nose of the Virgin anticline and south to the Virgin River.

White Reef Deposits

Silver

Commercial silver mineralization is sporadically distributed along the White Reef from a point south of the old town of Harrisburg to a point a few hundred feet north of the Barbee and Walker mine where the reef is covered by alluvium. The greatest silver concentrations appear to have taken place near the Thompson-Cobb area, the Leeds Mine and the Barbee and Walker mine area. In all three of these localities the ore deposits are restricted to the Leeds sandstone.

The individual deposits within these areas ranged from thin silver chloride plates along the bedding planes to replacements of parts of fossil trees. Hartley (personal communication, Dec. 1948) notes an interesting feature of mineralization near the fossil trees. He states that sporadic distribution of silver would progressively show higher silver content as mine cuts neared a tree. Very close to the fossil material the silver content was always high. His description suggests an aureole-like distribution of silver around the soft, partly decomposed fossil.

The lithology of the units containing silver on the White Reef is also variable. At the South Thompson mine, a white, fine-grained sandstone with 1/8 to 1/2 inch clay galls was mined for its silver content. Up dip 80 feet the bed grades into a buff, cross-laminated, fine-grained sandstone which is clay at the base. At the Cobb mine, mining operations were almost restricted to white sandstone beds containing abundant green to gray clay galls and balls. Some of the balls were as much as a foot or more in thickness and showed elongation parallel to the bedding. The galls were as much as a half inch or more in length. On the footwall, shale beds lens in and out along the strike. In the Nichols Mine, silver ore is reported to have coated many of the highly slickenslided fractures of a "soapstone" bed. The horizon is as much as four feet thick and lenses out completely 60 feet south of the four-foot thick zone. In the general area of these mines the main ore horizon occurred under a capping of lavender sandstone which graded into a yellow-brown sandstone and red micaceous sandstone below.

Similar ore deposits occur at the Leeds mine to the north. Here 40 feet below the Tecumseh sandstone a buff, fine-grained sandstone with thin, cross-laminations was extensively mined. Remarkably enough, within a few feet the ore bed grades laterally into a sandstone containing abundant clay balls a foot or more in diameter. Stratigraphically above, and possibly along the strike the beds change to alternating shale and sandstone beds about six inches thick. Apparently the latter two lithologic units did not contain much silver as they have not been mined. As a result of the decomposition of former plant material, natural molds have superimposed a high degree of porosity and increased the permeability on the main ore horizon in the mine. Iron oxide and copper carbonates commonly replace or stain much of the former plant substance and mold interiors.

North at the Barbee and Walker mine in the upper stope walls a finely laminated buff to whitish fine-grained sandstone in places finely cross-laminated occurs approximately 30 feet below the Tecumseh contact.

Copper

Malachite and azurite replacements of fossil plant material occur in some of the mines along the White Reef and also along its east face. Malachite constitutes more than 90% of the copper carbonate present. In every place, except one, the copper is directly associated with carbonaceous material. Iron-oxide stains are also locally abundant and associated with the copper minerals. At the Emily Jane property south of the Thompson adit, a fossil-plant horizon occurs as a lens more than three feet thick in buff to limonite-brown sandstone. The bed rapidly lenses out north and south along the strike. Limonite pseudomorphs after pyrite and associated chalcocite nodules are randomly distributed in the sandstone and occur with the copper carbonate replacements. Small lenses of buff to white sandstone containing copper carbonates north and south of the Thompson mine adit are exposed along the reef face. These lenses average less than three feet in thickness and thin rapidly on the strike, seldom extending more than 150 to 300 feet. Their extent on the dip is not known. In the Newton Mine a 2'-5' bed of abundant malachite-azurite plant replacements is exposed in the south drift. It is separated from a silver-bearing zone by a massive white sandstone three feet thick and a clay bed as much as a foot thick. Up dip the copper and silver zones appear to coalesce.

A notable lens of sandstone with copper-carbonates and iron-oxide replacements of fossil plants crops out at the south end of the Leeds mine surface stope. The lens extends 1050 feet south along the strike. The thickness ranges from a few inches to more than three feet. Iron oxide replacements of fossils are more abundant locally than the copper carbonates, but in general the malachite-azurite combination is the more common. The sandstone containing the minerals is buff, fine-grained and is cut off against a channel filling of lavender Tecumseh sandstone.

Other small showings of malachite and azurite occur north of the Leeds mine near the Honest Miner shaft and north of the Barbee and Walker mine. Some prospect pits and inclines have been put down on them, but their surface expressions are not as extensive as those already described.

Uranium-Vanadium

No visible uranium occurrences were noted on the White Reef. However, Stugard (p. 16, 1950) records assay data on a "soapstone" sample from 100 feet inside the Cobb mine. This is indicated as sample 2 in figure 8. Uranium content was 0.003 percent. Similarly at the Leeds Mine 0.005 percent uranium content was obtained from a grab sample at the mine entrance. He does not mention any visible uranium minerals in this area. Both the Leeds and Barbee and Walker tailings dumps failed to show any abnormal geiger counts.

Buckeye Reef

From deposits very similar to those on the White Reef, the Buckeye Reef produced 75 percent or more of the silver mined in the district. Copper carbonates are associated with and are separate from the silver occurrences, but these are less abundant than on the White Reef.

Silver

The character and occurrence of the silver deposits is almost identical with those already described with but two exceptions.

1. Silver occurred in a sheared sandstone cutting more than one stratigraphic unit, and

2. Silver ores occurred in both the Tecumseh and Leeds sandstone rather than the Leeds alone.

The variability in the stratigraphic positions of the ore deposits within the reef; their width, length, and thickness so characteristic of the White Reef deposits also applies to these deposits.

The ore consisted of: small grains of silver-chloride disseminated through certain zones in the sandstone, replacements of former reed-like and rush-like fossils, parts of trees, fillings in shear zones, thin plates of silver-chloride along bedding planes and occasionally as an associate of clay galls in sandstone. The majority of the deposits, however, were associated with plant remains. However, Rolker (p. 25-27, 1881) noted that the:

> southern and middle portions of the Buckeye Reef show less frequently vegetable remains than the remaining portion of the White Reef and in part these remains are absent. We find in the same line of bedding strata hold petrifications from six inches to three feet thick (the beds) which contain no silver ore, while above and below it silver is found in good permanent grades in strata showing a scarcity of vegetable remains. Again, I have seen a stratum where the upper two feet assayed about $30, then six inches assaying $100 or more, then 15 inches barren, and below it a layer of $20 rock, all of the strata being full of petrifications.

The silver-bearing sandstone lenses thinned and thickened within short distances along the strike of the Reef. Two producing horizons, separated by 15 or more feet of barren sandstone, in some places converged in a short distance on the strike or dip and formed a single lens. The thickness of the individual zones ranged from a few inches, as on Tecumseh Hill, to several feet as in the Buckeye Mine. Some zones contained phenomenally rich plates of silver-chloride in sandstone only a few inches thick, though above and below these, the silver content may have been very low or absent. In a number of places a thin horizon with a high silver content permitted the mining at a profit of several feet above or below, or both, of sub-marginal ore. Thus, many of the present stope faces do not reflect the original thickness of the highly mineralized horizons.

In general, the ore deposits were conformable to the bedding, though a gradual fading out of metal content within a certain bed occurred in a number of places. Many small slips filled with clay contained silver. As Rolker pointed out for the Buckeye mine (p. 29, 1881) a "throwing of the ore above or below" might occur, or the ore would quickly end beyond the slip. He also noted (p. 25-26, 1881):

> that an argillaceous sandstone ten inches to two feet thick may be present below the silver producing beds which often carried much silver and frequently showed solid sheets of horn silver along the seams of the thickness of a knife blade.

These silver occurrences, as he aptly adds, were not universally present throughout the district. Many of the open stopes on the Buckeye Reef show a foot wall of white to buff sandstone which has been swept perfectly clean. Apparently much of the silver was concentrated in the fines. The foot wall sandstone shows abundant impressions of clay galls and fossil plants, some partially replaced by copper carbonate. Newman (Personal Communication, May, 1948) observed that in the

Savage mine workings a "reddish micaceous sandstone is present above the ore-bearing white sandstone." Rolker records (p. 25, 1881) a similar observation for the mines nearby.

At the south end of the Buckeye Reef silver ore was mined from both the Tecumseh and Leeds sandstone beds and their contact north of the Stormont mine was extensively prospected. Near the gap leading to the farm land, south of the California mine, several inclines open into caved stopes in fine to medium-grained, lavender, finely-laminated and somewhat sheared sandstone. At the California mine silver ore was mined from at least two horizons, one within the Tecumseh sandstone approximately 10-14 feet from its contact with the overlying Duffin sandstone and the other at the contact of the Leeds and Tecumseh in a platy lavender sandstone. This same ore zone extended northward into the Maggie-Last Chance mines. A steep flexure east of the California shaft in the near surface stope suggests that mineralization was localized along this sheared and folded zone.

Five hundred feet southeast of the Savage shaft silver mineralization occurred in a sheared, brownish to lavender sandstone in a zone 40 feet wide and 300 feet long. (Plate VIII). This may well be the faulted northward extension of the shear zone of the California mine. At the Buckeye mine just north of the Savage shaft, ore bodies were from 18 inches to almost 20 feet thick. Small breaks caused the ore to jump 2-6 feet in overlying or underlying beds. Both the Buckeye and adjacent Kinner ore horizons were near the contact of the Tecumseh and Leeds sandstones.

On Tecumseh Hill the ore occurred in the Tecumseh sandstone and also at the contact of the Tecumseh and underlying Leeds sandstone. The open stopes show walls of finely laminated, lavender to gray sandstone. Most of the ore bodies on Tecumseh Hill were high grade, thin sandstone beds ranging from ten inches to possibly three feet in thickness. The individual ore deposits were small and near the surface. Huntley (p. 480, 1881) records that on the Manhatton, Silver Flat and Tecumseh properties:

> ore was found here from 4-15 feet below the grass in comparatively small bodies from 1-3 feet thick and 40 to 50 feet wide and long. Several faults of 4-6 feet and wave-like formations were noticed by Professor Maynard in summer of 1880.

Copper

Copper carbonate occurrences on the Buckeye Reef are not so prominent as those on the White Reef. Some showings, however, are abundant in the Buckeye Reef 500 feet south of the gap in the Leeds sandstone. Here malachite and minor azurite with limonite nodules replace fossil plants. The zone ranges to as much as 2 1/2 feet in thickness and extends over 120 feet along the strike. On the dip slope east of the large California mine dump a deep-green malachite occurs as grain-like masses and coatings of quartz grains in a fine-grained, white sandstone. However, small, partly replaced plant impressions occur along the bedding planes within an inch of the malachite in almost all cases. On the face of the reef to the east, a somewhat sheared white sandstone is stained with malachite over a thickness of three feet. Below it, in a buff, fine-grained sandstone, copper carbonate replaces plant fossils over a strike distance of 50-80 feet. Below this horizon and to the south other thin, white to buff sandstone beds contain minor malachite stains. Just north of the small thrust on the face of the Buckeye Reef, a 1 to 2 foot lens of buff, fine-grained sandstone 60 feet long shows prominent malachite plant replacements. North along the reef face other small sandstone beds containing malachite stains on plant fossils and generally less than three feet thick, extend short distances along the strike.

The most important copper carbonate deposits are approximately 1000 feet east of Fire Clay Hill

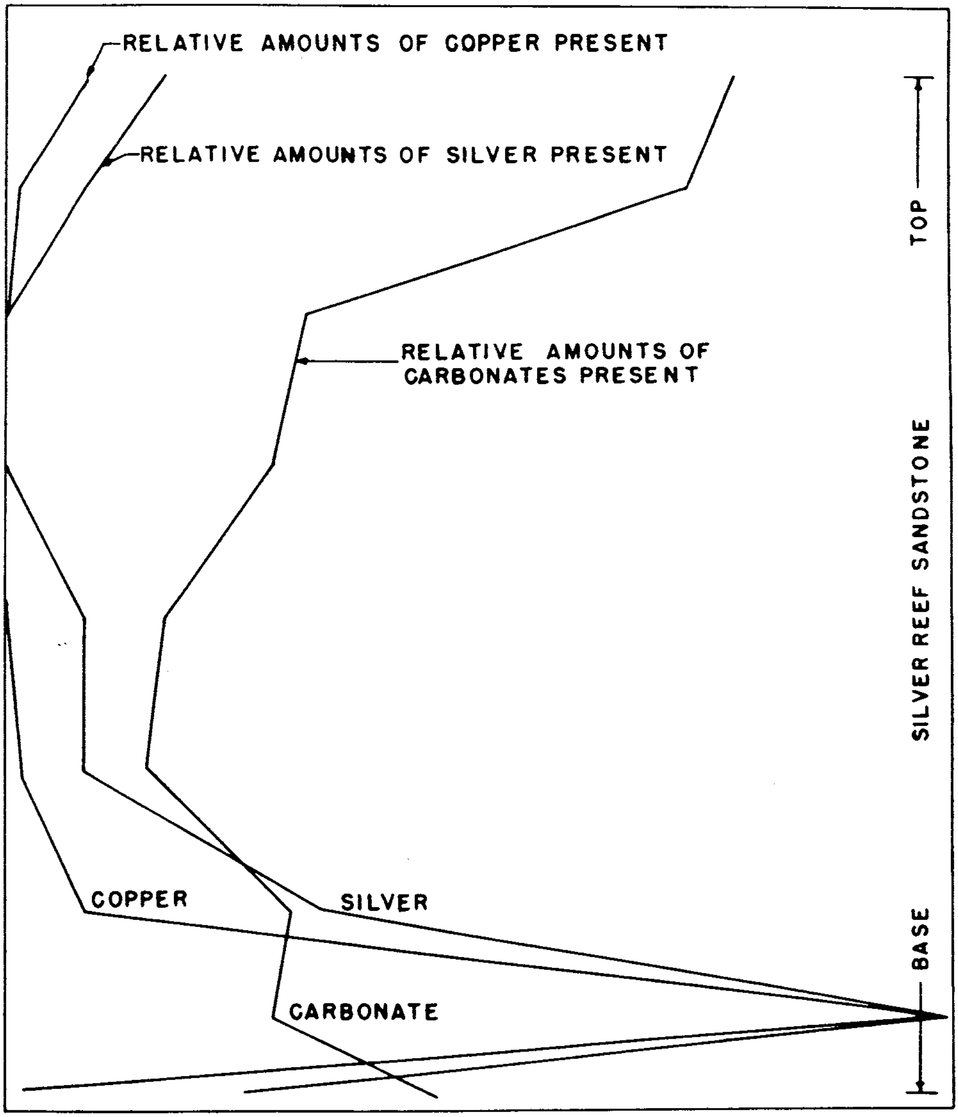


Figure 5. Relative amounts of copper and silver to carbonate content of Silver Reef sandstone.

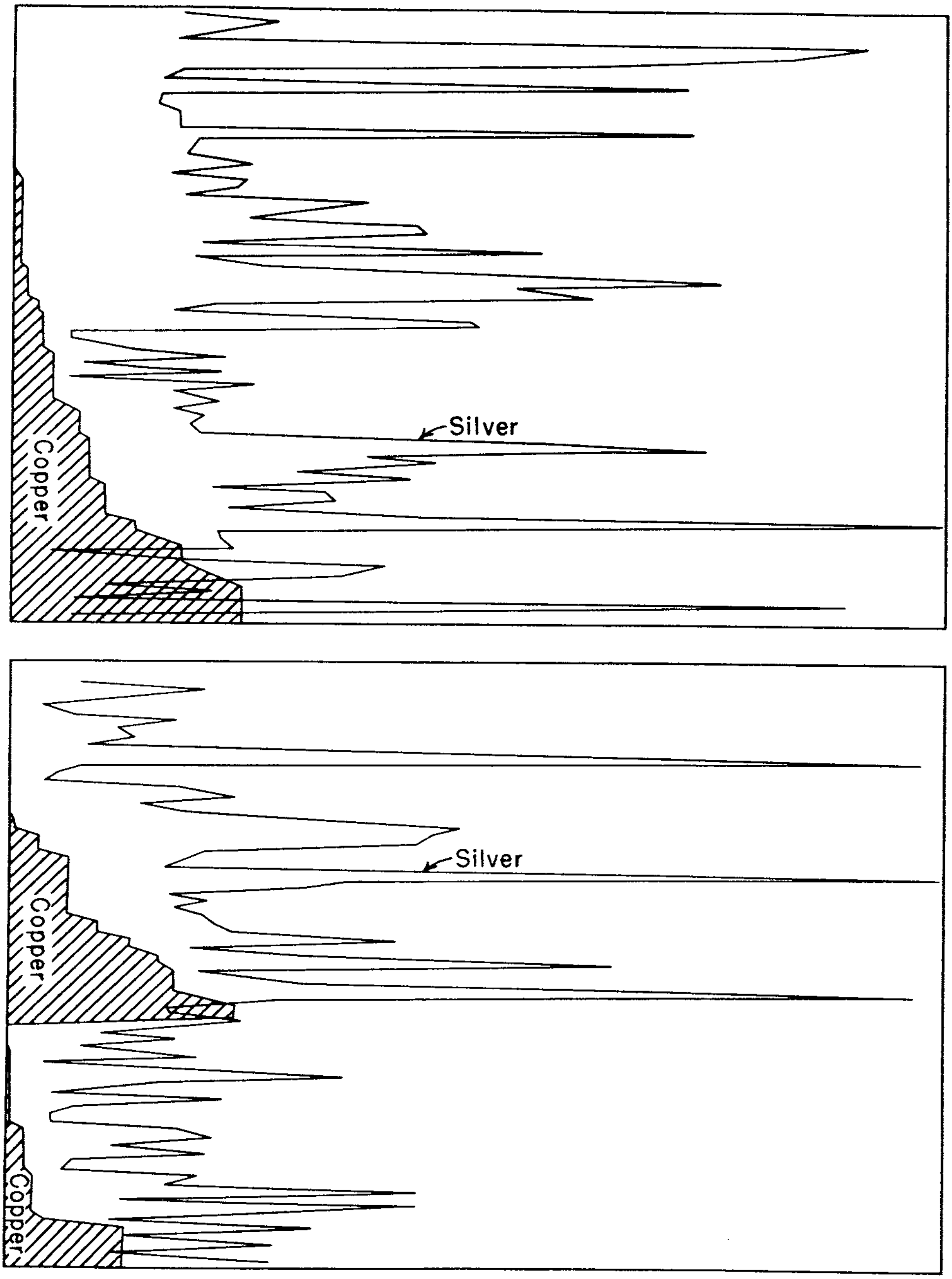


Figure 6. Relative copper silver ratios, White and Buckeye Reefs.

on the face of the Buckeye Reef. Here the beds are as much as 2 feet thick and extend 70 or more feet along the strike. A short distance eastward a lens over 260 feet in length is conformable to the bedding. The malachite and minor azurite occur in a porous, iron-oxide stained, fine-grained sandstone five feet below the Tecumseh sandstone contact. Locally, the sandstone bed thickens to 12 feet, but copper carbonate replacements are found only in parts of it. The bed containing the copper lenses out eastward along the strike. One-hundred feet east it appears again for 60 feet and is as much as one foot in thickness. The bed shows malachite replacements of fossil plants. Near the short adit west of the Leeds Reservoir, malachite stains associated with carnotite and volborthite (?) occur in sheared, buff, fine-grained sandstone.

Uranium-Vanadium

Uranium bearing minerals occur on the Buckeye Reef at various places, but in minor quantities. Occurrences of carnotite have been noted on the east side of Tecumseh Hill, just east of the Savage Shaft, on the Doyle shaft dump, in two small shafts 300 feet to the east, and in several prospect pits south and east of the Doyle shaft. Exploration work undertaken on several of these occurrences after the field work for this report had been completed exposed more of the details of the occurrences. Stugard (1951) summarizes these. On the enlargements of maps from Proctor's original report (Proctor, 1949), he has shown the areal distribution and position of the uranium ore zones on the Buckeye Reef.

Three ore zones are recorded. On Tecumseh Hill the inferred position of the uranium mineralization lies approximately 10 feet above the contact of the Leeds sandstone in the Tecumseh sandstone. South of the Doyle shaft two uranium ore zones are known. Stugard (1951) names these the upper and lower ore zones. The lower lies approximately 33 feet above the Tecumseh-Leeds sandstone contact, and the upper ore zone is 15 feet higher stratigraphically. The upper zone is exposed in several pits in the dip slope of the Buckeye Reef near the Doyle shaft. Showings of carnotite and relatively high Geiger-Mueller counter readings were noted by the author and Stugard approximately 800 feet northeast of the Leeds reservoir on the cliff face of the Buckeye Reef.

Samples 12, 17, 18, 23, 27, 30, 36, 37 and 38 (figure 8) were taken from Willis' exploration pit 375 feet south and slightly east of the Doyle shaft. Samples 16, 20, 28, 33, 34 and 35 (figure 8) were obtained 750 feet east and slightly south of the Doyle shaft on the face and slope of the Buckeye Reef. Stugard collected samples from the Tecumseh mine dump. These are represented by samples 5, 11 and 15 in figure 8. In a vertical diamond drill hole (Ehrhorn No. 1) south of the Tecumseh mine, and weighted average of vanadium for 12 feet (from 170-182.5 feet) was 0.12 percent. No uranium content was recorded for this depth. In addition Stugard collected 25 grab samples from the Christy tailing dump. A composite analysis of these showed 0.010 percent uranium and 0.07 percent V_2O_5 content. As noted in figure 8, these tailings represent the ores from at least six mines from the Buckeye Reef, and possibly others since custom ore was accepted by the mill. Samples 13 and 14 were collected from the Doyle shaft dump and probably represent the projection of either the upper or lower ore zone into the Doyle shaft underground workings.

Stugard's comments (1951) on the recently exposed ore showings of uranium describe in some detail the size and distribution of the largest known occurrences in the Silver Reef area:

> The largest uranium ore deposits known... are in the Tecumseh sandstone on Pumpkin Point (hill slope south and east of Doyle shaft). 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 ex-

posures over 55 feet total. A single exposure 430 feet to the west is believed to be part of the same ore zone. Two samples...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. One sample...is reported to contain 0.94 percent uranium and 4.30 percent vanadium oxide. A sample ...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. The samples...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.

Butte Reef

Silver

Very minor production has been reported from the Butte Reef, but three silver-bearing zones are known in the Silver Reef sandstone. West of the town of Leeds one zone lies at the Tecumseh-Leeds sandstone contact and another three to four feet below it. The upper ore horizon is a laminated, pink and white, fine-grained sandstone with numerous impressions of rushes and reeds partly replaced by copper carbonates. The lower zone is a white, finely laminated, fine-grained sandstone. The ore bodies apparently were small for the workings extend but a few feet into the reef. On the back slope of Leeds Hill (plate II), at 5-8 feet above the Leeds sandstone, a lavender, fine-grained sandstone with included fossil plant impressions was mined.

Copper

Copper carbonate minerals associated with plant remains are locally abundant along the east and west side of the Butte Reef in white sandstone, but none of the lenses are more than two to three feet thick and extend only a few tens of feet along the strike. Inaccessible mine workings at another locality on the north end of the Butte Reef did not allow an examination of the ore horizons there.

Uranium-Vanadium

Minor showings of uranium-vanadium mineralization were noted in a pit near the contact of the Tecumseh and overlying Duffin sandstone on the north slope of the Butte Reef. Stugard (1951) collected samples from these workings. Uranium content ranged from 0.039 percent to 0.23 percent. No other occurrences of importance are known for the Butte Reef area.

East Reef

Silver

Geologic conditions on the East Reef are very similar to those of the other three reefs. The majority of the silver deposits lie at or near the contact of the Tecumseh and Leeds sandstones. Two other ore horizons occur; one at the Duffin Mine in the Tecumseh sandstone 20 feet above the Leeds sandstone, and another on the Maud claim 2700 feet south of the Duffin Mine and 25 feet below the Tecumseh.

On the reef south of the Duffin mine prominent malachite with minor azurite and some silver replace and stain plant fossils. Here, a lens of sandstone as much as six feet in thickness includes plant fossils replaced by malachite. The lens thins to a few inches both north and south in approximately 300 feet. Similar lenses in the Leeds sandstone, though smaller in size, crop out south along the reef to the Virgin River.

Impregnations of carnotite and probable autunite occur locally in the Tecumseh sandstone at the Duffin and Toquerville mines. Other occurrences are present on the nose of the Virgin anticline in the Tecumseh sandstone. Malachite and carnotite partly replace plant remains in a buff, fine-grained sandstone. Some fair showings of carnotite, and malachite replacing and staining plant fossils occur approximately a thousand feet east of the axis of the Virgin anticline in a lens of buff to grayish sandstone six inches to 2 1/2 feet thick and six feet below a platy lavender sandstone (plate I). Minor amounts of the uranium-vanadium minerals occur below the lens on joint faces. The sandstone thins and thickens along the strike. Over a distance of 300-400 feet several prospect adits have been driven into the cliff face to prospect these showings. To the east along the eroded faces of the different fault blocks of Silver Reef sandstone, many prospect pits have been dug on similar showings of carnotite. The majority of these, however, are a few inches in thickness, and a few feet in length.

Structural Relationships of Mineralization

Channel Structures

It has been shown that Triassic streams which deposited the Silver Reef sandstone maintained a rather constant direction of flow in the mining area proper. Both the Tecumseh and Leeds sandstone deposited by these streams occur as a series of interfingering sandstone and minor shale lenses. Many of these channel fillings contain fossil plant material, distributed throughout their widths. In the South Thompson Mine, Leeds Mine, and in others on the Buckeye Reef, silver chloride and copper carbonates replaced the fossils and stained them to form the commercial ore deposits. Other channels filled with fine to medium-grained sandstone with included clay galls and balls locally contained rich silver deposits. Copper carbonates in quantity have not been found associated with this type of channel fill.

The Cobb Mine exemplifies the silver clay gall-ball type. A combination of this and the fossil plant variety occurs at different places in the area. Some of the mines at the contact of the Tecumseh and Leeds sandstone on Tecumseh Hill suggest this type of deposit, as do parts of the South Thompson mine area, the face of the White Reef to the east, and some prospect pits just south of the farm land gap on the Buckeye Reef. The silver mineralization is related to these channel fills, and even more closely to the included fossil plants and less so to the clay gall-ball conglomerate zones within the channels. The deposits are closely related to the thicker portions, but even here may be very sporadic. Not all channels however, contain commercial quantities of silver, as only a few in restricted zones, and mainly near or at the Tecumseh-Leeds sandstone contact, appear to have acted as loci of deposition for the ore minerals. An important secondary feature of the channels which resulted from the decomposition of the former plant substance is also important. These natural molds with carbon films on their surface have yielded high grade silver ore in the past.

The copper carbonate minerals are limited, however, to the lenses of channel fills containing plant-like remains. The lens of sandstone on the Emily Jane property on the face of the White Reef is especially notable in this respect, as are also the large lenses east of Fire Clay Hill and those on the East Reef south of the Duffin Mine.

Folds

Many geologists who have visited the mining district have suggested that a genetic relationship exists between the Virgin anticline and the silver mineralization. Though Rolker mentions the "horseshoe" (anticline) of the Buckeye Reef, he does not relate mineralizations to it. Butler (p. 154, 1920) observed a possible correlation between ore localization and the folding. Ball (1920) apparently was quite convinced of a direct correspondence for he noted: "the distribution (of the mineral deposits on the anticline) appears to be more than accidental and in fact causal." Both

Butler and Ball observed that a diminishing number of silver deposits occur south along the strike of the White Reef and suggested that the greater distance from the crest of the fold might be the reason for the decrease in number.

More detailed geologic mapping of the deposits indicates that the main deposits are more closely associated with the axis and west limb of a subsidiary fold of the Virgin anticline, i.e., the Leeds anticline of this report. The silver content was high on both the nose of the fold and on the west limb, yet the east limb of the same fold contains only sparse silver. The presence of a thrust fault between the Buckeye and White Reef further complicates the simple relationship offered by Ball and by Butler.

The Butte Reef, a faulted segment of the Silver Reef sandstone, is nearest the crest of the large Virgin anticline, yet only sporadic mineralization occurs in the sandstone. East of U. S. Highway 91, on the nose and crest of the Virgin anticline, silver occurrences in the Silver Reef sandstone are spotty and no mines were developed in this area. Finally, silver occurrences 16 miles southwest near Santa Clara, in the same sandstone apparently, have no direct relationship to the crest of a fold. Though an indirect relationship to the folding may be interpreted from the occurrence of silver on the nose of the Leeds anticline, other deposits considerable distances from the crest of the fold would indicate that folds were not important in localizing the ore.

Joints

Rolker (p. 29, 1881) pointed out that joints in the sandstones of the Buckeye and Kinner Mines caused the ore to jump from one bed to another. In some places silver mineralization stopped against them or was greatly diminished on the other side. One infers from his report that only joints containing clay fill affected ore in that manner. He also noted that some of the clay filling in the joints contained silver. However, his brief note would suggest minor importance to these as loci of mineralizing solutions and deposition of ore minerals.

Careful mapping of several hundred joints in the district failed to indicate any apparent relationship of trend of joints to trend of ore bodies. At the Newton and McNally mines on the White Reef one might be inclined to attach importance to the joints as some of the stopes appear to end against them. Assays of silver beyond the joint face in most cases, however, approximate those in pillars of the old stopes. Apparently the joints offered an easy breaking surface during blasting. The joint pattern doubtless was formed before the silver chloride mineralization as silver occurred in the clay filling of some of them.

Faults and Shears

Faults are not abundant in the Harrisburg mining district. The greatest number is on the nose of the Virgin anticline where they displace the Silver Reef sandstone. On the White Reef a fossil plant horizon now replaced by copper carbonates is displaced 50 feet on an oblique fault north of the Barbee and Walker Mine. On Tecumseh Hill several small faults displace the ore horizon a few feet. The Trail Hill fault drops the hanging wall of Tecumseh and Leeds sandstone to the east, but it is not known whether the downfaulted sandstone contains silver. It is possible that the ore itself has not been displaced, but only the horizon that was susceptible to mineralization.

The shear which begins in the California mine and trends north suggests a relationship to ore mineralization. Two stopes, one more than 200 feet long and almost 70 feet wide, are southeast of the Savage shaft. The stopes indicate that mineralization occurred in the lavender to buff-brown sandstones. North of the California and Maggie mines almost all of the known stopes end on the projection of this same shear zone. An exception occurs south of the above surface stopes where mining was carried to the face of the reef. Other than this, the general alignment of the stopes along the break strongly suggests that the zone acted as a pathway for the supergene ore solutions. It may have controlled to some extent the mineralization above and below it. At the California mine surface stope, ore was mined from the shear zone and a related sharp flexure. The shear zone is at least 10 feet wide and the fold much wider. Mining ceased when the beds assumed a more gentle dip. Another type of shearing mentioned by Butler (p. 588, 1920) occurs in the interbedded shales and in the horizons of small clay balls and galls. During movement of the beds, these were somewhat sheared and silver minerals are reported to have coated many of the fracture faces. Other than these suggestive relationships of shears to ore localization, most of the silver-copper-uranium bodies show little or no spatial relation to these structures.

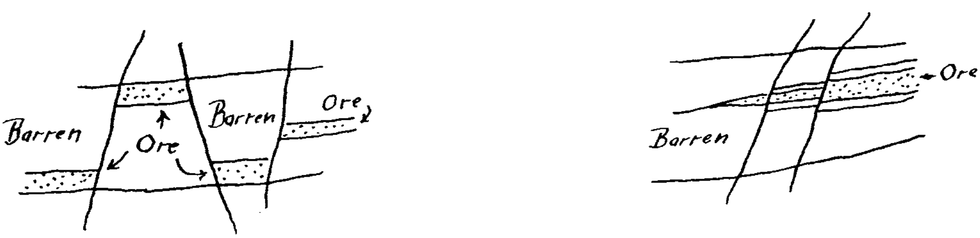


Figure 7. Small faults, Buckeye and Last Chance mines. (After Rolker, p.29, 1881).

Chemical Relationships of Mineralization

Relation of Silver, Copper, and Uranium to Carbonized Substance

A direct relationship exists between the silver copper and uranium-vanadium minerals and the fossil plants. It is almost universal for the copper mineralization, and a little less so for the silver. Apparently, the uranium-vanadium minerals may be deposited with or without visible fossil plant substance. Not only did the smaller plant fossils act as loci for deposition of the minerals, but large fossil trees were also important. Ball (1920) reports that one fossil tree yielded $14,000 in silver. Small pieces of carbonized wood, some lignitic in character, are still visible in some of the accessible workings. Most of these have a high silver content. All known mineralized fossil trees in the Silver Reef sandstone, as would be expected have been mined.

Relation of Silver Content to Carbonate Content

Ball (1920) suggested that a direct relationship might exist between the silver content and the carbonate content of the sandstone. He postulated that the silver mineral occurs as a replacement of the carbonate. Analyses of samples for carbonate content from the total thickness of both the Buckeye and White Reef failed to show any direct relationship to silver content. The few available specimens of silver ore did not replace carbonate minerals as indicated by microscopic study. However, the possibility remains that the drill cores analyzed for carbonate content were not representative of the ore rock, since values in the drill cores were low. Figure 5 shows the results of one of these analyses. Unhappily, the operators thought it unnecessary to analyze for any other elements than silver and copper, so the many hundreds of available assays are of no use in such a comparison.

Relation of Silver to Copper Content

It has been stated by some of the old residents in the area that high silver and copper content were not generally associated in the same ore horizon. In the present study it was thought that if a possible relationship, either direct or inverse, did exist between the silver-copper ratio a means of roughly predicting the presence or absence of silver from the visual amount of copper mineral present might be possible. A random selection of approximately 200 analyzed samples from both the White and Buckeye Reef was compared to note any possible quantitative relationship between the two metals. Figure 6 shows the results of this study. Since company regulations do not permit publishing of the actual values, a logarithmic ratio with no values assigned for the silver and copper was used for plotting purposes. The graph is drawn to show the copper values as a continuously increasing function, and the silver as the variable.

The most distinctive feature of the graph is the wide variation in the silver content when compared to a constantly increasing copper content. The Buckeye Reef samples show no apparent relationship. There is, however, a slight indication of a possible increase of silver content with increase in copper for the White Reef. Such a relationship would apply to the average case and not a specific one, however. A study of a greater number of samples than were available might further substantiate this. It is quite apparent that the presence of copper does not preclude high silver content, nor does the quantity of copper in the ore appear to offer any possibility of predicting the associated silver content.

Relation of Silver Content to Radio-Active Minerals

Since there are only a few places in the district where the uranium-vanadium minerals occur in any amount, and these localities are mainly outside of the main silver mining area, few assays were available for study. However, the lack of extensive mining operations near the occurrences is indicative of low silver values. Several samples with approximately 2 percent carnotite and some copper carbonate were assayed for silver, but in each sample the returns were low. The highest averaged 6.60 ounces of silver per ton, 2.58 percent of copper, and some uranium-vanadium. Figure 8 is a compilation of assays for uranium, vanadium, silver, copper and selenium. The twelve silver samples do not appear to show any direct relationship to the radio-active mineral content.

Relation of Radio-Active Minerals to Copper, Vanadium, and Selenium

Thirty-nine analyses, made available by the United States Geological Survey, (Stugard, 1951), were plotted using a progressively increasing uranium content. It was hoped that any inverse or direct relationship in amounts of the elements might be indicated by such a chart. As figure 8 demonstrates, the selenium content is highly erratic and does not appear to correspond to the uranium content. Likewise, the percent copper is quite variable and may either increase or decrease when uranium is present. Since the great majority of the uranium occurs in the mineral carnotite, an increase in the vanadium content should take place when uranium increases. This is indicated in a general way. Because vanadium oftentimes exceeds the expected amount, and sometimes is less than is required by the carnotite formula, it suggests that both uranium and vanadium minerals other than carnotite must be present. The excess vanadium can be accounted for in the mineral volborthite (a hydrous vanadate of copper, barium, and calcium) while autunite in minute grains or some other unknown uranium mineral might account for the excess uranium.

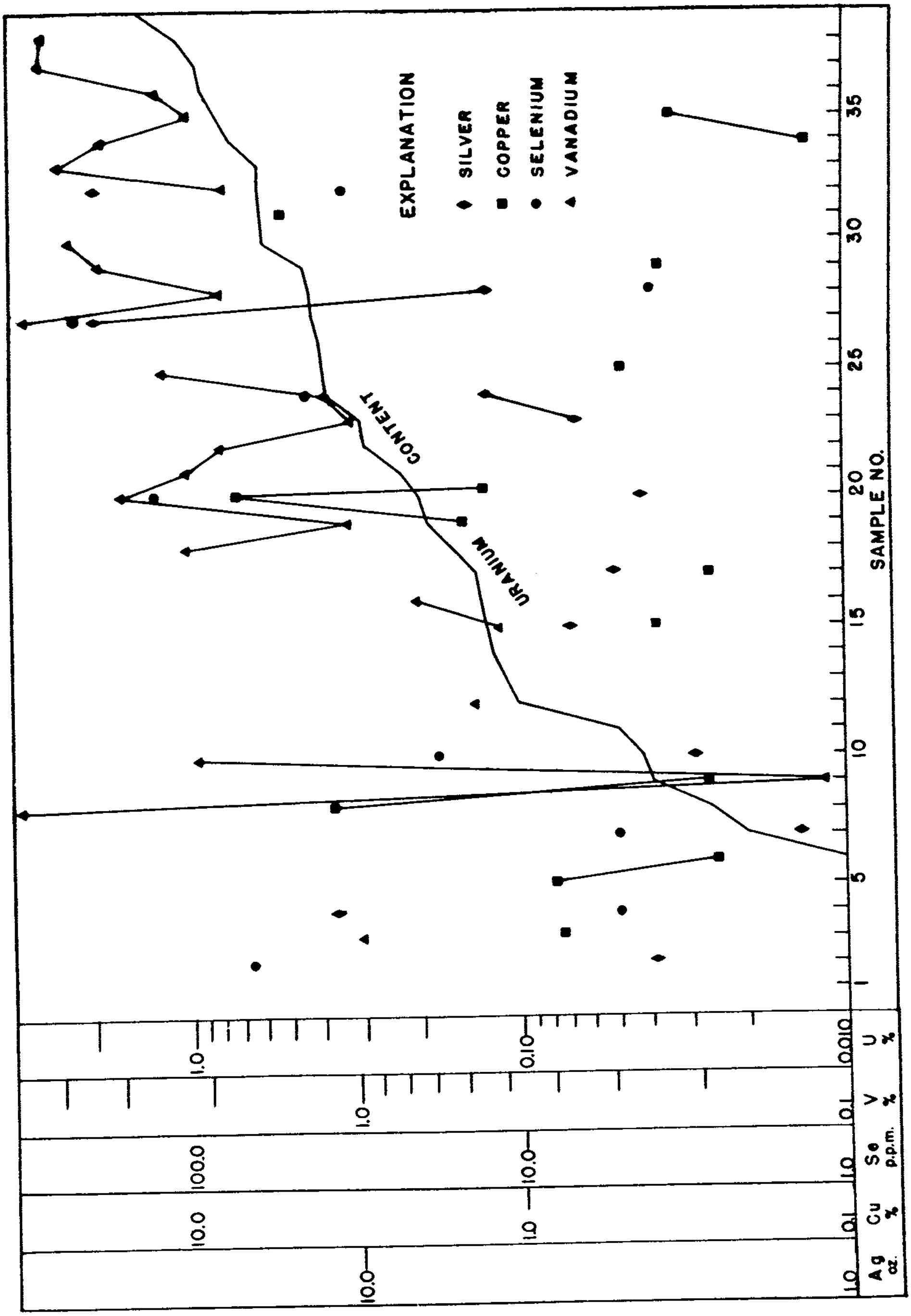


Figure 8. Uranium-vanadium-copper-silver-selenium ratios.

MINERALOGY

A rather simple assemblage of minerals make up the ore beds and other sandstones at Silver Reef. Cerargyrite, the major silver mineral, is associated with a host of minerals. Both the ore and non-ore-bearing sandstones consisted of 90 percent or more of quartz grains on the average, though locally feldspars might make up 30-40 percent of the rock. Generally, however, feldspars, muscovite, chlorite, calcite, iron oxide, and much lesser amounts of zircon, apatite (in quartz), tourmaline, and garnet constituted the less abundant minerals of the sandstone. Locally, malachite and azurite make up to 5 percent of the rock. Carnotite and probable autunite occur sporadically and in small amounts in the Tecumseh sandstone on the Buckeye and East Reef and in lesser amounts on the White Reef. Occasionally, iron oxide nodules and stains, chalcocite nodules, minor pyrite, and some silver sulfide occurred together. J. S. Newberry (p. 5, 1881) reported selenium in some of the ores. This was confirmed by the writer and also by Stugard (1950). Heavy minerals, i.e., those above 2.80 specific gravity, occur in very minor quantities in the Silver Reef sandstone. Mineralogical study of two complete sections of the sandstone indicates that they do not constitute more than 0.1 percent by weight for all grain sizes.

Cerargyrite, $AgCl$

Cerargyrite was the principal ore mineral of the old mining camp and its discovery by W. T. Barbee on Tecumseh Hill brought about the "boom" mining in the district. The mineral occurred in all of the silver ores and was commonly called "horn silver" or "chloride of silver" by the miners. Generally, it was found as a waxy violet to brown mineral, though in some mines it was white to gray and blended perfectly with the light colored sandstones. On exposure to light, the white cerargyrite gradually changed to violet-brown.

The mineral was disseminated within the silver-bearing sandstones, or occurred as thin plates along the bedding planes, surface films on shear planes in sandstone and shale, and as replacements of carbonized wood or smaller plant fossils (Plate X). Though it has been reported that silicified trees seldom contained the silver chloride, selected silicified fragments known to have occurred above the water table were assayed and gave the following results:

Gold - trace
Silver - 12.90 ozs./ton
Iron - 0.4%
Copper - 0.4%
Insoluble - 96.0%

<u>Embolite</u> (?), Ag (Br,Cl)

Though not identified or confirmed by the writer, the description by Messrs. Hartley, McMullin, and Colbath of a rare green silver mineral which they called "silver bromide", most closely resembles that of embolite, a silver-chloro-bromide with color a grayish green to yellowish green or yellow. Such a mineral would not be unexpected in the oxidized zone. Extended search of the dumps, however, failed to reveal it. The mineral the mining men described came from the Cobb mine.

<u>Native Silver</u>, Ag

Though this mineral was not confirmed by the writer, several of the former geologists and many of the old miners in the district verify its presence. According to McMullin (personal communication, 1947) native silver was locally abundant in the Thompson Mine on the White Reef. He reports that some rock specimens when broken with a hammer would not fall apart because of the tenacity of the wire silver. Small specks of native silver were also reported on the sheared faces of shale Jenney (p. 464, 1902) quotes Nesbitt as saying:

about 100 to 200 feet above water level on the slope of the beds (in the Barbee and Walker Mine) the ore was very rich, and small bunches of lignite coal, 4 to 10 inches across, were found imbedded in the soft sandstone with native silver deposited on thin scales on the joints of the coal. Most of the ore at this depth was silver sulphide.

Silver Selenide (?)

Newberry (p. 5, 1881) states that some of the ores at Silver Reef contained selenium. He noted that the average of four analyses of ore yielded 0.23 percent selenium and 0.26 percent silver. One other ore specimen is reported to have yielded 90 ounces of selenium to the ton. Unhappily, Newberry does not list the location of the samples, either as to mine or depth below the surface. Butler (p. 592, 1920) notes that the selenium might suggest that part of the silver content of the sandstone was combined in some form with it. Recalculation of Newberry's analyses to a possible silver-selenium composition yields Ag_2Se_3 if it be considered that it combined wholly with the silver. As far as is known no such mineral exists, nor do the element valences indicate such a composition. However, the selenium reported by Newberry could have been with other elements and not bear any relationship to silver content. Analysis by M. Coller for the writer of a rich fine-grained silver ore specimen from the Cobb mine stopes above water table yielded 46.23% silver and 16.66% selenium. X-ray patterns indicated cerargyrite lines, possible argentite (Ag_2S) lines, and some quartz. As far as could be determined the X-ray reflection lines for aguilarite /$Ag_2(S,Se)$ / were not apparent. Other samples showed good patterns for cerargyrite.

Argentite (?) Ag_2S

Argentite was not apparent in any of the samples collected in the mining district, except for the indication in the sample above. Very careful search of the mine dumps failed to show any. Ball as late as 1920 reports that he could find no mineral specimens for the silver sulfide reported by former engineers and geologists who had worked in the area. Apparently, most of the visible ore was milled and little of the higher grade ore left on the dumps.

Rolker (p. 26, 1881) first reported:

> The ore itself is what is known as cerargyrite or chloride of silver, which however, below true water-level will change to sulphuret of silver, with native silver in places.

The old miners state that in fossil trees at depths within the mines, two kinds of silver ore existed, the sulfide of silver and the silver chloride. The Leeds, Savage, and California mines are reported to have had both minerals present. W. M. Nesbitt, who worked at Silver Reef from 1878-88, stated to W. P. Jenney (p. 464, 1902):

> At one place a tree trunk, 18 inches in diameter was found, the heart wood was silicified and very hard, and carried 8-10 ounces of silver per ton. The sap wood and bark, 3-6 inches thick, were altered to soft crumbling lignite full of silver sulphide, it assayed 5,000 ounces of silver per ton.

Malachite $CuCO_3 \cdot Cu(OH)_2$

Malachite, the green copper carbonate mineral, is the most common copper mineral in the district. It replaces former plant material and rarely occurs disseminated within the sandstone. Locally, it is found as stains in the rock and as replacements of woody material. Only rarely does it completely replace fragments of fossil trees. The mineral occurs almost universally in white or buff sandstone and only sporadically in lavender sandstones. Under the microscope the malachite occurs as finely radiating masses between the quartz grains and appears to replace the kaolin groundmass. (Plate IX).

The mineral is most common on the White and East Reef, but it is locally abundant on the Buckeye Reef. The best occurrences are on the Emily Jane property near the Thompson Mine, in the Newton Mine to the north, and on the Maud claim on the East Reef where it locally constitutes 5 percent of a buff, fine-grained sandstone containing abundant plant fossils.

<u>Azurite</u>, $2CuCO_3 \cdot Cu(OH)_2$

Azurite occurs only with malachite and has not been reported or observed to occur singly in the district. The ratio of malachite to azurite approximates 10-1. The most abundant showings are in the Leeds Mine and in the Newton workings. Its occurrence is identical to that of malachite.

<u>Cuprite</u>, Cu_2O

Cuprite occurs in minute quantities in some of the copper stained buff, fine-grained sandstones. Rolker (p. 27, 1881) observed:

> another frequent occurrence is a foot or two foot seam of sandstone full of petrifications, charged with red oxide of copper, azurite, and malachite to some extent and carrying no silver.

The American Cyanimid Ore Dressing Laboratory (1946) also noted cuprite in minute quantities in some of the ore concentrations.

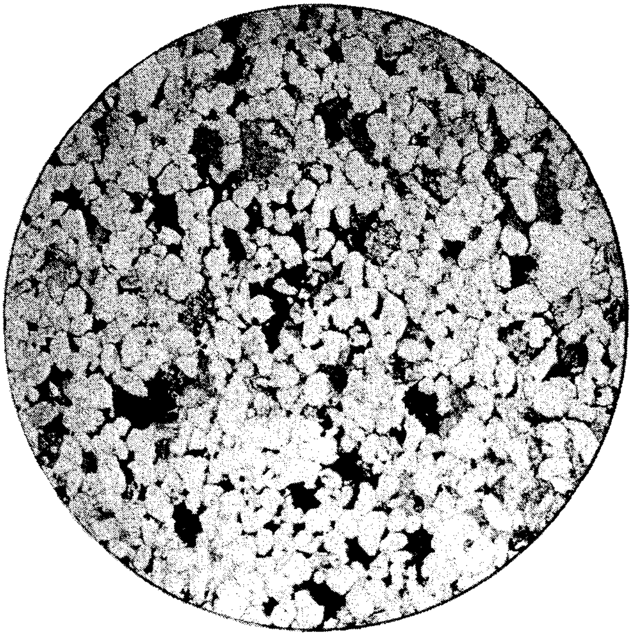
<u>Tenorite</u>, CuO

Ball (1920) reports the possible presence of tenorite, but was not certain of its identification. The writer could not verify the occurrence in the district.

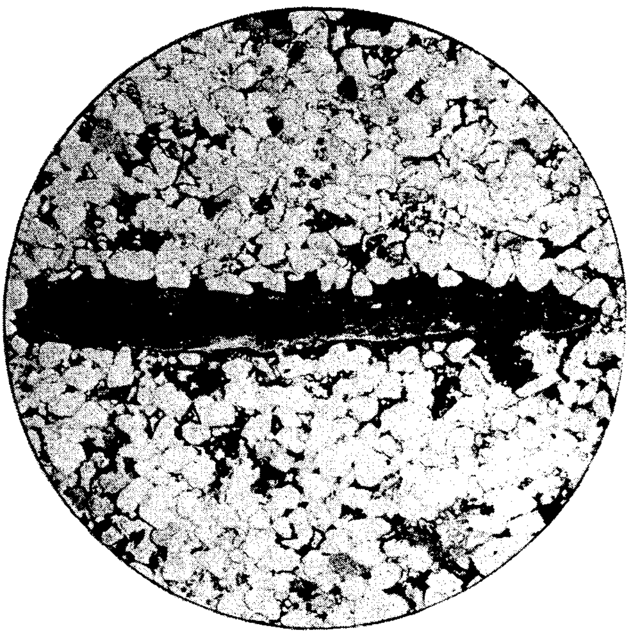
<u>Chalcocite</u> Cu_2S

Chalcocite is not an abundant mineral in the district. It most commonly occurs as small nodules as much as 1/2 inch or more in diameter. The outer surface shows a rusty brown coating, though the fresh mineral has the characteristic lead gray color of chalcocite. Many nodules occur in buff to white sandstone on the Emily Jane property and

Plate IX. PHOTOMICROGRAPHS OF MINERAL OCCURRENCES

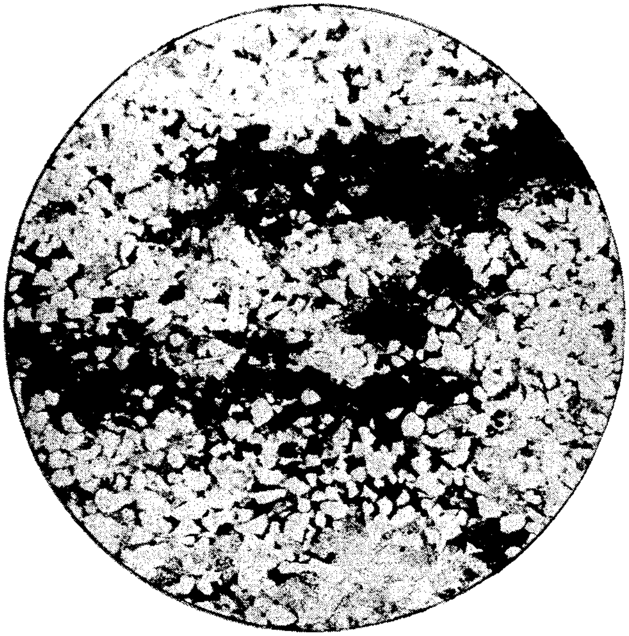


A. Malachite (medium gray) around quartz grains (15x).

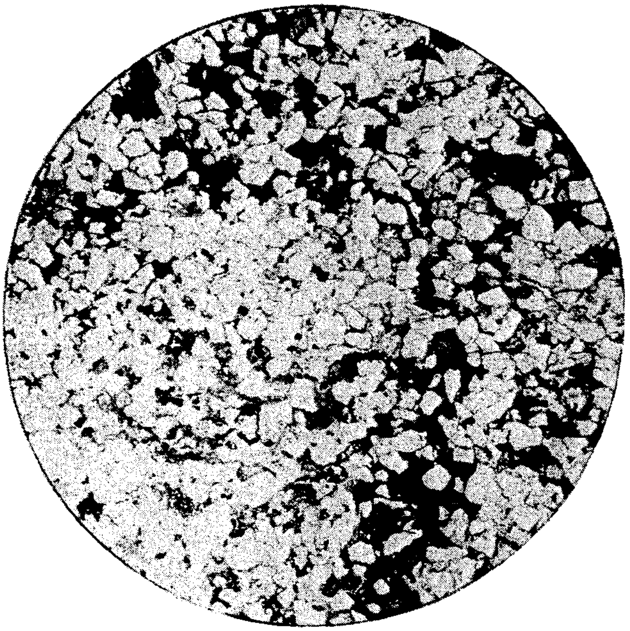


B. Partial replacement of plant remains by carnotite (15x).

Plate X. PHOTOMICROGRAPHS OF MINERAL OCCURRENCES



A. Cerargyrite (black) in quartz sandstone (white). Elongate plates are muscovite (15x).



B. Iron oxide (black) filling around quartz grains (white). Light gray rims around quartz (lower left) are carnotite (15x).

at the South Thompson, Cobb, and Duffin mines. Some of the older miners report occurrences in the Barbee and Walker, Last Chance, and Tecumseh mines. Small nodules of the mineral are also found south of the Duffin Mine on the East Reef.

Chalcocite concretions more than an inch in diameter occur below the Silver Reef sandstone in the Fire Clay Hill bentonitic shales. Hartley (personal communication) reports that he found some as much as six inches in diameter. Careful research of the area, however, failed to reveal any concretions that size, though one inch sizes occurred locally. The concretions could easily be overlooked as their external appearance is almost identical with the thousands of calcareous concretions which occur in the same bed. Some of the chalcocite concretions have a coating of malachite and iron oxide. Study of polished sections of some of the specimens indicates that chalcocite universally replaces pyrite and is in turn replaced by silica. (See plate XI A and B).

Chalcopyrite and Bornite
$CuFeS_2$ and Cu_5FeS_4

Though no chalcopyrite was found by the writer, the American Cyanimid Ore Dressing Laboratory reported very minor amounts of both chalcopyrite and bornite in ore concentrates from the Silver Reef. Dr. Hyrum Schneider, emeritus professor of geology at the University of Utah, recognized bornite in a small lens of sulphides replacing silicified wood. Small specks of the same mineral associated with pyrite and chalcocite replaced carbonized wood fragments in the ore horizon on the Maud claim.

Pyrite, FeS_2

Pyrite is a rather rare mineral in the district though the prominent local iron-oxide stains suggest a much wider distribution originally. Nesbitt reported to Jenney (p. 464 1902) that pyrite occurred in the Barbee and Walker main incline, and that some appeared at the water table. The writer recognized pyrite from a specimen of high grade silver ore replacing lignitic material from 430 feet down in the A. S. & R. shaft. As described above, pyrite is partly replaced by chalcocite in the small concretions in the Fire Clay Hill bentonitic shales. Other occurrences were noted in the Cobb Mine, South Thompson Mine, Emily Jane property, and the Maud claim on the East Reef.

Carnotite, $K_2O.2UO_3.\ V_2O_5.2H_2O$ (Approx.)

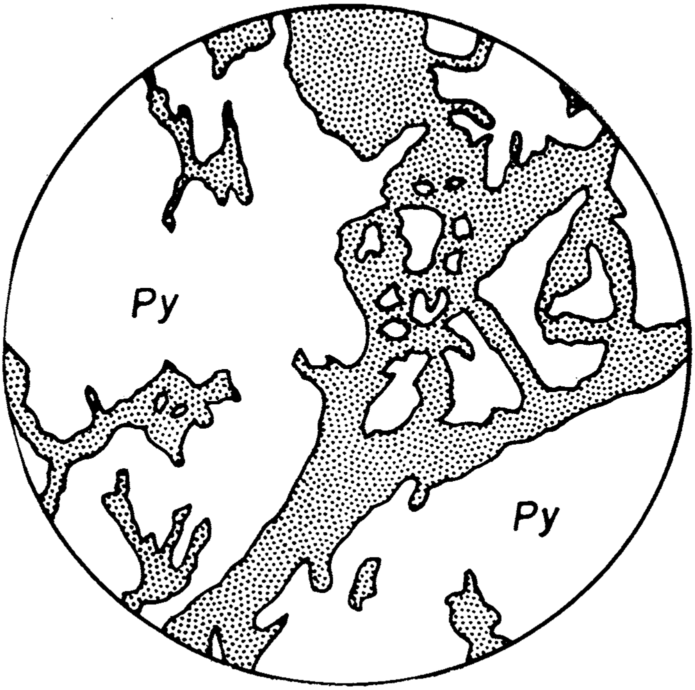
Carnotite occurs as a disseminated mineral replacing the cement of buff to white sandstone and as a coating around the quartz grains. Less often it is found in lavender sandstone in association with plant fossils. Under the microscope most of the grains show a yellow to yellowish green color, and appear to fill in between the grains of quartz replacing the kaolin groundmass. In two specimens from near the Doyle shaft carnotite has replaced orthoclase feldspar, and in another specimen has replaced a kaolinized relic of a former feldspar crystal. Commonly iron oxide stains occur with the carnotite, but whether they merely stain the mineral or were deposited at the same time is not clear. Silver chloride occurred as small veinlets cutting the carnotite in two places where they occurred together. (See Plate VI).

Autunite $Ca(UO_2)\ 2P_2O_5.8H_2O$

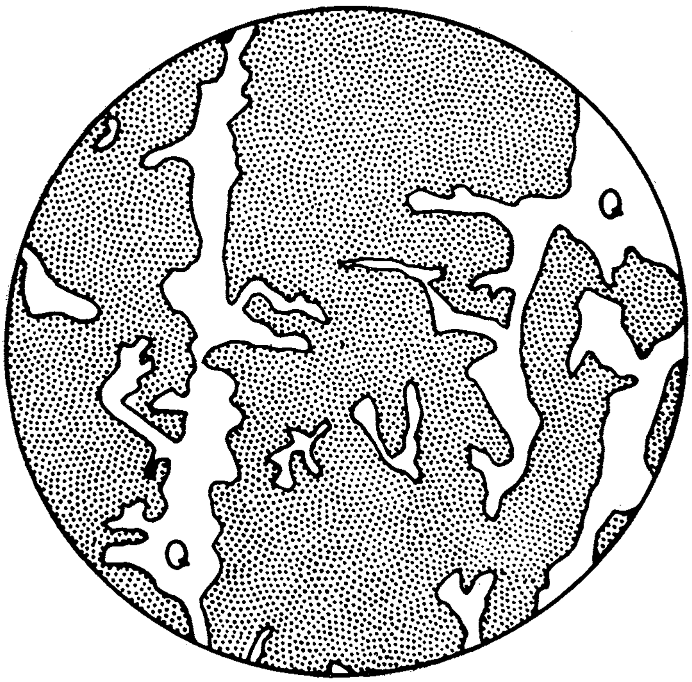
The mineral is reported in minute amounts. The lemon to sulphur yellow hydrous phosphate of uranium and calcium occurs sporadically and sparingly on the Buckeye and East Reef. Rolker (p. 5, 1881) states:

> I found the seams in which the vegetable remains are covered with autunite, which is quite frequent around the Gad shaft (east of Savage shaft) and two carbonates of copper, unproductive with pay seams frequently above and below them.

Plate XI. DRAWINGS OF PHOTOMICROGRAPHS



A. Chalcocite (stippled) replacing pyrite (Py) (50x).



B. Quartz veining and replacing chalcocite (stippled) (50x).

The quantity of the uranium mineral is insignificant in the surface showings. The mineral occurs with fossil plants near the Doyle shaft and also reed-like and woody substance in the Silver Reef sandstone on the north plunging nose of the Virgin anticline. Minute quantities occur in the lavender sandstone near the Vanderbilt and Duffin mines.

<u>Volborthite</u>, $6(Cu,Ca,Ba)O.V_2O_5.15H_2O$

Stugard (1951) suggested that volborthite might be present in the uranium-vanadium ores. Samples collected by the author in the recently excavated pits near the Doyle shaft show a yellowish-green micaceous mineral in a somewhat iron-stained sandstone. The mineral commonly occurs along fractures and as partial fillings of open spaces in the sandstone. More commonly it occurs as a dark olive green to yellow green extremely fine-grained coating on fractures.

Microscopic study indicates yellowish-green hexagonally shaped plates with refractive indices ranging from 2.01 to 2.03. The sign is positive. Both the micaceous appearing mineral and the very fine-grained coatings of a darker color have the same optical properties. Microchemical tests prove abundant copper and vanadium.

A qualitative spectrographic analysis on a sample from the pits south of the Doyle shaft gave the following results:

Major elements:	V, Cu
Minor elements:	(greater than 1%), Ca, Ba, Si, Fe, Mg, Al
Trace elements:	(less than 1%), Mn, Ni, Ag, Zn, Sc, Zr, Co?, Sr, Cd, B, Mo, Ti, Pb, Cr, Y, K.

Mr. R. K. Leininger, spectrographer, reports: "In addition, a possible trace of phosphorous was noted."

The fine-grained character of the mineral and its relative scarcity made it most difficult to obtain a pure sample. The relative abundance of Si, Fe, Mg, and Al might be accounted for in the quartz and clay content of the sandstone. All data suggest volborthite as the mineral.

Mineral occurrences have been noted in the Willis' pits south of the Doyle shaft, southward in the incline on the face of the reef, and in the new exploration pits at the north end of the B Reef, also on Tecumseh Hill and near the old gad shaft.

Gangue Minerals

All of the above minerals generally occur in association with or near to the silver-bearing horizons. However, mention has not been made of the more common minerals which comprise 95% of the rock. Cores from two diamond drill holes which completely cut the Silver Reef sandstone were disaggregated into individual mineral fragments by a gentle mortar-pestle treatment. Heavy minerals were separated from the light (less than 2.80 sp. g.) by bromoform. The separation indicated that for the two complete sections analyzed, the heavy minerals constituted less than 0.1 percent by weight of the individual samples.

Study of 349 grains of a representative split of 20 feet of typical sandstone from the Tecumseh beds yielded the results shown in Table 4.

A typical 10 foot sample of core from near the base of the Leeds sandstone was split down to approximately 300 grains and the minerals, identified under the microscope, with the results shown in Table 5.

Table 4. Mineralogical Analysis of Tecumseh Sandstone*

Light Minerals	Percent
Quartz: Subangular grains in the majority, minor subrounded, rare euhedral and subhedral. The quartz is mainly colorless with abundant inclusions of apatite, some tourmaline, and zircon. Some grains show a heavy coating of iron oxide which almost completely masks the mineral	91.9%
Colorless quartz shows prominent wavy-extinction under crossed-nicols	1.2%
Colorless quartz shows good secondary growth with the same optical orientation as the older grain	1.2%
Orthoclase feldspar: Of the few grains present, 50% appear fresh, colorless, and subhedral to anhedral. One grain has wavy extinction. The remaining grains are very much kaolinized and cloudy	2.1%
Plagioclase feldspar: A questionable grain of andesine feldspar and others of oligoclase composition make up the plagioclase group. The minerals are partially kaolinized, very cloudy, and subangular . .	1.2%
Calcite: All free grains of calcite are very angular and colorless, and probably represent cement of the original sandstone. .	1.2%
Chlorite: Four grains of chlorite were noted. Each grain showed the common anomalous interference colors under crossed nicols. At least one grain replaced original hornblende. All grains were subangular . .	1.2%
Iron-oxide as coatings on quartz grains fairly common, and almost completely masked some of the quartz. These stained grains have been lumped under quartz above. Some may well be other minerals, though shape , apparent relief along the edges of the grains, and colorless character of partially clean grains suggest quartz. . . .	
Heavy Minerals	None
Total:	100%
Total grains counted:	349

*From hole 5, 36.3-46.3 feet depth, U.S. Standard 120-mesh size fraction.

Table 5. Mineralogical Analysis of Leeds Sandstone*

	Percent
Light Minerals	
Quartz: Mainly subangular, some subrounded, the grains are colorless, 6.8% deeply iron stained. Less than 2% of quartz grains show secondary growth. Wavy extinction shows in three grains or approximately 1%. Inclusions in the quartz are abundant and consist mainly of apatite, zircon, tourmaline (?), and bubbles.	90.3%
Orthoclase feldspar: One grain is almost euhedral, the others mainly subhedral to anhedral and show the effects of weathering. Most of feldspar are fairly clear, but two grains are quite cloudy.	3.8%
Microcline: Two grains show the characteristic microcline twinning. Both are cloudy and show effects of weathering.	.63%
Plagioclase: Four grains of plagioclase feldspar, two show good albite twinning. Composition near albite-oligoclase. The grains are somewhat cloudy and altered in appearance	1.27%
Heavy Minerals	
Hypersthene (?): Three grains of possible hypersthene but lack of a suitable interference figure for the balsam mounted grains did not allow certainty of identification. Schiller structure and slight pleochroism visible. The mineral is pale greenish and subangular. .	.9%
Garnet: Light greenish garnet, angular shows good isotropism.	.9%
Calcite: Calcite occurs as cement around quartz grains and as angular and colorless fragments. Possibly most of the calcite represents cement grains broken loose from quartz during the disaggregation.	2.2%
Cement: Other than calcite cement iron oxide occurs on a number of the quartz grains. .	
Total:	100%
Total grains counted:	314

*From hole 5, 87.3-96.3 feet depth, U.S. Standard 170-mesh Size Fraction.

Besides the minerals in Tables 4 and 5, the following were observed in thin sections from different parts of the Silver Reef sandstone.

Muscovite

In certain parts of the sandstone, especially the middle section of the Tecumseh sandstone, muscovite commonly occurs as fine flakes along the bedding planes. Much finer grains occur on the bedding planes of the shales in the district. In thin sections the muscovite appears as colorless, elongate grains or as a warped plate of mica wrapping around the quartz grains. Locally, the mineral may be lightly iron-stained. (See plate X, A).

Kaolinite (?)

Fine shreds of kaolin make up part of the groundmass around the quartz grains in the sandstone. The proportion is low, probably averaging less than 3% of the rock. It also occurs as replacements of feldspar in the rock and only relict shapes of the feldspar may remain.

Calcite

Though calcite commonly occurs as an interlocking cement around the quartz grains in many of the individual sandstone beds isolated grains also may occur in the white, fine-grained Leeds sandstone. Near the Honest Miner shaft and in the diamond drill holes nearby, veinlets of white to colorless calcite as much as 1/4 inch wide fill many fractures in the rock. The mineral also makes up more than 94% of the composition of some of the calcareous concretions in the Fire Clay Hill bentonitic shales.

Gypsum

Though no gypsum is known to occur in the Silver Reef sandstone, it is abundant as selenite in small veinlets and thin beds in the overlying and underlying brick-red shales of the Silver Reef area. None of the observed occurrences are more than two or three inches thick.

Jasper

Jasper does not occur in the ore-bearing member of the Chinle formation, but its rather distinctive occurrence a few feet under the Silver Reef sandstone as a greenish shale makes it worthy of note. The mineral apparently replaces the shale as an aggregate of very fine-grained, red quartz and forms a bed which is continuous over many miles at practically the same horizon. The mineral also occurs in the Fire Clay Hill bentonitic shales generally near the bottom in a similar manner to the above. Here, however, it is banded red, green, yellow, and brown and may cut the bedding.

Halite

Though not observed in outcrop, the abundance of small solution cave-ins in the shales at the base of Fire Clay Hill and eastward, is suggestive of salt which has been dissolved away.

Montmorillonite

This variety of clay makes up a large proportion of the Fire Clay Hill bentonitic shales, and in some cases may constitute 60% or more of the rock. The rock composed of the mineral is generally gray-blue to purplish and has a common chert-like mineral concentrated at or near the base. Some of the clay galls and balls in the Silver Reef sandstone also contain a small proportion of the mineral. The swelling property of the clay when immersed in water and its almost complete disaggregation is very characteristic.

Apatite, Zircon, and Tourmaline

These minerals are in the minority and usually constitute less than 1 percent of the rock. Only occasional grains of the minerals are visible in thin section. Each grain shows its characteristic features. The apatite occurs as inclusions in quartz as does some of the tourmaline. However, both tourmaline and zircon may occur as isolated grains in the matrix of the sandstone. Only the tourmaline is colored and it usually assumes a light to medium green.

GENESIS

Any theory of origin for the Silver Reef deposits must take into account the following points:

(1). The occurrence of silver chloride in association with copper carbonates and minor amounts of uranium-vanadium minerals and some selenium.

(2). The known areal distribution of minor silver and copper content in the Silver Reef sandstone in the St. George basin.

(3). The localization of commercial ore deposits in light colored, terrestrial sandstones interbedded in red sandstones and shales of Triassic Chinle formation.

(4). The common association of the metallic minerals with plant remains.

(5). The concentration of silver and copper minerals in stratigraphic units within the sandstone member.

(6). The association of silver, and to a lesser extent copper, with clay galls.

(7). The paragenetic sequence of deposition of the different minerals in the deposits.

(8). The absence of associated intrusive rocks with the mineral deposits.

(9). The lack of silicification, sericitization, typical ore textures, and other usual accompaniments of hypogene deposition.

(10). The absence of recognizable feeder channels for the different ore bodies.

(11). The occurrence of silver- and gold-bearing chalcocite-pyrite concretions in a bentonitic shale 310 feet below the Silver Reef sandstone.

The occurrence of silver in Triassic sandstone at Silver Reef was a subject of lively debate for many years. Several theories were offered as an explanation of these unique deposits. The oldest recorded theory known to the writer was a short summary to the editor of the Engineering and Mining Journal (Mar. 12, 1877) by "C. F. A." who suggests that the ore was originally contemporaneous with the strata, and:

> richest where there is the most carbon ... There seems scarcely room for doubt that the deposition of the ores was perfectly contemporaneous with the formation of the sandstone strata in which it lies, or that it was precipitated as chloride and native silver at and during the time that the beds of sand were being deposited before it became rock, and while they were yet in a horizontal position.

Newberry (p. 269, 1880) favored a somewhat similar theory of contemporaneous origin. He believed that the minerals were precipitated from a body of mineral bearing waters by the action of decaying vegetation under possible marine conditions.

Rothwell (p. 25-6, 1880) was first to suggest in print that the mineralization had a genetic relationship to the volcanic flows in the area. He postulated that volcanic gases and solvent liquids passed through the sandstone at depth and leached the metals from the rock.

> Near the surface where temperature and pressures were much lower and vegetable remains present, the silver was preci-

> pitated in the insoluble form of sulfides.

Rolker (Rolker, 1881) followed in August, 1880 with a similar theory:

> At the time of the volcanic disturbance, metallic solutions, probably accompanied by steam and vapors ascended from below and percolated through these sandstone beds, which at that time were most porous. The pressure decreasing, the vegetable remains in some parts, ferruginous masses in others, precipitated the sulphurets of silver (and copper in places), while at other points the silver was no doubt deposited by evaporation, and neither of the two precipitants is found, the carbon having been completely consumed in decomposing the metallic salts.

Lindgren (p. 368, 1913) wrote that argentiferous chalcocite fragments were deposited with the sediments. The fragments were then dissolved by circulating water and later precipitated to form the commercial ore bodies.

Butler (p. 593, 1920) in his summary of the Silver Reef deposits is almost noncommital as to origin, though he does admit the possibility of Lindgren's theory. Butler also mentions the possibility of mineralization being related to igneous activity. However, in an earlier section of his report in which he summarizes data on deposits in sandstone of the Colorado Plateau, he regards the Silver Reef type in much the same manner as Lindgren, i.e., originally deposited as finely disseminated mineral particles in the sedimentary rocks.

Ball (1920) is not too clear in his statement on the theory of origin. In part he follows the concepts of Lindgren and Butler and states that the ores were, "subsequently introduced by circulating waters", though he doubts that the silver was derived from the erosion of a "silver district." He adds:

> ...the waters were relatively cold but whether remotely connected with igneous rocks or merely meteoric waters of artesian circulation we do not know.

Crane's (1920) ideas were very similar to Newberry's:

> ...it is probable that the silver and copper fed to the sea from some source, were held in solution as the sulphate until brought into the presence of carbonaceous matter, such as fossil reeds and trees so common to the ore horizon, when they precipitated as the sulphide, or possibly the silver came down in part as native silver.

Finally, Fischer (p. 943, 1937) in his discussion of similar deposits of copper-vanadium-uranium, in which he includes the Silver Reef deposits, theorizes that the deposits are syngenetic in origin: (underlining indicates Fischer's italics)

> ...*syngenetic in the sense that the concentration of the metals occurred at the time of the deposition of the beds in which they are found. The present minerals in all cases are believed to be epigenetic*.

He further states (p. 948-9) that the ore-bearing beds of the southwest are of terrestrial origin and were probably formed under flood plain conditions with local basins forming from time to time:

> In these basins lived or were deposited certain organisms, probably of the lower forms of life, that either directly or indirectly concentrated these metals from dilute solutions. In all probability the organisms that were responsible for the concentration of the vanadium (and uranium) differed from those

> that concentrated the copper and the silver. The form in which the metals were originally deposited and concentrated is not known, possibly they were in a colloidal state or possibly they were absorbed by certain material present. With the next shift of currents, possibly the next flood, the metal rich materials that accumulated in these basins were swept away and redeposited in the beds in which they are now found.

In a later publication on the vanadium deposits only, Fischer's (pp. 363-94, 1942) original working hypothesis is not mentioned.

> The origin of the ore and the factors that controlled localization cannot yet be satisfactorily explained. The ore minerals impregnate the sandstone and in their present form were deposited from solutions after the sands were deposited but the nature of the solutions is not understood, nor is the immediate source of the metals apparent.

Burwell's theory (as originally reported by Fischer, pp. 942,3, 1937) on the origin of a vanadium deposit is worthy of mention:

> He (Burwell) believes that the ore at Rifle was formed as a deltaic deposit of vanadiferous sands and that the carnotite deposits were formed by meandering, braided streams, the richest (vanadium) deposits probably forming in the main channels. These channel deposits, in his opinion, represent the deposition of vanadium- and uranium-rich materials. The original concentration of the metals occurred elsewhere and he recognizes that the manner and form of this concentration must be considered largely hypothetical.

The nine different men who have investigated or reviewed the general occurrence of the ores at Silver Reef offer two basic theories of origin:

The deposits are related to igneous activity.

The deposits are of sedimentary origin.

1. The metals were concentrated at the time of deposition.

2. Finely disseminated mineral particles were dissolved and the metals later concentrated by meteoric waters.

Summarizing, Rothwell, Rolker, and possibly Ball, favored an igneous origin whereas "C. F. A.", Newberry, Lindgren, Butler, Crane, and Fischer, proposed a sedimentary origin for the deposits.

A genetic relationship of the ores to igneous activity has met with little support and known facts do not seem to support this theory. The wide areal distribution of the silver and very similar copper-vanadium-uranium deposits of the Colorado Plateau, the extreme rarity of associated igneous rocks, the absence of alteration typically found in hydrothermal deposits, the very few ore minerals--none of which is a <u>certain</u> hypogene mineral, the lack of the usual textures (Lindgren, pp. 168-190, 1933) found in hydrothermal, epigenetic deposits, and the rarity or complete absence of feeding channels all seem to indicate that the deposits are not directly related to igneous activity.

The similar theories of "C. F. A.", Newberry, and Crane fail to explain some major features of the deposits. "C.F.A." proposed that the deposition of the ores was perfectly contemporaneous with the formation of the sandstone strata which would imply a continuity in depth for the ore deposits. He also believed that the silver was originally precipitated as a chloride or native silver. The failure of the ores to continue in depth with the same richness as those at the surface, the presence of sulfides at or near the water table, and decrease in the silver chloride content appears to invalidate his concept. Newberry's theory failed for the same reason, as increasing mining depth brought decreasing metal content. Crane's concept differs in that he stated that the deposits were formed under marine conditions and deposited as sulfides and possibly native silver. The continental characteristics of the enclosing Silver Reef sandstone is contrary to Crane's concept of marine deposition. Also, under normal marine conditions chloride ions would be far in excess of hydrogen sulfide and the silver ions carried in by the streams would be precipitated as the silver chloride and not the sulfide. However, lagoonal conditions might have prevailed under Crane's theory and sulfide deposition might have been possible. But the terrestrial character of the sediments and the lack of a reasonable explanation for the origin of the mineral particles or mineral-bearing waters leaves much to be explained in his and the other theories.

Fischer's original concept fits many of the observed field facts for the deposits. Yet, if one considers the very dilute solutions he implies, and the depositional environment which he postulates. It seems doubtful that the "agent or agents" would be in sufficient number, or more significantly the addition of dilute mineral-bearing waters to the lakes great enough to supply the needed metallic content before the next flood would sweep through the area and carry the mineral particles away. However, Fischer apparently has abandoned his original concept for he does not mention it in his later published work.

Lindgren's and Butler's concepts present much that is consonant with the known facts. Neither, however, offered any conclusive data on the origin of the metallic particles, and this is the great deficiency in their theory. The mineral particles they suggest are undoubtedly possible, the circulation of ground water, especially in porous sandstone, a proven fact, and the possibility of leaching and reprecipitation a certainty as demonstrated in many mining districts of the west.

The streams which supplied the supposed mineral particles from a crystalline area must have drained a very broad area and flowed a considerable distance. The nearest source to the east would have been in Colorado, to the south deep in Arizona, west, far into Nevada, and north over a hundred miles, and probably more, for Triassic rocks earlier than Chinle crop out through much of these areas even at the present time. The very fine grain size ranging from 0.1 to 0.15 mm. in diameters locally larger, suggests that only the smallest of metallic particles, if such truly existed, could have been carried by the streams in the mining area. Their theory when applied to other like deposits also requires a source large enough not only to have supplied a thickness of several thousands of feet of rock over hundreds of square miles through the Upper Permian, part of the Triassic, and into the late Jurassic, but also a sufficient metallic content of uranium, vanadium, copper, and silver for the numerous deposits of the southwest. Why also should one or two horizons receive the greatest portion of these metals, while rocks of similar lithology and composition adjacent to it are barren, or nearly so? Finally, the rather unusual fact that throughout the world these same type of deposits occur in the same periods makes interesting speculation as to a possible broader control than may have been obtained in some local area.

With such a variability in hypotheses for the origin of the Silver Reef deposits it would be difficult indeed to propose one which more closely fit the observed facts without including much of that which has already been suggested. Since this study is concerned with the Silver Reef area, it is not the purpose of the paper to urge a new theory of origin for the adjacent Colorado Plateau deposits, but in so far as possible to explain the local conditions. Many of the data undoubtedly will fit into the broader picture, perhaps others will not, as local conditions of deposition must have varied considerably during Triassic and Jurassic times.

In general, the concepts of Lindgren, Butler and Fischer, in part, offer a good basis of discussion, and it is believed that a few modifications a more reasonable picture of the genesis may be considered.

A brief review of the known minerals in the deposit listed in Table 6 reveals the important fact that none is of undoubted hypogene or primary origin.

Table 6

"Ore" Minerals at Silver Reef, Utah

Silver sulfide	Chalcocite	Carnotite
Silver selenide (?)	Chalcopyrite	Autunite
Native silver	Bornite	Volborthite
Cerargyrite	Cuprite	
Embolite (?)	Tenorite	Pyrite
	Malachite	Hematite
Gold	Azurite	Iron Oxides (Limonite?)

Minerals reported to have occurred below water table include chalcocite, pyrite, native silver, and silver sulfide. Each of these minerals, so far as is known, was directly or closely associated with plant remains. Most generally they occurred in decomposed wood or lignite-like substance. These minerals, and possibly chalcopyrite and bornite, represent the original minerals in the deposit before oxidation took place.

It is not difficult to postulate the possible chemical reactions which may have occurred to form the minerals now present in the deposit. As pyrite appears to be one of the earliest of sulfides we may write a familiar reaction suggested for the solution of pyrite (p. 159, Emmons, 1917):

$$\underline{FeS_2} + 7\ O + H_2O \longrightarrow FeSo_4 + H_2SO_4$$

$$2FeSO_4 + H_2SO_4 + O \longrightarrow Fe_2(SO_4)_3 + H_2O$$

In turn the ferric sulfate could react on the chalcocite in the following possible manner:

$$Fe_2(SO_4)_3 + \underline{Cu_2S} \rightarrow CuSO_4 + 2FeSO_4 + CuS$$

$$Fe_2(SO_4)_3 + CuS + 3O + H_2O \rightarrow CuSO_4 + 2FeSO_4 + H_2SO_4$$

Chalcopyrite and bornite might also be taken into solution when exposed to circulating ground water containing oxygen:

$$\underline{CuFeS_2} + 8O \rightarrow CuSO_4 + FeSO_4$$

$$\underline{Cu_5FeS_4} + 2H_2SO_4 + 18O \rightarrow 5CuSO_4 + 2H_2O + FeSO_4$$

If silver sulfide also occurred in or near the chalcocite it, too, would be dissolved. Cooke (p. 9, 1913) adds that a little ferric sulfate in solution will considerably increase the solubility of silver in dilute sulfuric acid. He suggests that ferric sulfate probably oxidizes any hydrogen sulfide that is formed, thus removing it from solution so that the further solution of silver sulfide is not suppressed. Emmons (p. 255, 1917) notes that the ionization constant (neglecting activities of the ions) is:

$$\frac{(Ag+)2 \quad (SO_4=)}{Ag_2SO_4} = K$$

On the basis of the above, an increase in sulfate ion in solution should decrease the silver in solution. Actually the reverse occurs. Cooke (p. 16, 1913) suggests that in part, an $AgSO_4^-$ ion is formed which is not affected by the presence of the SO_4 ion. The following reaction is possible:

$$Ag_2S + H_2SO_4 \rightarrow Ag_2SO_4 + H_2S$$
$$(Ag+) \quad (AgSO_4^-$$

in combination with:

$$Fe_2(SO_4)_3 + H_2S \rightarrow 2FeSO_4 + H_2SO_4 + \underline{S}$$

which quickly removes the H_2S formed and prevents reprecipitation of silver as sulfide.

The original uranium-vanadium minerals which occurred in the deposits are not known, nor is the selenium composition. Thus it is impossible to predict what chemical reactions may have taken place to form the minerals found today. It can be stated that they are related, at least spacially, with plant remains, but the mode of precipitation is unknown. However, all of the elements except uranium, vanadium, selenium and phosphorous which make up the minerals are abundant in the enclosing rocks and available for chemical reaction. Even phosphorous is possible from the chemical breakdown of some of the apatite exposed on the quartz grains, but a more logical source would be the plants themselves. Twenhofel (p. 26, 1932) notes from Schuette's and Hoffman's work (p. 249-254, 1927) that some aquatic plants analyzed from Lake Mendota at Madison, Wisconsin had a phosphorous content of 0.23% for Vallisneria and 0.13% for Potamogeton. Some of the rush-like and reed-like plant fossils in the Silver Reef sandstone may well have had a phosphorous content which on decomposition of the plants would be available for chemical reaction with the other elements to form torbernite and autunnite. The possible source of the uranium-vanadium and selenium will be discussed later.

The soluble sulphates of copper and silver would be readily precipitated under certain chemical conditions during the downward migration of the solutions. For example,

$$Ag_2SO_4 + 2NaCl \rightarrow \underline{2AgCl} + Na_2SO_4$$

might be a likely reaction, since salt is known in beds above and below the Silver Reef sandstone and could be readily taken into solution and carried into the ore horizon. The reason why silver chloride generally precipitated in the presence of fossil remains is not known, though adsorption on the finely divided carbonaceous particles may have been important.

Copper sulphate could react with acid carbonate waters to form malachite and azurite respectively (Kemp, p. 24, 1906):

$$2CuSO_4 + 2H_2Ca(CO_3)_2 \rightarrow \underline{CuCO_3 \cdot Cu(OH)_2}$$

$$+ \underline{2CaSO_4} + 3CO_2 + H_2O$$

$$3CuSo_4 + 3H_2Ca(CO_3)_2 \rightarrow \underline{2CuCO \cdot Cu(OH)_2}$$

$$+ \underline{3CaSO_4} + 4CO_2 + 2H_2O$$

From microscopic evidence it is known that both malachite and azurite locally replaced calcite cement. Emmons (p. 180, 181, 1917) suggested the following reactions for malachite and azurite respectively:

$$2CuSO_4 + 2CaCO_3 + 5H_2O \rightarrow \underline{CuCO_3 \cdot Cu(OH)_2}$$

$$+ \underline{2CaSO_4} \cdot 2H_2O + CO_2$$

$$3\ CuSO_4 + \underline{3CaCO_3} + 7H_2O \rightarrow \underline{2CuCO_3 \cdot Cu(OH)_2}$$

$$+ \underline{3CaSO_4} \cdot 2H_2O + CO_2$$

Garrel's and Stine's recent experimental work (pp. 21-30, 1948) on the replacement of calcite by basic copper chloride, and their "tentative" experiments with copper sulphate solutions and calcite are of interest. According to them (p. 30, 1948) in the latter experiment a "basic copper sulphate (exact form undetermined)" formed at the surface of calcite rather than malachite as would have been expected by Emmons' formula. Future work along these lines may well change some of the now generally postulated chemical reactions. However, the green mineral at Silver Reef was identified as malachite.

The above reactions are only suggestive of those which may have taken place to form the secondary minerals of the deposits. The presence of chalcocite nodules in the oxidized zone, many of them with a film of malachite around them, implies that locally reducing conditions may have been more powerful than the oxidizing and as a result the cuprous sulfide did not go into solution. Interestingly enough, fossil plant remains are abundant around or very near these chalcocite nodules, though locally limonitic pseudomorphs after pyrite may be found with the copper.

The secondary minerals of the deposit appear to have concentrated mainly in the channels of the most permeable sandstones. These sandstones contain abundant openings as a result of the decomposition of the plants and the natural molds which remain. The silver content, of course, is not wholly restricted to these channels, but almost all commercial deposits were either related to them or to permeable bedding planes where molds also remained after the decomposition of plants which were deposited on these planes. The argument might be offered that the localization was the result of the plants and that the channels were secondary in importance, yet, outside the channels there are but few plant fossils. Thus, the two features are directly related.

Though the above discussion may account for the secondary minerals of the deposits, it still does not explain the source of the minerals below the water table. The close relationship of the minerals to plant fossils lead most writers to suggest that the fossil plants acted as reducing agents and converted soluble sulphate to insoluble sulfides. Bastin (p. 424, 1933) suggests that the plants' influence, however, may be more largely physical than chemical and mentions that no experimental evidence has shown that reductions of sulphates to sulfides can proceed at ordinary temperatures. His final statement is worthy of note:

Since it is quite possible that further experimentation will supply such evidence, it would be highly incautious at present to summarily dismiss the possibility of direct reduction.

Other field data are highly suggestive that reductions do occur near plant substances. The writer, with others, has observed small carbonaceous remains in red shales surrounded by a gray or light green zone. Similarly in red sandstones, carbonaceous substances are enclosed by a bleached zone of white sandstone which suggests that the ferric iron has been reduced to the more soluble ferrous variety and carried away in solution. Mason (Mason, B.H., personal communication) observed an interesting occurrence at the Kawau Copper Mine in New Zealand. The mine had just been opened after being closed for many years. Copper sulphate solutions trickling down over decaying mine timbers apparently had been reduced to native copper. He observed no nails nearby which might have precipitated the metallic copper. Hintze (p. 204, 1904) records a similar occurrence in the Black Mine at Chessy, France. Further, the occurrence of commercial silver deposits in white to light buff sandstone, with associated plant remains, all interbedded in red shales and sandstone suggests that reducing conditions must have been essential to the precipitation of the minerals.

In a presentation of a summary of this paper before the Utah Academy of Science of 1950, Mr. W. R. Anderson, consulting geologist, reported (personal communication) that he had found native copper on pine cones and chalcopyrite with plant remains from Bingham Canyon, Utah, all of recent origin.

Other possibilities exist. Hydrogen sulfide may have been generated by the decomposition of the plants or bacterial action associated with their decay and precipitated the sulphates as sulfides. Generally, hydrogen sulfide results from sulphur-bearing compounds in animal remains according to Bastin (quoted from Stagnitta-Balistreri: Die Verbreitung der Schweifelwasserstoffbildung unter den Bacterien. Arch. fur Hygiene, Bd. 16, 1893, 33-34). Yet, he also notes that plant extracts rich in sulphur-bearing proteins:

> yielded hydrogen sulfide when innoculated with the same types of bacteria that yield this gas from animal extracts

From the experience of the writer as well as that of other workers in the district, plants were partly decomposed or altered from their original state before precipitation of the metallic minerals. This may not be universally true as Butler (p. 153, 1920) and others describe wood in which the cellular structure is preserved in copper ore replacing vegetable matter. The soft, carbonized wood and flakes of sulfide in the Silver Reef area would imply that the attendant chemical changes during decomposition may be an important factor in producing reducing chemical conditions. Since most organic matter after death is brought to a more stable form by the action of bacteria, this may indicate that the bacteria are either directly or indirectly the true cause of the results above. Some interesting observations and experiments were made by Lovering (p. 45, 1928), who noted spongy masses of copper in:

> black clayey material full of organic remains. Blackened blades of grass, partly decomposed twigs and other materials of similar nature are plentiful.

He suggests that cupric sulphate was reduced to elemental copper by the action of organic compounds, and by a series of interesting experiments was able to show that indirectly the bacteria reduced the copper sulphate by means of the excreta produced by them. Such a reaction might possibly apply to the native silver, but it would not explain the sulfides.

ZoBell (p. 159, 166, 1946) summarizes much of the important literature on the action of bacteria on sulfur compounds. Though he deals mainly with marine bacteria, he does mention that "sulfate reducers" were isolated from ditch water and also from soil. ZoBell also points out the interesting fact (p. 166) that selenate in the presence of organic matter with oxygen excluded may be reduced (p. 159, 1946) by bacteria. His statement that:

> The absence of free oxygen, the presence of sulfate, and the presence of organic matter are the chief requirements for the activity of sulfate-reducing bacteria.

is analogous to conditions which probably existed at Silver Reef.

The familiar example of pyrite in coal offers support that sulphate solutions can be reduced to the sulfide state. The same might apply in the case of black shales and associated pyrite, but animal life may have been more important under these conditions than plant, and any hydrogen sulfide generated by life processes or death could cause precipitation of the sulfide. The origin of the celebrated Kupferschiefer of Mansfield, Germany bears many analogies to the above, and the action of bacteria associated with the decay of animals and plants has been cited for these deposits (p. 415, Lindgren, 1933). Yet, it must be remembered these were formed under marine conditions, the Silver Reef under continental conditions.

Silver Chloride, native silver, and less significantly the copper carbonates, also occur with clay galls and clay balls in channels. Three factors may have been important in this localization: (1). The minerals were adsorbed on the large amount of surface area of the colloidal particles, (2). The reducing action of materials present with the shale, since light green clay galls are reported to have carried much higher silver content than red ones, precipitated the minerals. (3). The chlorine and carbonate ions were associated with the clay galls and caused precipitation of the minerals. Since both native silver and silver chloride occur together on the fracture surfaces of the clay it is suggested that (1) and (2) were probably the most important factors.

The paragenetic sequence of the minerals could not be fully determined from the specimens available. Certainly, though, one sequence could not be expected to apply over the entire district. In one locality solution may have taken place while precipitation was going on in another. Variation in the concentrations of the different substances could alter the course of the chemical reactions. That these variations did exist is shown by the limonite stains from decomposition of pyrite in some localities and not in others, malachite in abundance in one place but absent in others, etc. However, a general sequence is indicated. Pyrite does appear to be an early mineral as is chalcocite and possibly silver sulfide. The position of bornite, chalcopyrite, and the original minerals of uranium-vanadium is not known. It is apparent from the nature of the minerals that the carbonates of copper, chloride of silver, and the uranium-vanadium minerals are clearly the secondary products of original sulfides and other mineral substances. Whether silver chloride was always later than the carnotite cannot be said, though in the few sections studied this was true.

The wide areal distribution of silver in the Silver Reef sandstone and in some of the sandstones and shales both above and below the member is suggestive of either a widespread source or a very rich original source of solutions or mineral particles. That solutions did carry the compounds is verified by the occurrences of the minerals below the ground water level as sulfide replacements and filling of carbonaceous substances. This condition suggests that the carbonaceous material must have received its mineral content after its burial or just following its deposition. It seems impossible to assume that the living plant had accumulated such a metal content, especially as fossil fragments of trees several feet long were in several instances extremely rich in silver. The real problem is not the replacement or substitution of the plant tissues for this can be observed, but the source of the metallic content of the solutions.

Perhaps geologists have searched too long for some vein or igneous source beyond the broad Triassic basin of deposition. The possibility exists that a source or sources within the basin may have been overlooked. Certain features of the sediments underlying the Silver Reef sandstone are at least suggestive.

Numerous concretions-like nodules of silver-gold-bearing chalcocite and pyrite occur in a bentonitic shale 310 feet stratigraphically below the Silver Reef sandstone. These minerals are known to occur in the bentonitic shale over many miles. In the A. S. & R. shaft assays of this bed showed 0.45 oz./ton in silver. This might raise the query as to whether such a horizon as this or similar ones, partly of direct volcanic origin, might be able to supply the necessary metals for such a district as the Silver Reef. Or is the occurrence only an oddity and not likely to be present elsewhere? R. S. Cannon (personal communication, Sept., 1948) of the U. S. Geological Survey referred the writer to some literature which indicated that others had recognized somewhat analagous occurrences.

Lawson (p. 444, 1913) records the presence of minute amounts of gold in Chinle shales. His description of the shale properties tallies well for a bentonite-like shale.

> One of the most striking properties of the Shinarump (now Chinle) clay is its behavior in water. Samples of the clay taken in the field are usually moist and

> the amount of water which may be driven off at 105°C is very considerable. But when a fragment of the clay is immersed in water it immediately swells enormously and breaks down rapidly into an incoherent flat cone....The swollen clay of this surface layer dries out and becomes a loose, fluffy pulp of extreme lightness, softness and incoherence.

C. Lausen (pp. 610-617, 1936) noted minute quantities of mercury in the Chinle shales near the locality of Lawson's report. It was first recognized when efforts to recover gold from the shales by amalgamation resulted in a greater amount of mercury being recovered than the original amount used. Lausen mentions that the shales are bentonitic but cannot relate them directly to vulcanism.

Touwaide (pp. 140-1, 1930) also records an interesting occurrence of copper in four clay beds interstratified with volcanic tuffs. He suggests that the copper was extracted from the pyroxenes of the tuff by connate waters and later precipitated, possibly by "hydrogen sulfide or some other compound derived from the organic matter included in the clay." Silver also occurred in this deposit.

More recently, Koeberlin (pp. 458-461, 1938) in a discussion of Fischer's (pp. 609-651, 1937) paper brings out some important points. Basing his concept on Emmon's theory of mineral-bearing fluids "collecting in the upward bulges" or "cupolas" of batholiths, he suggests that if the rock cover is fractured or permeable, the "magmatic extract" may form veins and lodes. The crux of his discussion is:

> But Emmons does not stress the fact that the combination of a cupola with a suitably fractured rock cover is after all a very fortuitous circumstance and that a far greater part of the magmatic mineralized fluid collecting under the roof of the batholith would probably be ejected

into the atmosphere wherever the batholith forces vents through the weak points of the roof. Such vents would be more likely to occur in the main dome where the greatest accumulation of expressed mineralized fluid might be expected to occur. Such an amplification of Emmons theory was forcibly impressed on me in seeking an explanation for the minute gold content, about 1 to 5 cents per short ton of a deposit of many billions of tons of volcanic ash filling a part of the central valley of Chile. This gold is absolutely syngenetic, still locked in its glassy matrix of volcanic ash.

Any sulfides, as Koeberlin notes, would be ejected in a similar manner in minute particles, easily oxidizable, over a wide expanse of territory. The particles and/or solutions would then begin their journey to the sea or some other resting place. The significance of such a concept is at once a most important one. Cannon's comment is most apropos:

> This is the first expression I have seen in the literature of my idea that major extravasations of metal rich volcanic materials are an inescapable corollary of the Graton-Emmons-Butler theories of ore genesis.

In a study of the high selenium content of rocks and soils, Beath and his associates (p. 20, 1946) point out that:

> a volcanic tuff (Tertiary) in Fremont County, Wyoming, is particularly significant because of its large amount of water-soluble selenium attaining a maximum of 187 ppm.

Their quantitative analysis of minor constituents of a tuff near Lysite, Wyoming is also of interest:

Table 7

Minor Constituents of Tuff*
Lysite, Wyoming
(C. S. Gilbert, Analyst)

	Bed 2	Bed 3
MnO	50.0 ppm	0.0 ppm
V	100.0 ppm	0.0 ppm
Co	5.0 ppm	10.0 ppm
Ni	6.3 ppm	29.4 ppm
Se	187.0 ppm	175.0 ppm

* Table from Beath, Hagner, and Gilbert, Bull. 36, Geol. Surv. of Wyoming.

As shown by this analysis, not only is the selenium content of significance, but the other metallic elements are in such amounts as to merit comment. Complete solution of the vanadium and the selenium content would yield sufficient quantity of the elements to merit serious thought to such tuffs or similar tuffs being primary sources for these and other elements. How much of the vanadium is "available" for solution is not known, but the authors report that 96% of the selenium is water soluble. The known occurrence of selenium with the vanadium-uranium ores of the Colorado Plateau and also with the silver deposits at Silver Reef with an associated vanadium-uranium mineral is of notable interest.

Summary

The occurrence of secondary "ore" minerals in the Silver Reef sandstone is assumed to be the result of: (a) Solution of former ore minerals deposited as replacements of plant material and as probable mineral particles in the sandstone, (b) Reprecipitation as new compounds partly filling natural molds left by decomposing plant substances and as replacement of both macroscopic and microscopic carbonaceous substances localized along the bedding planes and in Triassic stream channels in the Silver Reef sandstone.

The absence of associated intrusive rocks; wide areal distribution of the deposits; and the lack of silicification, sericitization, typical ore textures, and other features considered distinctive of hypogene deposition, strongly suggests that the original minerals of the deposits did not have a hypogene origin.

Finally the occurrence of silver, copper, and gold in a bentonitic shale below the Silver Reef sandstone, and evidence in other localities in the southwest of similar occurrences of metals in concentrations in excess of those in average volcanic rocks leads the author to propose the following theory of origin:

The Silver Reef metals were probably dissolved mainly as sulphates or eroded away as actual minute mineral particles, or both, from Triassic volcanic tuffs, now altered to bentonites, and the metals transported to the area of the mining district by Triassic streams and underground waters. Here the compounds in solution were precipitated by decaying plants or associated bacteria and the mineral particles were deposited as detrital grains. The evidence suggests that most of the dissolved metals were deposited as sulfides from sulphate solutions under strong reducing conditions brought about either by: (1) generation of hydrogen sulphide through bacterial action on the vegetation or (2) the direct or indirect action of sulphate reducing bacteria associated with the plant remains. In some places adsorption on clay galls or on finely divided carbonaceous particles may have been important in localizing the minerals. The known partial paragenetic sequence suggests that pyrite was one of the first minerals to precipitate from solution and that it later may have acted as a precipitant of chalcocite and other sulfide minerals. With uplift and erosion of the area the circulation of ground water brought about the oxidation of pyrite and solution of many of the other sulfides. These were carried downward and by a process of secondary enrichment the present deposits were formed.

THE MINES

Most of the important mines in the district were under company management during the productive period of the camp. Many of them were interconnected and production came from a group rather than a single mine. All of them were shallow, the deepest extending approximately 330 feet below the surface. Water presented no problem in the mines on the White Reef, but all mines just north of the California and to the south along the Buckeye Reef had to be pumped continually. At the present time all of the mines on the Buckeye Reef south of the Hartman shaft are flooded.

On the basis of production and areal distribution the mines are readily divided into six main groups:

1. The Thompson-Cobb area including the South Thompson, Thompson, Cobb, Newton, Nichols, and McNally mines.

2. The California-Kinner group which includes the California, Maggie, Last Chance, Savage, Buckeye, and Kinner mines.

3. Tecumseh Hill area with the Silver Flat, Tecumseh, Stormy King, and Manhatton mines included.

4. The Leeds and Leeds No. 2 mines.

5. The Barbee and Walker area.

6. The East Reef group including the Vanderbilt, Toquerville, Duffin, Brissacher, and Maud mines.

Thompson-Cobb area. - The Thompson-Cobb area is penetrated by at least 4000 feet of workings, not including stopes. Each mine is reached by an adit along the backslope of the White Reef. At the Thompson mine a caved adit 200 feet long extends from the face of the White Reef through the underlying shales and into the ore horizon of the Silver Reef sandstone. From this adit an incline continues down the dip approximately 160 feet. Figure 11 shows the general relationship of the workings of this mine and the others of the group.

All of the openings are in excellent condition and have held open with little or no timber over a long period of time. The majority of them are within a few tens of feet of the surface with the exception of the Cobb incline and lower drift. The incline parallels the 30 degree dip of the ore bed for 500 feet. At 210 feet on the incline a drift to the north connects to the Nichols mine through a raise. This level is flooded.

At least two and possibly three silver producing horizons occur in the Thompson-Cobb area 8-10 feet and 40 feet respectively below the Tecumseh sandstone contact. The silver ore occurs in lenses of white, fine-grained sandstone associated with greenish clay galls and balls, and appears to be limited to the width of the individual lenses. The ore lenses pinch sharply along the strike.

A sheared shale horizon in the Nichols mine is reported to have contained high-grade silver ore as coatings along the shear planes. Copper carbonate minerals are locally abundant in some of the mines, especially in the Newton, Cobb, and South Thompson. The ore bodies mined thus far were as much as 280 feet in length and 120 feet in width, but mineable ore is still present in the faces of many of the stopes in this group of mines.

Leeds and Leeds No. 2 mines. - The Leeds mine and to a lesser extent the Leeds No. 2 mine (see figure 12) produced a considerable tonnage of ore during the early history of the district. The Leeds No. 2 mine has about 300 feet of workings and is reached by two shafts in the flat west of the A. S. & R. shaft. Colbath (personal communication) reports that it has been connected to the Leeds mine to the north, but these workings were not accessible nor were the maps.

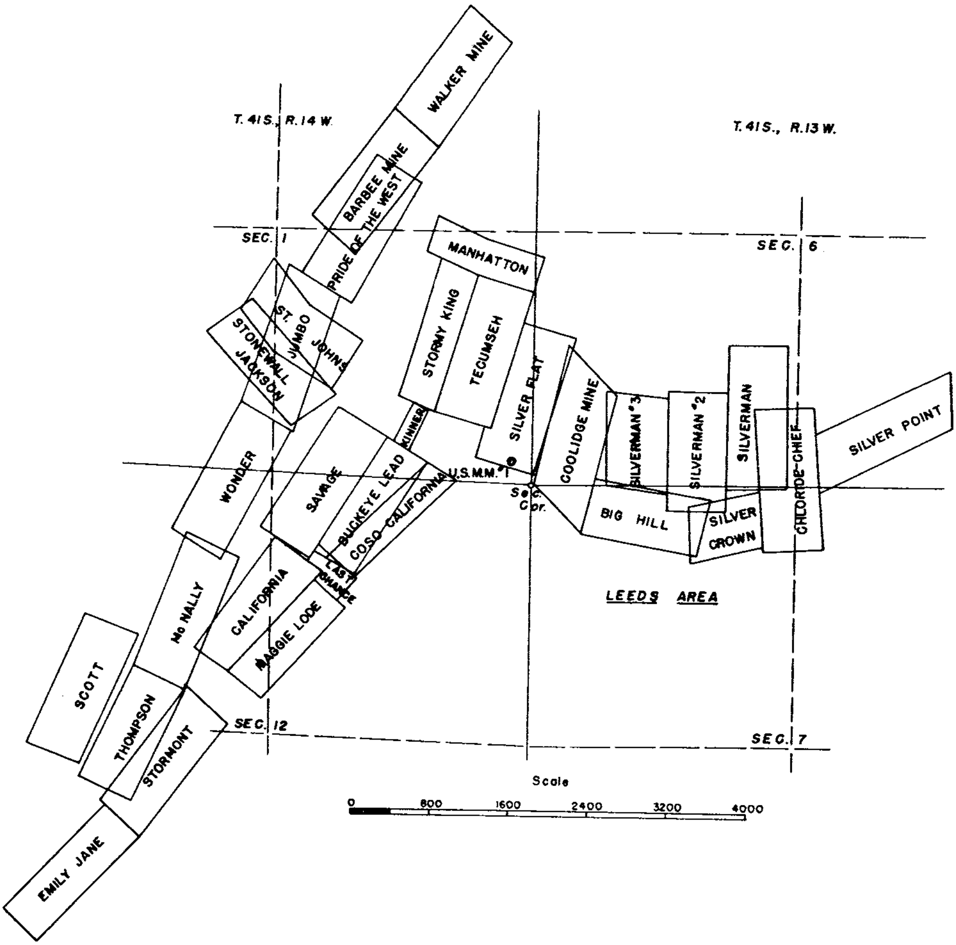


Figure 9. Patented claims (1948) in the Leeds, Utah, area.

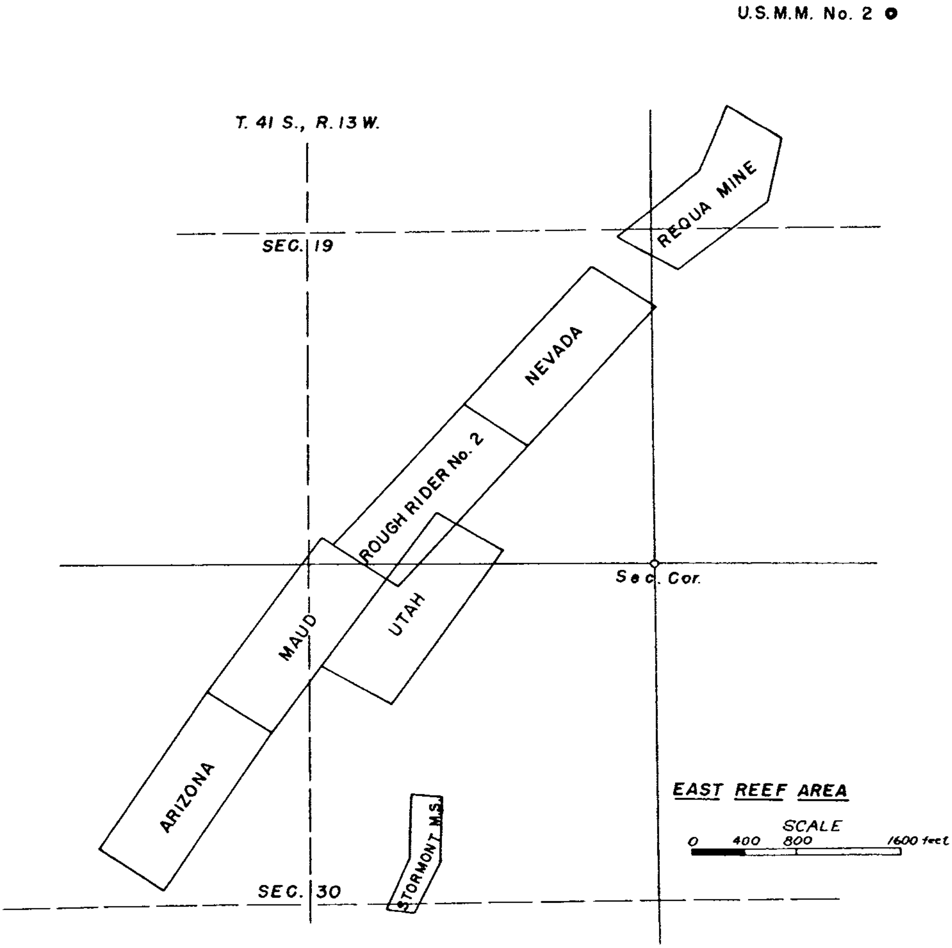


Figure 10. Patented claims (1948) in the East Reef area, southeast of Leeds, Utah.

In the Leeds No. 2 mine the ore similar in grade to that in the main Leeds mine, occurred in a white, fine-grained sandstone within the Leeds sandstone. A green shale horizon several feet thick cut out much of the ore bed in this mine.

The stopes of the Leeds mine, 430 feet north of the Leeds No. 2 mine, are reached by a 150 foot adit at the base of the White Reef on the west, and a 2-compartment shaft on the flat. Ore was stoped from the three upper levels. Two other levels were driven at greater depth and are connected by an incline which slopes 30 degrees with the bedding. Most of the underground openings are still accessible. The surface stope which was opened up from the upper two levels averages 300 feet long and 150 feet wide.

Three ore zones were mined, and where these zones coalesced the stopes were more than 10 feet high. The silver minerals occurred in a buff, fine-grained, finely cross-laminated sandstone containing malachite and azurite in the Leeds sandstone and ranged from 25 to 30 feet below the Tecumseh sandstone contact.

Barbee and Walker area. - The Honest Miner and Barbee and Walker mines make up this group. The Honest Miner mine is 1150 feet north-northeast of the Leeds mine on the back-slope of the White Reef. On the west a shaft 97 feet deep connects with another shaft 110 feet east through a stope which is 10-13 feet wide. Production valued at a few thousand dollars is recorded from a white, fine-grained sandstone containing replacements of plants by malachite.

The Barbee and Walker mine incline is 2050 feet north-northeast of the Honest Miner shaft. Only a part of the mine is accessible by a 30 degree incline in the plane of bedding on the east face of the White Reef. The lower levels are caved and inaccessible. As far as is known water was not a problem in the deeper workings during the productive period of the mine. The silver minerals apparently were finely disseminated in a 3-4 foot bed of buff to white finely laminated fine-grained sandstone. A production of almost a million dollars is recorded by the original Barbee and Walker company.

Emily Jane-Stormont area. - The Stormont and Emily Jane mines have many similar characteristics. They lie at the south end of the Buckeye Reef, the ore occurs in a like position in both mines, and the lithology and mineralogy of the ore horizon is practically the same.

No maps were available
Most of the workings are caved or filled with water. Water is reported to have played an important part in the closing of the mine when major mining operations ceased in 1879, but lessees or "chloriders" probably mined in the workings at a later date.

The ore horizon ranged from almost nothing to five feet in thickness and the silver minerals occurred in a fine-grained, white to gray sandstone just below the contact of the Tecumseh-Leeds sandstones. The ore ran as much as 100 ounces per ton, but the average probably did not exceed the 20-25 ounce average of the camp. Near the Farm Land gap at the south end of the Buckeye Reef several inclines open into caved stopes along the bedding in lavender sandstone 12 feet above the basal Tecumseh. The workings are almost completely caved probably as a result of the abundant shearing which cuts the bedding at an acute angle. Copper carbonate minerals replace fossil plants at the contact of the Leeds and Tecumseh sandstones just south of the above inclines.

California-Kinner Group. - This group of mines on the Buckeye Reef includes some of the most important former producers in the district. Figure 12 shows more than 20,000 feet of workings exclusive of stopes. The major part of them is flooded at the present time and is, of course, inaccessible. Data on these mines were obtained from discussion with former owners and operators: Colbath, Hartley, and Newman and from old mine maps.

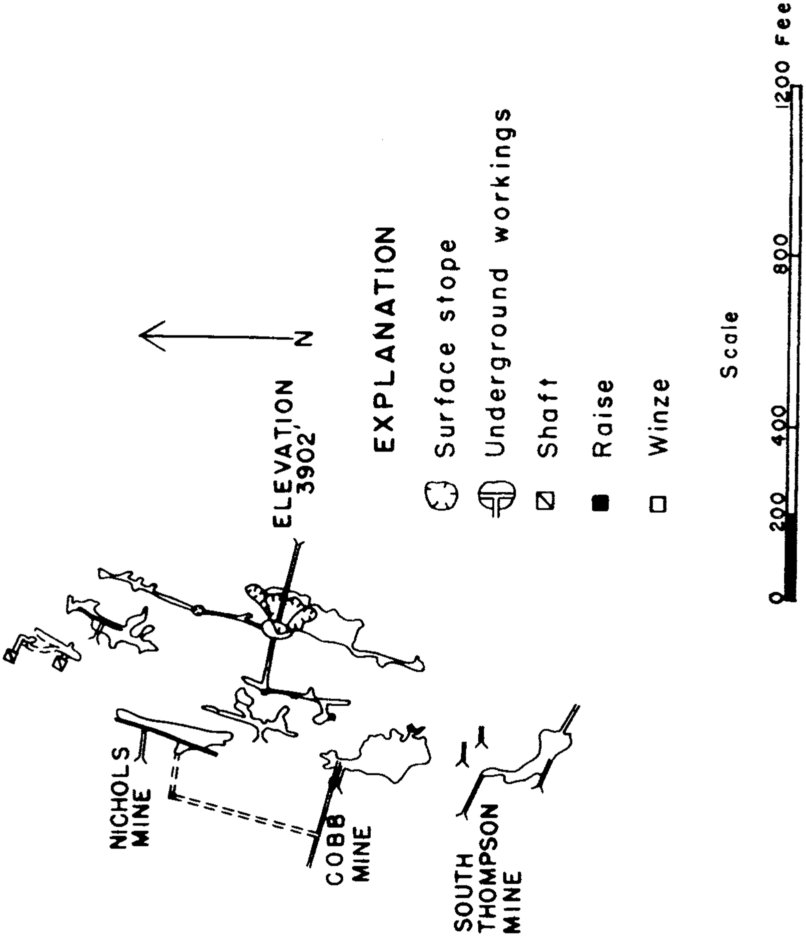


Figure 11. Known underground workings in the South Thompson-Cobb-Nichols mine area.

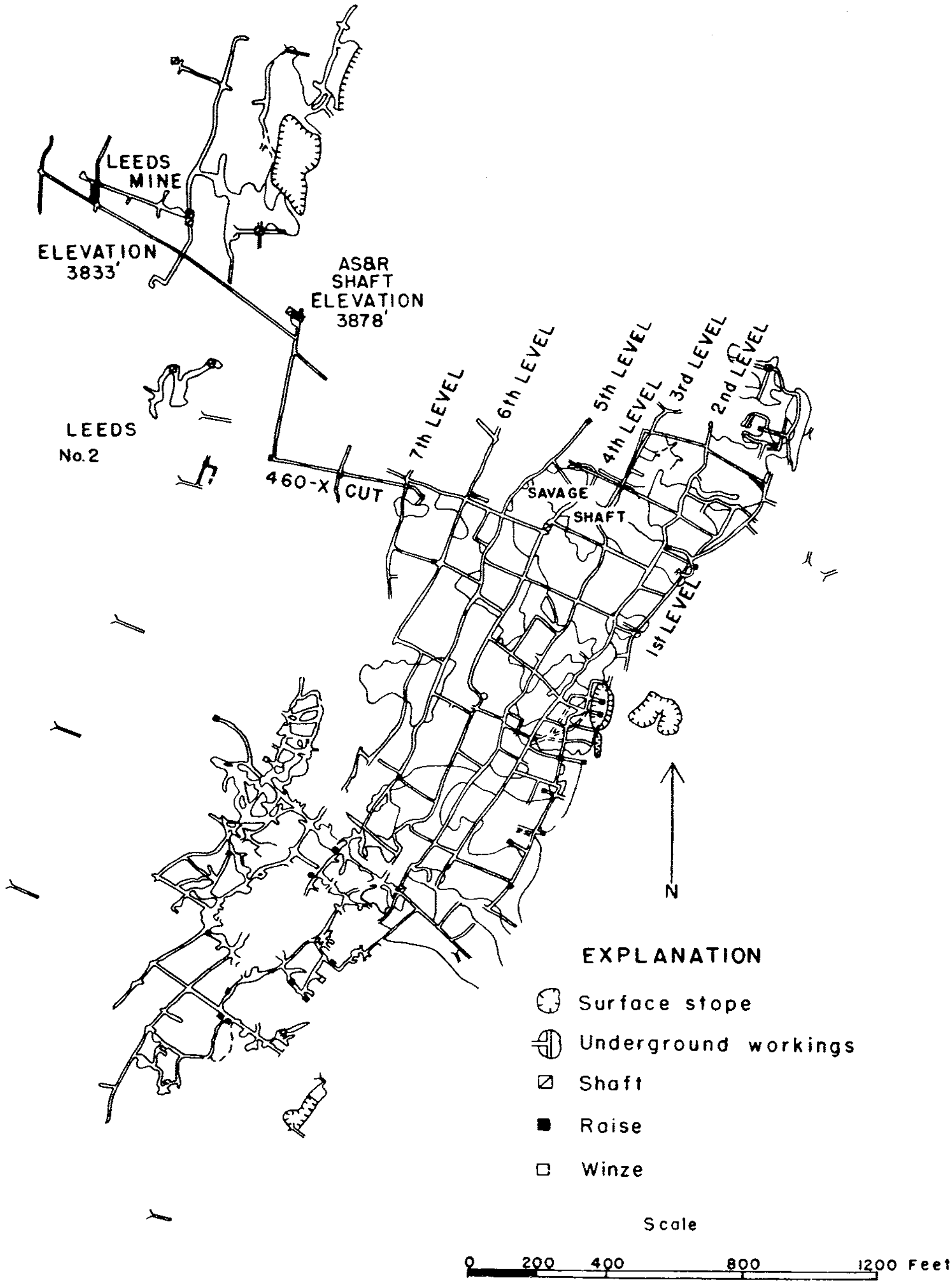


Figure 12. Known underground workings in the Leeds-California-Savage mine area.

All of the underground workings are interconnected from the California mine on the south to the Kinner on the north. The California mine was developed by five levels. Whereas to the north 1700 feet, at the Savage Mine, ore was produced from 7 levels.

The deepest workings probably occur in the old Maggie mine at a depth of 330 feet below the surface. At this mine shrinkage stopes were carried to the face of the Buckeye Reef. North of these stopes the eastward extent of the underground workings appears to have stopped at a shear zone trending N. 10-30 E. The mine workings on this section of the Buckeye Reef are connected to the A. S. & R. shaft through an incline from the Savage stope to the 460 cross-cut of the shaft. As far as is known, the underground workings, though flooded, have held open with the exception of part of the California mine which caved after the water was pumped from it in 1929. Water was struck at a shallow depth in the California mine and also was reached to some extent in the Maggie during the early operations of the mines.

The ore beds occur within a few feet either side of the contact of the Tecumseh-Leeds sandstone. The thickness of the ore zones ranged from a few inches to several feet. Locally, as in the Buckeye and Last Change Mines, coalescence on the dip of two or more ore horizons resulted in an ore zone 20 or more feet in thickness. Both the near surface stopes and dumps indicate that the silver occurred in a white to lavender fine-grained sandstone, which contained plant impressions throughout the beds or concentrated along the bedding planes. Copper, though not abundant, replaced part of these plant remains. At the California mine ore occurred in thin-bedded alternating lavender and white, fine-grained sandstones, somewhat sheared and strongly flexed. North at the Maggie Mine the bed graded into an alternating series of white, fine-grained sandstones and reddish brown shales 1-2 inches or more thick. An exception to the general ore occurrence is notable a few hundred

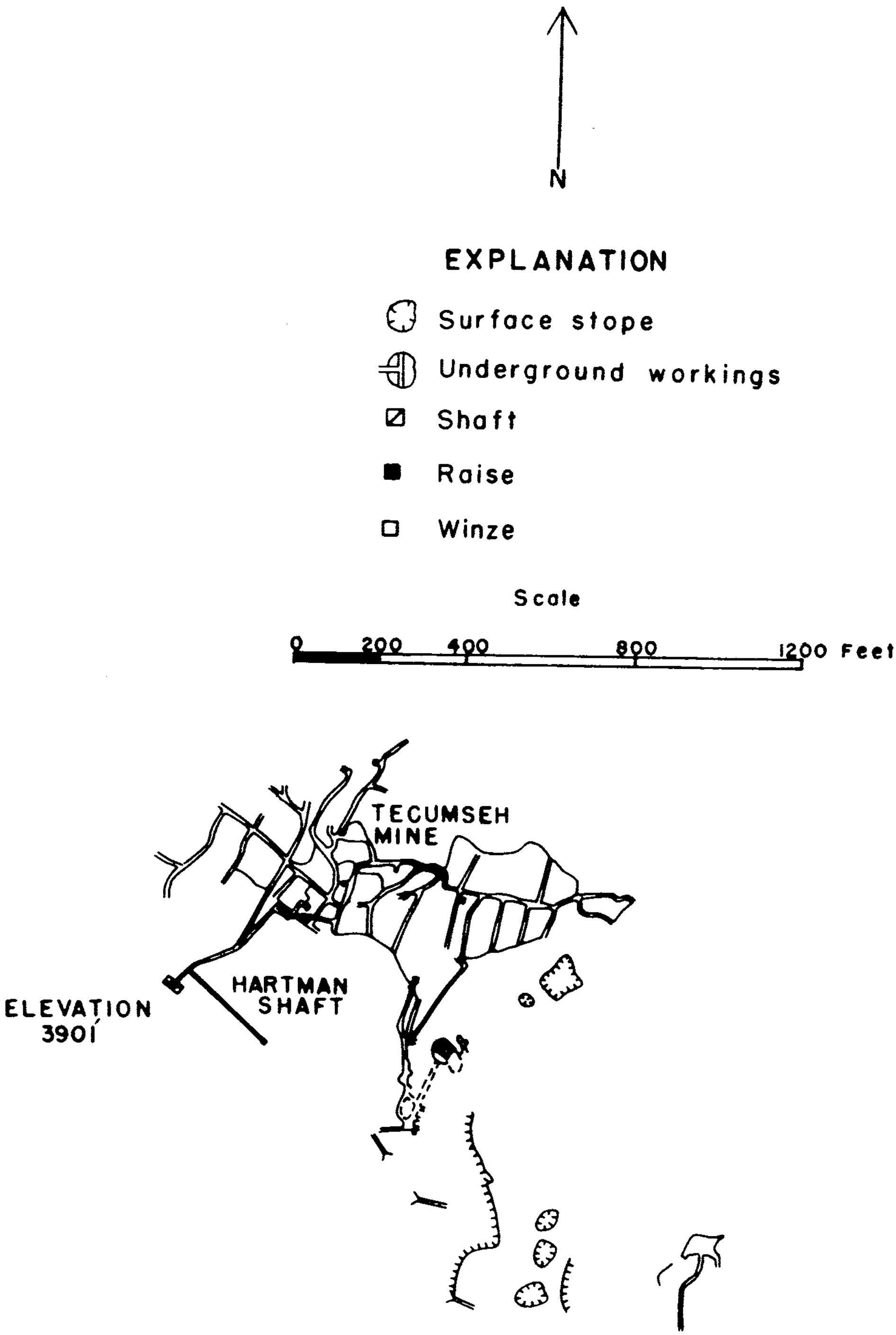


Figure 13. Known underground workings in the Tecumseh mine area.

feet southeast of the Savage Shaft where silver minerals were apparently deposited across the bedding in a shear zone in brownish to lavender sandstones. Mineralized rock was stoped for some 220 feet along the strike of the shear and to 40 feet in width.

Tecumseh Hill Group. - The original discovery of ore in place was made on the Silver Flat claim on the east side of Tecumseh Hill. In many places on the hill surface strata were literally stripped from the area to recover the silver. Later, Tecumseh Hill itself was honeycombed by underground workings. Most of these are now only partly accessible and many of the accessible workings are partly backfilled with waste rock. Known workings shown in figure 13 include not more than 50 percent of the total of the Tecumseh Hill area. Mining was confined to the Tecumseh sandstone beds on the north nose of the hill, but near the center ore was mined from the contact of the Tecumseh and Leeds sandstone. According to old records (Macfarlane, p. 76, 1877) the ore beds were thin, averaging only 10-18 inches in thickness. Some of these, however, were exceptionally rich and had thin plates of cerargyrite along the bedding planes. Barbee's original shipment from this area ran $502 to the ton.

The ore occurred in at least three horizons as silver was mined from the Tecumseh-Leeds sandstone contact and two other horizons 7-10 feet and 20 feet respectively above the Tecumseh basal contact. Some of the extensive Manhatton mine stopes occur approximately 30 feet above the Tecumseh basal contact. The main ore horizon was a finely laminated, fine-grained, lavender sandstone which contained numerous impressions of small fossil plants along the bedding. In some places these fossils were replaced by silver chloride. Near the middle of Tecumseh Hill a white to buff fine-grained sandstone containing plant fossils partly replaced by malachite and also some clay galls was mined for its silver content.

YEAR	BARBEE AND WALKER COMPANY Mines Controlled: Barbee & Walker	STORMONT MINING & MILLING COMPANY Mines Controlled: Stormont, Buckeye, Thompson, McNally, Last Chance	LEEDS COMPANY Mines Controlled: Leeds Leeds #2	CHRISTY MINING & MILLING COMPANY OF CALIFORNIA Mines Controlled: Tecumseh, Silver Flat, Silver Crown, Silver Point, Chloride Chief, Maggie, California, Manhatton, Stormy King	REFERENCES
1877			Feb., 1877-Leeds 5 Stamp Mill. Autumn, 1877-company organized.	Christy Company incorporated fall of 1877.	Engineering and Mining Journals - A.I.M.E.
1878	Barbee & Walker 5-Stamp mill completed March, 1878	July 4, 1878, Stormont Mill completed.		Jan., 1878, 5-Stamp mill completed. Production $302,537.	
1879	June 23, 1879 fire destroyed Barbee Mill.	Stormont Mining & Milling Co. incorporated July 19, 1879.	Production $114,436 Mill from custom ores and others yielded $768,321.58 to 6-1-80.	Production $245,466	Mining Record of New York; Tenth Annual Census, Vol 13, p. 13; "Precious Metals", p. 482.
1880	Barbee & Walker Silver Mining Co. incorporated June 1, 1880. Feb. 27, 1880 mill rebuilt. Production $211, 581.	Production $484,110.	Production $29,255.	Production $272,084.	Tenth Annual Census, vol. 13, p. 13; "Precious Metals", p. 482, Director of the mint; also a quote from "Mining Record".
1881	Production $205, 524, Labor strike 3-15-81 to 7-17-81	Production $265,658 Operations suspended 2-1-81 to 7-1-81.	Production $11,300 10-10-81 to 12-31-81. Leeds Mill down for almost 2 years to October 10, 1881	Production $316,040	Report of the Director of Mint, "Precious Metals" for 1881, p. 239 (H.C. Burchard)
1882	Production (100,000+ ozs. of silver. Company in financial embarrassment.	Production 239,975 ozs. of silver.	Company into hands of creditors.	Production $372,426.	Report of the Director of Mint, "Precious Metals" for 1882, p. 254 (H.C. Burchard)

1883	Production-no record. Worked by Gillespie-Lund & Co. 16 men employed.	Production (182,000 ozs.) (50 men employed)		Production $262,310.	Report of the Director of Mint, "Precious Metals" for 1883, p. 617, (H. C. Burchard)
1884	Production not known. Company into liquidation.	Production-no record. 90 men employed.		Production 234,217 ozs. Company called Christy Mining Co. (Reorganized?).	Report of the Director of Mint, "Precious Metals" for 1884, p. 403, (H. C. Burchard).
1885		Production-no record. 10 stamps operating.		5 stamps operating. No record of production.	Report of the Director of Mint. "Precious Metals" for 1885, p. 181, (J. P. Kimball).
1886		Production $167,000.	Leeds Mill purchased by Harding, Bailey & Nesbitt and converted to leaching plant. Failure because of copper content.	Production $232,000.	Report of the Director of Mint, "Precious Metals" for 1886, p. 225, (J. P. Kimball).
1887		Idle during greatest part of year. Company end?		For 1887-88 listed as mainly production from Christy and La Virgin. Doubtful if old company still existent. No production record.	Report of the Director of Mint, "Precious Metals" for 1887, p. 243 (J. P. Kimball).
1888				Production $263,466 La Virgin Mill.	

Table 8. Available history and production of major companies and mines at Silver Reef, Utah, 1877-1888. Production listed probably includes custom ore sent through the respective mills from different mines in the district.

East Reef Group, Vanderbilt Mine. - A few small mines and many prospect pits and inclines penetrate the East Reef from the Vanderbilt mine south to the adit on the Maud claim. The Vanderbilt is reached by a 120 foot incline and a few small drifts most of which are accessible. Butler (p. 586, 1920) records a $24,000 production from the mine from 240 tons of ore. The silver occurred in a white, fine-grained sandstone within the Leeds sandstone 2-3 feet below the Tecumseh basal contact. Small faults trending north 20 west drop the beds a few feet to the east.

Toquerville Mine. - The Toquerville mine is 1400 feet south of the Vanderbilt and is accessible by a main incline and two small openings along the face of the reef. Approximately 800 feet of workings are accessible along the face of the East Reef. The stopes are small, the largest being approximately 25 feet wide and 35 feet long, and not exceeding five feet in height. Lagging along the incline walls may cover other small stopes. Other small, partly caved stopes occur along the face of the reef just south of the main incline, but as far as could be determined these do not connect with the main workings.

Mining was complicated by several faults trending north 20 west, 70-75 degrees east, with a downdrop to the east. The main incline ends against a fault which strikes N. 11 W. and dips 74 E. The ore horizons occur as small 2-4 foot thick lenses of white, fine-grained sandstone which thicken and thin down the dip. The lenses lie 2-6 feet under the Tecumseh sandstone basal contact. Minor amounts of copper carbonates are associated with plant remains in the ore bed. According to Butler (p. 586, 1920) several hundred tons of ore averaged $50.00 per ton in silver. Small showings of carnotite disseminated in lavender sandstone occur 200 feet northeast of the main incline.

Duffin Mine. - The Duffin Mine lies in a small valley south of the prominent volcanic cone on the East Reef. Several inclines open into small stopes and 900 feet of partly accessible workings. A caved shaft on the east side of the reef was originally used to withdraw the ore from the mine. The ore occurred in a lens of lavender to gray fine-grained sandstone 20 feet above the contact of the Tecumseh-Leeds sandstones. Carnotite, malachite, minor azurite, and small specks of silver chloride are visible in some of the dump specimens.

Maud, Utah, and Rough Rider claims. - Considerable development work was done along the west face of the East Reef south of the Duffin mine. Two short adits cut the reef from a valley on the back slope on the Utah claim. Several inclines and shafts are on the dip slope of the reef west of the adit portals. Mining appears to have been restricted to shipments of sorted ore from the south adit and Maud inclines. The shipments probably do not exceed a thousand tons. The beds consist of fine-grained, buff to white sandstone which contain abundant malachite replacing and staining plant remains. On the Maud claim a bed with prominent amounts of malachite 300 feet long and to six feet thick crops out along the west face of the reef. All of the ore horizons are in the Leeds sandstone in this area and lie a few feet below the Tecumseh contact.

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