

ECONOMIC GEOLOGY OF THE SULPHUR DEPOSITS

AT SULPHURDALE, UTAH

by

Enrique Levy Rodriguez

A thesis submitted to the faculty of the
University of Utah in partial fulfillment
of the requirements for the degree of

Master of Science

Department of Mining and Geological Engineering

University of Utah

August, 1960

This Thesis for the M.S. degree

by

Enrique Levy Rodriguez

has been approved

August, 1960

Committee

Major Department

440511

ACKNOWLEDGEMENTS

I wish to express my appreciation to all those individuals and organizations that have contributed their efforts and have provided financial assistance for the completion of this investigation.

This investigation is part of the Survey of Mineral Resources of Utah sponsored by the University of Utah Engineering Experiment Station under the direction of M. P. Nackowski.

The government of El Salvador awarded to me a two-year scholarship to study Economic Geology at the University of Utah. Dr. M. P. Nackowski has guided these studies and also suggested the topic for this thesis. His assistance has been invaluable in directing the project and preparing the manuscript.

The American Sulphur and Refining Company was very helpful in providing lodging during the field work period. Their staff and directors contributed with their physical efforts, knowledge of the property, and records of information not available in publications.

The staffs and graduate students of the Mining and Geological Engineering Department and Geology Department also contributed greatly to the project.

TABLE OF CONTENTS

	PAGE
ABSTRACT	1
INTRODUCTION	3
Purpose and Scope	3
Previous Work	4
History and Production	6
Location and Accessibility	8
Physical Features and Water Resources	11
GEOLOGY	13
Stratigraphy	14
Rocks of Pennsylvanian Age	15
Oquirrh formation	15
Rocks of Permian Age	17
Pakoon limestone	17
Coconino sandstone	18
Kaibab limestone	19
Rocks of Cretaceous Age	20
Price River conglomerate	20
Rocks of Tertiary Age	21
Volcanic flows and pyroclastics	21
Rocks of Pleistocene to Recent Age	25
Basalt flows and cinder cones	25
Water-laid tuffs	25
Alluvium	26
Structure	27
Front Range Faults	27
Prince Albert Fault	29
Excelsior Fault	29
GEOLOGY OF ORE DEPOSITS	31
Description of Sulphur Deposits	31
Sulphurdale and Victor Conqueror Orebodies	31
Prince Albert Orebody, Mariposa, and Queen Victoria Prospects	35
Excelsior Orebody and New York Prospect	36
Sulphur King Orebody and Philadelphia Prospect	38
Black Mine Prospect	39
Mineralogy	39

	PAGE
Ore Minerals	40
Sulphur	40
Iron sulphides	40
Gangue Minerals	41
Siliceous Sinter, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$	41
Gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$	43
Quartz, SiO_2	44
Zonation of Mineral Deposits	44
Paragenesis of Ore and Gangue Minerals	46
Genesis of Ore Deposits	47
Ore Reserves	51
Suggestions for Exploration and Prospecting	61
ECONOMIC ASPECTS	63
Mining Methods	63
Mining Costs	64
Market Potential	65
CONCLUSIONS	67
BIBLIOGRAPHY	69
APPENDIX	71

LIST OF ILLUSTRATIONS

FIGURE	PAGE
1. Index Map of the Sulphur Deposits, Sulphurdale, Beaver, and Millard Counties, Utah	9
2. Principal Sulphur Deposits, Sulphurdale, Beaver, and Millard Counties, Utah	10
3. Composite Stratigraphic Section, South Pavant Range, Millard County, Utah	16
4. Cove Fort Cinder Cone and Basalt Flows. View Looking Southwest	33
5. Sulphurdale Open Pit. View Looking Southwest .	33
6. Excelsior Pit. View Looking West	37
7. West Face of Excelsior Pit. High Grade Sulphur Ore Showing Relic Bedding of the Replaced Price River Conglomerate	37
8. Photomicrograph of a Thin Section Showing the Colloform Texture of the Iron Sulphides (Fe) Enclosing Elemental Sulphur (S)	42
9. Photomicrograph of a Thin Section Showing Sulphur with Disseminated Iron Sulphides (Fe-S) in a Groundmass of Opaque Microcrystalline Sulphur and Iron Sulphides. Colloform Opal (O) Enclose Sulphur	42
10. Photomicrograph of a Thin Section Showing Plagioclase Phenocrysts (P) Completely Replaced by Amorphous Silica in a Groundmass of Amorphous Silica and Iron Sulphides	45
11. Photomicrograph of a Thin Section Showing the Fibrous Texture of Gypsum (G) and Angular Fragments of Quartz (q). Dark Areas are Voids.	45
12. Location Map of the Diamond Drill Holes at the Victor Conqueror Orebody, Millard County, Utah	53

LIST OF ILLUSTRATIONS (Continued)

FIGURE	PAGE
13. Vertical Cross Sections of the Victor Conqueror Orebody, Millard County, Utah	54
14. Location Map of the Diamond Drill Holes and Vertical Cross Sections at the Sulphur King Orebody, Millard County, Utah	55
PLATE	
I. Geologic Map and Vertical Cross Sections of the Sulphurdale Sulphur Deposits, Beaver and Millard Counties, Utah	in pocket
II. Detailed Geologic and Vertical Cross Sections Map of the Excelsior Orebody and New York Prospect Pit, Millard County, Utah	in pocket
III. Detailed Geologic and Vertical Cross Section Map of the Prince Albert Orebody, Queen Victoria and Mariposa Prospect Pits, Millard County, Utah	in pocket
IV. Detailed Map Showing Diamond Drill Hole Locations and Vertical Cross Section at the Sulphurdale Deposit, Beaver County, Utah	in pocket

LIST OF TABLES

TABLE	PAGE
I. Mineralogical Vertical Zoning	46
II. Analysis of Water from Sulphurdale, Utah . . .	50
III. Tabulation of Ore Reserves	58
IV. Summary of Ore Reserves	58
V. Summary of Ore Reserves	60
VI. Results of the Drilling Program	60
VII. Estimate of Mining Cost	64

The study area is located on the western border of the Tushar Range and south of the main range. It has been active up to Pleistocene and Recent times. A block of Paleozoic sedimentary rocks on the west side of the mapped area forms a horst bounded by Tertiary faults. The horst block has a total exposed stratigraphic thickness of 2,000 feet. The stratigraphic sequence from bottom to top is: Pennsylvanian Onondaga limestone, Permian Kanab limestone, Permian Coconino quartzitic sandstone, and the Permian Kanab limestone. The graben to the east is composed mainly of Tertiary volcanic flows and Cretaceous Snake River conglomerate. The strata generally strike N. 30° to 30° E. and dip 30° to 40° E.

The Tertiary volcanic flows are porphyritic quartz latites, latites, and andesites. The pyroclastics are mainly andesitic lapilli tuffs. Basalt flows were extruded and cinder cones were built on the valley floor as a result of renewed volcanism during Pleistocene and Recent times. Downslope of the streams by the basalt flows created shallow-water lakes where stratified beds of tuff deposited.

A classification of the sulphur deposits is proposed, emphasizing the type of rock that serves as host. Three main types are found. 1) Sulphur deposits in water-laid tuffs. 2) Sulphur deposits in conglomerate. 3) Sulphur deposits in recent breccia talus slopes.

The minerals present in the sulphur deposits are classified as ore and gangue. Ore minerals are sulphur and iron sulphides. Gangue minerals are siliceous sinter.

ABSTRACT

The purpose of this study is to describe the geology of the Sulphurdale area and of the sulphur occurrences. The distribution, size, and grade of the sulphur deposits were determined. The mineralogy was studied and hypotheses concerning mode of origin and depositional controls proposed.

The sulphur deposits of the Sulphurdale area are located in Millard and Beaver Counties, Utah in T. 25 S., R. 6 W. and T. 26 S., R. 6 W. S.L.B.M. The area studied includes 18 square miles.

The area geologically mapped is at the eastern border of the Basin and Range Province. Normal faults trending N. 15° E. to N. 75° E. and dipping to the west, east, and south are the most important structural features in the area. The fault that demarcates the western border of the Tushar Range and South Pavant Range has been active up to Pleistocene and Recent times. A block of Paleozoic sedimentary rocks on the west side of the mapped area forms a horst bounded by Tertiary faults. The horst block has a total exposed stratigraphic thickness of 2,600 feet. The stratigraphic sequence is as follows: Pennsylvanian Oquirrh limestone, Permian Pakoon limestone, Permian Coconino quartzitic sandstone, and the Permian Kaibab limestone. The graben to the east is composed mainly of Tertiary volcanic flows and Cretaceous Price River conglomerate. The strata generally strike N. 20° to 30° E. and dip 30° to 40° E.

The Tertiary volcanic flows are porphyritic quartz latites, latites, and andesites. The pyroclastics are mainly andesitic lapilli tuffs. Basalt flows were extruded and cinder cones rose from the valley floor as a result of renewed volcanism during Pleistocene and Recent times. Damming of the streams by the basalt flows created shallow-water lakes where stratified beds of tuff deposited.

A classification of the sulphur deposits is proposed, emphasizing the type of rock that serves as host. Three main types are found. 1) Sulphur deposits in water-laid tuffs. 2) Sulphur deposits in conglomerate. 3) Sulphur deposits in recent breccia talus slopes.

The minerals present in the sulphur deposits are classified as ore and gangue. Ore minerals are sulphur and iron sulphides. Gangue minerals are siliceous sinter,

gypsum, and quartz. A composite mineralogical zoning of the sulphur deposits is proposed. From top to bottom the following minerals predominate: gypsum; gypsum and sulphur; sulphur; sulphur, pyrite, and marcasite; pyrite and marcasite; pyrite.

The sulphur deposits are undoubtedly associated with thermal springs of solfataric nature. Low temperature, silica-bearing solutions rich in hydrogen sulphide gas have permeated favorable beds depositing sulphur near the water table. The precipitation of the sulphur is accomplished by the partial oxidation of the hydrogen sulphide gas. The iron sulphides precipitated below the water table from the mixing of acid surface waters and ascending hydrothermal solutions charged with hydrogen sulphide gas and ferrous ions.

Ore reserves total 4,845,000 short tons with a sulphur content of approximately 850,521 long tons. Future exploration for extensions of known sulphur orebodies or new ones should be concentrated along the same structures that have localized the existing deposits.

The sulphur ore has been mined by open pit methods. The ore has been processed by the following methods: a) thermal, b) flotation, and c) solvent extraction. The location and relatively low grade of the sulphur deposits makes a future venture largely dependent on a local market for a successful operation. The Sulphurdale property enjoys a freight advantage to some consumers over other distributors of sulphur and sulphuric acid in the Intermountain area.

INTRODUCTION

I. PURPOSE AND SCOPE

The purpose of this study is to describe the geology of the Sulphurdale area and of the sulphur occurrences. The distribution, size, and grade of the sulphur deposits and prospects were determined. The mineralogy was studied and hypotheses concerning mode of origin and depositional controls proposed.

The study included field and laboratory investigations. The stratigraphic sections were measured with a cloth tape and Brunton compass. The detailed maps of the individual sulphur deposits were surveyed with a steel tape and a Brunton compass. All traverses were closed and tied to claim corners or section corners. Errors in elevation were corrected by distributing equally the total error among the stations, but only if this individual correction did not exceed 0.5 foot per station. Geology of the deposits was plotted on these maps. At the Sulphurdale orebody the elevation of the top of the sulphur beds was established at all points possible by using a Brunton compass and a cloth tape.

Rock samples were collected in the field and studied petrographically. Their lithology, mineralogy, ore mineral textures and paragenesis, and types of alteration were

recorded.

The diamond drill core available from King's exploration program was examined. Samples were selected for petrographic examination.

Laboratory investigations included polished section and thin section examination, X-ray diffraction analyses, and differential thermal analyses.

The geology of the Sulphurdale area was plotted on a planimetric map drawn with the radial line plotter from controlled aerial photographs. The scale of this map is one inch equal 1,500 feet.

Field work was initiated on the 26th of July, 1959 and completed on the 26th of September, 1959. Laboratory work was conducted in the period from October, 1959 to May, 1960.

II. PREVIOUS WORK

Geologic investigations of the district have been intermittently conducted from 1883 to 1959. Russell (18) visited and described the Cove Creek sulphur deposits in 1883. In 1907 Lee (16) described the sulphur deposits and proposed a hypothesis for their origin. Lee recognized the association of the deposits with faults. Lee also stated that the sulphur was deposited by the partial oxidation of the H_2S gas. Sulphuric acid formed by further oxidation of H_2S to SO_3 in water.

The most extensive and comprehensive work was done by Clarence R. King (12) in 1951 and 1952 during an exploration program for the Chemical Corporation of America at their property. Sulphur reserves were estimated by diamond drilling. Core recovery was poor due to the friability of sulphur ore. Drill holes were bottomed when elemental sulphur content decreased and sulphide sulphur content increased. Partial spectrographic analysis of the iron sulphides showed unusual amounts of nickel (0.03 to 0.3 per cent) and cobalt (0.05 to 0.5 per cent). No hypotheses were proposed by King to explain the presence of iron sulphides below the elemental sulphur.

The volcanic sequence in the Tushar Mountains was mapped by Callaghan (5) in 1939. The volcanic rocks of the Marysvale uranium district were described by Kerr (14) in 1957.

The sedimentary rocks of the South Pavant Range have been described and classified by Gary W. Crosby (6). His classification has been followed in this thesis.

The origin of sulphur, pyrite, and marcasite has been studied extensively. Allen, Crenshaw, and Johnston (1) have done outstanding work in the occurrence and stability fields of marcasite and pyrite. They performed experiments at the Geophysical Laboratory--Carnegie Institution of Washington and concluded that marcasite forms under very acid conditions and pyrite under alkaline conditions.

III. HISTORY AND PRODUCTION

Around 1855 Mormon settlers sent to populate areas south of Salt Lake City discovered the sulphur deposits in the vicinity of Cove Creek and mined sulphur on a small scale to make gunpowder. A fort built by Brigham Young at the site of Cove Fort to protect settlers against Indian raids and to serve as a station on the road from Salt Lake City to St. George was finished in 1867.

Du Faur (9) states that Mr. Ferdinand Dickert first discovered the sulphur deposits in the vicinity of Cove Fort in 1869, and between 1872 and 1875 he discovered other prospects north of Cove Fort. In 1883 Mr. Dickert put up a processing plant that worked with great success. This plant extracted the sulphur from the ore by the thermal process. In 1885 the property was transferred to a stock company. At this time, according to Du Faur (9) Professor von Rath estimated the existence of 1,300,000 tons of sulphur at the Sulphurdale orebody.

The deposits were a source of domestic sulphur from about 1890 to 1906, during which period production was about 1,000 tons of sulphur per year. During 1893 all the United States domestic production of 1,200 tons was mined from the Cove Creek district (22).

In about 1918 Mr. Morrisey acquired the property and organized Utah Sulphur Industries. This company and other lessees exploited the Sulphurdale orebody and other deposits

in the area intermittently from 1918 to about 1949 (12).

No systematic exploratory work was ever undertaken to determine the character, extent, and grade of the discovered orebodies. Until recent operations open pit mining and overburden stripping was done with a team of horses and a scraper. Only high grade ore was mined. Waste piles averaging from 10 to 15 per cent sulphur are now seen at the Sulphurdale pit. This very selective mining has also resulted in a haphazardous pattern of cuts and benches. Recently open pit mining was done with a model 25 Northwest shovel and a D-4 Caterpillar bulldozer.

In 1937 Freeport Sulphur Company did sufficient drilling to determine that the sulphur deposits were not suitable for Frasch process mining (13). In 1950 the Chemical Corporation of America undertook a diamond drilling program to block out reserves of elemental sulphur ore at the Sulphurdale, Victor Conqueror, and Sulphur King orebodies. Diamond drilling was chosen in order to gain information on the structure and texture of the ore (13). The exploration program was designed and developed in 1950 and 1951 by King and King, consulting mining engineers. In 1953 prospecting was done with a cesspool digger at the Excelsior and Prince Albert pits.

Sulphur was extracted from the ore by thermal process until 1951, when a flotation mill was constructed. No production was reported from the property during the short time

of operation of the flotation mill. King (12) reports that in 1953 the interest now represented by the United States Sulphur and Chemical Corporation obtained control of the properties with an option to buy. A plant to produce sulphur by a solvent extraction process started production in 1955. No production figures are available from this last period of operation.

The property is now owned by Mr. Thomas Neal from Los Angeles, California and the Sulphurdale Mining Company, a Nevada corporation.

IV. LOCATION AND ACCESSIBILITY

The sulphur deposits of the Cove Creek district are located in Millard and Beaver Counties, Utah in T. 25 S., R. 6 W. and T. 26 S., R. 6 W., Salt Lake Base Meridian. The area studied includes about eighteen square miles (Figures 1 and 2).

The Sulphurdale deposit is one mile east of U. S. highway 91 at Sulphurdale which is about two miles south of Cove Fort. All the other deposits are located in Millard County northeast of Cove Fort and north of Utah highway 13. The Sulphur King deposit, the Black Mine prospect, and the fluorspar prospects are on a north south improved dirt road one-half mile east of Cove Fort. A road just east of Fishlake National Forest boundary leads to the Excelsior deposit and the New York and Mariposa prospects. A road three miles east

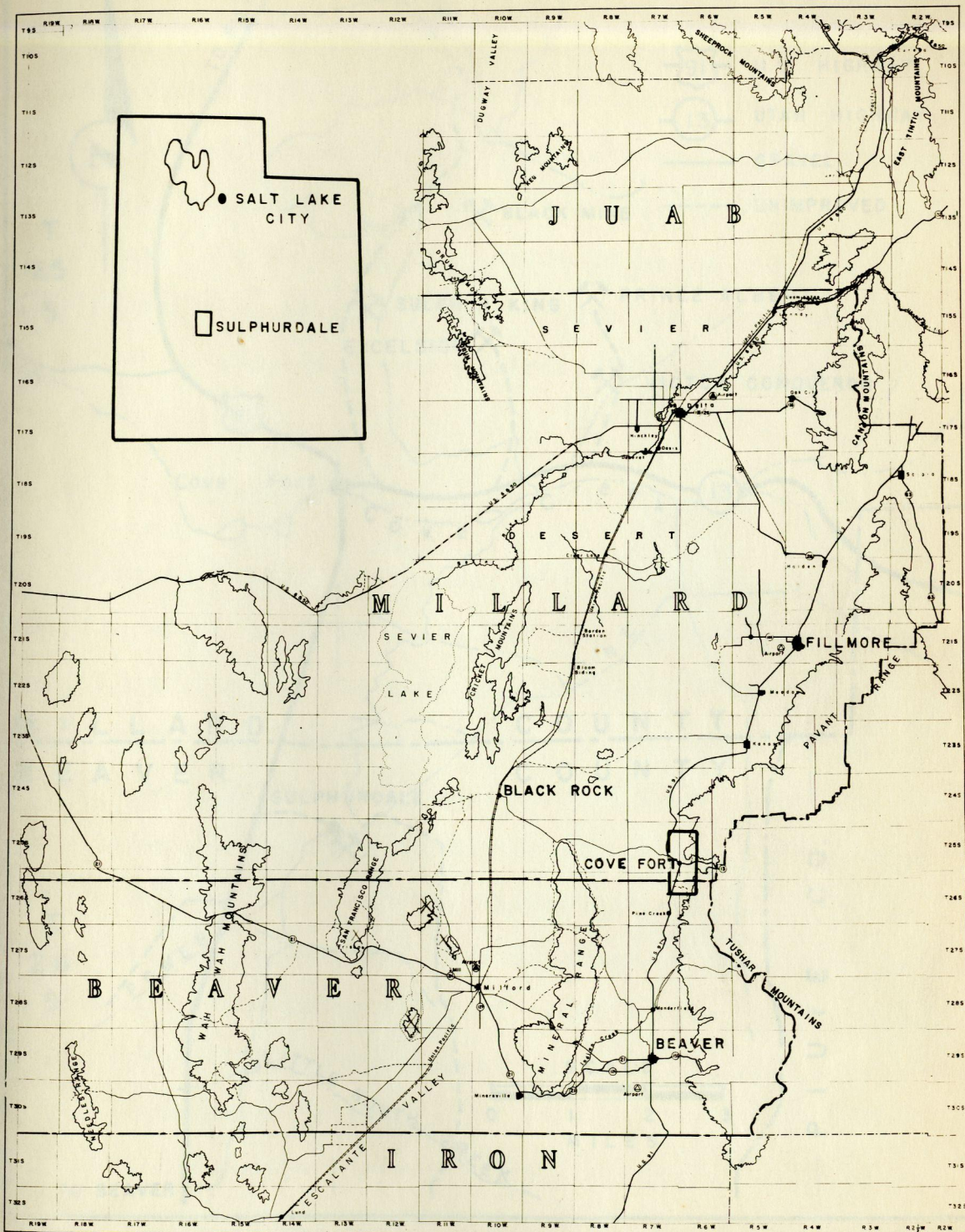


FIG. 1 INDEX MAP OF THE SULPHUR DEPOSITS
SULPHURDALE
BEAVER AND MILLARD COUNTIES, UTAH

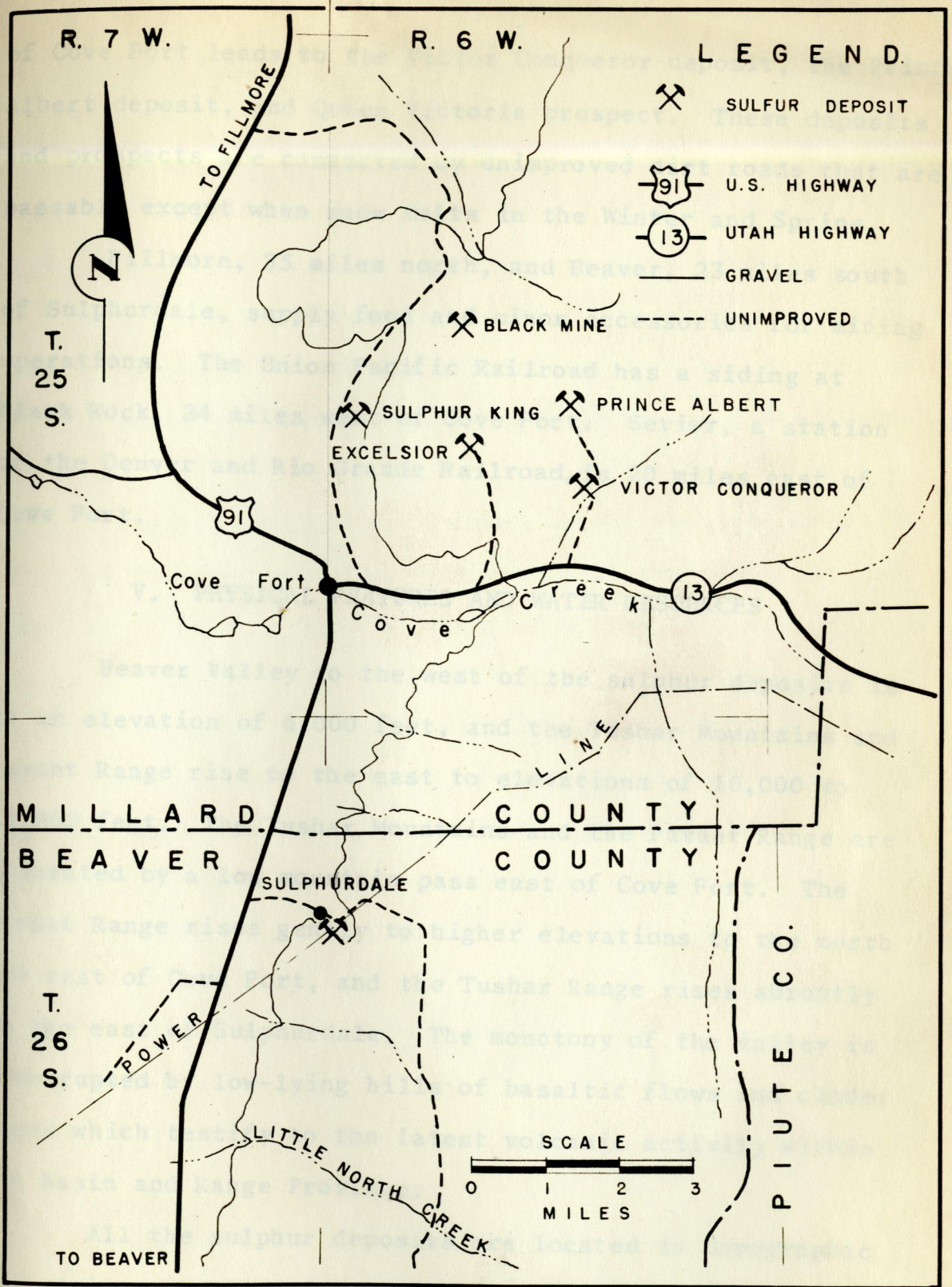


FIG. 2 PRINCIPAL SULFUR DEPOSITS,
SULPHURDALE
BEAVER AND MILLARD COUNTIES, UTAH

(AFTER BULL. OF UNIV. OF UTAH, VOL. 50, NO. 18)

of Cove Fort leads to the Victor Conqueror deposit, the Prince Albert deposit, and Queen Victoria prospect. These deposits and prospects are connected by unimproved dirt roads that are passable except when snow melts in the Winter and Spring.

Fillmore, 35 miles north, and Beaver, 23 miles south of Sulphurdale, supply food and minor accessories for mining operations. The Union Pacific Railroad has a siding at Black Rock, 24 miles west of Cove Fort. Sevier, a station of the Denver and Rio Grande Railroad, is 20 miles east of Cove Fort.

V. PHYSICAL FEATURES AND WATER RESOURCES

Beaver Valley to the west of the sulphur deposits is at an elevation of 6,000 feet, and the Tushar Mountains and Pavant Range rise to the east to elevations of 10,000 to 12,000 feet. The Tushar Mountains and the Pavant Range are separated by a low mountain pass east of Cove Fort. The Pavant Range rises gently to higher elevations to the north and east of Cove Fort, and the Tushar Range rises abruptly to the east of Sulphurdale. The monotony of the valley is interrupted by low-lying hills of basaltic flows and cinder cones which testify to the latest volcanic activity within the Basin and Range Province.

All the sulphur deposits are located in topographic depressions surrounded by low hills or at the flanks of north-trending ridges.

The drainage pattern is largely modified dendritic. The main streams flow west into the valley. Smaller tributaries trend north-south. The drainage pattern is controlled by structurally elevated blocks and north-south faults.

Moisture from snow and rain amount to 14 to 15 inches per year. All the streams, including Cove Creek, are fed mainly by precipitation and are intermittent since precipitation during the summer months amounts to but a few cloudbursts.

Several springs are located in the mountains directly east of Sulphurdale; some of them occur along the trace of the Front Range fault. These springs have provided water for plant and culinary use at Sulphurdale. A small reservoir has been built at the site of the plant to receive the waters from these springs. A short adit in the hillside just east of the Sulphurdale pit has cut into fractured and porous porphyritic volcanic flows. The walls of this adit are wet and some water flows out on the floor of the adit.

GEOLOGY

The southern end of the Pavant Range and the northern extreme of the Tushar Mountains are at the eastern margin of the Great Basin.

Paleozoic and Cretaceous sedimentary rocks crop out in the northeastern and north parts of the area mapped. The oldest formation is the limestone sequence of the Pennsylvanian Oquirrh formation which is overlain unconformably by the Permian Pakoon limestone. Next and higher in the stratigraphic section is the Permian Coconino quartzitic sandstone. The Permian Kaibab limestone overlies conformably the Coconino sandstone. The youngest sedimentary formation is the Cretaceous Price River cobble-boulder conglomerate that unconformably overlies the Oquirrh formation. The Price River conglomerate is overlain by the Tertiary volcanic rocks. The sedimentary rocks generally strike N. 10° W. to N. 45° E. and dip 20° to 34° E. and SE.

Most of the area is covered by Tertiary volcanics. The volcanic flows range in composition from quartz latite to andesite. The pyroclastics are predominantly andesitic lapilli tuff.

Kerr (14) contends that the volcanic rocks which overlie the conglomerate in the South Pavant Range are early Tertiary and thus belong to the Bullion Canyon Series.

Crosby (6) has designated these same rocks as Mount Belknap Series that were extruded during Pliocene time. If the Bullion Canyon volcanics extended as far north as the Mount Belknap volcanics, the first designation would be more appropriate.

Dating of the volcanic rocks was not attempted since extensive faulting separates this area from the area mapped by Callaghan (5).

Cinder cones and basalt flows cover the western part of the area. They are part of a wide zone of recent volcanic rocks that extends from Fillmore to the Utah-Arizona border.

The basalt flows probably modified the drainage along the front of the Tushar Mountains and southern Pavant Range by damming west-flowing streams and creating shallow-water lakes. Water-laid tuff accumulated in these lakes from the intermittent explosive activity of the nearby volcanoes. The areal extent of these Quaternary lake beds is not known since they not only have been covered by alluvium but also have been eroded by streams. Silicified, more resistant patches of these lake beds remain. The sulphur deposits are probably of late Pleistocene and more likely of Recent age. The valleys and stream courses are covered with silt, sand, and gravel.

I. STRATIGRAPHY

The sedimentary sequence ranges in age from

Pennsylvanian to Recent. Detailed sections were measured at three different places. The Kaibab limestone and the Coconino sandstone were measured on the west slope of Dog Valley Peak. The Pakoon limestone and the Oquirrh formation were measured on a ridge north of the Salt Lake gully and on the ridge east of the Sulphur King orebody. The Price River conglomerate was not measured since it is faulted and only partly exposed due to the cover of Tertiary volcanic rocks and Quaternary alluvium. The volcanic rocks were neither measured nor dated. Following is a discussion of the several stratigraphic units exposed in the area.

Rocks of Pennsylvanian Age

Oquirrh formation. The Oquirrh formation is the oldest sedimentary sequence in the area. The Oquirrh forms the steep escarpment northeast of Cove Fort. This ridge curves northeast toward Dog Valley and represents a fault line escarpment. The strike of the beds changes from N. 15° W. to N. 30° E. The dip also varies from 20° E. to 32° E.

Near the escarpment the limestone has been strongly brecciated and silicified. Faults in the vicinity of the Sulphur King parallel to the escarpment have produced stratigraphic throws of 400 feet and 250 feet. -

South of the Salt Lake gully the Oquirrh is overlain unconformably by the Price River conglomerate, and north of this gully it is overlain unconformably by the Pakoon

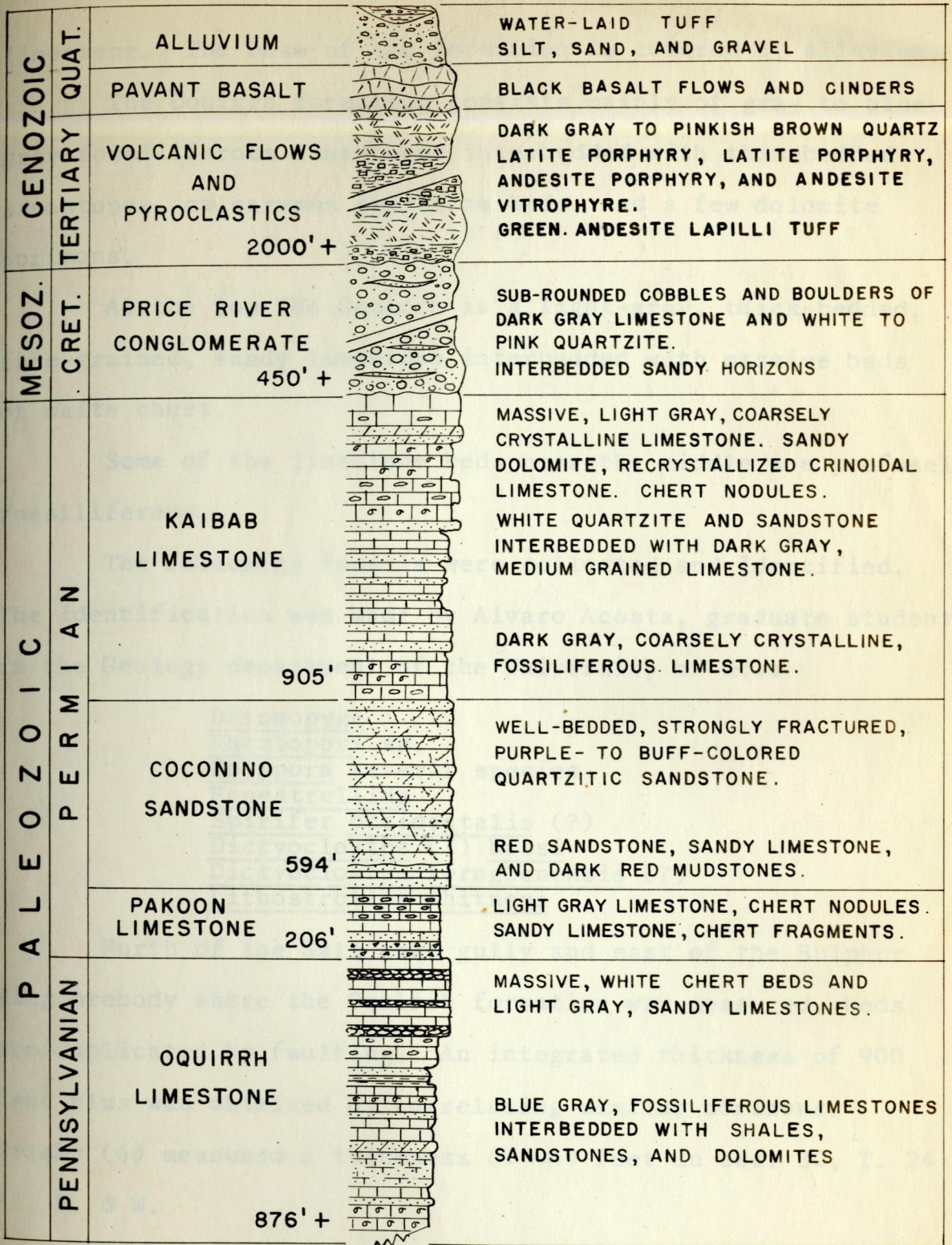


FIG. 3 COMPOSITE STRATIGRAPHIC SECTION
SOUTH PAVANT RANGE, MILLARD COUNTY, UTAH

limestone. The base of the formation is covered by alluvium.

The Oquirrh formation consists mainly of gray to blue-gray fossiliferous limestones interbedded with thin-bedded sandstones, calcareous sandstone beds, and a few dolomite horizons.

At the top the Oquirrh is a light-gray, thick-bedded, fine-grained, sandy limestone interbedded with massive beds of white chert.

Some of the limestone beds near the middle are profusely fossiliferous.

The following fossils were collected and identified. The identification was made by Alvaro Acosta, graduate student in the Geology department of the University of Utah:

Ditomopyge
Rhombopora sp.
Polypora several species
Fenestrellina
Spirifer occidentalis (?)
Dictyoclostus (?) bassi
Dictyoclostus fernglenensis (?)
Lithostrotion whitneyi

North of the Salt Lake gully and east of the Sulphur King orebody where the Oquirrh formation was measured, beds are duplicated by faulting. An integrated thickness of 900 feet plus was obtained by correlating similar horizons. Crosby (6) measured a thickness of 949 feet in sec. 30, T. 24 S., R. 6 W.

Rocks of Permian Age

Pakoon limestone. The Pakoon limestone is overlain by

the conspicuous red sandstone and quartzitic sandstone of the Permian Coconino formation.

At the east slope of the front range immediately southwest of the Salt Lake gully, the base of the Pakoon formation is overlain unconformably by the Price River conglomerate. The beds strike N. 30° E. and dip 20° E.

The Pakoon formation is composed essentially of light-gray, fine-grained limestones with abundant black chert nodules and lenses of very dense, resistant limestone. The base consists of 40 feet of a sandy limestone with bedded, angular chert fragments. This is a conspicuous marker bed. No fossils were found in these strata.

North of the Salt Lake gully the Pakoon measured 206 feet. In sec. 21, T. 24 S., R. 6 W. Crosby (6) measured a thickness of 174 feet.

Coconino sandstone. The Coconino quartzitic sandstone forms a steep slope along the ridge that descends eastward from Dog Valley Peak. Its reddish color is somewhat masked by the profuse vegetation of scrub oak. Outcrops were also found on the southwest slope of the high ridge east of the termination of the Salt Lake gully. The beds strike N. 40° E. and dip 27° E. North of the Prince Albert deposit a small block of Coconino sandstone has been uplifted and is in fault contact with the Price River conglomerate.

The Coconino sandstone consists of a series of well-bedded, strongly fractured, purple-to buff-colored quartzitic

sandstones. The bottom of the strata is well defined by 100 feet of red sandstones, sandy limestones, and dark red mudstones.

On the west slope of Dog Valley Peak the thickness of the Coconino sandstone is 594 feet. Crosby (6) measured 288 feet for this formation in sec. 31, T. 24 S., R. 6 W.

Kaibab limestone. The Kaibab limestone forms the high ridge of the east wall of Dog Valley. In the northern part of the area mapped the Kaibab limestone is in fault contact with the Tertiary volcanics and Price River conglomerate. Further north the Triassic Moenkopi thin-bedded, red shales, sandstones, and limestones overlie the Kaibab limestone in the normal sequence. The Kaibab wedges out toward the south and west in the vicinity of the Mariposa prospect pit. West of this pit the Kaibab formation overlies conformably the Coconino quartzitic sandstone.

The beds in the northern part strike N. 10° E. and dip 34° E. In the vicinity of the Soap Springs fault the strike changes to N. 45° E. and the strata dip 30° to 45° E. Near the top of the section the beds are massive, light-gray, and coarsely crystalline limestone.

Recrystallized crinoidal limestones, some sandy dolomite horizons, and white quartzite beds are interbedded with dark-gray, medium grained limestones. These limestones notably have abundant streaks and nodules of dense, chemically

resistant limestone that weathers brown and stands out in relief. At the bottom of the section the limestone is dark gray, coarsely crystalline, and fossiliferous.

Only a few cup corals and crinoid stems were collected near the top of the formation. Unfortunately it was not possible to identify these fossils.

The thickness of the Kaibab limestone on the west slope of Dog Valley Peak is 905 feet. Crosby (6) measured a thickness of 1,193 feet in sec. 28, T. 24 S., R. 6 W.

Rocks of Cretaceous Age

Price River conglomerate. The Price River conglomerate caps the ridge northeast of Cove Fort. South of the Salt Lake gully outcrops of the conglomerate abruptly swing eastward finally disappearing under a cover of volcanics. On the east side of the Soap Springs fault, the conglomerate reappears again in northeast-trending ridges near the Mariposa and Prince Albert pits.

South of the Excelsior orebody the Price River conglomerate is in fault contact with the volcanic rocks. Near the fault the conglomerate is difficult to recognize due to strong silicification and brecciation.

The conglomerate beds generally strike N. 30° E. and dip 25° to 30° SE. Faulting has disturbed the beds near the Excelsior orebody where they strike N. 65° W. and dip 20° SW.

The Price River conglomerate consists of sub-rounded

cobbles and boulders of dark-gray limestone and purple to white quartzite. A sandy horizon with sub-rounded limestone granules outcrops in the hillside above the Queen Victoria prospect diggings. The voids between the sand grains are filled with a red, hematitic cement. This sandy horizon may represent channels within the conglomerate blanket. It outcrops consistently above the sulphur deposits in conglomerate.

West of the Excelsior orebody the Price River conglomerate has an estimated thickness of 450 feet. This thickness was calculated from aerial photographs.

Rocks of Tertiary Age

Volcanic flows and pyroclastics. The Tertiary volcanic rocks cover more than two-thirds of the area. The high mountain front east of Sulphurdale is composed entirely of volcanic rocks and rises at least 3,000 feet above the valley floor. North of Utah Highway 13 the volcanics have low relief and occupy north-trending ridges. In this area the volcanic rocks cap the conglomerate. East of the Excelsior deposit the volcanic rocks overlap the Prince Albert fault advancing north and east into the South Pavant Range.

The volcanic flows studied in thin section include quartz latite porphyry, latite porphyry, andesite porphyry, and andesite vitrophyre. In the field all the flow rocks are porphyritic with phenocrysts of plagioclase feldspar in a

groundmass that varies in color from dark gray to pinkish brown. Under the microscope, phenocrysts show alignment. The groundmass is very fine, less than 0.01 mm., and is probably composed of feldspar laths. Some of the andesine phenocrysts are zoned with orthoclase rims. Biotite phenocrysts have poikilitic plagioclase and zircon.

The quartz latite rocks were found east of Sulphurdale at a place called Rocky Point. Megascopically, these rocks are greenish brown and have plagioclase and potash phenocrysts in a very fine, dense groundmass. Cracks and vugs are filled or lined with opal and quartz crystals. Microscopically, the essential minerals identified and their relative proportions are as follows: andesine, 45 per cent; orthoclase, 40 per cent; and quartz, 10 per cent. Accessory minerals are biotite and magnetite. Alteration has produced incipient carbonate.

North of the Prince Albert pit and east of the Soap Springs fault the volcanic rocks are mainly latite porphyry. Here they also overlie the conglomerate. Megascopically, the plagioclase and potash feldspar phenocrysts show conspicuous flow structure. The groundmass is pinkish brown and fine-textured. Microscopically, the essential minerals observed and their relative proportions are as follows: andesine up to 4 mm., 35 per cent; orthoclase up to 2 mm., 30 per cent; quartz, less than 5 per cent. Magnetite is the more important accessory mineral. The feldspar phenocrysts

are speckled with clay minerals. Calcite is very prominent. Some chlorite was also observed. The groundmass is microcrystalline, 0.1 to 0.01 mm., and possibly contains laths of plagioclase crystallites.

The andesite porphyry was observed overlying the conglomerate west of the Mariposa prospect pit. In this area the volcanic rocks are only about 100 feet thick. Megascopically, these rocks are dark gray, dense with plagioclase feldspar and hornblende phenocrysts in a very fine groundmass. The phenocrysts show marked flow structure. Microscopically, the essential minerals and their relative proportions are andesine phenocrysts 2 to 3 mm., 15 per cent; quartz, less than 5 per cent; and hornblende, about 4 per cent. Biotite is an accessory mineral. The groundmass is microcrystalline, less than 0.01 mm., and possibly consists of plagioclase feldspar. The index of refraction of the groundmass is greater than that of balsam. Alteration of the ferromagnesium minerals has produced minor biotite and pyrite.

The andesite vitrophyre outcrops in the low hills north of the sulphurdale pit. Megascopically, these rocks are green with pink bands. Plagioclase phenocrysts show pronounced flow structure. Microscopically, the essential minerals and their relative proportions are andesine phenocrysts greater than 2 mm., 24 per cent; quartz, less than 5 per cent. Magnetite is an important accessory mineral. The groundmass is microcrystalline, less than 0.01 mm., and

hyaline. The glassy groundmass shows pronounced flow structure. The glassy bands alternate with bands of an aphanitic microcrystalline groundmass. These bands have abundant, incipient, acicular magnetite crystals.

The pyroclastic rocks studied in thin section include welded tuffs and lithic lapilli tuffs. West of the Soap Springs fault the pyroclastics in general overlie the volcanic flows.

On a hill 300 feet north of Sulphurdale outcrops a red, vesicular, welded tuff. Megascopically, the welded tuff contains dark red, angular, porous fragments. Some sanidine phenocrysts are also identifiable. Microscopically, the essential minerals and their relative proportions are glass shards, 80 per cent; sanidine phenocrysts, 5 per cent; and quartz fragments, 5 per cent. Also, hematite which fills the pores and cracks, and pyrite were observed.

A lithic lapilli tuff sample was collected on top of the ridge east of the Philadelphia prospect pit. In hand specimen this rock contains green, angular, lithic fragments less than 32 mm. in a red, aphanitic groundmass. Under the microscope the green fragments have 20 per cent andesine phenocrysts in a very fine, less than 0.1 mm., groundmass of plagioclase laths. The red groundmass also shows andesine phenocrysts, 15 per cent, and angular fragments of quartz. Hematite veinlets and clay alteration of the feldspars are prominent.

Quartz veins with minor amounts of gold and silver are found in a wide east-trending zone south of the Prince Albert fault. The volcanic rocks within this zone are strongly kaolinized. Propylitization is also pronounced within this zone.

Rocks of Pleistocene to Recent Age

Basalt flows and cinder cones. The basalt flows and cinder cones are outside of the area mapped. The basalt flows outcrop in the valley directly west of Sulphurdale. Wells drilled at Cove Fort and Dog Valley have intersected the basalt at shallow depth and continued down to 200 feet.

The cinder cone in the vicinity of Sulphurdale rises over 1,000 feet above the level of the valley. The fact that the crater is now only a slight depression may indicate perhaps that the cinder cone attained a higher elevation in the past (see Figure 4, page 33).

The basalt is black and vesicular. The cinders are red and black with numerous gas vesicles.

Water-laid tuffs. This rock formation is best exposed in the Sulphurdale pit. Other isolated outcrops have been found toward the north. Similar rocks were found in shallow pits at the Victor Conqueror orebody.

The water-laid tuffs are well-stratified and interbedded with thin layers or lenses of black mud and silty beds.

White, sulphur-barren, siliceous sinter layers are also interstratified with the tuff.

The water-laid tuff is composed of poorly sorted, white, very porous fragments of tuff and sand cemented with elemental sulphur. Some of the layers are thin-bedded and free of pebbles. The thicker layers have abundant sub-rounded pebbles and cobbles of porphyritic volcanic rocks. These pebbles are colored white, green, and red. The pebbles are highly silicified where sulphur is abundant. The silt content of the beds seems to increase away from the mountain front.

The tuff beds have a thickness of 60 to 100 feet. This is an estimated thickness obtained from outcrops and core drilling samples.

Alluvium. Alluvium includes valley fill, stream gravels, bench gravels, alluvial fan remnants, and landslide masses. Gentle slopes of sand, silt, and gravel cover the bedrock along the mountain front and main stream courses.

North of the Prince Albert deposit a blanket of silt and volcanic rock fragments cap the low ridges obscuring the actual extent of the sedimentary rocks. On top of the ridge south and west of the Mariposa prospect pit quartzitic sandstone blocky fragments are spread profusely over the Price River conglomerate.

Angular fragments of limestone preserved at the Sulphur King deposit and Black Mine have probably resulted from the

accumulation of breccia at the foot of a fault. One mile south of Sulphurdale recent movement of the fault blocks has produced large landslide masses.

II. STRUCTURE

Faults strike N. 15° E. to N. 75° E. and dip steeply to the east, west, and south. They have formed a series of uplifted step-faulted blocks and a graben.

The normal faults offset Tertiary-Quaternary Sevier River sediments along the eastern edge of Dog Valley (6). Along them and south of Sulphurdale, canyons have a deep "V" shape and their outlets are constricted. Near these fault zones landslides and thermal springs point to continuous or recurrent unrest from the Tertiary to the present time.

Conjugate joints were observed in the volcanic rocks east of Sulphurdale. One set has a strike of N. 35° E. and a vertical dip; the other set strikes N. 55° W. and dips 85° S.

Sulphur deposits are spatially related to the faults. These faults served as channels for the thermal springs that were active during and after the late volcanism. The thermal spring waters carried the sulphur that was deposited in the porous beds of the water-laid tuff, the quartzite-limestone conglomerate, and the recent breccia talus slopes. Following is a discussion of the more important faults in the area.

Front Range Faults

The western border of the Tushar Mountains and South

Pavant Range are defined by large faults. One of these faults strikes N. 25° E. and dips 55° E. at the site of the Soap Springs. A ledge of completely silicified and brecciated volcanic rock shows conspicuous slickensides. This fault has been traced in the aerial photographs north of Utah highway 13 and then recognized again in a deep gully northeast of the Mariposa prospect. At this point the Kaibab limestone has been strongly silicified and fractured. The topographic saddle at the bottom of the east slope of Dog Valley Peak is probably on this fault. An uplifted block of Kaibab limestone outcrops west of the fault. On the east side, Cretaceous Price River conglomerate overlain by Tertiary volcanics forms the downdropped block.

The east side of the Sulphurdale orebody is bound by a fault that parallels the major fault described above. The fault trace is visible southward along the front of the Tushar Mountains; but northward its trace has been obliterated by the erosion of the relatively soft volcanic rocks. Northeast of Cove Fort this fault continues at the foot of the escarpment formed by an uplifted block of Paleozoic sediments. Two sulphur deposits and the fluorspar prospects are located on this fault zone. It also is marked by outcrops of silicified and brecciated rock found at the base of the escarpment. North of the Black Mine, Crosby (6) has mapped this fault or a branch of it which offsets Tertiary-Quaternary high level gravels.

East of the Sulphur King deposit two branch faults were located by recognizing repetition of the strata in the Oquirrh formation. These faults strike approximately north and join the main fault in the vicinity of the West Fluorspar prospect.

Prince Albert Fault

About 400 feet south of the Excelsior deposit, a fault trending N. 75° E. and probably dipping steeply to the south makes a sharp contact of Price River conglomerate to the north and Tertiary volcanics to the south.

Hydrothermal solutions flowing along this fault have produced a wide zone of intense silicification of the conglomerate and propylitization of the volcanics.

The Philadelphia prospect pit is at the west end of the Prince Albert fault. The Prince Albert fault and the Soap Springs fault intersect with no noticeable displacement observed either in the field or on the aerial photographs.

Intense silicification and fracturing of the rocks was observed along an east-trending fault northwest of the Prince Albert pit. This fault has uplifted a small block of Permian Coconino sandstone.

Excelsior Fault

Another large fault was located about 2,000 feet east of the Black Mine. At this point, the Oquirrh formation is strongly silicified and brecciated. The fault appears to dip

to the east and clearly offsets the Pakoon limestone in the vicinity of the Salt Lake gully (see Plate I).

The Excelsior orebody was probably localized by thermal spring solutions ascending on the plane of the Excelsior fault and branching fractures.

A classification of the sulphur deposits is proposed emphasizing the type of rock that serves as a host. Three main types are found:

1. Sulphur deposits in white, very porous water-lain tuff which is interbedded with siliceous sinter deposited from thermal spring activity. Examples of this type are the Sulphurdale and Victor Conqueror orebodies.

2. Sulphur deposits in Cretaceous quartzite-limestone conglomerate in which the limestone is either altered to gypsum or replaced by very porous, white siliceous sinter. Examples of this type are the Excelsior, Prince Albert, Mariposa, Queen Victoria, and New York.

3. Sulphur deposits in recent talus slopes of Paleozoic limestones at the base of Tertiary faults. Siliceous sinter fills the spaces between the limestone fragments and also replaces the limestone. Gypsum is abundant. The Sulphur King and the Black Mine are examples of this type.

Sulphurdale and Victor Conqueror Orebodies

The Sulphurdale and Victor Conqueror orebodies have very similar structural and mineralogical characteristics. They are in topographic depressions and are surrounded by

GEOLOGY OF ORE DEPOSITS

I. DESCRIPTION OF SULPHUR DEPOSITS

The sulphur deposits are disseminated and bedding replacement. A classification of the sulphur deposits is proposed emphasizing the type of rock that serves as a host. Three main types are found:

1. Sulphur deposits in white, very porous water-laid tuff which is interbedded with siliceous sinter deposited from thermal spring activity. Examples of this type are the Sulphurdale and Victor Conqueror orebodies.
2. Sulphur deposits in Cretaceous quartzite-limestone conglomerate in which the limestone is either altered to gypsum or replaced by very porous, white siliceous sinter. Examples of this type are the Excelsior, Prince Albert, Mariposa, Queen Victoria, and New York.
3. Sulphur deposits in recent talus slopes of Paleozoic limestones at the base of Tertiary faults. Siliceous sinter fills the spaces between the limestone fragments and also replaces the limestone. Gypsum is abundant. The Sulphur King and the Black Mine are examples of this type.

Sulphurdale and Victor Conqueror Orebodies

The Sulphurdale and Victor Conqueror orebodies have very similar structural and mineralogical characteristics. They are in topographic depressions and are surrounded by

Tertiary volcanic rocks (see Figure 5). The sulphur occurs as small, bright-yellow grains or crystals filling pores and lining cavities of a white, very porous, well-bedded water-laid tuff with interstratified siliceous sinter.

Now at the Sulphurdale orebody hydrogen sulphide gas emanations are very profuse and issue through small vents or fractures. Most of the sulphur is disseminated in the porous beds of the water-laid tuff. The sulphur is also combined with finely divided, black iron sulphides including pyrite and marcasite. In places the iron sulphides outcrop along fractures or vents of continued solfataric activity. A zone of mixed iron sulphides and elemental sulphur extends down to 172 feet below the surface at the location of drill hole No. 23 (see Plate IV).

At the Sulphurdale pit some of the beds of water-laid tuff are poorly sorted and contain well-rounded pebbles of volcanic rocks. These pebbles vary in color from light-gray to green and pink. The pebbles are completely silicified but still show ghosts of their phenocrysts. Most of these beds are mineralized. Other beds, 2 or 3 feet thick, are silty and barren of sulphur. They extend laterally only a few feet.

In surface outcrops exposed to atmospheric conditions the sulphur is bleached. The color reappears if the surface is scratched lightly with a pick.

The Sulphurdale orebody has been well outlined by

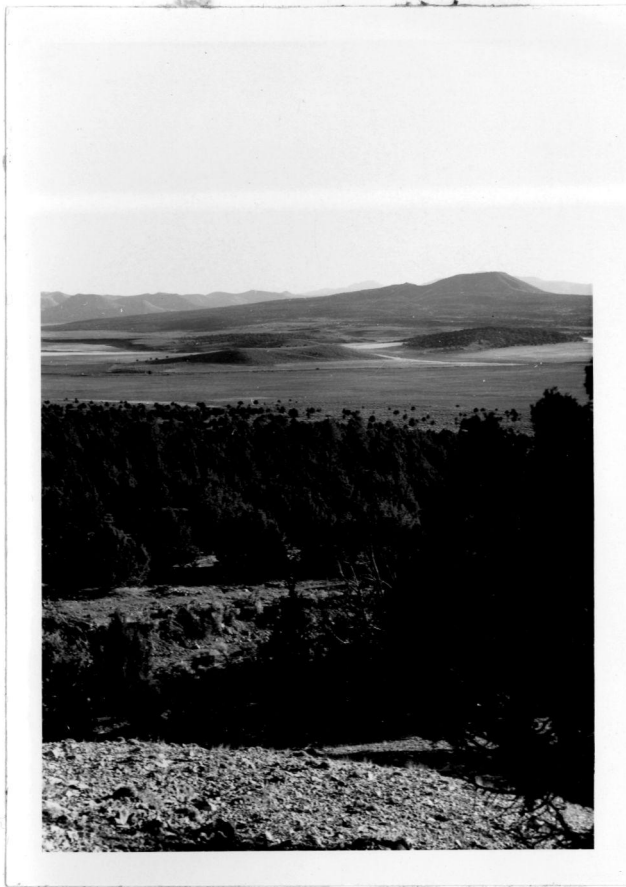


Figure 4. Cove Fort cinder
cone and basalt flows. View
looking southwest.

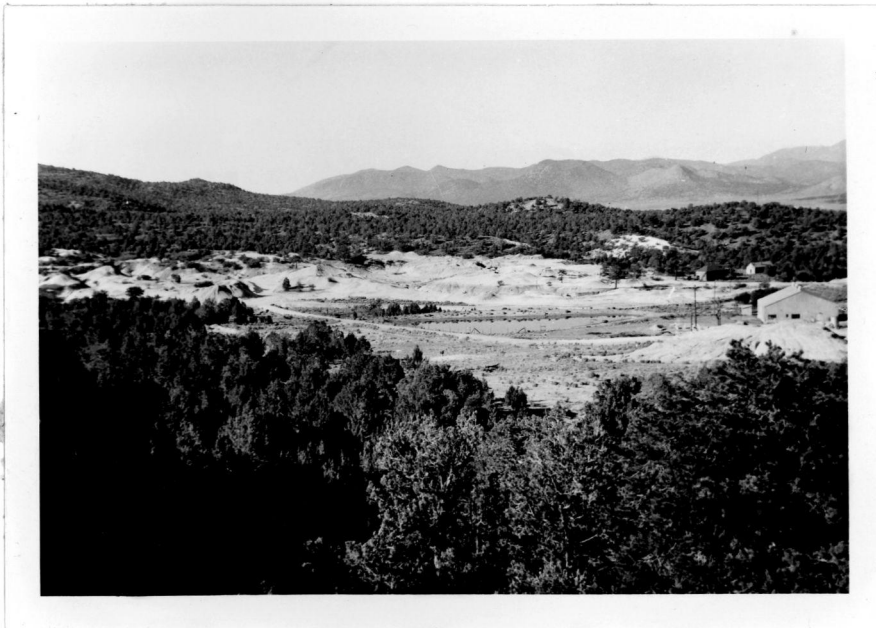


Figure 5. Sulphurdale open pit.
View looking southwest

drilling on all sides except to the north and northeast directions. The maximum dimensions are 1,500 feet in a north south direction and 800 feet in an east west direction. Overburden ranges up to 20 feet. The east side of the orebody rests over a porphyritic latite flow and is bound by a fault that the water-laid tuff overlaps. These flows are strongly jointed and coated with clay and limonite stain along planes parallel to the fault. At the bottom of the trench (see Plate IV) where the fault is exposed hydrogen sulphide gas bubbles through the wet mud. Epsomite collects at the bottom of the trench. The clay around the trench has a bluish green color possibly due to the formation of ferrous sulphate. At this trench and only 10 feet from the surface, several masses about 3 feet in diameter of black sulphides were excavated.

Information about the Victor Conqueror orebody has been obtained from drill logs (see Figures 12 and 13, pages 53 and 54). As outlined by drilling the Victor Conqueror orebody has a basin shape. The dimensions of this orebody are 600 feet in an easterly direction and 200 feet in a northerly direction. A few prospect pits have encountered ore only a few inches below the surface. The soil over the orebody is mixed with white fragments of tuff. This deposit has beds of water-laid tuff interstratified with barren bands of silty material and very hard siliceous fragments. Most of the holes that cut elemental sulphur ore have also encountered heavy iron sulphides near the bottom.

The Victor Conqueror orebody is structurally controlled by a N. 15° E. major early Tertiary fault, the trace of which is only 800 feet to the west of the orebody.

Prince Albert Orebody, Mariposa, and Queen Victoria Prospects

The Prince Albert orebody (see Plates I and III) is located on the west side of a northeast-trending ridge north of the Victor Conqueror orebody. The Queen Victoria is situated on the east side of the same ridge and directly east of the Prince Albert. The Mariposa pit is about 1,000 feet west of the Prince Albert. These three occurrences of sulphur are probably related to a fault which is almost entirely concealed by alluvium. This fault strikes N. 5° E. and dips about 67° E. The probable dimensions of the Prince Albert orebody are 300 feet in a northerly direction and 300 feet in an easterly direction.

At the Prince Albert pit the sulphur fills the pores of a highly porous but apparently dense siliceous sinter. Quartzite pebbles are few. The sulphur at the Queen Victoria and Mariposa prospect pits fills the pores and lines cavities of a white, very porous and light weight siliceous sinter. Quartzite pebbles are more abundant in these two deposits than at the Prince Albert orebody.

Deep red hematitic soil caps the Prince Albert orebody and is also present above the Mariposa and Queen Victoria pits. Gypsum is abundant below this red capping and replaces

the limestone pebbles.

Vertical cross section A-A' (see Plate III) shows that the Queen Victoria prospect pit is approximately at the same elevation as the top of the sulphur at the Prince Albert orebody.

Excelsior Orebody and New York Prospect

The Excelsior orebody (see Plates I and II) is located about 4,500 feet northwest of the Victor Conqueror. The New York prospect pit is situated 1,100 feet west of the Excelsior pit.

The Excelsior deposit is perhaps the largest of the sulphur deposits in conglomerate (see Figure 6). The probable dimensions of this orebody are 400 feet in a northerly direction and 200 feet in an easterly direction. It is probably related to both the Prince Albert and Excelsior faults (see Plate II). These two faults would also limit the orebody to the south and east.

The sulphur occurs in a white, porous mass of siliceous sinter filling pores and lining cavities. This porous mass surrounds pink to bleached quartzite pebbles. Gypsum is abundant in some areas of the pit, but generally occurs in lesser amounts where sulphur is richer. A road cut around the pit where the cesspool holes are located shows abundant gypsum. The red hematitic soil is again present directly above the orebody. At the west face of the pit (see Figure 7) the orebody shows relic bedding of the Price River



Figure 6. Excelsior pit. View looking to the west.



Figure 7. West face of Excelsior pit. High grade sulphur ore showing relic bedding of the replaced Price River conglomerate.

conglomerate. The replaced beds strike N. 60° W. and dip 20° SW.

At the top of the hill between the Excelsior and New York the conglomerate is strongly silicified. This silicified zone is about 400 feet wide and extends 2,000 feet north of the Excelsior pit. The conglomerate within this zone is very hard and strongly brecciated. Few quartzite pebbles are still identifiable and limonite stain is very strong.

Sulphur King Orebody and Philadelphia Prospect

The Sulphur King orebody (see Plate I) is located about 4,500 feet west of the Excelsior orebody. This orebody has been well outlined by drilling on all sides, but the depth of the ore has not yet been established conclusively (see Figure 14, page 55). The Sulphur King deposit extends 200 feet in a northerly direction and 150 feet in an easterly direction.

This deposit is probably related to the fault at the base of the escarpment, which probably limits the orebody on to the east.

The Sulphur King orebody is covered entirely by alluvium. Overburden ranges up to 10 feet. A few shallow pits show very high grade, yellow, crystalline sulphur and gypsum. The sulphur and gypsum fill pores and cracks in a white, porous siliceous sinter. A few angular, black limestone fragments are also mixed in this mass. Thermal spring activity has provided abundant silica, and the material in

places consists entirely of well-stratified thin beds of siliceous sinter.

The Philadelphia prospect pit is located about 1,500 feet directly south of the Sulphur King. The white, dense siliceous sinter in the small pit does not contain any sulphur.

Black Mine Prospect

The Black Mine prospect (see Plate I) is located about 8,000 feet northeast of the Sulphur King orebody. This deposit is situated along the same fault that has localized the Sulphur King orebody. The Black Mine pit is about 200 feet long in a northerly direction and about 100 feet wide in an easterly direction.

The ore exposed in the pit is high grade. The sulphur is yellow, crystalline and fills the pores and cavities of the white, very porous siliceous sinter. Black limestone fragments are also mixed in the ore. This is the only other deposit where black sulphur has been found.

II. MINERALOGY

The minerals genetically associated with the sulphur deposits are discussed. The mineralogy of the sulphur deposits is relatively simple. The minerals present are classified as ore and gangue.

Ore Minerals

Ore minerals are those naturally occurring minerals that can be economically mined and processed. These minerals include sulphur and iron sulphides.

Sulphur. This is the most abundant ore mineral in all the workings developed presently. It occurs as disseminated, orthorhombic, small crystals (from 0.1 mm. to 5 mm.) with a bright yellow color. The sulphur lines the cavities and fills the pores in the porous beds of the water-laid tuff and siliceous sinter. Massive yellow sulphur also occurs in thin strata interbedded with layers of disseminated ore.

The elemental sulphur is also found as a dark gray, massive aggregate with a translucent sheen (see Figure 9, page 42). This black sulphur is not common and has been found only at the Sulphurdale orebody and the Black Mine prospect. Petrographically the black sulphur is composed of elongated grains of highly birefringent and finely divided (less than 0.01 mm.) sulphur in a groundmass of an opaque unidentified material. This opaque material is probably sulphur with disseminated finely divided iron sulphides.

Iron Sulphides. Iron sulphides are very profuse below the zone of elemental sulphur. They include microcrystalline marcasite and pyrite. Very small pyrite cubes and pyritohe-drons (less than 0.1 mm.) were found only in a drill core sample 27 feet below the collar elevation of hole No. 38 at

the Sulphurdale orebody. The pyrite occurs in nests in a highly altered volcanic rock.

Black, massive iron sulphides have been reported at the bottom of most drill holes. Also, at the east boundary of the Sulphurdale orebody masses of black sulphides 3 feet in diameter were excavated only 10 feet from the surface. These blocks were found along the trace of the fault that limits the east side of the Sulphurdale orebody. A polished section and a thin section (see Figure 8) of the black iron sulphides show clearly their colloidal nature. Bands of iron sulphides with a colloform texture enclose areas of elemental sulphur.

The very fine grain size of the iron sulphides does not permit distinguishing between pyrite and marcasite, hence it is not possible to determine the relative proportions of these two minerals. X-ray diffraction patterns show a larger peak for pyrite than that of marcasite. Pyrite is more abundant than marcasite if the absorption coefficient of these two minerals is the same.

Gangue Minerals

Gangue minerals are those naturally occurring minerals that, although intimately associated with the ore minerals, are not of commercial value. They include siliceous sinter, gypsum, and quartz.

· Siliceous Sinter, $\text{SiO}_2 \cdot n\text{H}_2\text{O}$. Dana (7) lists siliceous

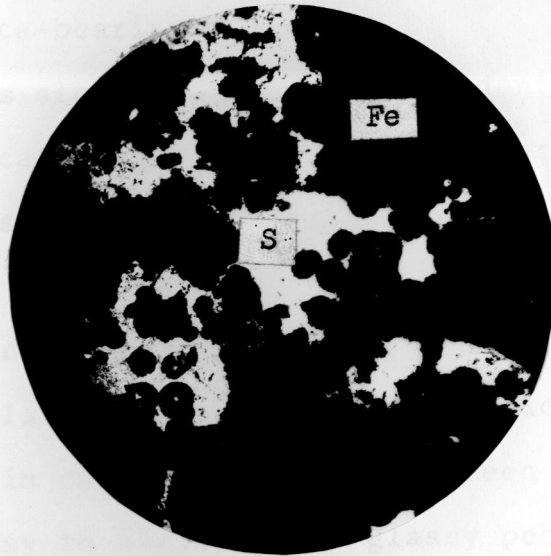


Figure 8. Photomicrograph of a thin section showing the colloform texture of the iron sulphides (Fe) enclosing elemental sulphur (S).

X 80 uncrossed nicols



Figure 9. Photomicrograph of a thin section showing sulphur with disseminated iron sulphides (Fe-S) in a groundmass of opaque microcrystalline sulphur and iron sulphides. Colloform opal (O) enclose sulphur.

X 80 uncrossed nicols

sinter as a variety of opal which is deposited at low temperatures from silica-bearing solutions.

Siliceous sinter is the most abundant of the gangue minerals genetically associated with all three types of sulphur deposits. At the Sulphurdale and Victor Conqueror orebodies it is found replacing volcanic pebbles and cobbles, forming bands or layers interstratified with and also capping the water-laid tuff. The silica replacing the volcanic pebbles varies in color from white to green to pink. The texture is glassy to earthy. The glassy pebbles have a conchoidal fracture in concentric layers in a manner similar to an onion skin. Elemental sulphur has been deposited between the layers.

The earthy siliceous sinter is pure white, porous, and light weight. It is intimately associated with both the elemental sulphur and black iron sulphides.

Microscopically the siliceous sinter replacing the volcanic rocks is seen as an opaque whitish groundmass, and as transparent colloform bands replacing andesine phenocrysts (see Figure 10, page 45).

Gypsum, $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$. Gypsum is more abundant in all the sulphur deposits in conglomerate and fault breccia talus slopes. The gypsum in these deposits is always more abundant directly above the orebodies. The amount of gypsum decreases markedly as the amount of sulphur increases. The gypsum is

usually the crystallized variety selenite. The crystals are transparent, broad, and often reach 5 cm. in length. At the Queen Victoria prospect in a bulldozer cut 25 feet above the sulphur outcrop gypsum replaces limestone pebbles. Some of the limestone pebbles are only partially replaced on the outside by a spongy, white gray mass of gypsum. The core is made of gray to buff bleached limestone.

Microscopically the gypsum from the Sulphur King ore-body shows a typical fibrous structure. The gypsum is clearly replacing angular fragments of limestone and enclose small grains of hematite. These grains of hematite are probably formed by oxidation of the iron sulphides. The thin section has about 20 per cent voids that might have been filled or lined with sulphur crystals or siliceous sinter (see Figure 11).

Quartz, SiO₂. Most of the quartz is found in small amounts either as detrital fragments or as remnants in the altered volcanic rocks. The quartz grains in altered rocks are euhedral and subhedral. Some of these grains have rounded and corroded edges. Some of the quartz was probably precipitated from mineralizing solutions.

Zonation of Mineral Deposits

Field evidence, data from drill core samples, and laboratory studies indicate a vertical zoning of ore and gangue minerals.

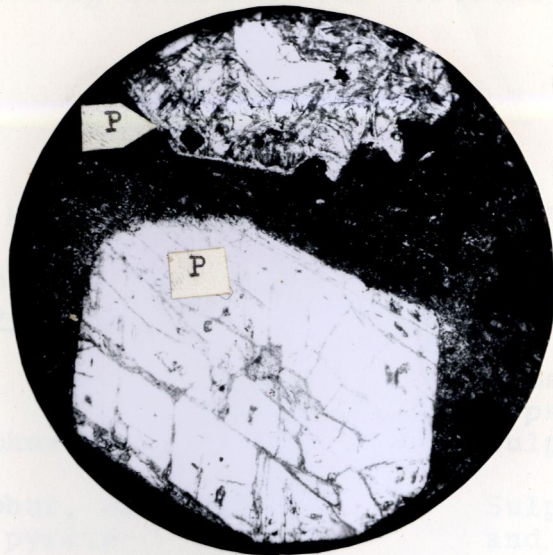


Figure 10. Photomicrograph of a thin section showing plagioclase phenocrysts (P) completely replaced by amorphous silica in a groundmass of amorphous silica and iron sulphides.

X 80 uncrossed nicols

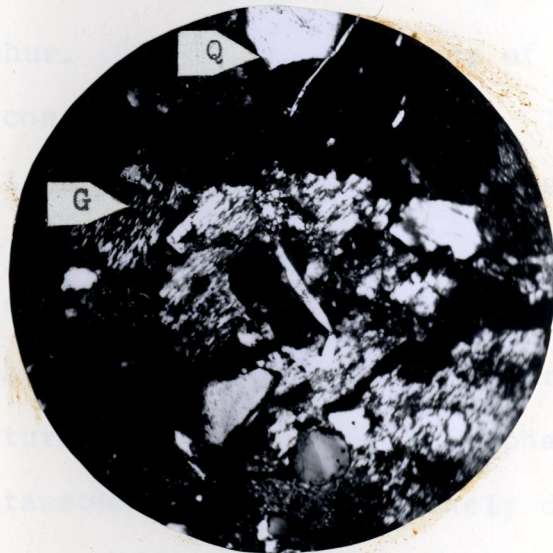


Figure 11. Photomicrograph of a thin section showing the fibrous texture of gypsum (G) and angular fragments of quartz (Q). Dark areas are voids.

X 80 crossed nicols

The following mineralogical vertical zoning is apparent.

TABLE I
MINERALOGICAL VERTICAL ZONING

	<u>Sulphur deposits in volcanic rocks</u>	<u>Sulphur deposits in sedimentary rocks</u>
TOP (Surface)	Sulphur	Gypsum Gypsum and sulphur Sulphur
	Sulphur, marcasite, and pyrite	Sulphur, marcasite, and pyrite
	Pyrite and marcasite	Pyrite and marcasite
BOTTOM (172')	Pyrite?	Pyrite?

Paragenesis of Ore and Gangue Minerals

Colloform iron sulphides (see Figure 8) enclose elemental sulphur. The curved surfaces of the colloform iron sulphides are convex toward the sulphur. This suggests that the sulphur filled open spaces and is younger than the iron sulphides.

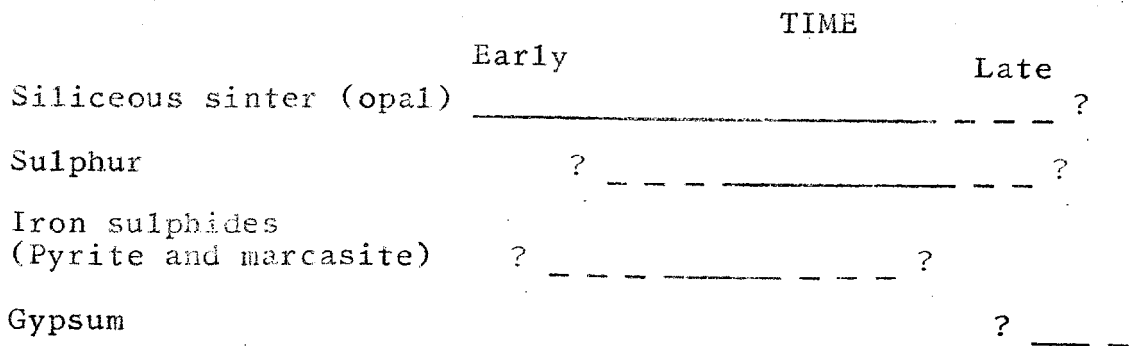
Figure 9 shows a large sulphur grain crossed by parallel lines of iron sulphide grains. This texture resembles the exsolution texture of chalcopyrite and sphalerite and suggests simultaneous deposition. Finely disseminated iron sulphides are also aligned zonally along the crystal surfaces of the coarsely crystalline elemental sulphur. This texture suggests alternating successive deposition. Opal shows a

boxed structure that encloses sulphur and also cuts across the lamellar structure of elemental sulphur. No definite paragenetic relationship can be established between opal and sulphur from this texture. Opal totally replaces the plagioclase phenocrysts (see Figure 10) and is also intermixed with the iron sulphides. Opal could then have been precipitated previously to and contemporaneously with the sulphur and iron sulphides.

Gypsum replaces angular fragments of limestone (see Figure 11) and shows a typical fibrous texture. Field evidence seems to indicate that gypsum was formed later than all the other ore and gangue minerals.

Most of the quartz identified in thin sections is either detrital or else residual from the alteration of the volcanic rocks. Consequently, paragenetic relationships of quartz are not considered.

The following diagram illustrates the composite paragenetic sequence of all the sulphur deposits based on available data.

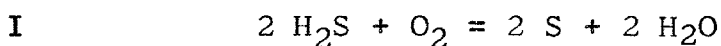


Genesis of Ore Deposits

The sulphur deposits studied are undoubtedly associated

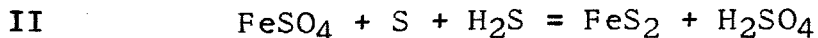
with solfataric thermal spring activity. Low temperature, silica bearing solutions were rich in hydrogen sulphide gas and ferrous ions. Ore and gangue minerals were and are being deposited from these solutions by precipitation and replacement.

These solutions permeated porous beds depositing or precipitating elemental sulphur near the water table. The precipitation of sulphur was probably accomplished by the partial oxidation of hydrogen sulphide gas. The following formula illustrates deposition of elemental sulphur by partial oxidation of hydrogen sulphide:

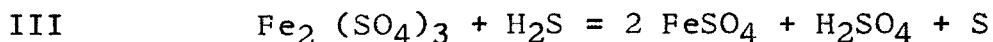


The manner of deposition of the iron sulphides, pyrite and marcasite, poses a difficult problem since only limited information and a few samples are available from the diamond drill holes. The hypothesis presented conforms with the information compiled and with previous experimental data obtained by Allen et al. (1). It is proposed that the black, finely crystalline to colloidal iron sulphides were precipitated from acid solutions enriched in ferrous sulphate. Mixing of highly acid waters containing sulphuric acid and ascending hydrothermal solutions charged with hydrogen sulphide and ferrous ions in the presence of sulphur will precipitate pyrite and marcasite simultaneously. Precipitation of pyrite and marcasite occur under reducing conditions

most likely below the water table. The following reaction shows the formation of iron sulphide by combining ferrous sulphate, sulphur, and hydrogen sulphide (1).



The elemental sulphur in equation II was previously precipitated or formed by the reduction of the ferric sulphate to ferrous sulphate. The following equation from Allen et al. (1) describes the reduction of ferric to ferrous sulphate.



The elemental sulphur and ferric sulphate formed in the oxidizing zone were made available either by a rising water table or by flooding of the oxidized zone by rising hydrothermal solutions.

The relative amounts of pyrite and marcasite have been shown by Allen et al. (1) to be related to acidity and temperature. Under highly acid conditions and low temperatures marcasite would be more abundant. Pyrite would increase as the acidity of the solutions decreases and temperature rises.

At the Sulphurdale orebody, a metallic coating of iron sulphides formed at the surface shows a relative ratio of 6 : 5 for the height of the pyrite to marcasite peaks from the X-ray diffraction pattern. The black iron sulphides formed only a few feet beneath the surface have a ratio of 2 : 1 for the height of the pyrite to marcasite peaks. At

Sulphurdale the chemical conditions necessary for the deposition of pure marcasite were not favorable since pyrite is always dominant.

The following table of the chemical analysis of the water at Sulphurdale demonstrates its acid nature and abundance of sulphate radical.

TABLE II
ANALYSIS OF WATER FROM SULPHURDALE, UTAH

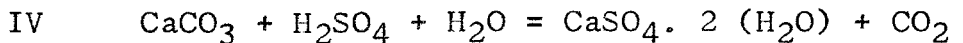
	ppm
Dissolved solids at 180° C	8,816
" " " 130° C	10,810
Suspended matter	52
Silica (SiO ₂)	124
Ferrous oxide	560
Ferric oxide	802
Aluminum	0
Calcium	158
Magnesium	232
Sodium	1
Potassium	144
Carbonate radical	0
Bicarbonate radical	0
Sulphate radical	7,602
Free sulphuric acid	4,523
Chlorine	79
Nitrate radical	1.7
Free sulphur	3.6

(W. M. Barr, 1905, U.S.G.S.)

Siliceous sinter replaces the limestone pebbles in conglomerate and breccia talus slopes deposits. Near the water table sulphur forms in the interstices and cavities of the silicious sinter. Below the water table ascending waters charged with ferrous ions and hydrogen sulphide mix with meteoric waters

rich in the sulphate radical and precipitate iron sulphides.

Gypsum is formed as a secondary product by the reaction of the limestone with acid waters rich in sulphuric acid. The surface waters manufacture free sulphuric acid by the total oxidation of hydrogen sulphide. The following reaction illustrates the formation of gypsum by combining calcium carbonate, sulphuric acid, and water.



The red hematitic soil capping the sulphur deposits in conglomerate is a weathering product probably derived from the oxidation of sedimentary or hydrothermal pyrite.

III. ORE RESERVES

The ore reserve calculations are based mainly on the diamond drilling program completed by King and King, consulting engineers, Los Angeles, California. In 1953 additional work was done with a cesspool digger at the Excelsior, Prince Albert, and Mariposa pits. This information has also been used to calculate the ore reserves of these orebodies. Detailed geologic mapping of the Sulphurdale, Excelsior, and Prince Albert orebodies has resulted in a more accurate estimate of their reserves of ore. The ore reserves of the Victor Conqueror and Sulphur King are those calculated by King and King (12). No recalculation was made since these two orebodies do not have surface exposures.

At the Sulphurdale orebody (see Plate IV) spacing of the drill holes is irregular. Outside of the pit area King used 100-foot intervals. The Victor Conqueror and Sulphur King (see Figures 12 and 14) have regularly spaced drill holes at 100-foot intervals.

King (12) in his calculations of the ore reserves defined ore as follows: "Sulphur ore is that which has a grade higher than 12 percent combined elemental sulphur and sulphide sulphur, and the ratio of overburden to ore is equal or less than 1.5 : 1.0." King also used the factor of 16 cubic feet per ton to convert volume of ore to tons of ore in place. The same cut-off grade and tonnage factor were used in the following estimation of reserves.

The ore reserves are classified as follows: Proved ore is that which has been blocked or outlined on four sides either by drilling or by outcrops. The degree of certainty assigned to proved reserves is 100 per cent. Probable ore is that which has been discovered on two sides only, either by drilling or by interpolation between known outcrops. The degree of certainty assigned to probable reserves is 50 per cent. Possible ore is that which only one side is known, either below the present bottom of the orebody or else extrapolated beyond the present lateral limit. The degree of certainty assigned to the possible reserves is 25 per cent.

To calculate average grade and tonnage of the ore reserves at the Sulphurdale orebody cross sections were

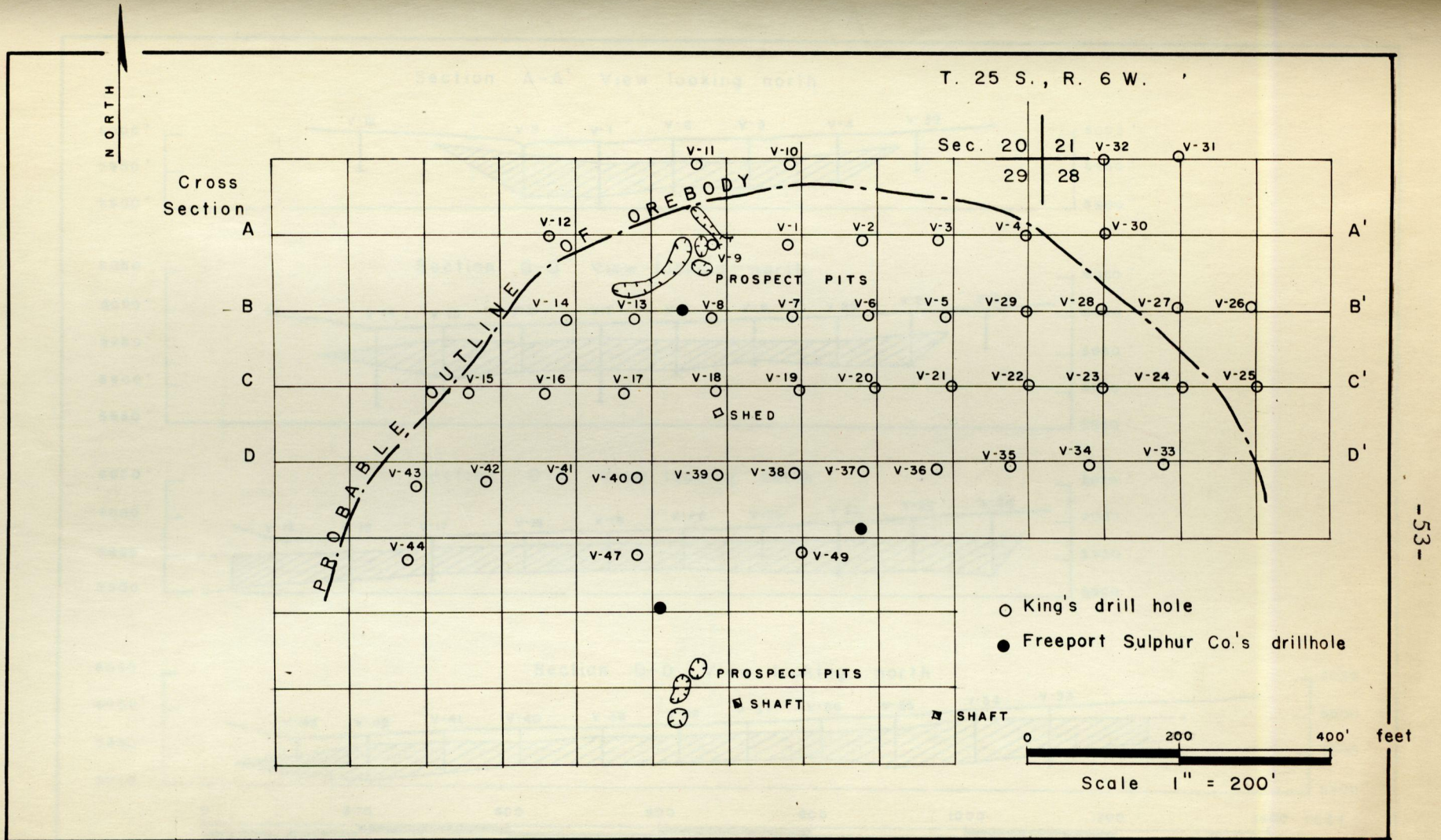


FIG. 12 LOCATION MAP OF THE DIAMOND DRILL HOLES AT THE
 VICTOR CONQUEROR OREBODY, MILLARD COUNTY, UTAH
 (From unpublished report by King & King)

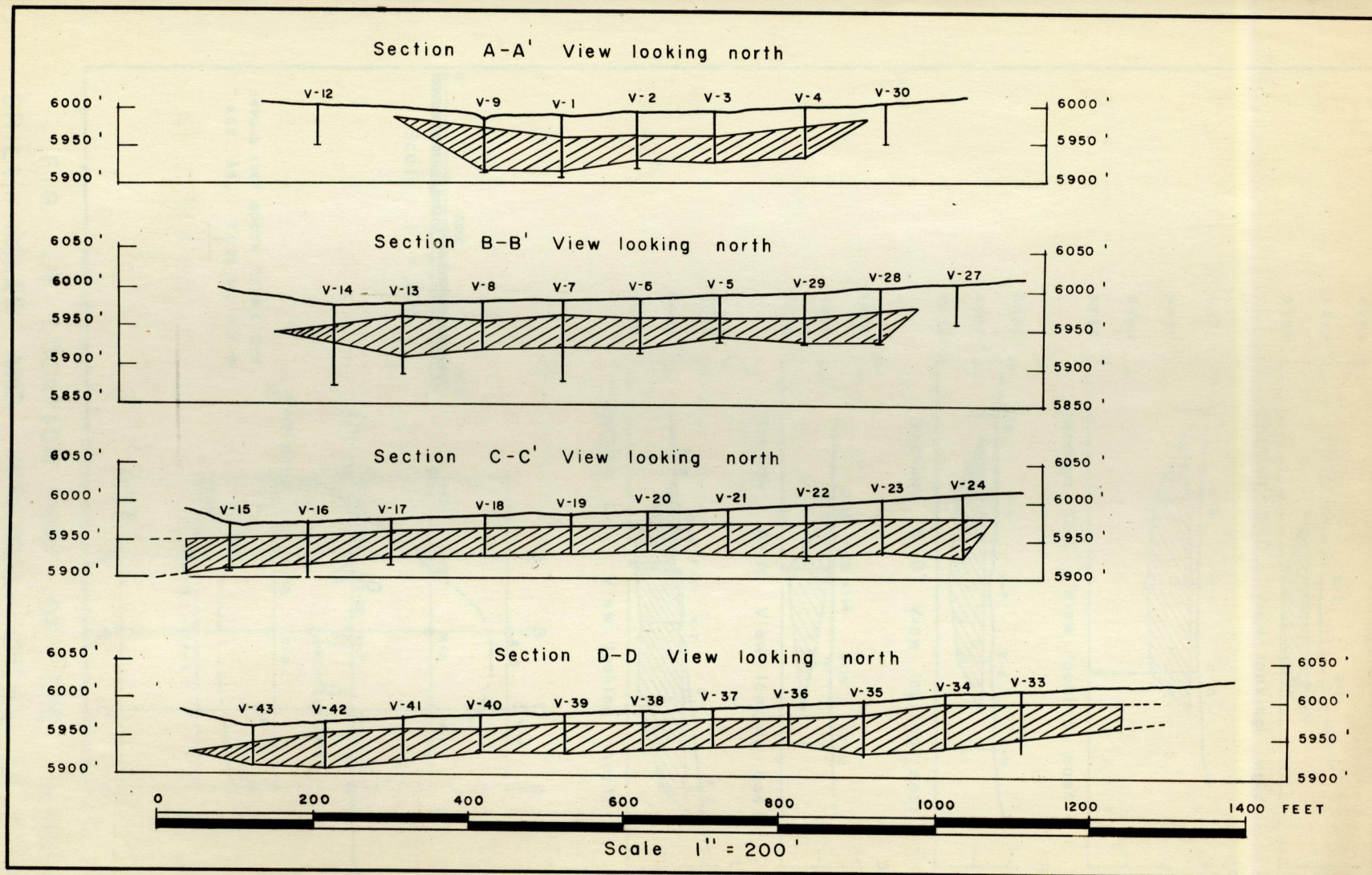
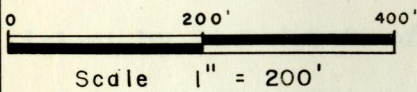
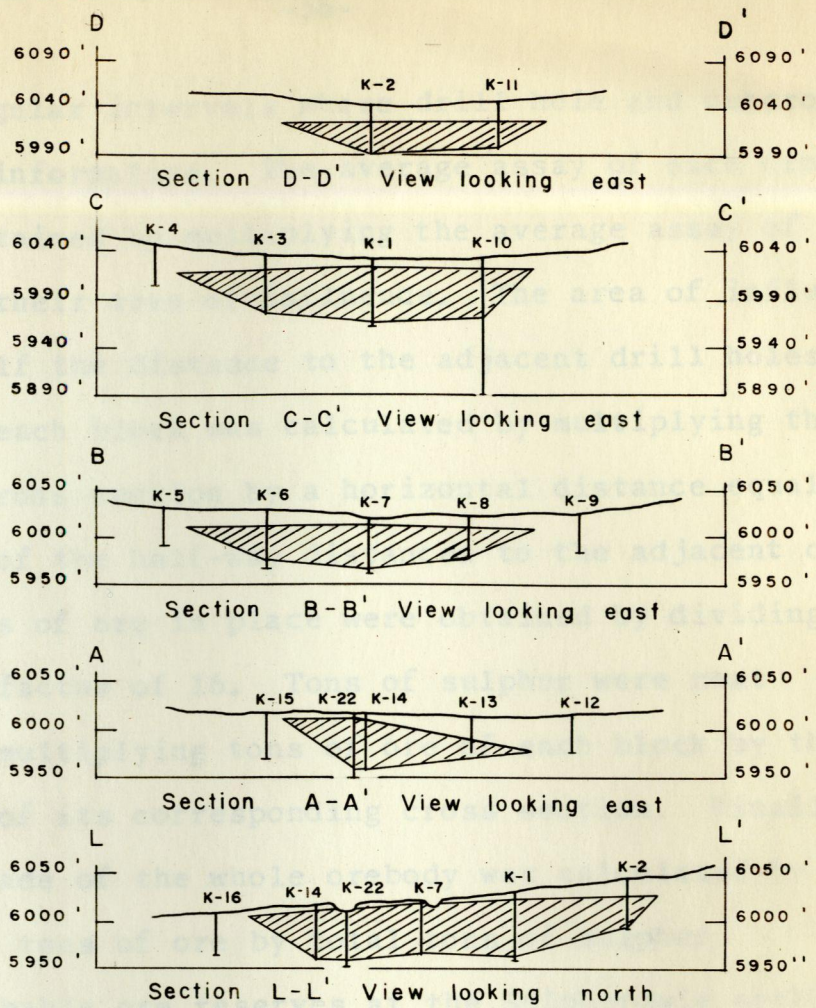


FIG. 13 VERTICAL CROSS SECTIONS OF THE VICTOR CONQUEROR OREBODY, MILLARD COUNTY, UTAH

(From unpublished report by King & King)



1490.13 FEET SOUTH TO NE COR.
SEC. 25, T. 25 S., R. 6 W.

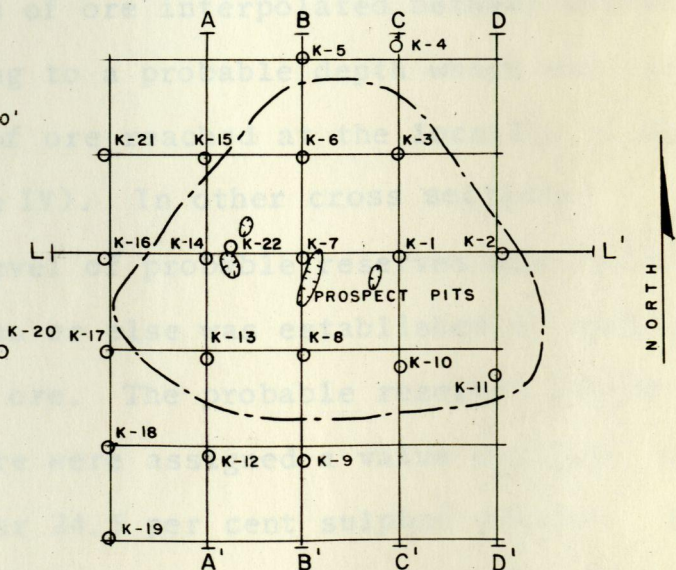


FIG. 14 LOCATION MAP OF THE DIAMOND DRILL HOLES AND VERTICAL CROSS SECTIONS AT THE SULPHUR KING OREBODY, MILLARD COUNTY, UTAH

(From unpublished report by King & King)

chosen at irregular intervals where drill hole and outcrop data are more informative. The average assay of each cross section was obtained by multiplying the average assay of each drill hole by their area of influence. The area of influence extends one-half the distance to the adjacent drill holes. The volume of each block was calculated by multiplying the area of each cross section by a horizontal distance equal to the summation of the half-way distances to the adjacent cross sections. Tons of ore in place were obtained by dividing the volume by the factor of 16. Tons of sulphur were next calculated by multiplying tons of ore of each block by the average grade of its corresponding cross section. Finally the average grade of the whole orebody was calculated by dividing total tons of ore by total tons of sulphur.

The probable ore reserves at the Sulphurdale orebody include both sections of ore interpolated between proved ore, and also ore extending to a probable depth which was established by the depth of ore reached at the location of drill hole No. 1 (see Plate IV). In other cross sections the bottom of this level of probable reserves was set either at a similar elevation or else was established by taking a similar thickness of ore. The probable reserves interpolated between the proved ore were assigned a value equal to that of the proved reserves or 24.5 per cent sulphur content. The probable reserves extending to the probable limit were assigned an arbitrary value of 20 per cent. The average grade for all

probable reserves was obtained by weighting these two averages against their corresponding tonnages.

The bottom of the possible ore reserves at the Sulphurdale orebody was set at an elevation of 6150 (see Plate IV). The sulphide zone extends to a depth of 170 feet below the collar elevation of hole No. 23. The inferred bottom of this sulphide zone is then 100 feet higher than the elevation of the bottom of the sulphides at the site of drill hole No. 23. The average combined sulphur content of the possible ore reserves was arbitrarily set at 20 per cent, a value slightly lower than the value of the probable ore reserves.

The average grade at the Excelsior and Prince Albert was estimated from the sample assays of the cesspool digger. The average grade of the Black Mine was estimated by visual comparison of the ore with similar types of ore from the Sulphur King. The tonnages of the three deposits were calculated by multiplying their probable plan area by an estimated thickness. This thickness was estimated from drill hole data or outcrops. The following tables indicate the results obtained from the calculations of ore reserves.

TABLE III
TABULATION OF ORE RESERVES

Name of Deposit	Type of Reserves	Per Cent Grade	Short Tons Ore	Long Tons Sulphur
Sulphurdale	Proved	24.5	994,187	217,290
	Probable	20.7	583,521	107,803
	Possible	20.0	829,330	148,118
	TOTAL		<u>2,407,038</u>	<u>473,211</u>
Victor Conqueror	Proved	14.8	1,000,000	132,164
	Possible	14.8	1,000,000	132,164
	TOTAL		<u>2,000,000</u>	<u>264,328</u>
Sulphur King	Proved	30.0	200,000	53,580
Excelsior	Probable	30.0	88,000	23,575
Prince Albert and Mariposa	Probable	25.0	120,000	26,790
Black Mine	Probable	30.0	30,000	8,037

TABLE IV
SUMMARY OF ORE RESERVES

Type of Ore and Name of Deposit	Long Tons of Sulphur
Proved Ore: Sulphurdale Victor Conqueror Sulphur King	404,034
Probable Ore: Sulphurdale Excelsior Prince Albert & Mariposa Black Mine	166,205
Possible Ore: Sulphurdale Victor Conqueror	<u>280,282</u>
	850,521

King and King (12) detail in the following paragraphs the method used in handling the data obtained from drill logs and assays:

Tonnage estimates taken for each orebody are the mean of two estimates: an estimate of tonnage resulting from cubication by planimeter area of orebody multiplied by the average ore thickness as determined from the plotted sections thru the orebody; (reduced to short tons by the factor of 16 cu. ft. of ore in place per short ton); and an estimate of tonnage resulting from multiplying the average ore section area taken from the plotted sections by the total coordinate length of the various sections; reduced to short tons by the same . . . factor of 16 cu. ft. per short ton.

.....

Sulphur content of the orebodies as reported in the following summary of ore reserves is believed to be conservative. Core recovery in all of the orebodies drilled . . . was difficult, and reliance had to be placed on sludge samples. Customary weighting of core and sludge assays was practiced wherever possible, but due to the fact that a pronounced tendency to lose sulphur exists at all stages of drilling and sludge sample handling, . . .; we believe that sludge samples represent a lower, rather than a higher sulphur content of the ore.

The following table of ore reserves is the final result of the calculations carried out by King and King (12):

TABLE V
SUMMARY OF ORE RESERVES

Proved Ore

<u>Orebody or Prospect</u>	<u>Stage of Drilling</u>	<u>Average Grade & Sulphur</u>	<u>Short Tons Ore</u>	<u>Long Tons Sulphur</u>
Sulphurdale	Complete	23.1	900,000	186,350
Sulphur King	Complete	30.0	200,000	53,500
Victor Conqueror	1/2	14.6	1,000,000	130,400
Total proved ore		19.8	2,100,000	370,250

Probable Ore

Victor Conqueror	15.0	1,000,000	134,000
Prince Albert and Mariposa	30.0	400,000	107,000
Excelsior	20.0	200,000	37,500
Black Mine	25.0	200,000	44,500
Total probable ore	20.0	1,800,000	323,000

The following table (13) illustrates the results of the drilling program undertaken in 1950 and 1951.

TABLE VI
RESULTS OF THE DRILLING PROGRAM

Total footage of drill holes	6,316
Average depth of holes (feet)	60
Deepest hole (feet)	172
Shallowest hole (feet)	25
Average direct cost per ft. of hole	\$ 4.25
Total short tons of ore proved on 100 ft. grid	2,100,000
Short tons proved per ft. of drill hole	332.5
Average overburden ratio (overburden thickness/ore thickness)	0.65
Average grade of ore as shown by drill samples (per cent elemental and sulphide sulphur)	19.8

The proved ore reserves at the Sulphurdale orebody differ from those of King's report because first, geologic mapping done recently has established more accurately the top of the sulphur ore. This has permitted the use of more closely spaced cross sections. Second, King's average grade for the whole orebody is 23.1 per cent. The average grade calculated here is 24.5 per cent. This average grade was obtained by adding to the weighted average of 22.3 per cent a factor of 10 per cent to compensate for known sulphur losses. Sulphur is known to be lost both in the drill hole and in the collection of sludge samples. King (12) offered no explanation or details of the calculations of ore reserves of the Prince Albert, Excelsior, and Black Mine.

IV. SUGGESTIONS FOR EXPLORATION AND PROSPECTING

Future prospecting for extensions of known sulphur orebodies or new ones should be concentrated along the same structures that have localized the existing deposits. North of Utah highway 13 the persistence of a deep red soil over the known sulphur deposits in the conglomerate may be a reliable exploration guide for the presence of sulphur. Several such areas exist in the immediate vicinity of the Prince Albert and Excelsior deposits.

To establish the effectiveness of the drilling method to be used experimental drilling should be undertaken near the edge of an outcrop. The assay of the drill hole is

then compared with the assay of a channel sample taken near the drill hole.

All the sulphur deposits are easily mined by open pit methods. Mining costs in the past have been relatively low since most of the ore does not need blasting, and transportation of the ore does not in any case involve distances greater than six miles. To process the ore to extract the sulphur the following methods have been used: a) Thermal, b) Flotation, c) solvent extraction. The market potential for sulphur and sulphuric acid will largely depend on the efficiency of the plant used to process the low grade ore.

1. MINING METHODS

All the sulphur deposits in the vicinity of Sulphurdale have been exploited in the past by open pit methods. The overburden consists mainly of unconsolidated soil mixed with gravel and boulders. This overburden varies from a few inches to about 30 feet. In most orebodies the top of the ore horizon is fairly uniform. The ore is friable and can be mined easily with a bulldozer equipped with a back ripper. Lenses of hard, high grade sulphur must be blasted. The large volume of readily hydrogen sulphide gas would not permit mining by underground methods.

The maximum depth of mining in a large scale operation will probably reach 100 feet. King and King (12) state that

ECONOMIC ASPECTS

All the sulphur deposits are easily mined by open pit methods. Mining costs in the past have been relatively low since most of the ore does not need blasting, and transportation of the ore does not in any case involve distances greater than six miles. To process the ore to extract the sulphur the following methods have been used: a) Thermal, b) flotation, c) solvent extraction. The market potential for sulphur and sulphuric acid will largely depend on the efficiency of the plant used to process the low grade ore.

I. MINING METHODS

All the sulphur deposits in the vicinity of Sulphurdale have been exploited in the past by open pit methods. The overburden consists mainly of unconsolidated soil mixed with pebbles and boulders. This overburden varies from a few inches to about 30 feet. In most orebodies the top of the ore horizon is fairly uniform. The ore is friable and can be mined easily with a bulldozer equipped with a back ripper. Lenses of hard, high grade sulphur must be blasted. The large volume of deadly hydrogen sulphide gases would not permit mining by underground methods.

The maximum depth of mining in a large scale operation will probably reach 100 feet. King and King (12) state that

this depth of mining is not excessive for large open pit mining by means of carryalls, Sauerman dragline scrapers, or power shovel and movable conveyors. The method used would depend on the size of the orebody and the scale of mining.

II. MINING COSTS

King and King (12) cite that in 1951 mining for a pilot plant was contracted at a price of 60 cents per ton delivered at the plant, including stripping. The contractor used a small dragline scraper loading 6 x 6 trucks over a "trap", plus one D-7 bulldozer for stripping. At a rate of 200 short tons per day, the contractor made an adequate profit.

In the table that follows, King and King (12) have estimated the cost of mining based on a mining rate of 500 to 600 tons per day. The equipment is amortized in three years. Haulage to plant and stripping of overburden is included:

TABLE VII

ESTIMATE OF MINING COST
(King and King, 1951)

<u>Cost Item</u>	<u>Unit Cost</u> <u>\$/short ton</u>
Amortization of equipment	\$ 0.14
Operating supplies and repairs	0.12
Direct labor and supervision	0.20
Fixed charges (Insurance, etc.)	0.04
Engineering & indirect overhead & office expense	<u>0.08</u>
Total estimated cost of mining, delivered at plant	\$ 0.58

This cost of \$0.58 per short ton of ore is calculated before taxes, royalties, depletion, or depreciation. Amortization of mining equipment has been included because of the short life of heavy earthmoving equipment under operating conditions at the Sulphurdale properties (12).

III. MARKET POTENTIAL

Sulphur is mainly used in the manufacture of sulphuric acid, carbon disulphide, and sulphur dioxide. Other materials such as hydrogen sulphide derived from sour natural gas and pyrites are generally converted directly to the end products. Very little sulphur is used as an end product (25).

The only distributor of sulphuric acid in Utah is the Garfield Chemical Plant located at Garfield, Utah. The Garfield plant produces approximately 1,100 tons of sulphuric acid daily. This by-product plant uses the contact method for the treatment of the gases from the copper smelter. The distribution and sale of the acid is made locally to Western Phosphates Company, oil refineries, uranium mills, and the Geneva steelworks. The current price of sulphuric acid is \$20.00 per short ton f.o.b., Garfield, Utah.

Mr. William Neale (personal communication) of Los Angeles, California has made an intensive study of the market for sulphur and sulphuric acid in the Intermountain area. Mr. Neale claims an immediate market exists for 115 tons daily of sulphur (99.5 per cent) at a price of \$32.00

to \$36.00 f.o.b., Sulphurdale, Utah. In addition, there is an immediate market for 415 tons daily of sulphur (99.5 per cent) at a price of \$19.00 to \$21.00 f.o.b., Sulphurdale, Utah.

The location of the sulphur deposits and their relatively low grade makes a future venture largely dependent on a local market for a successful operation. The Sulphurdale property enjoys a freight advantage to some consumers over other distributors of sulphur and sulphuric acid in the Intermountain area.

CONCLUSIONS

The sedimentary and volcanic rocks in the area are transected by several major normal faults. These faults have created a series of step-faulted blocks and a graben. The step-faulted blocks are composed of Paleozoic sedimentary rocks. The graben is covered by Tertiary volcanic rocks and Cretaceous Price River conglomerate.

All the sulphur deposits in the vicinity of Sulphurdale are intimately associated with thermal springs of solfataric nature. The locus of ore deposition is at the intersection of Tertiary faults and favorable beds of porous water-laid tuff, quartzite-limestone conglomerate, and recent breccia talus slopes. The sulphur deposits in water-laid tuff are located in topographic depressions. Those in conglomerate outcrop on the sides of northeast-trending ridges capped by a deep red hematitic soil.

The sulphur deposits are disseminated and bedding replacement. A composite mineralogical vertical zoning is apparent. From top to bottom the following minerals predominate: gypsum; gypsum and sulphur; sulphur; sulphur, pyrite, and marcasite; pyrite and marcasite; pyrite. Pyrite seems to predominate over marcasite. An overlapping of the mineralogical vertical zones has been produced either by a rising water table or else by flooding of the oxidized zone

by ascending hydrothermal solutions.

Within the iron sulphides zone elemental sulphur was precipitated both simultaneously and later than the iron sulphides. Gypsum seems to have formed later than all other ore and gangue minerals.

Elemental sulphur precipitated near the water table in the interstices of the water-laid tuff and siliceous sinter. Iron sulphides precipitated below the water table by mixing of acid meteoric waters and ascending hydrothermal solutions rich in ferrous ions and hydrogen sulphide gas.

Future exploration for extensions of the known sulphur deposits or new ones should be concentrated along the same structures that have localized the existing deposits. The future of the property as a commercial operation will largely depend on the efficiency of the plant to process the low grade ore at a competitive cost with other types of operation.

BIBLIOGRAPHY

- (1) Allen, E. T., Crenshaw, J. L., Johnston, John, 1912, The mineral sulphides of iron: *Am. Jour. Sci.* (4), vol. 33, pp. 54-66.
- (2) Buerger, M. J., 1934, The pyrite-marcasite relation: *Am. Mineralogist*, vol. 19, pp. 37-61.
- (3) Butler, B. S., and others, 1920, Ore deposits of Utah: *U. S. Geol. Survey Prof. Paper* 111, p. 106.
- (4) Butler, B. S., 1956, Mineralizing solutions that carry and deposit iron and sulphur: *Mining Engineering Trans.*, pp. 1012-1016.
- (5) Callaghan, Eugene, 1939, Volcanic sequence in the Marysvale region in southwest-central Utah: *Trans. Amer. Un.*, pt. 3, pp. 438-452.
- (6) Crosby, Gary Wayne, 1959, Geology of the South Pavant Range, Millard and Sevier Counties, Utah: Unpublished M.S. thesis, Brigham Young University, p. 59.
- (7) Dana, Edward Salisbury, 1951, A textbook of mineralogy, fourth edition: John Wiley & Sons, Inc., New York.
- (8) Day, David T., 1885, Sulphur: *U. S. Geol. Survey Min. Res.*, 1883-1885, p. 866.
- (9) DuFaur, A. Faber, 1887, The sulphur deposits of southern Utah: *Eng. & Min. Jour.* 44, p. 450.
- (10) Eardley, A. J., 1951, Structural geology of North America: Harper & Brothers, New York.
- (11) Edwards, A. B., 1954, Textures of the ore minerals: Australasian Institute of Mining and Metallurgy, Melbourne, Australia.
- (12) King, Clarence R., 1954, Report upon the Cove Creek sulphur properties, Sulphurdale, Utah; Unpublished report, King & King, Los Angeles, California.
- (13) King, Clarence R., 1953, Cove Creek Sulphur; *Mining Engineering*, April, pp. 375-378.
- (14) Kerr, Paul F., Brophy, G. P., Dahl, J. G., and Woolard, L. E., 1957, Marysvale, Utah, uranium area: *Geol. Soc. Am.*, Special Paper 64.

BIBLIOGRAPHY (Continued)

- (15) Lewis, Robert S. and Varley Thomas, 1919, The mineral industry of Utah: Utah Univ. Bull. 10, No. 11, (Utah Eng. Sta. Dept. Met. Research Bull. 12).
- (16) Lee, W. T., 1907, The Cove Creek sulphur beds, Utah: U. S. Geol. Survey Bull. 315, pp. 485-489.
- (17) Newhouse, W. H., 1925, The paragenesis of marcasite: Econ. Geol., vol. 20, pp. 54-66.
- (18) Russell, I. C., 1883, Sulphur deposits in Utah and Nevada: Eng. & Min. Jour. 35, pp. 31-32.
- (19) Russell, I. C., 1883, Sulphur deposits of Cove Creek, Utah: Am. Jour. Sci. 125 (3S, 25), p. 158.
- (20) Shimer, Hervey W. and Shrock, Robert R., 1948, Index fossils of North America: John Wiley & Sons, New York.
- (21) Stokes, H. N., 1901, On pyrite and marcasite: U. S. Geol. Survey Bull. 186, 50 pp.
- (22) Wideman, F. L., 1957, A reconnaissance of sulphur resources in Wyoming, Colorado, Utah, New Mexico, and Arizona: U. S. Bur. Mines Information Circular 7770, pp. 28-37.
- (23) Woodruff, E. G., 1907, Sulphur deposits at Cody, Wyoming: U. S. Geol. Survey Bull. 340, pp. 451-456.
- (24) The sulphur data book, 1954, Freeport Sulphur Co., McGraw Hill Book Co., New York.
- (25) Chemical Economics Handbook, 1957, vol. VII: Stanford Research Institute, Palo Alto, California.

APPENDIX

THICKNESS OF ORE AND ASSAYS OF DIAMOND DRILL
HOLES AT THE SULPHURDALE OREBODY
(from unpublished report by King & King)

<u>Drill Hole No.</u>	<u>Feet of Ore</u>	<u>Weighted Assays</u>		
		<u>Per Cent Sulphur</u>	<u>Per Cent Sulphide Sulphur</u>	<u>Per Cent Total Sulphur</u>
H 1	14	18.5	4.1	22.6
H 2	25	5.0	4.5	9.5
H 3	25	6.0	6.5	12.5
H 4	18	15.7	1.4	16.1
H 5	21	18.1	0.3	18.4
H 6	--	---	---	---
H 7	--	---	---	---
H 8	23	15.9	7.1	23.0
H 9	27	23.5	3.0	26.5
H 10	45	19.3	7.1	26.4
H 11	15	14.6	15.4	30.0
H 12	--	---	---	---
H 13	24	---	---	---
H 14	--	---	---	---
H 15	21	10.3	11.0	21.3
H 16	15	20.3	2.1	22.4
H 17	32	24.2	2.1	26.3
H 18	23	21.2	2.0	23.2
H 19	--	---	---	---
H 20	19	0.72	---	---
H 21	--	---	---	---
H 22	--	---	---	---
H 23	15	5.8	10.6	16.4
H 24	11	15.5	12.9	27.4
H 25	18	11.2	6.5	17.7
H 26	--	---	---	---
H 27	--	---	---	---
H 28	--	---	---	---
H 29	23	7.1	5.8	12.9
H 30	17	16.6	3.3	19.9
H 31	28	15.9	5.2	21.1
H 32	--	---	---	---
H 33	--	---	---	---
H 34	20	20.4	3.9	24.3

THICKNESS OF ORE AND ASSAYS OF DIAMOND DRILL
HOLES AT THE SULPHURDALE OREBODY
(Continued)

<u>Drill Hole No.</u>	<u>Feet of Ore</u>	<u>Weighted Assays</u>		
		<u>Per Cent Sulphur</u>	<u>Per Cent Sulphide Sulphur</u>	<u>Per Cent Total Sulphur</u>
H 35	19	24.7	2.6	27.3
H 36	16	21.2	4.0	25.0
H 37	22	22.0	7.1	29.1
H 38	12	9.5	5.3	14.8
H 39	15	12.2?	11.2?	23.4?
H 40	--	---	---	---
H 41	--	---	---	---
H 42	--	---	---	---
H 43	--	---	---	---
H 44	--	---	---	---

THICKNESS OF ORE AND ASSAYS OF DIAMOND DRILL HOLES
AT THE VICTOR CONQUEROR OREBODY

Weighted Assays

<u>Drill Hole No.</u>	<u>Feet of Ore</u>	<u>Per Cent Sulphur</u>	<u>Per Cent Sulphide Sulphur</u>	<u>Per Cent Total Sulphur</u>
V 1	41	19.0	3.5	22.5
V 2	30	9.6	0.6	10.2
V 3	33	8.4	0.2	8.6
V 4	36	5.2	7.6	12.8
V 5	22	7.3	1.5	8.8
V 6	40	13.6	0.2	13.8
V 7	42	16.5	0.2	16.7
V 8	20	8.0	0.2	8.2
V 9	56	15.0	0.5	15.5
V 10	28 +	---	---	---
V 11	40 +	---	---	---
V 12	28 +	---	---	---
V 13	58	15.6	0.2	15.8
V 14	23	23.1	0.2	23.3
V 15	43	6.3	0.6	6.9
V 16	32	21.4	0.2	21.6
V 17	33	17.2	0.4	17.6
V 18	37	30.4	0.3	30.7
V 19	35	15.6	0.3	15.9
V 20	36	15.2	0.2	15.4
V 21	42	9.7	0.2	9.9
V 22	48	8.7	0.2	8.9
V 23	45	8.5	0.2	8.7
V 24	57	6.4	1.5	7.9
V 25	--	---	---	---
V 26	--	---	---	---
V 27	--	---	---	---
V 28	40	4.4	2.3	6.7
V 29	35	4.0	0.9	4.9
V 30	--	---	---	---
V 31	--	---	---	---
V 32	--	---	---	---
V 33	39	5.9	0.5	6.4
V 34	30	16.3	0.2	16.5
V 35	54	18.0	0.3	18.3
V 36	23	16.0	0.3	16.3
V 37	42	7.0	0.4	7.4
V 38	20	16.9	0.2	17.1
V 39	22	25.6	0.4	26.0
V 40	15	22.6	0.9	23.5
V 41	45	16.0	0.4	16.4
V 42	51	33.2	0.5	33.7
V 43	16	25.1	0.3	25.4
V 44	23	3.5	0.5	4.0

THICKNESS OF ORE AND ASSAYS OF DIAMOND DRILL HOLES
AT THE SULPHUR KING OREBODY

<u>Drill Hole No.</u>	<u>Feet of Ore</u>	<u>Weighted Assays</u>		
		<u>Per Cent Sulphur</u>	<u>Per Cent Sulphide Sulphur</u>	<u>Per Cent Total Sulphur</u>
K 1	57	36.4	0.5	36.9
K 2	32	---	---	---
K 3	47	33.0	0.9	33.9
K 4	--	---	---	---
K 5	--	---	---	---
K 6	35	28.7	2.0	30.7
K 7	47	19.7	0.9	20.6
K 8	30	18.3	0.2	18.5
K 9	--	---	---	---
K 10	52	19.6	0.5	20.1
K 11	16	---	---	---
K 12	--	---	---	---
K 13	--	---	---	---
K 14	--	---	---	---
K 15	--	---	---	---
K 16	--	---	---	---
K 17	10	14.0	1.5	15.5
K 18	--	---	---	---
K 19	--	---	---	---
K 20	--	---	---	---
K 21	--	---	---	---
K 22	31	20.0	10.0	30.0