UTAH GEOLOGICAL AND MINERALOGICAL SURVEY
affiliated with
THE COLLEGE OF MINES AND MINERAL INDUSTRIES
University of Utah, Salt Lake City, Utah

GEOLOGY OF SALT LAKE COUNTY

BULLETIN 69 • PRICE $2.50 • NOVEMBER, 1964

1896

UTAH GEOLOGICAL AND MINERALOGICAL SURVEY

103 Civil Engineering Building
University of Utah
Salt Lake City, Utah 84112

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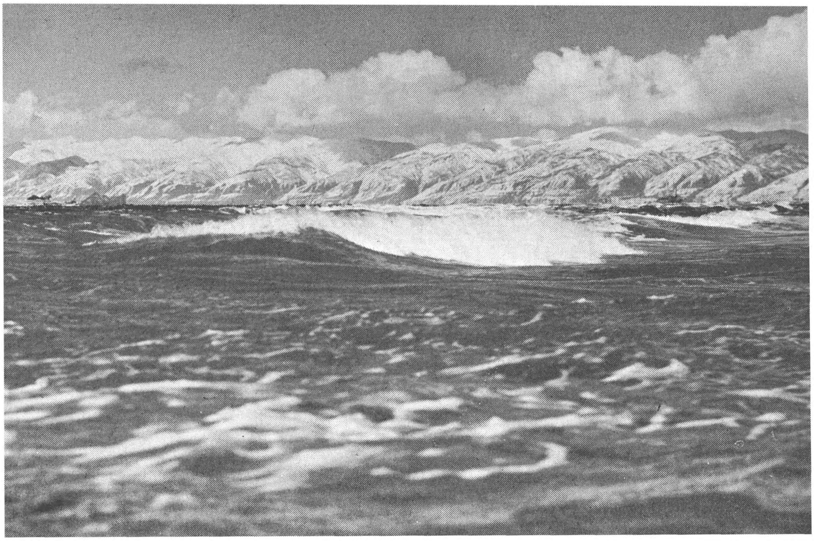
DIRECTORS:

William P. Hewitt, 1961-
Arthur L. Crawford, 1949-1961

GEOLOGY OF SALT LAKE COUNTY



Storm waves on Great Salt Lake. View looking easterly toward the Wasatch Mountains. Note various wave-cut Bonneville terraces at base of range. Saltair is at center left; former sodium-sulphate plant is at right center. (Photograph taken in late 1930's—courtesy Clyde Anderson)

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FOREWORD

Compiled and edited by Arthur L. Crawford, this volume was first planned in 1955. Then in 1960 it was suggested that the enclosed map (back pocket) be exhibited at the International Geographical Union convention to be held in Stockholm in August of that year. In order to meet necessary deadlines, compilation of the text was delayed, and energies were devoted to the production of the map which was exhibited at the convention. The Utah Geological and Mineralogical Survey regrets that in meeting the 1960 deadline the names of those who generously contributed field notes for the production of the map were omitted. Among those thus slighted were:

M. M. Bell
J. M. Boutwell
F. C. Calkins
M. D. Crittenden
A. J. Eardley
A. E. Granger
H. C. Lambert
R. E. Marsell
B. J. Sharp
L. W. Slentz
R. L. Threet

It is with deep appreciation that the Utah Geological and Mineralogical Survey acknowledges their help, the significant financial contributions from the University of Utah's Research Fund which permitted the printing of the map, and the interest and patience of the contributors to the text.

William P. Hewitt
Director

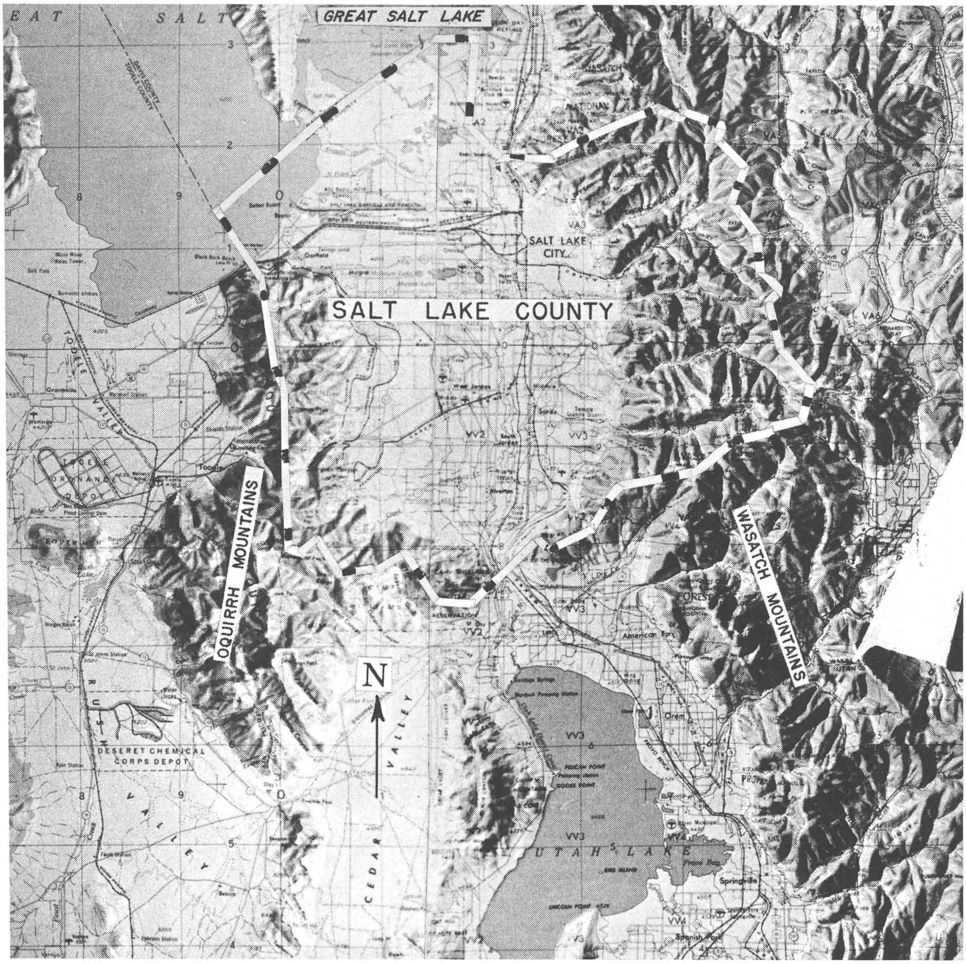

Figure 1. Physiographic Map of Salt Lake County Area. (Photograph from Army Map Series Relief Maps—courtesy Salt Lake Tribune)

SECTION I –

GENERAL GEOLOGY OF SALT LAKE COUNTY

by Max D. Crittenden, Jr.[2]

INTRODUCTION

The wealth and variety of geologic features to be found in Salt Lake County are, for an area its size, probably unexcelled anywhere in the world. Its layered rocks record events spanning more than a billion years: within an hour one can see deposits formed by ancient glaciers at a time when life had not yet evolved sufficiently to yield abundant fossils; redbeds laid down in wind-swept deserts or in fringing swamps, when giant reptiles dominated both land and sea; areas that have had a classic place in the evolution of our ideas about mountain building; or the effects of Pleistocene glaciation or of Lake Bonneville, the fresh-water lake whose shorelines are carved on the mountain slopes a thousand feet above Great Salt Lake. To these may be added a bewildering array of igneous rocks, both intrusive and extrusive, and metal deposits which have led to the development of several major mines, among them the world's largest open-pit copper mine.

The following description, though containing many technical terms, is not designed for the professional geologist; rather it is hoped that it will arouse the interest of anyone who is curious about the way the earth was formed and about the way our knowledge of it is derived. Above all, it is hoped that this account will convey some of the excitement that comes from a comprehension of the vastness of geologic time, and will give new meaning to the awesome beauty of mountain and desert with which we are surrounded.

Although every effort has been made to give credit to those whose work has been used, both the space available and the nature of the account make it impossible to document the source of each piece of information or to fully separate elements that are purely factual from those that involve considerable speculation. For these shortcomings the writer can only beg the indulgence of his colleagues. To those interested in following further one of the many topics that are mentioned briefly or perhaps only hinted at, the references will provide at least a starting point.

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1. Publication authorized by the Director, U.S. Geological Survey.
2. Geologist, U.S. Geological Survey, Menlo Park, California.

TABLE I

MAJOR SUBDIVISIONS OF GEOLOGIC TIME

Era	Period	Epoch	Estimated ages of time boundaries in millions of years*
Cenozoic	Quaternary	Recent	
		Pleistocene	1
	Tertiary	Pliocene	13
		Miocene	25
		Oligocene	36
		Eocene	58
		Paleocene	63
Mesozoic	Cretaceous	Late	90
		Early	135
	Jurassic	Late	
		Middle	
		Early	181
	Triassic	Late	
		Middle	
		Early	230
Paleozoic	Permian	Late	
		Early	280
	Carboniferous systems Pennsylvanian	Late	
		Middle	
		Early	
	Mississippian	Late	
		Early	345
	Devonian	Late	
		Middle	
		Early	405
	Silurian	Late	
		Middle	
		Early	425
	Ordovician	Late	
		Middle	
		Early	500
	Cambrian	Late	
		Middle	
		Early	600 ?
Precambrian		Younger	
		Older	3,000+

* Dates from Kulp, 1961

THE MEASUREMENT OF GEOLOGIC TIME

Since man first gazed at the stars, he has wondered about the age of the earth. At first, guided only by his senses and by unwritten legend, a few thousand years seemed long enough. Thus Archbishop Usher concluded in 1654 that the earth was created in 4004 B.C., and this figure was not seriously challenged for nearly 200 years.

But as man's knowledge of the earth increased, and as he began to use observation as a means of learning about the past, geologists came to recognize that the thousands -- indeed hundreds of thousands -- of feet of rocks they saw exposed could not have been deposited in so short a time. Similarly, biologists recognized that the astonishing changes in animal life recorded in these rocks could not have taken place so quickly. One of the first attempts to estimate the age of the earth by actual measurement was based on the reasoning that the salt content of the sea could be compared with the annual salt increment added by the rivers of the earth to yield a figure in years for the age of the seas. The value of 90 to 100 million years obtained from this calculation was a vast leap from Archbishop Usher's estimate, but it was still far short of reality.

The discovery of radium by Mme. Curie in 1898 led scientists almost at once to recognize that uranium, changing to lead by radioactive decay, constitutes an atomic clock from which the age of the uranium-bearing mineral could be determined. By 1907, this "uranium-lead" method, as it came to be called, had been used to show that a uranium mineral from Connecticut was 410 million years old; another from Ceylon was found to be more than 2 billion years old. The disadvantage of this method was that suitable uranium minerals are rare, and dates therefore could be obtained from only a few scattered localities throughout the world. Today, however, the techniques associated with the development of atomic energy make it possible to measure the minute quantities of other radioactive elements present in ordinary rocks and minerals. The "potassium-argon" method, for example, can be used on any rock containing biotite and on many containing hornblende, feldspar, or volcanic glass. By means of these and other "atomic clocks", a widely accepted scale of geologic time has been built up for the earth. The subdivisions of geologic time commonly used by geologists and the dates associated with them are shown in Table I. These dates, used throughout the text, are based on an article by Kulp (1961) in Science magazine. The reader interested in a less technical account is urged to consult his local library or an article by Knopf (1957) in Scientific Monthly.

THE RECORD OF LAYERED ROCKS

Rocks of Precambrian Age

THE OLDEST ROCKS

Rocks more than a billion years old are exposed in two small areas of Salt Lake County. A unit called the Farmington Canyon Complex of Eardley and Hatch (1940) crops out at the north edge of the Salt Lake County map on the slopes of City Creek Canyon and extends northward outside the map area toward Bountiful Peak and Ogden. It consists of ancient sediments now transformed to gneiss and schist by regional metamorphism (the effects of high temperature and pressure associated with deep burial). During their recrystallization, these gneissic rocks were invaded and "soaked" by solutions from which grew coarse-grained glassy quartz and salmon-pink feldspar. The age of these rocks has been determined, by study of some of their radioactive components, to be at least 1,580 million years (Giletti and Gast, 1961; Odekirk, 1962).

A second group of old rocks, called the Little Willow Formation (formerly series), is exposed in the steep narrow canyon of that name on the front of the Wasatch Range just north of Little Cottonwood Canyon. The most abundant rocks in this formation are white, tan, or pale greenish-gray gneissic quartzite, and brown or dark greenish-gray schist derived from sandy shale or siltstone. Locally these beds contain pebbles or cobbles, which have been stretched and flattened to a lenticular or even spatulate shape. After they were laid down, but before they were folded, the sediments were invaded by thick sills and dikes of dark-colored igneous rock, probably diabase or gabbro. These are now converted to amphibolite, a dark-green to nearly black sheared rock consisting of hornblende and chlorite. While deeply buried, the Little Willow rocks were subjected to strong folding and recrystallization. As a result, the layers now are nearly vertical, and trend northeast almost at right angles to the rocks that overlie them. The age of the Little Willow Formation has not been determined, but similar rocks along the Green River at the east end of the Uinta Mountains were folded and recrystallized at least 2.3 billion years ago (Hansen, 1963).

YOUNGER PRECAMBRIAN ROCKS

Big Cottonwood Formation: The oldest rocks that still preserve most of their original sedimentary features are a 16,000-foot sequence of quartzites and shales called the Big Cottonwood Formation. They are well exposed in the spectacular lower gorge of Big Cottonwood Canyon, for which they were named. The quartzites range from pinkish or white near the base, though greenish or gray in the medial part near Storm Mountain, to white or tan near the top in the vicinity of Mill B South Fork; all of them tend to weather to a rusty brown in places, but still they are lighter colored and much more massive than the interbedded shales. The latter are bluish gray or bluish purple near the base, gray or rusty brown in the medial part, and greenish or red-purple near the top. Ripple marks, crossbedding, mudcracks, and shale flake conglomerates are present throughout, indicating that the entire sequence was deposited in shallow water or on mud flats that were intermittently exposed to the air. The base of the formation rests on a smooth erosion surface, and the lowest beds contain rounded cobbles and abundant angular debris of the more highly metamorphosed rocks below.

The Big Cottonwood Formation (Figure 2) is virtually free from the effects of regional metamorphism; the most sensitive rocks, the shales, still contain original flakes of mica, and except where they have been affected by contact metamorphism related to the intrusion of the Little Cottonwood stock, do not show widespread shearing or recrystallization. In close proximity to the north edge of the stock, near the head of Mill B South Fork and Stairs Gulch, they are converted to dark-colored, dense, fine-grained rocks called hornfelses that contain andalusite, an aluminum silicate; along the western edge of the stock, near the mouth of Big Cottonwood Canyon and on the slopes of Little Willow Canyon to the south, they are converted to lustrous blue-gray schist.

Mineral Fork Tillite: The name Mineral Fork Tillite was given to an assemblage of dark-colored rocks that crop out in and near Mineral Fork of Big Cottonwood Canyon. The major component is a massive black or dark gray rock, consisting of boulders, cobbles, and pebbles of quartzite, limestone, or granitic rocks scattered through a matrix of angular sand-size fragments. This rock is believed to be tillite, an ancient indurated glacial deposit. Smaller amounts of varved shale, bedded sandstone, and ordinary conglomerate are present also.

The Mineral Fork Tillite was deposited in two apparently east-trending basins, a northern one about 1,300 feet deep, now exposed in Mill B North Fork of Big Cottonwood Canyon, and a southern one about 2,800 feet deep in Mineral Fork (Figure 3). These are broad smooth-bottomed basins scooped out of the upper surface of the underlying Big Cottonwood Formation; the great thickness of the deposits can be verified by direct measurement of the tillite and by measurement of the thickness of shale and quartzite cut out below the unconformity.

The glacial origin of this unit was suspected by Hintze (1913) and was elaborated upon by Blackwelder (1932). The best evidence is an abundance of soled, faceted, and striated cobbles in some outcrops; supporting evidence is obtained from the character of the underlying surface, which shows elongate rounded "roches moutonnées" (sheep back) forms. No fossil striae (grooves or scratches made by ice) have been found. The black color, which is due to a small percentage of carbon, is characteristic of Precambrian tillite in many other parts of the world. Rocks that are correlated with the Mineral Fork Tillite are exposed in small scattered areas from the Sheep Rock Mountains (Cohenour, 1959, p. 19), about

Figure 2. View of north wall of Little Cottonwood Canyon. Lower slope is jointed "granite" of Little Cottonwood stock; ridge crest, including Twin Peak and Dromedary Peaks, is Big Cottonwood Formation. North end of Oquirrh Mountains and Great Salt Lake in distance.

fifty miles southwest of Salt Lake City, to the vicinity of Pocatello, Idaho (Ludlum, 1942).

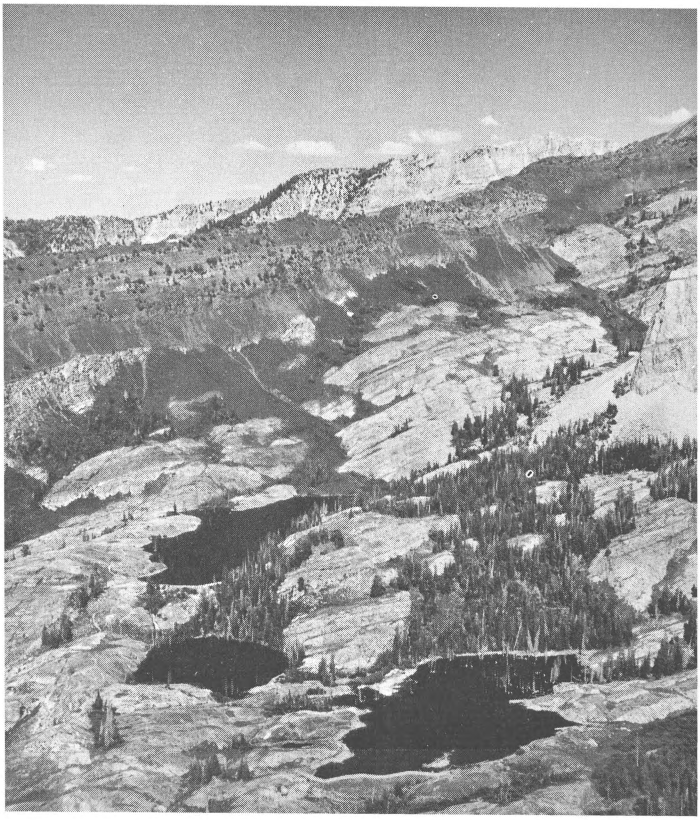

Figure 3. View east across lakes at head of Mill B South Fork showing glaciated rocks of Big Cottonwood Formation (light-colored, foreground) and Mineral Fork Tillite (forming dark ridge). (See also Figure 29.)

Mutual Formation: The youngest Precambrian rocks in this area are grayish-red or purplish-red quartzite and shale called the Mutual Formation. Where this unit reaches the mountain front west of Mount Olympus, it is about 1,200 feet thick, and its lowest beds, which here are quartzite, rest with apparent conformity (without evidence of tilting or erosion) on the highest shale of the Big Cottonwood Formation. To the east, however, the Mutual rests on the tillite of the northern basin, and here it is evident that there was erosion both before and after deposition of the tillite because the Mutual Formation coarsens abruptly, first to pea-size grit, then to cobble conglomerate, and finally in the cliffs east of Mineral Fork to bouldery conglomerates containing blocks up to 10 feet long of the underlying tillite.

<u>Age and Correlation of Younger Precambrian Units</u>: The age of the Big Cottonwood and Mutual Formations and the intervening tillite can only be designated as younger than 1,500 million years and greater than the 600-million-year age generally assigned to the base of the Cambrian. It seems fairly certain that these rocks as a group correlate with much of the Uinta Mountain Group; they are nearly identical in lithology and both have a sequence of grayish-red rocks (Mutual Formation) at the top (Williams, 1953, p. 2737); the tillite has not been recognized in the Uinta Mountains, however. Correlation with similar rocks at greater distances such as the Belt Series of Idaho and Montana is logical, but much more speculative.

Regional Unconformity at the Base of the Palezoic

Following deposition of the Mutual Formation, the area was gently tilted and was eroded to a smooth featureless plain. The erosion surface thus formed bevels the gently tilted layers of rock deposited earlier, and when younger rocks are finally laid down on the surface, they too seem to truncate the underlying rocks. The resulting discordance in the stratigraphic section is called an "unconformity" (Figure 4). One such unconformity --

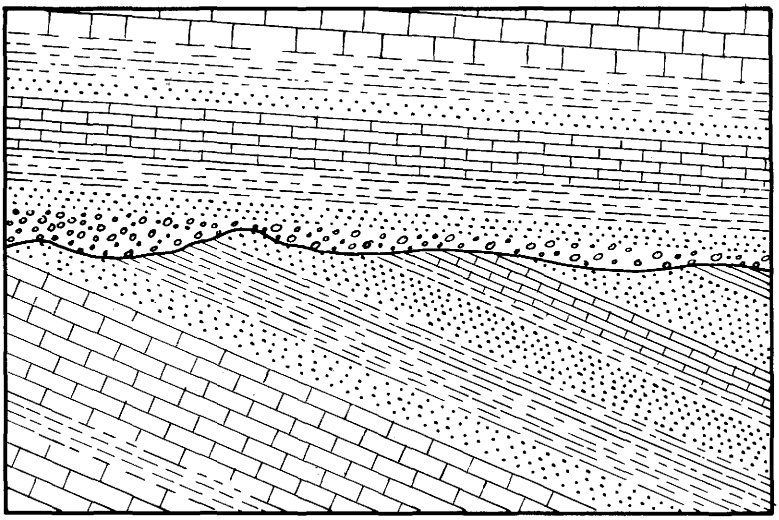

Figure 4. Angular unconformity between two sets of strata. The lower and older rocks were uplifted and tilted at a moderate angle, then eroded. The area was later submerged and a new series of rocks was laid down on the eroded surface. Both the erosion surface and the enclosing rocks now dip at a low angle due to later tilting or folding.

now tilted to an angle of about 60 degrees -- can be seen high on the western face of Mount Olympus, where erosion, preceding the deposition of the Cambrian sediments, truncated at a low angle the beds of the Mutual Formation. On the north slopes of City Creek Canyon this same surface is cut on the Farmington Canyon Complex, the eroded roots of an ancient mountain range. The time interval represented by this erosion surface may have been as great as that between the appearance of the first well-formed life on earth and the present. Eventually, however, the area subsided beneath a vast sea that encroached slowly from the west, bringing, as its first deposits, cleanly washed coarse gravel composed mainly of resistant rocks. This sea, which gradually deepened and became more extensive, persisted here or nearby for nearly 400 million years.

The Cordilleran Geosyncline

During much of the Paleozoic Era (about 600 million to about 225 million years ago) the site of Salt Lake County lay beneath a vast inland sea. The position of the shoreline varied -- sometimes it was nearby, sometimes as far east as Colorado; a chain of volcanic islands in central Nevada and at times extensive chains of mountains separated this sea from the Pacific Ocean. Although water extended continuously across the whole area, the site of Salt Lake City was near a hinge line that separated two quite different provinces: to the west lay a long narrow depositional trough, the Cordilleran geosyncline, which extended from Mexico into Canada. The floor of this trough subsided steadily, permitting sediments to accumulate over large areas to a thickness of more than two miles, and in places to as much as eight miles. East of the hinge line the sea extended across a relatively stable platform that subsided only a few thousand feet during the same time.

The kind of sediment that accumulated depended on the distance from the shoreline and on the type of material being brought in by streams. When the shoreline was nearby, sand and mud derived from the land were dominant -- the Tintic Quartzite which forms the top of Mount Baldy above Alta is such a deposit. When the shoreline was distant, the only materials to accumulate were the limy shells of the animals that teemed in the shallow seas. Gray limestones formed in this way are exposed in the cliffs of the Devils Castle, at the head of Little Cottonwood Canyon and near the mouth of Mill Creek Canyon.

Following is a brief description of the rocks laid down in the Cordilleran trough during the Paleozoic Era (Cambrian through Permian).

Rocks of Cambrian Age

The first deposits of the encroaching Cordilleran seas were almost pure quartz-sand. They accumulated to a thickness of a thousand to three thousand feet, and now form the Tintic Quartzite. As the seas deepened and the shoreline receded eastward, the deposition of sand gave way to mud and finally to calcareous ooze. These materials are now represented by the shale and thin limestones of the Ophir Formation (400 feet thick) and the Maxfield Limestone (absent to 1,000 feet thick). In the area near Salt Lake City the transition from sand to mud took place in Middle Cambrian time, perhaps 550 million years ago.

Regional Unconformity of Late Devonian Age

Although deposition continued for many millions of years and many thousands of feet more of calcareous ooze accumulated in the parts of the basin now exposed both south and north of the area near Salt Lake City, the sedimentary record in this area was interrupted by uplift and erosion. This uplift produced a west-trending peninsula which may have been much like the present Uinta Mountains were they to be surrounded by a broad shallow sea. This uplift extended westward from the Uinta Mountains through Salt Lake City to at least 30 or 40 miles beyond the Stansbury Mountains. As soon as the rocks were uplifted above the sea, they were attacked by the elements, and sediment -- at first coarse conglomerate, later sandstone -- accumulated in the surrounding seas. These coarse sediments, the Stansbury Formation of Stokes and Arnold (1958), record the sharp initial uplift, which took place in Late Devonian time, some 360 million years ago.

Within a short time by geologic standards, seas once more spread across the area, and, following a thin accumulation of calcareous mud (now represented by the Pinyon Peak Limestone and lower part of the basal Mississippian limestone of the map), the deposition of fairly clean calcareous ooze was resumed.

Rocks of Mississippian Age

Throughout most of the Mississippian Period deposition of limy materials continued at a relatively uniform rate over much of northern Utah. Dark-gray fossiliferous limestone or dolomite formed during this time make up most of the Gardison (formerly Madison) and Deseret Limestones, which total about 1,000 feet thick; similar rocks interbedded with sandstone form the overlying Humbug Formation.

Rocks of Late Mississippian Age through Early Permian Age

From Cambrian through Early Mississippian time, conditions were similar over the shelf and basin areas, and as a result, the same rock formations are recognizable in both. Beginning in the Late Mississippian, however, and until Late Permian time when conditions again stabilized, rock units of identical age in the two areas show marked differences, particularly in thickness. In the Oquirrh Mountains, for example, rocks between the top of the Humbug Formation and the base of the Park City

Formation are as much as ten times as thick as rocks in that same interval in the Wasatch Range immediately to the east. In recognition of these differences, the thicker rocks to the west are informally called the Oquirrh Mountains facies; the thinner rocks to the east are informally called the Weber Canyon facies. The extent of the Oquirrh Mountains facies in northwestern Utah is approximately that shown in a ruled pattern on Figure 6. As that figure indicates, the rocks of the Weber Canyon facies were deposited essentially where they are now, whereas the rocks of the Oquirrh Mountains facies were deposited some tens of miles west of their present location and were transported bodily eastward by earth movements.

WEBER CANYON FACIES

In the Wasatch Range north of its junction with the Traverse Mountains, the time interval between the Late Mississippian (about 300 million years ago) to Early Permian (about 275 million years ago) is represented by about 2,200 feet of rocks. Beginning at the base, these are: the Doughnut Formation (Late Mississippian, 300 feet thick), consisting of dark shale and limestone; the Round Valley Limestone (Early Pennsylvanian, 400 feet thick) -- designated the Morgan Formation on the map of Salt Lake County (in pocket) and by Calkins and Butler (1943, p. 28-29) -- consisting of pale-gray limestone with characteristic salmon-pink chert and silicified fossils; and the Weber Quartzite (Middle Pennsylvanian, 1,500 feet thick), consisting of interbedded cherty limestone, limy quartzite in the lower part and mainly vitreous white quartzite in the upper part.

OQUIRRH MOUNTAIN FACIES

In the Oquirrh Mountains, the Traverse Mountains, and the Wasatch Range south of the head of Dry Canyon and Deer Creek (Utah County), the Oquirrh Mountains facies comprises the following sequence of formations: the Great Blue Limestone (Late Mississippian and averaging 2,500 to 2,800 feet thick), consisting of dark-gray fossiliferous limestone and less abundant shales; the Manning Canyon Shale (Late Mississippian in the lower part and Early Pennsylvanian in the upper part, 1,500 to 2,000 feet thick), consisting of black shale, thin-bedded dark-gray limestone, and rusty-weathering thin beds of sandstone; the Oquirrh Formation (Early Pennsylvanian to Early Permian, and ranging from 12,000 to more than 20,000 feet thick), consisting of interbedded limestone and limy quartzite in the lower part and interbedded tan to white limy to vitreous quartzite in the upper part; the Kirkman Limestone (Early Permian, absent to 1,600 feet thick), consisting of pale-gray-weathering, laminated or brecciated limestone; and, at the top, the Diamond Creek Sandstone (Early Permian, absent to 1,000 feet thick), consisting of gray, red, or buff fine- to coarse-grained crossbedded sandstone thought to be at least locally of windblown origin. Local variations in lithologic succession within the Oquirrh Mountains facies permit subdivision into at least two distinct subgroups of rock -- the Bingham and Rogers Canyon sequences.

Bingham Sequence: Recent geologic studies in the Oquirrh Mountains have shown that the rocks of the central area near Bingham (Welsh and James, 1961) are different in thickness and to a smaller extent in character from those at the northern end (Tooker and Roberts, 1961). Analysis of these differences has led Tooker and Roberts (1963) to designate the rocks of the central part as the Bingham sequence. This sequence includes all the formations of the Oquirrh facies, though temporal equivalents of the Kirkman Limestone and Diamond Creek Sandstone (not shown separately on Salt Lake County map) do not show their characteristic lithology.

The thickness of beds in the Bingham sequence between the Humbug Formation and the base of the Park City Formation amounts to about 22,000 feet. It is thus about ten times as thick as the rocks of the same interval in the Weber Canyon facies, but not as thick as those of the area east of Mount Timpanogos (Baker, 1947). Limestones of the Bingham sequence are locally replaced by ore in the underground mines west of Lark.

Rogers Canyon Sequence: In the northern part of the Oquirrh Mountains, the rocks between the top of the Humbug Formation and the base of the Park City Formation are only about 10,000 feet thick; they include at the base some anomalous beds which have the appearance of the lower part of the Oquirrh Formation in the sequences to the south, but contain Mississippian fossils. The fact that these rocks are somewhat thinner and are resting on a thrust plate that dips north and northwest has led Tooker and Roberts (1963) to conclude that this sequence is in some degree intermediate between the thickest part of the Oquirrh Mountains facies and the thin units of the Weber Canyon facies.

Park City Formation

In both the Wasatch Range and the Oquirrh Mountains, the disparate units of the two facies are overlain by rocks of the Park City Formation (Early Permian). This unit is well exposed near the mouth of Mill Creek Canyon southeast of Salt Lake City, where it is about 850 feet thick, and in Coon Canyon in the Oquirrh Mountains, where it is 750 feet thick. Limestones in the lower part of this unit contained some of the rich bodies of ore mined at Park City in the early days of that camp. The medial part of the formation is shale containing beds of phosphorite and is regarded as a tongue of the Meade Peak Phosphatic Shale, of the Phosphoria Formation. The presence of phosphorite in these rocks indicates a period of marked crustal stability in sharp contrast to the rapid subsidence that characterized the period immediately preceding.

Rocks of Triassic Age

The Triassic Period, beginning about 225 million years ago, brought to an end the prolonged period during which the area of Utah and adjoining states lay beneath the sea. As a result of a broad emergence, the area near Salt

Lake City became part of a semiarid flood plain on which brilliant red or purple mud and silt accumulated, forming the Woodside and Ankareh Formations, which are so strikingly exposed immediately east of Salt Lake City, particularly in Red Butte Canyon and at the mouth of Parleys Canyon. These same rocks, given different names (Moenkopi, Shinarump, and Chinle), are known over wide areas of southeastern Utah, and show that these same conditions persisted over much of the western part of the continent. During the Early Triassic, in the midst of this Period, the sea temporarily transgressed eastward, reaching perhaps halfway to the present site of the town of Vernal, and deposited limy muds and sand that constitute limestone of the Thaynes Formation. Fossils of distinctive coiled shellfish that characterized these seas were found in abundance in one place east of the University of Utah and gave their name to Cephalopod Gulch. In all, some 2,500 feet of rocks accumulated during this Period. The names currently applied to these rocks by the U.S. Geological Survey and those shown on the map are indicated in Table II.

TABLE II

NOMENCLATURE OF TRIASSIC ROCKS NEAR SALT LAKE CITY, UTAH

Used in Text		Salt Lake County Map (in pocket)	Probable Correlatives in Southeastern Utah
Ankareh Fm.	Stanaker Mbr.	Chinle Formation	Upper members of Chinle Formation.
	Gartra Grit Mbr.	Shinarump Formation	Basal conglomeratic sandstones, such as Shinarump and Moss Back Members of Chinle Formation.
	Mahogany Mbr.	Ankareh Shale	Moenkopi Formation
Thaynes Formation		Thaynes Limestone	
Woodside Formation		Woodside Shale	

Rocks of Jurassic Age

Conditions of aridity which may have continued from Triassic into the Period designated Jurassic (beginning about 180 million years ago) resulted in the accumulation of thick deposits of pale-orange windblown sand (Nugget Sandstone, about 800 feet thick), which forms the upper slope of the large roadcuts just north of the mouth of Parleys Canyon. Thin slabby layers of this rock, locally bleached white, have been quarried from many places between there and Park City and have been used extensively for building stone. In southeastern Utah the corresponding unit is called the Navajo Sandstone.

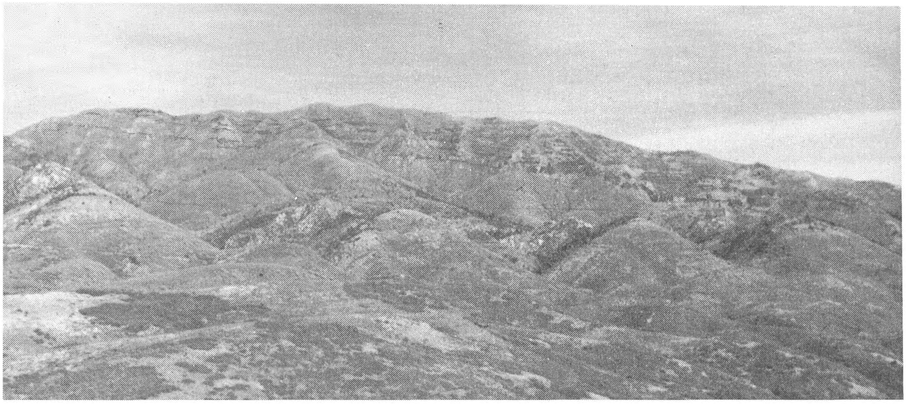

Figure 5a. Horizontally bedded Tertiary conglomerates (Knight Formation) in skyline ridge, overlying steeply dipping Mesozoic sediments that are exposed in middle distance as hogback ridges. View looking northerly from Little Mountain. (Courtesy Richard Tolman)

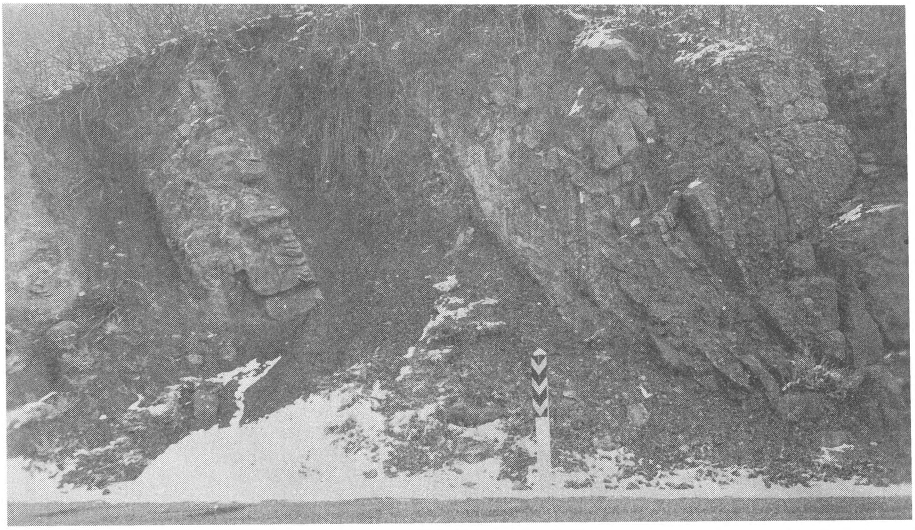

Figure 5b. Steeply dipping Mesozoic sediments (Kelvin Formation) as seen in road cut at head of Emigration Canyon. View looking easterly from left center of Figure 5a.

Beginning perhaps 150 million years ago, in Middle and Late Jurassic time, seas once more invaded this area from the west, depositing limy ooze and mud that now constitute the Twin Creek Limestone. This unit forms pale-gray twisted craggy outcrops along the north slope of Parleys Canyon beginning about a mile east of the canyon mouth, in and around the quarries where it is mined for the manufacture of cement, and extending east to the dam at the Mountain Dell Reservoir. During the waning stages of this marine epoch, dark-red mud, now the red shale of the Preuss Sandstone (Imlay, 1952), accumulated in salty estuaries or lagoons.

Rocks of Cretaceous Age

A distinctive unit about 100 feet thick consisting of white nodular limestone and lavender shale called the Parleys Member of the Kelvin Formation (Crittenden, 1963) is now regarded as of Early Cretaceous age (135 million years). It is well exposed about three miles up Emigration Canyon, on the ridge north of Mountain Dell Reservoir, and in roadcuts about a mile west of Parleys Summit. This unit was earlier (Granger and Sharp, 1952; Granger, 1953) regarded as a possible correlative of the Morrison Formation of southeastern Utah, but the Morrison is not believed to extend west of Peoa.

The upper member of the Kelvin Formation is a 1,500-foot unit consisting of pale-red to reddish-brown siltstone and sandstone interbedded with beds of coarse conglomerate. These coarse sediments give the first direct evidence of earth movements, probably mainly to the west and south. These movements, though they resulted in coarse debris being shed into the area of the Wasatch Range, did not produce enough tilting to be measurable here.

The redbeds of the Kelvin give way upward to pale-tan or yellowish-brown sandstones that constitute the Frontier Formation. These rocks were probably mainly deposited by streams near the edge of an inland sea that this time lay to the east. Beds of coal formerly mined near Coalville record the position of coastal swamps.

UNCONFORMITY AT THE TOP OF THE FRONTIER FORMATION

Following the deposition of the Frontier Formation, perhaps 85 to 90 million years ago, the sea was pushed from this area for the last time. Rugged folded mountains now stood to the west, and uplift and folding, formerly distant, now began to affect this area directly. As a result the rocks deposited earlier, which up to this time had only been gently tilted from their original position, were bent into folds in which the beds dipped from 10 or 20 degrees to vertical. Erosion took place simultaneously until the mountains that resulted from the pulse of uplift were reduced to a lowland which was later covered by the succeeding coarse conglomerates. This unconformity is to be seen at the head of Mountain Dell and Emigration Canyons (Figure 5).

WANSHIP FORMATION OF WILLIAMS AND MADSEN (1959)

Lying unconformably on the upturned edges of rocks at least as old as the Twin Creek is a body of coarse conglomerate whose cobbles and boulders consist mainly of sandstone of the underlying Frontier Formation, with smaller amounts of Oquirrh or Weber Quartzite and limestone of Carboniferous age. This unit, originally designated Cretaceous (?) conglomerate by Granger and Sharp (1952, p. 15), is inferred to be a correlative of similar coarse rocks that Williams and Madsen (1959, p. 123) have named Wanship for their outcrops on the Weber River about 15 miles to the east. No fossils have been found in these rocks in Salt Lake County, but if Williams' correlation is correct, these rocks are of medial Late Cretaceous age (about 85 million years old).

A second unconformity separates the rocks of the Wanship from a younger conglomerate, which is distinguished because it contains a much higher percentage of limestone boulders and also contains boulders of Precambrian or Tintic quartzites, which are conspicuously lacking in the Wanship. Originally this unit was designated the Almy(?) Conglomerate by Granger and Sharp (1952, p. 16) and simply Tertiary conglomerate No. 1 by Granger (1953). Because of its stratigraphic position, it is tentatively correlated with the Echo Canyon Conglomerate of Williams and Madsen (1959, p. 123) and is combined with the Wanship on the Salt Lake County map.

UNCONFORMITY AT BASE OF KNIGHT CONGLOMERATE

A third unconformity, the one representing the most intense deformation, separates rocks that are presumed to be Cretaceous from those that are presumed to be Tertiary. In exposures near the head of Emigration Canyon, the rocks below stand steeply or locally have been tilted past the vertical, whereas the overlying Knight Conglomerate, resting on an erosion surface that bevels smoothly across the whole area, dips gently eastward and northward (Figure 5a). Although there undoubtedly were rugged highlands to the west on which these conglomerates were deposited, the surface on which they were deposited in Emigration Canyon was relatively flat. The interval of mountain building and erosion represented by this unconformity was not long by geologic standards (probably not more than a few million years), but its significance as measured by the amount of uplift and erosion that took place is probably greater than any other. The combined effects of this and earlier uplifts were sufficient to remove from the area near Bountiful Peak all of the sediments deposited since the Cambrian and to permit the Knight Conglomerate to rest directly on older Precambrian rocks. The cumulative uplift required to accomplish this amounts to more than 25,000 feet, almost the height of Mount Everest.

Rocks of Tertiary Age

TERTIARY LIMESTONE

On the Salt Lake Salient (Figure 7) there are outcrops of poorly consolidated red sandstone, sandy limestone, and water-laid tuff, with some interbedded pale-gray limestone. In City Creek similar beds are associated with andesitic volcanics. Until clear fossil evidence is forthcoming, the exact age of these rocks is uncertain, but they occupy the same position as the Evanston Formation (latest Cretaceous and Paleocene) of southwestern Wyoming and the Flagstaff Limestone (Paleocene and Eocene ?) of central Utah.

KNIGHT CONGLOMERATE

Overlying unconformably the units described above and overlapping onto older rocks of all ages is a nearly flat-lying unit, the Knight Conglomerate, which consists of cobbles and boulders of a wide variety. It forms a continuous sheet from the head of Mountain Dell Canyon almost to Grandview Peak at the head of City Creek Canyon. It is also exposed on the Salt Lake Salient north of the Capitol, for several miles in the lower part of City Creek Canyon, and along the "North bench" above Eleventh Avenue. The thickness in these places must be several thousand feet. From its relations elsewhere, this unit is presumed to be of early Eocene age (about 55 million years old).

The Knight Conglomerate appears to be the last of the series of coarse rocks derived from the recently created western highlands. Though the evidence has been obscured by block faulting west of the Wasatch Range, these bodies of conglomerate must originally have formed wedgelike masses that were thickest near their western sources, but which thinned eastward where they intertongue with fine sediments that were accumulating at the same time in vast inland lakes that occupied much of southwestern Wyoming and of eastern Utah just south of the Uinta Mountains. The breakup of this integrated eastward drainage pattern, marking the early stages in the formation of the present basins and ranges, probably followed the deposition of this unit, perhaps accompanied by widespread volcanism.

TERTIARY VOLCANIC ROCKS

Volcanic rocks, mainly of andesitic composition and presumed to be of Tertiary age, are exposed at a number of places in Salt Lake County. No attempt will be made to describe them individually, nor to indicate their relative ages. On the Salt Lake County map some units are separated, for example, the Butterfield andesite flows, the South Mountain andesite flows and the Rose Canyon latite-andesite volcanics in the southern Oquirrh Mountains and the adjoining western part of the Traverse Mountains. These are cut locally by necks or plugs that presumably represent vent fillings from which at least some of the nearby rocks were derived.

Similar rocks are exposed in the eastern part of the Traverse Mountains, and in a few smaller areas, not shown on the county map, near the crest of the Wasatch Range near the summit of Parleys Canyon. Until these rocks are all dated by radiometric means, their relative ages and the correlation between them are uncertain. They are indicated as Oligocene on the map of Salt Lake County by analogy with the rocks of the Norwood Tuff from which fossils collected by Eardley (1944, p. 845) were dated as Oligocene. The most recent work by Gazin (1959, p. 137) and his written communication (1959) suggest that the Norwood should be regarded as latest Eocene, a distinction mainly of academic interest. Radiometric dates of 36.0 to 37.5 million years were obtained from the Norwood Tuff by Evernden and others (1964).

Rocks of Miocene (?) and Pliocene Age

Almost no Tertiary rocks younger than Oligocene are to be found within the mountains that bound Salt Lake Valley. In the basin, however, and locally on its slopes are small areas that appear to constitute the older parts of the fill that must underlie most of the valley at depth. The most widespread of these rocks are light-colored mainly unconsolidated sediments referred to as the Salt Lake Formation. They consist mainly of silt and clay and commonly contain some volcanic ash. In many places this unit appears to have accumulated in fresh-water lakes. Coarser phases no doubt accumulated locally around the edge of these basins, but most such rocks are covered by later deposits and are known only from well logs.

A coarse conglomerate of possible late Pliocene age, the Harkers Fanglomerate of Slentz (1955, p. 28), is exposed along the eastern edge of the Oquirrh Mountains. It is probably typical of the coarse angular debris that, though commonly buried beneath later deposits, must have accumulated in alluvial fans at many places around the margins of the valley.

Rocks of Pleistocene and Recent Age

Extensive deposits of conglomerate, sand, silt, and clay at or near the surface in Salt Lake Valley were deposited by streams flowing in from its margins and by lakes that occupied it during periods when glaciers formed and melted in the mountains. These rocks will be described in later sections dealing with glacial history and Lake Bonneville.

INTRUSIVE ROCKS

At various times in the past, bodies of molten rock (magma) have formed at depth within the earth and worked their way slowly upward. When such material breaks out at the surface, it produces a volcano, and the rocks that result are called volcanic. When the molten material fails to reach the surface and cools at some depth, it produces bodies of intrusive rock that cut across and interrupt the earlier formed sedimentary layers. Heat from such bodies recrystallizes and locally causes chemical alteration of the surrounding rocks. More important economically, the gases streaming outward from the cooling magma often carry with them in solution small amounts of metallic elements that crystallize in fractures or replace the wall rocks to form ore deposits.

The largest mass of intrusive rock in Salt Lake County is the Little Cottonwood stock -- a body of coarse-grained granitic rock which forms the massive walls in the lower part of Little Cottonwood Canyon (Figure 2); it is the site of the Temple quarries and the underground storage vaults being constructed by The Church of Jesus Christ of Latter Day Saints. Offshoots of these coarse rocks are exposed to the north in Ferguson Gulch. A similar but somewhat smaller body, the Alta stock, crops out between Alta and Brighton, and it is reasonable to guess that the ore deposits of the Alta-Cottonwood area (Calkins and Butler, 1943) are associated with these bodies or their deeper parent sources. Here and there in the Wasatch Range as at the mouth of Mill Creek Canyon, Parleys Canyon, and at many places in Big Cottonwood Canyon, plugs a few hundred feet across and narrow dikes and sills only a few feet or a few tens of feet thick cut through the sedimentary rocks. Because they have cooled more rapidly, such bodies are generally finer grained than the larger bodies described above.

The most important body of intrusive rock in Salt Lake County is the Bingham stock, the site of Kennecott's copper mine in Bingham Canyon. This is a pipelike body of porphyry (a rock consisting of coarse crystals in a finer groundmass) with a very irregular outline averaging about a mile in diameter. It is now almost wholly within the confines of the Bingham Pit (James, Smith, and Bray, 1961). Here ore-bearing solutions moving upward and outward deposited the ore minerals (mainly chalcopyrite) in fractures in the porphyry and formed replacement deposits, principally of zinc, lead, and silver minerals, in the surrounding country rocks.

Other smaller bodies of intrusive rock are to be found at Ophir and Mercur, each with its halo of mineralized rock.

MOUNTAIN BUILDING

Perspectives of Time and Space

The record of time and events contained in the layered rocks has already made it clear that the "everlasting hills" which from man's immediate perspective seem so firm and unyielding are the product of more than a billion years of ceaseless change -- the sea has advanced and retreated time and again; basins have been formed and filled with debris carried in from adjoining highlands; whole mountain ranges have risen and been reduced to lowlands by erosion. Viewed from this perspective, even solid rocks are astonishingly mobile and ephemeral. The purpose of the following

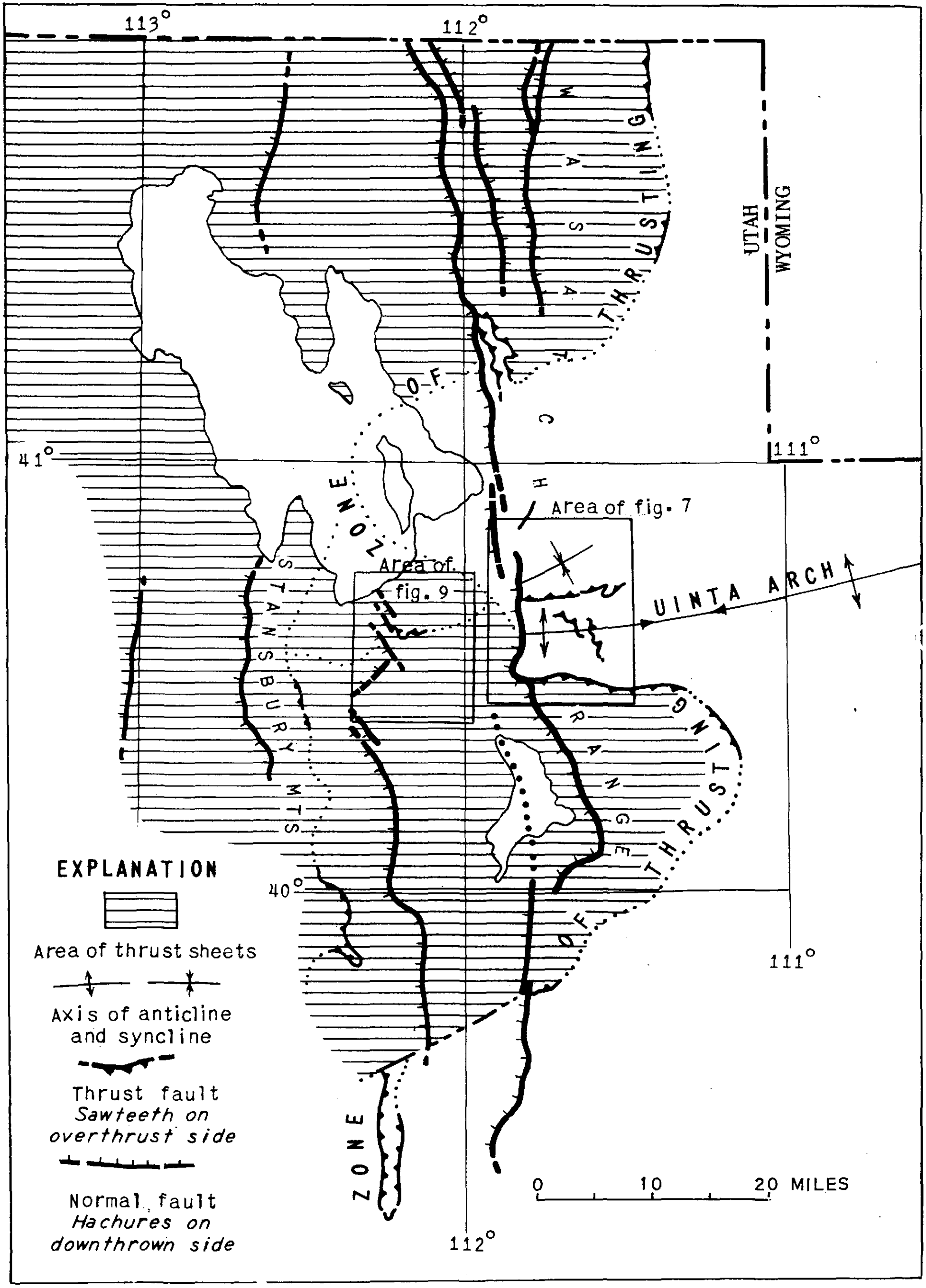

Figure 6. Structural setting of Salt Lake area showing relation of Uinta arch, belt of thrusting, and later normal faults.

discussion will be to examine the results of this mobility and to deduce from the structures as we now see them a more detailed history of their formation.

Structural Setting

The Salt Lake area lies at the intersection of two major tectonic elements of western United States: (1) a great east-trending upwarp -- the Uinta Mountains -- that now extends from just east of Kamas to the Colorado line, and (2) a north-trending arcuate belt of folds and thrust faults that extends from southern Nevada into Idaho and Montana (Figure 6). Because both of these elements are very old and have influenced each later episode of mountain building, the area of their intersection in Salt Lake County is of unusual complexity and interest.

In the following discussion the structural features of the Salt Lake area are described in the order in which they were formed, beginning with the oldest. It will be helpful at the outset to recall that the present mountains and valleys are geologically very recent features -- the product mainly of the last 10 or 20 million years. In simplest terms, the present mountains are giant tilted blocks, broken by faults and partly buried by sediments. Because the blocks are tilted eastward, one sees looking from Salt Lake City toward the Oquirrh Mountains the back slope of one such block, sculptured of course by erosion. The Wasatch Range is a similar eastward-tilted block, but in this case we see from Salt Lake City the broken front edge of the block. Except for the effect of erosion, this is like looking at a cross section of the earth before the block faulting began. From this cross section, and from study of the surrounding area, we can see that the fracture that defines the present mountain block broke across earlier structures of several kinds. If the theory of simple block faulting is correct, we should find the continuation of these structures in the downfaulted block, and perhaps even in the Oquirrh Mountains. Actually, it has been known for many years that the geologic features exposed in the Oquirrh Mountains do not match those of the Wasatch Range. From this it has gradually become evident that the sediments of the Salt Lake Valley conceal other structures that provide an explanation for these anomalies.

Internal Structure of the Wasatch Range

UINTA ARCH AND PARLEYS CANYON SYNCLINE

The largest structural feature within the Wasatch Range is the Uinta arch, a broad anticline that crosses the range almost at right angles and is a continuation of the anticline that forms the Uinta Mountains proper (Figure 7). The axis of this fold is exposed at the front of the range just north of the mouth of Little Cottonwood Canyon, and extends eastward about through Alta and Brighton. Although it was probably more or less level when formed, the axis of the fold now plunges eastward about 30 degrees. This eastward plunge continues to a point between Park City and Kamas; there the fold rises again in the Uinta Mountains (Figures 6 and 7).

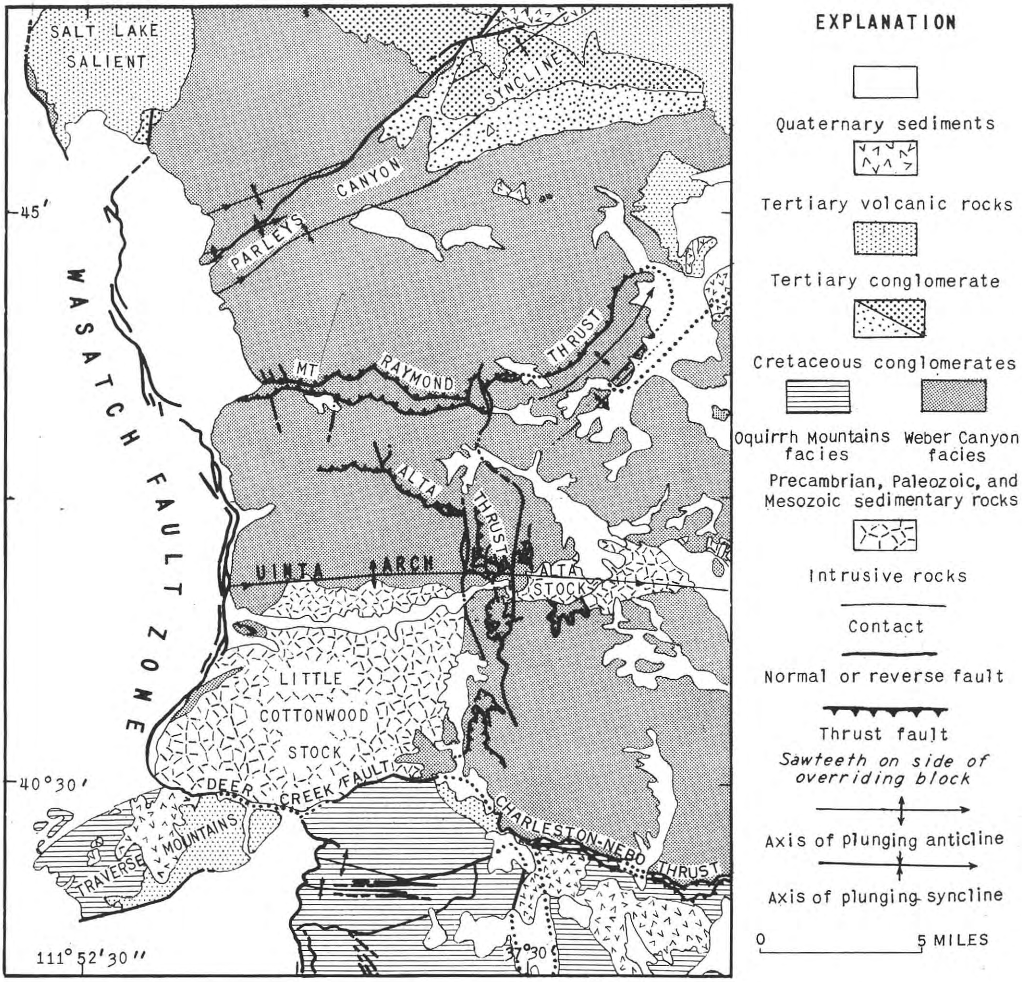

Figure 7. Internal structure of the Wasatch Range. Compiled from Granger and Sharp (1952), Crittenden and others (1952), Baker and others (1961), Baker (1961), and Bullock (1958).

North of the Uinta arch is a corresponding downfold, the Parleys Canyon syncline. The common limb shared by these two folds exposes rocks whose total thickness exceeds 40,000 feet. The old rocks in Little Willow Canyon may thus be depressed to a depth of six miles along the axis of the Parleys Canyon syncline. The central part of the syncline is a multiple fold, appearing at the mountain front as two synclines, one in Parleys Canyon, the other in Emigration Canyon, separated by the small tightly folded Spring Canyon anticline which reaches the mountain front about on the projection of East 2100 South Street. The general trend of these synclinal structures is about N. 60° E., and like the anticline to the south, they plunge eastward.

Most significant for the unraveling of the structural history is the relation of the Parleys Canyon syncline to each of the major unconformities between the rocks of Late Cretaceous and Tertiary age. Granger and Sharp (1952, plate IV) have shown that each successive conglomerate unit is folded about a slightly different axis, and that the present attitude of the rocks older than the Frontier Formation is due to the effects of at least three successive periods of crustal compression during which earlier formed structures were steepened. The uplift and deformation of the Parleys Canyon syncline and its adjoining anticlines can thus be broken into three discrete pulses, and as the age of the intervening conglomerates is more closely established by regional mapping, the time and duration of these pulses is becoming more clearly known. Present evidence suggests that the first pulse occurred 85 to 90 million years ago preceding the deposition of the Wanship Formation, the second perhaps 75 million years ago preceding the deposition of the Echo Canyon Conglomerate, and the third 60 to 70 million years ago, preceding the deposition of the Knight Conglomerate.

FOLDED THRUST FAULTS

At several places in the Wasatch Range the normal succession of "younger rocks lying upon older" is interrupted or apparently reversed owing to the fact that one slice of the earth's crust has slid or been pushed over the top of another. The surface on which such sliding takes place is called a thrust fault or overthrust and is distinguished from other kinds of faults by the fact that it is nearly parallel to the bedding of the surrounding rocks. The best known faults of this type in the Wasatch Range are the Alta and associated overthrusts that are extensively exposed both on the surface and underground near Alta (Calkins and Butler, 1943, p. 55) and the Mount Raymond thrust that extends across the range from Neff Canyon to Kimballs Junction (Figure 7) (Crittenden, Sharp, and Calkins, 1952, p. 23). Inasmuch as these faults are among the oldest structures discernible in the range, they have been affected by most of the processes that have been active since their formation. As a result they are complicated and locally obscure. The Alta thrust, probably a little the older of the two, is cut by the Alta stock and is offset thousands of feet by two large sets of normal faults. More important, it is affected by the same folding that has brought the enclosing rocks to their present position. As a result, though it now dips mainly eastward, or in places northward, Calkins and Butler (1943, p. 56) described drag and overturning beneath the fault surface that could only have been formed if the rocks in the overriding block moved from west to east. Moreover, they showed that each higher block in the sequence of slices came from a little farther west than the one below. Except that it is older than the Alta stock (Cretaceous ?) the age of this fault is unknown. Indirect evidence suggests that it may be as old as Early Cretaceous (125 million years before the present).

The Mount Raymond thrust also is cut by normal faults and has been deformed by the folding that produced the Uinta arch and the Parleys Canyon syncline. Though from Neff Canyon to the head of Mill Creek the fault strikes nearly due east and dips steeply to the north, this attitude is completely reversed south of Kimballs Junction, where it becomes involved in small subsidiary folds and is bent into a tight S-curve. Strong overturning and drag on the north slope of Big Cottonwood Canyon show that the Mount Raymond thrust also moved from west to east, and this, combined with its relation to the beds above and below, indicates that its surface originally was nearly flat. The age of this fault, again, can only be determined indirectly. Present evidence suggests strongly that it is younger than the Frontier Formation but older than the Wanship Formation (that is, 85 to 90 million years before the present).

A folded fault closely resembling the Mount Raymond thrust was observed by Granger and Sharp (1952, plate 1) in City Creek, where it cuts out much of the Weber Quartzite. This fault is not shown on section C-C' of the present map, though the extreme thinness of the Weber Quartzite is otherwise unexplained.

The Charleston-Nebo Thrust

The fault that probably has the largest displacement of any in the Salt Lake area, the Charleston-Nebo thrust, is not shown on the map of Salt Lake County (in pocket). It was first recognized by A. A. Baker (1947) as a thrust fault which brought older rocks over younger along the south edge of the Deer Creek Reservoir on the Provo River (Figure 7). Baker's mapping showed that it continued east and south toward Strawberry Reservoir (Bissell, 1952), and regional synthesis by Eardley (1951, p. 329) suggested that this fault was continuous underground with the Mount Nebo thrust to the south and the Willard thrust to the north. The probability that these thrusts are all part of a broad zone of eastward-moving thrusts was at first only tentatively suggested by Eardley (1944, p. 866) but can now be much more fully documented. Evidence from several sources suggests that the displacement may amount to 40 miles or more (Crittenden, 1961). The principal movement in this area probably took place about 75 to 80 million years ago.

The approximate trace of the Charleston-Nebo thrust within Salt Lake County is shown on Figures 6 and 7. It has the character of an ordinary thrust fault from Strawberry Reservoir to a point just east of American Fork Canyon. There it becomes involved with a low-angle normal fault, the Deer Creek fault; this fault, now concealing the Charleston-Nebo thrust, crosses the crest of the range in the saddle just north of Boxelder Peak (Baker and Crittenden, 1961) and reaches the front of the Wasatch Range at its junction with the east Traverse Mountains in Corner Canyon, southeast of Draper. A tiny remnant of the thrust fault may be preserved on the spur just south of the mouth of Little Cottonwood Creek, but its main westward continuation is broken by the faults along the front of the range and is concealed at depth beneath Salt Lake Valley. Farther northwest it is believed to pass under the edge of Great Salt Lake somewhere near the salt evaporators, and to bend northeastward again between Antelope Island and Fremont Island (Figure 6).

The recognition of the Charleston-Nebo thrust in Salt Lake County offers an explanation of at least two features that have long puzzled geologists: (1) it explains why there is no westward continuation in the Oquirrh Mountains of the great Uinta and Parleys Canyon folds (Beeson, 1927, p. 778; Gilluly, 1932, p. 71); and (2) it explains why Upper Mississippian and Pennsylvanian rocks of the Oquirrh Mountains and Mount Timpanogos are so different in thickness and locally in character from those of the part of the Wasatch Range east of Salt Lake City. Regional study indicates that the rocks that now form the Oquirrh Mountains were originally deposited somewhere in western Utah and that they moved eastward to their present position as part of a series of thin strongly folded thrust sheets (Figure 8). This suggests that the Charleston-Nebo thrust, or an equivalent sliding surface, must extend westward, perhaps at a depth of 2 to 5 miles, beneath the entire Oquirrh Mountains (Mabey and others, 1963).

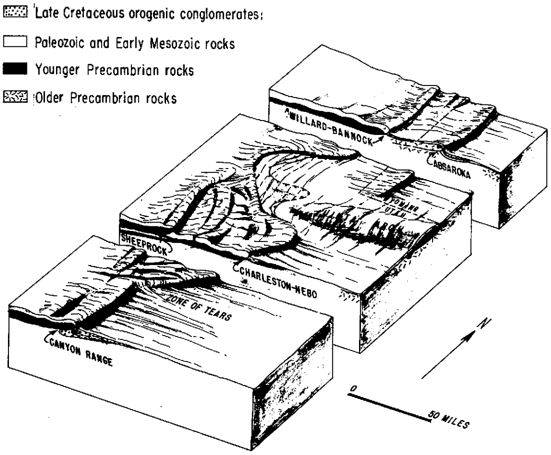

Figure 8. Block diagram showing overlapping and lobate form of Laramide thrust sheets in central Utah.

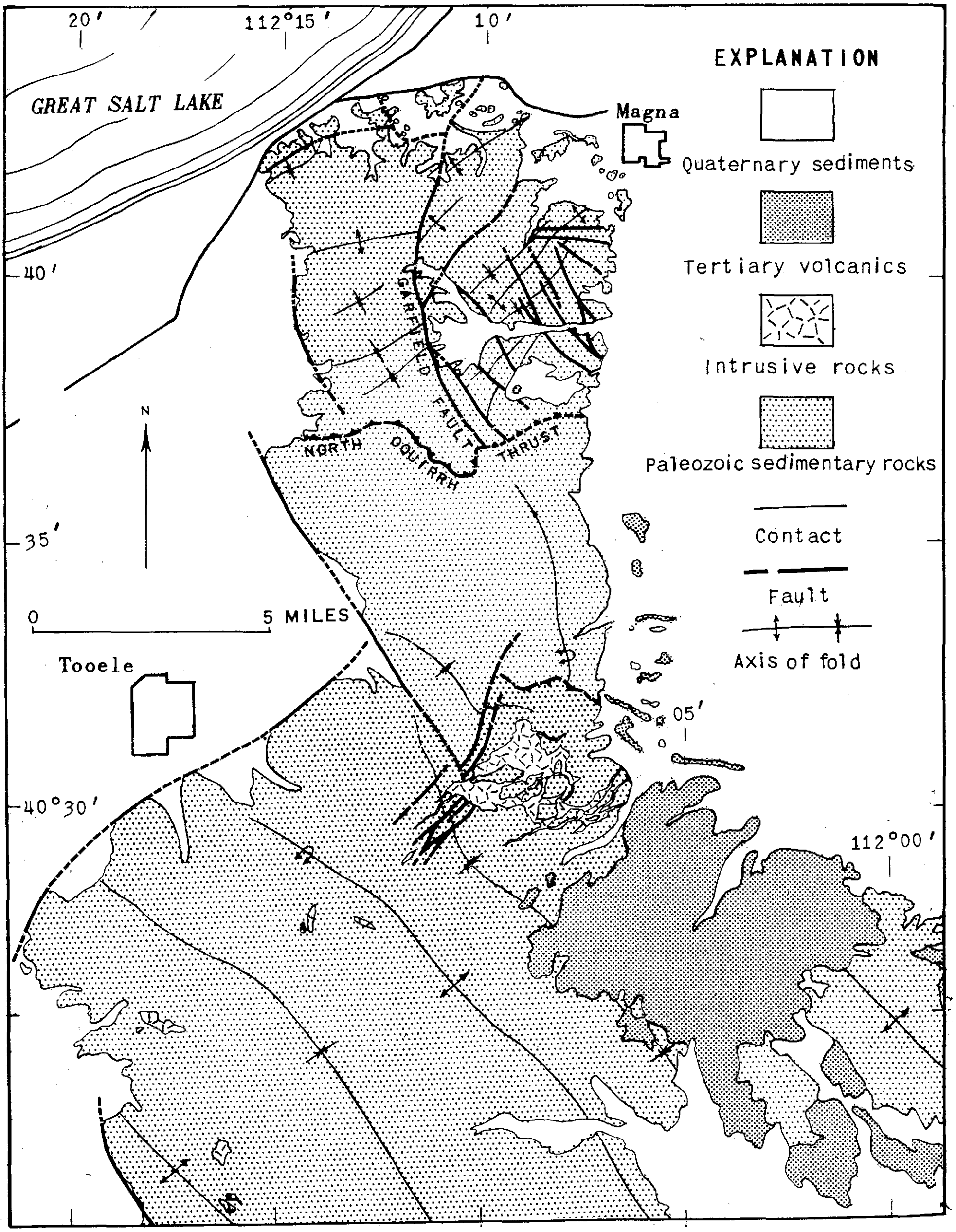

Figure 9. Internal structure of the Oquirrh Mountains. Compiled from Roberts and Tooker (1961), James and others (1961), and Gilluly (1932).

Internal Structure of the Oquirrh Mountains

The Oquirrh Mountains, as just noted, are part of a thrust sheet that has moved bodily eastward relative to the Wasatch Range. Partly as a result of those movements, and partly as a result of still earlier events, the rocks of the Oquirrh Mountains are strongly folded, and these folds are in turn broken by other thrust faults. A description of the resulting complex structures as they are now known follows; it should be noted, however, that the exact sequence of events that has given rise to these structures is still not fully understood.

THE NORTH OQUIRRH THRUST

Recent study of the Oquirrh Mountains by geologists of the Kennecott Copper Company (James, Smith, and Welsh, 1961) and the U.S. Geological Survey (Tooker and Roberts, 1961) has shown that the rocks and the structure of the central Oquirrh Mountains, in which the Bingham mine is located, are strikingly different from those of the northern part of the range near Garfield. Both groups of workers recognize that these differences result from the fact that the range is broken near Nelson Peak by another thrust fault called the North Oquirrh thrust, and that the rocks to the north and south accumulated in different places and have been folded in a different manner.

The North Oquirrh thrust (Figure 9; not shown on the Salt Lake County map, in pocket) crosses the crest of the range about a mile south of Nelson Peak. It strikes about east and west and dips about 30 degrees north; though this dip would normally carry the trace of the fault north into Harkers Canyon, it is offset by a series of normal faults and may reach the east edge of the range somewhere near Barneys Canyon (Roberts and Tooker, 1963, oral communication). For convenience in description, the structural block south of the thrust is called the Bingham block and that to the north is called the North Oquirrh block.

BINGHAM BLOCK

The structures in the Bingham block are predominantly northwest-striking folds (Gilluly, 1932), somewhat asymmetrical or locally overturned toward the east. On a large scale, these structures form the northern end of a broad arcuate series of folds that more or less parallel the leading edge of the Charleston-Nebo thrust (Figure 6). Many individual structures, for example, can be traced southward into the east Tintic Mountains. This pattern is consistent with the theory that these folds were formed as curving wrinkles in a lobe of the thrust front that advanced toward the ancestral Uinta Basin but was held back on the north and south.

NORTH OQUIRRH BLOCK

The overriding block of the North Oquirrh thrust is divided into two structural units by the north-trending Garfield fault, a steeply dipping tear fault which ends southward against the thrust. The block west of the Garfield fault, the Lake Point block, is characterized by east- to east-northeast-trending tight folds, overturned toward the south. Some of these are particularly well shown along U.S. Highway 40 just southwest of Black Rock Beach (Figure 10). The block east of the fault, the Magna block, is characterized by northeast-trending folds that are open rather than overturned; many are arcuate and are convex northwestward. This block is cut by a number of northwest-trending normal faults, some of which may have formed at the same time as the North Oquirrh thrust.

Figure 10. Tight folds south of Black Rock at north end of the Oquirrh Mountains. (Photograph by R. J. Roberts)

Present evidence suggests (Roberts and Tooker, 1961, p. 36) that the folds in the two blocks were formed prior to and during the southeastward movement of the two blocks on the North Oquirrh thrust; counterclockwise rotation of the Magna block relative to the Lake Point block during this movement may account for the difference in trends of the fold axes.

Origin of the Present Mountains and Basins

BASIN AND RANGE PROVINCE

Between the Sierra Nevada in California and the Wasatch Range in Utah is a distinctive topographic province characterized by long narrow isolated nearly parallel mountain ranges separated by elongate basins filled with unconsolidated sediments. This area, aptly named the "Basin and Range province," is of such a unique character compared with the usual more continuous mountain chains that Dutton described its closely aligned mountain ranges as "an army of caterpillars crawling toward Mexico" (Nolan, 1943, p. 142).

Speculation about the origin of this belt of peculiar topography began nearly a hundred years ago and has been the subject of heated discussion in geologic journals the world over (for a summary see Nolan, 1943, or Louderback, 1923). It is generally accepted now, however, that the ranges are bounded on one or both sides by faults, and that movement on these faults is responsible for both the shape and elevation of individual mountain blocks. Geophysical studies (for example, Cook and Berg, 1961) have shown that the intervening basins may extend as far below the present surface of the valleys as the mountains extend above; some even extend below sea level. From this it is evident that the basins must have moved downward as the mountain ranges moved upward.

Wherever evidence is available, the fractures between the mountains and the adjoining basin -- the bounding faults -- slope toward the basin. They are thus of the kind called normal faults; that is, the hangingwall has moved downward relative to the footwall.

Between the bounding faults, the rocks seem to have acted like fairly rigid blocks, for commonly the ranges in one part of the province are all tilted in the same direction, and the intervening valleys give evidence of similar one-sided tilting and subsidence. The Oquirrh Mountains, the Wasatch Range, and the intervening Salt Lake Valley show this relation. An east-west cross section from Markham Peak to Twin Peaks (Figure 11) which passes near Midvale shows that the Oquirrh Mountains and the Salt Lake Valley together are part of an eastward-tilted block modified by faulting along several zones beneath the alluvium. The same eastward tilt is repeated in the Wasatch Range.

WASATCH FAULT

The major fracture separating the Oquirrh block from the mountain block to the east lies along the front of the Wasatch Range and is appropriately named the Wasatch fault. The western face of the Wasatch Range has been cited for more than fifty years as a classic example of the effects of block faulting. Only a few outstanding localities can be mentioned here.

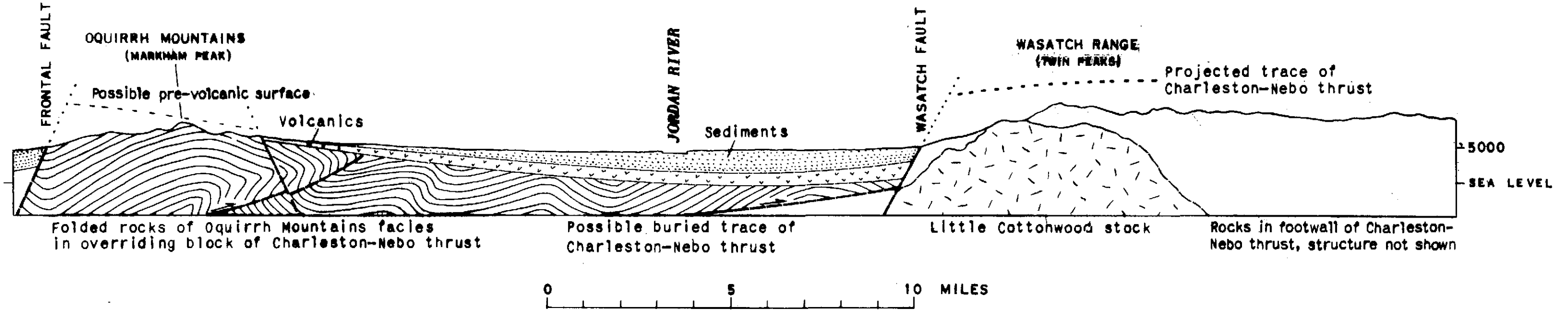

Figure 11. Generalized cross section from Markham Peak in Oquirrh Mountains through Twin Peaks in Wasatch Range.

Viewed from the bluff at the south edge of Granite, just south of the mouth of Little Cottonwood Creek, the face of the range east of Draper looks as though a giant slightly concave bite had been taken out of it. The steep mountain ridges are planed off at the ends forming triangular facets (Figure 12) that are almost a hallmark of a fault escarpment. East of Draper on the lower part of one facet is a gently sloping bare rock surface that is polished and grooved (slickensided) by the grinding motion of one rock-mass past another. This is an actual exposure of one of the sliding surfaces along which the mountains rose and the valley subsided. Similar surfaces are to be found in a few small areas along the face of the range between Big Cottonwood Canyon and Mount Olympus, generally on the upper surface of crags of the most resistant rock.

One of the most spectacular exposures of an actual fault plane is in the gravel pits (Figure 44) east of U.S. Highway 89-91 at the north edge of Salt Lake City. Here, for hundreds of feet, one can see a gently undulating nearly vertical face of Cambrian limestone or of Quaternary gravel deeply grooved by the grinding action of the rocks that moved past it.

A third evidence for block faulting along the front of the Wasatch Range is the offset of bedrock units. This is best demonstrated in the area of the Salt Lake Salient. The Cambrian Tintic Quartzite, if projected from upper City Creek, would reach the mountain front near the Capitol, but the rocks nearest the Capitol are Mississippian; the Tintic has been offset to a point off the edge of the map north of Becks Hot Springs, implying a displacement, if vertical, of about 10,000 feet. The fault causing it must be old, for it is now partly buried by gravel. Similar evidence is found in the Traverse Mountains, though it is complicated there by the fact that the rocks of the Wasatch Range and the Traverse Mountains lie in different thrust blocks. Even so, the Pennsylvanian rocks of the Traverse Mountains run into the mountain front about where the base of the Cambrian would be expected if it were not cut out by the Little Cottonwood stock, thus indicating a minimum displacement of some 5,000 feet. Making allowance for the thrust faults, the actual displacement in this area also must be at least 10,000 feet. The maximum displacement known is in Utah Valley opposite Mount Timpanogos, where gravity data (Cook and Berg, 1961, p. 82) show that bedrock has been faulted down to depths of several thousand feet below the present lake level. Combined with the height of the mountains to the east, this indicates a displacement of 12,000 to 15,000 feet.

RECENT SCARPS

The most striking evidence that the Wasatch fault is a recent feature is the series of fresh scarps that extend along it for most of the length of Salt Lake County. The most spectacular are those at the mouth of Little Cottonwood Canyon (Figure 13), where the moraines on the south side of the canyon are cut and displaced some fifty feet. Somewhat older scarps are to be seen in a nearly continuous zone from a point near First South and

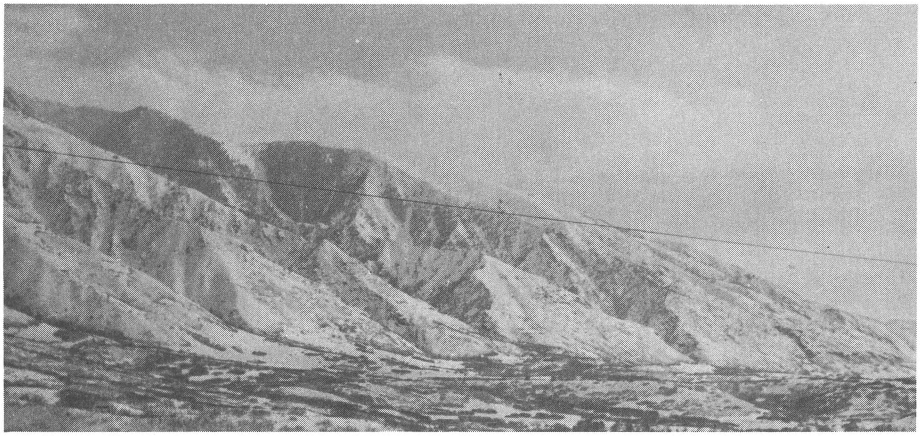

Figure 12. Triangular facets along Wasatch fault south of the mouth of Little Cottonwood Canyon. (Photograph by A. J. Eardley)

Figure 13. Fault Scarp. Mouth of Little Cottonwood Canyon, looking northwest parallel to Wasatch fault. (Photograph by R. E. Marsell)

1300 East Streets in Salt Lake City to Holladay opposite Mount Olympus where it merges with the main Wasatch fault zone. For most of this distance, the faults are within the built up area of Salt Lake City. In a few places, excavation in this area has exposed the fault plane (A. J. Eardley, personal communication). Elsewhere the position of the fault is marked by the fact that all the streams crossing the slope have cut deep narrow ravines east of the fault and have built broad low gravel fans to the west. It can also be identified in this interval by its effect on ground water (Marine, 1961).

From Holladay south to Corner Creek, the fault is marked by a branching and rejoining pattern of scarps cutting gravel and sand of Lake Bonneville and more recent stream deposits. These scarps are particularly well exposed a hundred feet or so east of Wasatch Boulevard within the first quarter of a mile south of the mouth of Big Cottonwood Creek and on the benchlands farther south a few hundred yards east of Wasatch Boulevard near its intersection with 7800 South Street. Throughout this area (Figure 13) the scarp is so fresh that brush and other vegetation have not had time to become re-established on the surface.

Although the age of these scarps, and hence the date of the last large movements on the Wasatch fault, cannot be precisely fixed[3], they probably were formed sometime within the last thousand years. Even though there have been no displacements within historic time, scarps of similar throw, and with a strikingly similar appearance, have been formed recently at several places in the western states, notably Dixie Valley, Nevada, in 1954 (Slemmons, 1957) and Hebgen Lake, Montana, in 1959 (Witkind and others, 1962). Surface displacements of a foot or two were observed in Hansel Valley north of Great Salt Lake in 1934 (Walter, 1934), and intermittent small earthquakes in the vicinity of Salt Lake City leave little doubt that the processes of mountain growth and valley subsidence are continuing.

EARTHQUAKES AND MOUNTAIN BUILDING

That large earthquakes are the result of earth movements of the sort described above is too well known to require elaboration. The effects of the Dixie Valley displacement were felt as far away as San Francisco and Salt Lake City; those of the Hebgen Lake faulting as far as Seattle, Washington.

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[3] Dr. Walter P. Cottom, Emeritus Professor of Botany, University of Utah, believes that certain species of long-lived trees, notably juniper or mountain mahogany, situated along the fault at the time of the last displacement might record such a displacement in their annual growth rings; if such trees could be found, the age of the last displacement might be determined. Tree ring studies by Fred Buss of Brigham Young University on shorter-lived scrub oak and hackberry trees indicated no abnormal growth within the last 150 years (personal communication to A. L. Crawford, 1922).

Each of these earthquakes was of a magnitude roughly comparable with many that surely must have accompanied the faulting along the front of the Wasatch Range.

To gain some idea of the size and frequency of such events in the past, let us presume that the observed 10,000 feet of displacement on the Wasatch fault has taken place within the last 20 million years. If the rate were uniform, and each increment of uplift involved a 5-foot displacement, this would imply that there have been 2,000 such displacements during that time, or one every 10,000 years. The available evidence from offset of glacial and lake features suggests that the present rate is well above this average, and that the time interval between major displacements may be considerably less than this. The geologic record plainly says that earthquakes are a normal and expectable feature of the intermontane province. If man adapts himself wisely to such an environment, he will plan and build in full anticipation of the recurrence of these events.

RESUMÉ OF GEOLOGIC HISTORY

In briefest terms, the geologic history of the Salt Lake area may be divided into three phases:

Phase of Geologic History	Duration
1. Geosynclinal	From about 1,500,000 to about 200,000,000 years ago.
2. Orogenic (formation of mountains by folding)	From about 100,000,000 to about 40,000,000 years ago.
3. Block Faulting	From about 20,000,000 years ago to present.

During much of the geosynclinal phase the area lay beneath the sea; at times subsiding slowly, at times more rapidly. At first, mountainous or continental areas lay only to the east; later island arcs or mountain chains arose in the sea to the west. The sediments accumulated during this long epoch attained a thickness of as much as eight miles.

The crustal unrest that gave rise to the island arcs and mountain chains within the sea seems to have progressed eastward somewhat like a wave. It reached the Salt Lake area about 100 million years ago and ushered in an epoch of mountain building referred to broadly as the Laramide orogeny. During this epoch, the area that had for eons been slowly subsiding now rose above the sea forming a broad mountainous highland. The thin-layered sediments were unstable on its gentle slopes and moved slowly eastward in a series of thin wrinkled sheets (Figure 8). These slid over one another, as in the Oquirrh Mountains, or moved forward as lobes or tongues, as in the Charleston-Nebo area. Due to erosion, which attacked the uplifted areas almost as rapidly as they were formed, these mountains probably never had the smooth-folded appearance diagrammatically shown in Figure 8, but formed rugged mountain chains more like the Alps or Himalayas. Streams carried coarse debris -- the products of this erosion -- eastward into what is now eastern Utah and southwestern Wyoming.

From about 40 million to about 20 million years ago, comparative quiet ensued and erosion reduced much of the area to a comparatively subdued surface.

The present epoch began perhaps 20 million years ago with the formation of north-south fractures that cut across all the earlier-formed structures. Along some of these fractures, molten rock reached the surface, and volcanic rocks accumulated to great thickness around local vents and formed thin sheets over much wider areas. Progressive movement along the north-south fractures gradually defined the present mountains, while the debris from their newly uplifted slopes filled the subsiding valleys.

And what of man? Only during the very last stages of this final phase, as the chill of the glacial epochs fell across the earth, perhaps a million years ago, did manlike creatures evolve on the warm ancient continents of the earth, probably Africa and Australasia. The present record suggests that it may have taken another 900,000 years for man to reach western North America. Of the remaining 100,000 years, probably another 90,000 passed before the earliest civilizations arose in China and Egypt. Compared with our geologic starting point, some two billion years ago, this last 10,000 years, which encompasses all of civilized history, is equivalent to less than the final inch in the height of Mt. Everest. Small wonder that we find it difficult from our human perspective to give a sense of reality to the sweep of time and change that the geologic story encompasses!

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SECTION II – GUIDE FOSSILS FOR THE LAYMAN

by Byron J. Sharp[1]

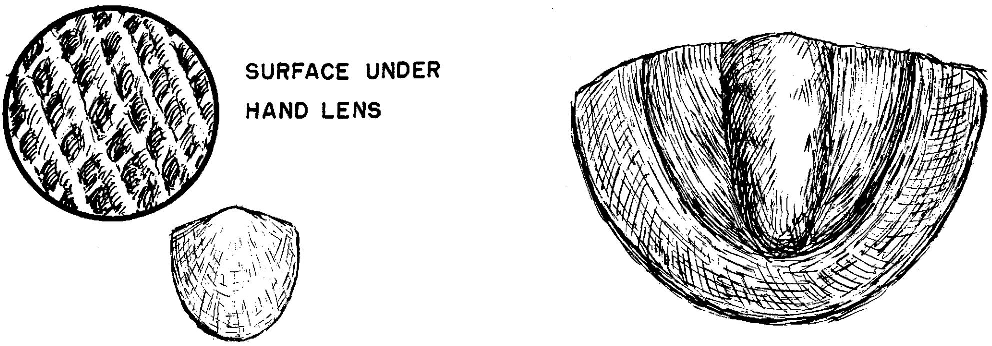
The fossils illustrated here by the author were suggested and supplied by Dr. W. L. Stokes of the University of Utah. Only generic names of fossils will be used in this paper.

The symbol X 1 on an illustration indicates that it is about 60 per cent of the actual fossil size, and the symbol X 1/2 indicates that the illustration is only 30 per cent of the actual fossil size.

It is possible to find fossils in any locality where a fossil-bearing formation is exposed. However, some localities afford better collecting than others; and where fossils are particularly abundant in any given formation, the locality will be mentioned in this paper.

Not all of the previously discussed sedimentary formations in the area contain fossils; however, they are common to abundant in the Ophir Shale, Pinyon Peak Formation, Madison Limestone, Deseret Limestone, Great Blue Limestone (thick section), Oquirrh Formation (thick section), Park City Formation, Thaynes Formation, and Twin Creek Limestone.

The Ophir Shale crops out near the mouth of Neffs Canyon and in Big Cottonwood, Little Cottonwood, and City Creek Canyons. Micromitra and Glossopleura were collected from this formation in Neffs Canyon.



Micromitra X1

Glossopleura X1

Figure 14. Representative fossils of the Ophir Shale. Illustrations are about the same size as the actual fossils.

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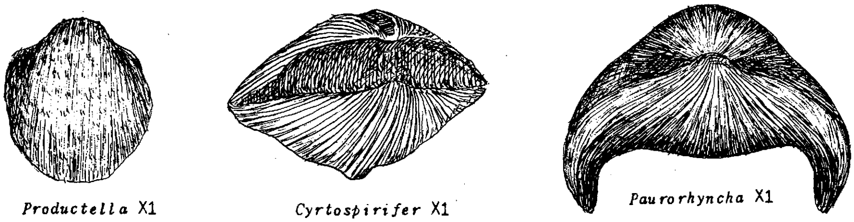
[1] Geological Engineer, U. S. Atomic Energy Commission, Grand Junction, Colorado.

The Pinyon Peak Formation crops out on Becks spur, and fossils collected from this locality include Crytospirifer, Productella, and Paurorhyncha.



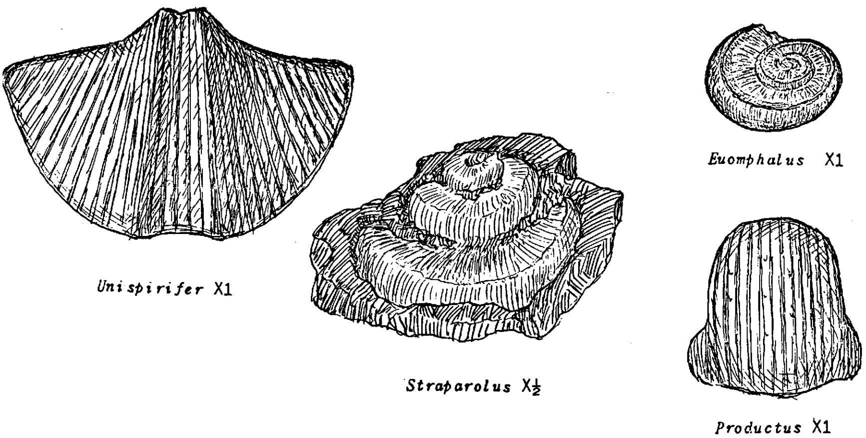
Productella X1

Cyrtospirifer X1

Paurorhyncha X1

Figure 15. Representative fossils of the Pinyon Peak Formation.

Typical of the highly fossiliferous Madison Limestone are Unispirifer, Productus, Straparolus, and Euomphalus. This formation crops out in City Creek, Neffs, Little Cottonwood, and Big Cottonwood Canyons.



Unispirifer X1

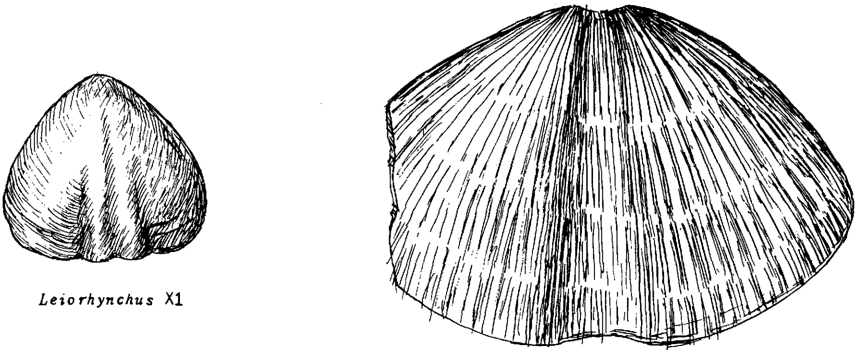
Straparolus X½

Euomphalus X1

Productus X1

Figure 16. Representative fossils of the Madison Limestone.

The Deseret Limestone overlies the Madison and crops out in the same areas. Fossils found in this formation include Leiorhynchus and Spirifer.

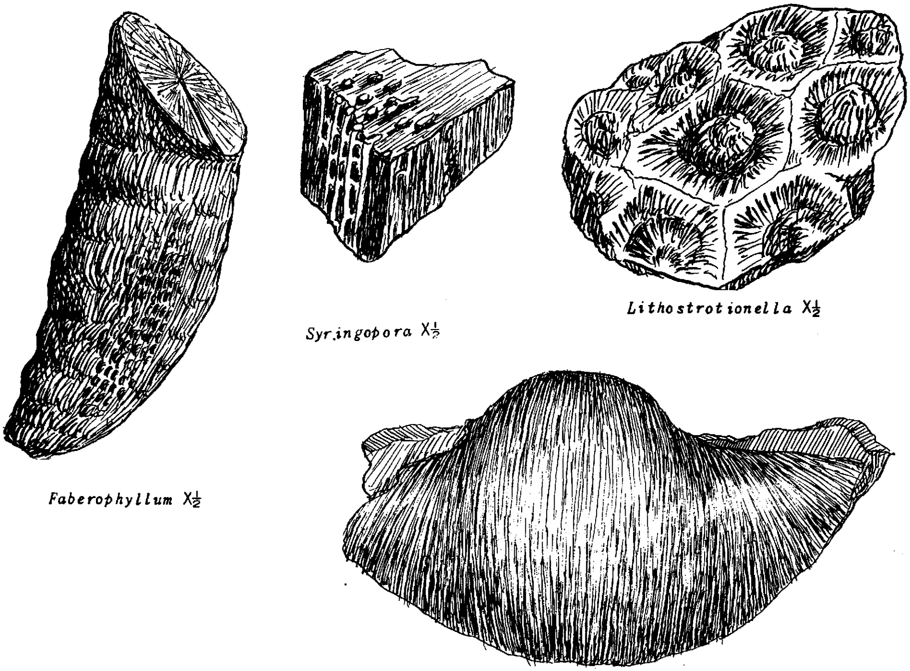


Leiorhynchus X1

Spirifer X1

Figure 17. Representative fossils of the Deseret Limestone.

The Great Blue Limestone crops out at the southern end of the Oquirrh Mountains and at Becks spur. Fossils found in this formation include Faberophyllum, Syringopora, Striatoferra, and Lithostrotionella.



Syr.ingopora X½

Lithostrotionella X½

Faberophyllum X½

Striatofera X½

Figure 18. Representative fossils of the Great Blue Limestone.

The Oquirrh Formation makes up the main eastern mountain front of the Oquirrh Mountains. The fossiliferous limestones of the formation have yielded the following suite of fossils: Fenestella, Chaetetes, Neospirifer, Antiquatonia, and Fusulina.

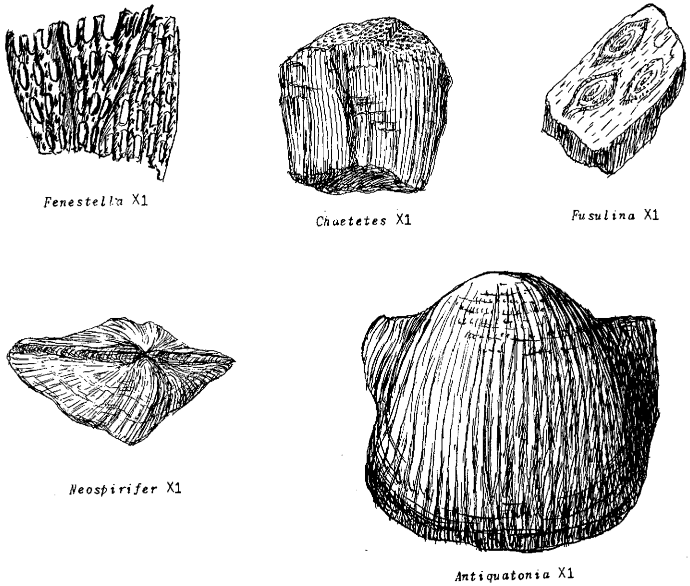


Figure 19. Representative fossils of the Oquirrh Formation.

The highly fossiliferous Park City Formation crops out in Dry Canyon, in the mouth of Mill Creek Canyon, and in upper Big Cottonwood Canyon. Some of the fossils found in this formation include Bathymonia, Punctospirifer, Composita, Chonetes, Rhynchopora, Waagenochoncha, Orbiculoidea, and Productus.

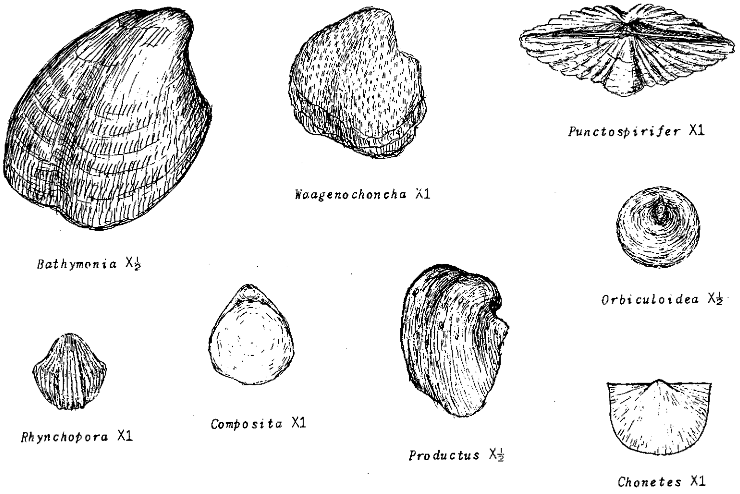
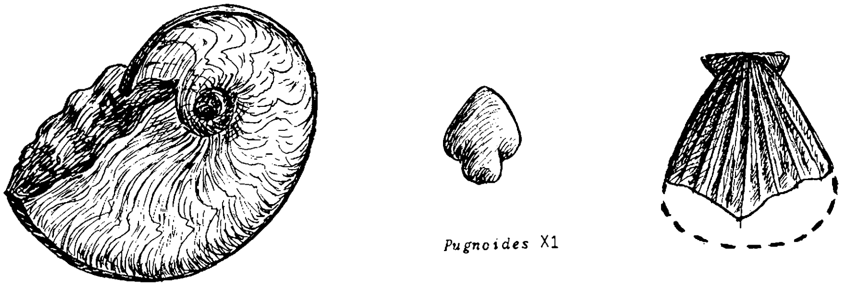


Figure 20. Representative fossils of the Park City Formation.

The Thaynes Formation is also highly fossiliferous, and the main collecting locality is in Cephalopod Gulch behind the University of Utah between Red Butte and Dry Canyons. Some of the fossils collected here include the cephalopod *Meekoceras*, and also *Pugnoides* and *Monotis*. This formation also crops out near the head of Red Butte Canyon and on the Wasatch Mountain front between Parleys and Emigration Canyons and between Mill Creek and Parleys Canyons.



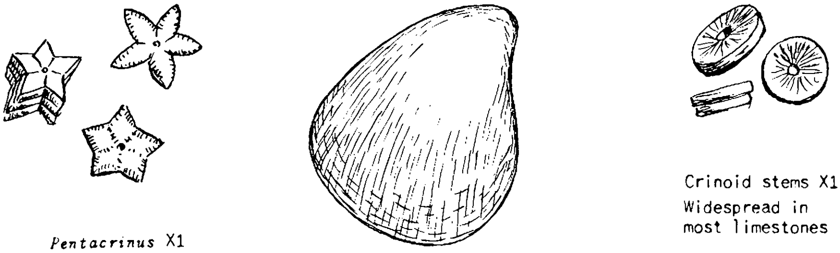
Meekoceras X1

Pugnoides X1

Monotis X1

Figure 21. Representative fossils of the Thaynes Limestone.

The Twin Creek Limestone crops out mainly in Parleys and Emigration Canyons. Two of the common fossils found in the formation are *Camptonectes* and *Pentacrinus*, a crinoid stem found in abundance near the Little Mountain ski area parking lot.



Pentacrinus X1

Camptonectes X1

Crinoid stems X1
Widespread in most limestones

Figure 22. Representative fossils of the Twin Creek Limestone.

Crinoid stems, in general, are found widespread throughout this portion of the geologic section in most limestones.

SECTION III – GLACIATION

by R. E. Marsell[1]

When one views Salt Lake Valley from a vantage point, such as the steps of the State Capitol, certain "land forms" may be recognized as having been formed by processes no longer in operation. Most conspicuous of these "relic" forms are the abandoned shorelines of ancient Lake Bonneville (Figure 31), whose waters once covered the valley floor and the benchlands along the flanks of the surrounding mountains. Great Salt Lake is the vastly shrunken remnant of the former huge lake.

Looking more closely, in the vicinity of the mouths of Bells Canyon and Little Cottonwood Canyon at the southeast corner of the valley, boulder-strewn ridges and hills constitute the moraines left by the melting ice at the distal ends of the glaciers that formerly occupied these canyons. Although the rivers of ice have long since vanished, many features in the landscape attest their former presence.

Since glaciers are formed only where there are (or were) permanent "snowfields," from which they are nurtured, the thirty-three glaciers, once present in that part of the Wasatch Range within Salt Lake County, have disappeared along with the snowfields that fed them. Contrary to popular belief, Utah has neither snow fields nor glaciers at the present time. Some snow banks in sheltered places persist until late summer in the higher portions of both the Wasatch and Uinta Mountains, but these are snow banks, not glaciers.

That section of the Wasatch Range due east of Salt Lake City was too low in elevation to permit sufficient accumulation of snow to produce permanent snowfields, and hence no glaciers ever occupied this part of the range. But as one approaches the loftier peaks and ridges to the southeast, the former presence of the glaciers is at once apparent, especially from the air (Figure 23). Instead of the narrow V-shaped valley bottoms and the broad, rounded ridges of the subdued, mature, stream-worn topography of Emigration and Parleys Canyons, for example, one finds deep, U-shaped valleys, flat-bottomed, with over-steepened walls and sharp knife-like bounding ridges that are typical of glacial topography. These glaciated valleys commence in crescent-shaped, cliff-walled basins called "cirques" that are often the sites of jewel-like mountain lakes. It is the sculpture by mountain glaciers that has produced the awe-inspiring, rugged beauty of the choicest mountain scenery, both in the loftier parts of the Wasatch Range and to even a greater degree in the Uinta Mountains.

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Figure 23. Aerial view of U-shaped glacial trough of Little Cottonwood Canyon and of Bells Canyon to the right (south). South lateral moraine of Little Cottonwood Canyon glacier in foreground just left of center. The notched terminal moraine of Bells Canyon glacier can be seen in right foreground. (Photograph by A. J. Eardley)

Figure 24. V-shaped entrance to Parleys Canyon occupied by U. S. Highway 40. (Photograph courtesy Deseret News)

Glacial deposits in Salt Lake County were early noted by the geologists of the Fortieth Parallel Survey (King, 1878) but were not mapped in detail. The first careful reconnaissance study of the glaciation in the Wasatch and Uinta Mountains was made by Atwood in 1907, and his findings were published as U.S. Geological Survey Prof. Paper 61 in 1909. Atwood's work in the Wasatch Range was greatly handicapped by lack of an adequate topographic base map; and, of course, air photos were still in the distant future. More recently Richmond (1961) and Morrison (1961) have mapped the former glaciers of the Wasatch, and the new geologic map of Utah nicely shows the glacial deposits of the Uintas. But even today (1963), when both excellent topographic maps and air photos are available, no detailed study of the glaciation of the Wasatch or the Uintas has been made.

Figure 25. Cirques heading Red Pine Fork, Maybird Gulch, and Hogum Gulch (from left to right, respectively) —three hanging valleys, south tributaries of Little Cottonwood Canyon. Looking south across Little Cottonwood Canyon from the Little Cottonwood-Big Cottonwood divide. (Photograph courtesy Max P. Erickson)

Atwood was an able observer, and his graphic descriptions of the tremendous changes wrought by the ice masses while present in the range have not been excelled. He mapped the former glaciers in Salt Lake County according to the basins (cirques) in which they formed, giving an identifying number to each basin on his map. Basins 27, 28, and 29, for example, developed at the western and northwestern base of Lone Peak (elev. 11,253 feet). All three of these extinct tongues of ice reached the margin of Salt Lake Valley at the foot of the range.

The largest and longest of the above-mentioned three glaciers was the one that formerly occupied Bells Canyon (Figure 23). Atwood's description, in part, follows:

> "At the mouth...there is a series of symmetrical lobate moraines of magnificent proportions. The ridges are sharp wedge-shaped forms extending almost a mile beyond the mouth of the canyon and rising nearly 500 feet above the highest Bonneville terraces and 700 feet above the stream bed at their western end... The crests of the main lateral moraines slope gently westward, indicating approximately the surface slope of the ancient glacier near its end.
>
> Within the main moraines, and probably while the ice yet occupied the upper part of the valley, water accumulated and formed a lake. . . The waters rose in this intermoraine basin until it reached the pass located near the middle of the terminal moraine. The lake was then drained by the outlet stream as it cut its gorge into the loose glacial material.
>
> Above the moraines at the mouth of Bell (Bells) Canyon, the valley is a great rock gorge. The form of this gorge and the smoothed condition of its bare rock walls suggest at every step the amount and vigor of the work done by the ice that occupied the gorge and built up the moraines at its lower end. The trail upstream crosses great irregular masses of drift. The ascent is by a series of gentle reaches and abrupt rock ledges. Above each ledge the valley bottom is somewhat level or rolling. Lakes or old lake beds are of frequent occurrence. The stream descends by rapids or falls from one bench or step in the canyon to the next below.
>
> The entire fall from the catchment basin to the mouth is about 4,470 feet, an average of nearly 1,000 feet per mile. This very high gradient accounts for the vigorous ice action recorded on the rock surfaces throughout the upper portion of the valley and in the massive moraines at and near the mouth."

The small post-glacial stream in Bells Canyon has been unable to destroy or even greatly modify the massive moraines that block entrance to the canyon. Man has artificially restored the ancient morainal lake by erecting a dam across the outlet, creating a small reservoir.

Atwood recognized an older, much weathered and deeply eroded deposit of morainal material outside and beyond the topographically distinct horseshoe-shaped moraines that encircle Bells Canyon. Much of the larger rock fragments in this older moraine are so disintegrated that they may be readily crumbled between the fingers. From the evidence observed here and elsewhere throughout the Wasatch and Uinta Mountains, Atwood concluded that the region experienced two ice epochs, the older glaciers being more extensive than the younger, and that the interglacial interval was much longer than post-glacial time.

This duality of glaciation, first deduced by Atwood, has been confirmed by most subsequent investigators. More recent studies (Marsell, 1947) have found remnants of a third and still older morainal deposit perched high on the north wall of Little Cottonwood Canyon, 2,500 feet above the present canyon floor.

Little Cottonwood Canyon, the next drainage north of Bells Canyon, contained the longest and largest of the ancient glaciers in Salt Lake County--or for that matter, in the entire Wasatch Range. The Little Cottonwood glacier benefited from the substantial amounts of ice contributed by six of the seven valleys entering the main canyon from the south. From the north there are few tributaries, and none that contained moving ice. The deepening and widening of the main canyon of Little Cottonwood destroyed the former concordant junctions of the tributaries so that those that contained ice on the south side are now "hanging valleys" whose streams descend the main canyon wall in cascades and rapids.

As viewed from Salt Lake Valley, Little Cottonwood Canyon has a beautifully symmetrical U-shaped form, typical of the vigorously glaciated canyons of the region, and in marked contrast with the V-shaped profiles of nearby Big Cottonwood and Parleys Canyons (Figure 24). The Little Cottonwood glacier was over 14 miles long, and the ice was at least 650 feet thick near its terminus.

In describing the moraines at the mouth of Little Cottonwood Canyon, Atwood pointed out that:

> "The main south lateral moraine. . . is a ridge with a narrow crest (Figure 26), at places not more than 8 or 10 feet wide. The surface of this moraine, as well as the surfaces of all the Little Cottonwood moraines, is strewn with white granite boulders procured by the glacier in the lower part of its course. The crest of the main south lateral moraine rises 340 feet above the flood plain of Little Cottonwood at the mouth of the canyon.
>
> The north lateral moraine is not ridgelike, but is a great bank of drift lodged on the side of the mountain (Figure 27). The upper limit of the north lateral moraine material is at about the same elevation as the moraine crest south of the valley."

The distribution of the moraines at the mouth of Little Cottonwood Canyon shows a notable northward turning of the glacier after leaving the canyon; this may be due to the greater westward extension of the south wall of the canyon. The terminal moraine, doubtless once present, has been destroyed by the vigorous stream erosion of Little Cottonwood Creek in post-glacial time.

From two basins at the west base of the Twin Peaks-Dromedary Peak area on the Little Cottonwood-Big Cottonwood divide, a small glacier descended

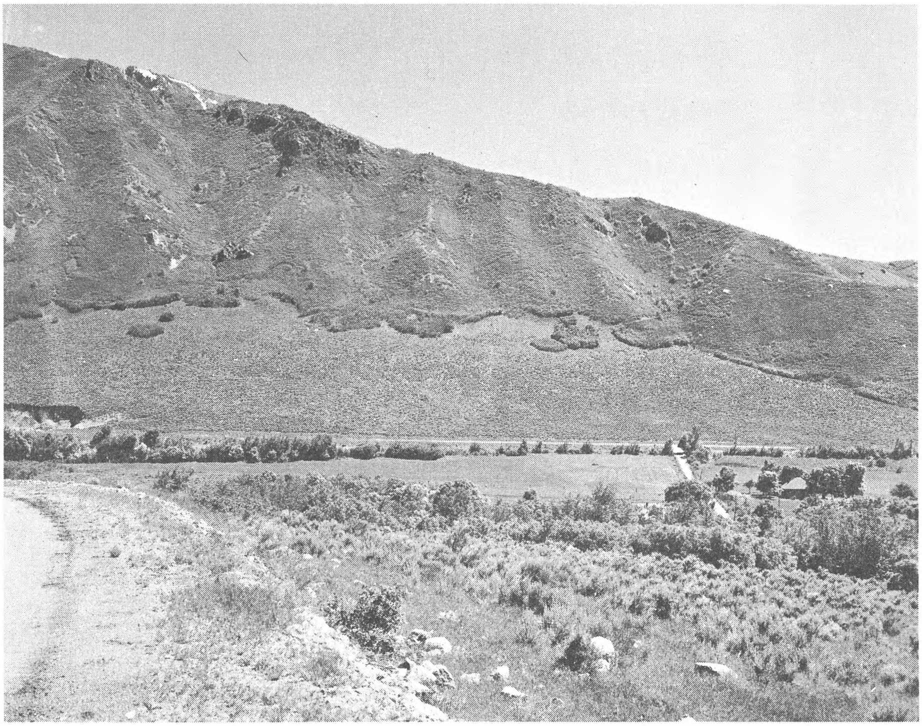

Figure 26. South side of mouth of Little Cottonwood Canyon, showing flat valley floor scoured in Precambrian bedrock and a portion of the lateral moraine at extreme right.

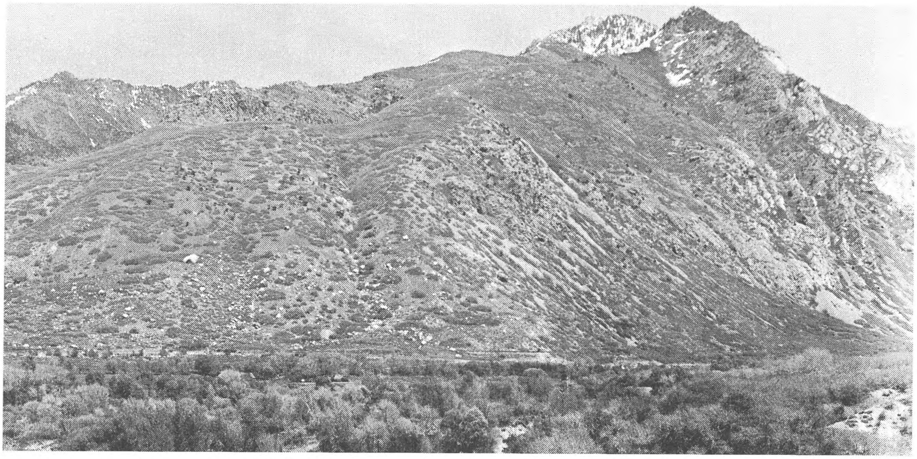

Figure 27. North side of the mouth of Little Cottonwood Canyon, showing scattered boulders of moraines lodged against north wall. (Photograph by Bill Shipler)

westerly a little over three miles down Little Willow Canyon (not labeled on the Salt Lake County map) to the margin of the range. Atwood observed

> "The postglacial part of the gorge is V-shaped, but if this lower portion be filled in, the cross section of the valley would have a symmetrical U-shaped form."

Continuing on north, a small tongue of ice once occupied Ferguson Canyon, a steep ravine that descends to the mountain base just south of Big Cottonwood Canyon. Only a small remnant of its greatly subdued terminal moraine remains opposite the mouth of the canyon. Atwood failed to recognize the former presence of a glacier in Ferguson Canyon.

Attention has already been called to the contrast in profiles of lower Little Cottonwood and Big Cottonwood Canyons. In Atwood's words:

> "As approached from the west, or the Bonneville Basin, Big Cottonwood Canyon does not appear to have been glaciated... In contrast to the smooth U-shaped form of Little Cottonwood Canyon, the Big Cottonwood gorge is rugged and somewhat V-shaped. Great cusps or points of rock project from the sides of the gorge, and pinacled, rugged faces stand out as indications that glacier ice never moved down the valley."

However, upon closer investigation, Atwood discovered time modified signs of an epoch of older glaciation which had begun to alter the V-shaped canyon profile. Thus:

> "The rock ledges (lower stairs) protruding into the valley near the upper power plant, about four miles above the mouth of the canyon, show by their striated, grooved, and polished surfaces unmistakable marks of ice action";

This older glaciation had insufficient time to finish the "reaming" of the canyon and to develop the typical, smooth, U-shaped trough accomplished in Little Cottonwood Canyon, where two or more epochs of ice had the combined effect of shaping the classical glaciated canyon profile. For three miles above the mouth of Mill B South Fork, Big Cottonwood Canyon does not appear to have ever been affected by ice. Mill B South Fork tributary, however, was occupied by vigorous glaciers during each ice epoch. From this tributary during one of the older epochs flowed a shallow, feeble glacier to the mouth of the canyon. But during the last ice epoch, when all former evidence was either obliterated or completely masked by the ice piled high in the Mill B basin, the glacier which flowed from it reached down Big Cottonwood Canyon for half a mile, and continuing his examination of Big Cottonwood Canyon upstream, Atwood found that

Figure 28. Roche moutonnée of glaciated bedrock in Mill B South Fork near Lake Blanche, Big Cottonwood Canyon. Note the smoothed and polished "stoss" side with perched erratic.

Figure 29. Glaciated Mineral Fork Tillite in Little Cottonwood catchment basin, the "conglomerate" of Atwood (1909).

> "Big Cottonwood Canyon for several miles above the mouth of Mill B (South Fork) contains no traces of occupancy by a glacier, this portion of the gorge having an unmodified river erosion form."

He deduced that:

> "The points of contrast between the valley of Mill B and the glaciated lower portion of Big Cottonwood, together with the fact that a portion of the main canyon above the mouth of Mill B is unglaciated, show clearly that the ice which passed through the lower portion of Big Cottonwood Canyon belonged to the earlier glacial epoch and represented the maximum extension of the Mill B glacier, while the more recent work throughout the length of the tributary valley belongs to the later glacial epoch."

Thus, the only glacier in Big Cottonwood Canyon to reach its mouth was a small glacier from the Mill B (South Fork) tributary that entered and occupied the main canyon only in its lower reaches. The Mill B glacier of the younger epoch failed to extend down the main canyon more than half-a-mile, where it deposited a bulky, now tree-covered, moraine against the south canyon wall.

Perhaps in no place in the Wasatch Mountains are the abrasive effects of ice erosion as well preserved as in the basin at the head of Mill B South Fork, generally known as the Lake Blanche basin (Figures 3 and 28). Again quoting Atwood:

> "In the amphitheatral basin the rock in the bottom is for the most part a hard quartzite, and yet there, at the very beginning of ice action, this hard rock was wonderfully and beautifully polished, grooved, and striated. The stoss sides of prominences (Figure 28) are, almost without exception, so smoothed that it is difficult to walk over them if they have much slope. At one place the trail, wide enough for a horse to walk on, is located in a great glacial groove...within the basin of Mill B there are three rock-basin lakes. These basins, having maximum depths of 20 feet, were gouged out by the ice."

Eastward, the next tributary entering Big Cottonwood Canyon from the south is Mineral Fork (Figure 29), which was also glaciated but neither its ice of the older nor of the younger epoch reached the main canyon. Still farther east, in the adjacent Mill D South Fork, a much larger glacier descended to the main canyon and joined a glacier coming down upper Big Cottonwood Canyon. At the junction of the Mill D glacier and the one descending the main canyon, a 300-foot hill blocks both canyons and marks the combined terminal moraines of the two glaciers. The Big Cottonwood streams, briefly ponded by the bulky terminal moraines, rose and cut an outlet at the contact of the moraine and the north wall of the main canyon. Thus, the present course of the stream was countersunk part way up the bedrock slope of the pre-glacial canyon wall, imparting to this reach of Big Cottonwood a uniquely asymmetrical cross profile.

Continuing up Big Cottonwood Canyon from the massive moraines at the mouth of Mill D South Fork, five tributary canyons coming from the south were strongly glaciated (Figure 30) and contained small ice tongues that in each instance reached the larger glacier in the main valley and persisted after the ice in Big Cottonwood proper had retreated upvalley. These tributary glaciers breached the lateral moraine of the main glacier, leaving at each side of the notch their own smaller lateral ridges of drift within the main valley.

Figure 30. Glaciated bedrock in Mill B South Fork, Lake Blanche region of Big Cottonwood Canyon.

As in neighboring Little Cottonwood Canyon to the south, no tributary glaciers entered Big Cottonwood Canyon from the north wall. However, ice from the main glacier pushed into the lower ends of a number of the tributaries entering from the north side of the canyon, forming ice dams that ponded the drainage in the tributaries and formed alluvial flats, portions of which still remain from 500 to 600 feet above the main valley floor.

The catchment basin above Brighton at the head of Big Cottonwood Canyon is as large as any in this portion of the Wasatch Range, being a combination of several closely associated cirques, each containing one or more charming mountain lakes. Atwood noted that:

> "A narrow crest separated the basins of Big and Little Cottonwood canyons, but the latter, being located on the windward side of the crest, received and retained a larger amount of snow than the former, or leeward, basin. . . At one place in the rim separating basins 38 and 50 (Little Cottonwood and Big Cottonwood cirques) a band of ice connected the two great glaciers.

The next glaciated canyon north of Big Cottonwood is Neff Canyon, a short steep drainage that enters Salt Lake Valley at the northern margin of Mt. Olympus, east of the town of Holladay. Evidently Atwood failed to recognize the remnants of old moraines present near the mouth of Neff Canyon. These glacial deposits belong to next-to-the-last glacial epoch and were first called to the writer's attention by Charles W. Wilson, Superintendent of the Salt Lake City Water Department, in 1947.

The Neff Canyon glacier was only two and one-half miles in length and received small tongues of ice from tributaries entering the main canyon from the south, the largest of these coming from Thomas Fork, the smallest, from North's Fork. The main glacier began in a now greatly-subdued cirque at the head of Neff Canyon, known as Peterson Basin.

Mill Creek Canyon, next north of Neff Canyon, is the last canyon in the Wasatch Range in Salt Lake County in which Atwood found evidences of glaciation. He describes remnants of till terraces beginning about two miles upstream from the canyon mouth and rising "about 90 feet above the stream. These terrace remnants are in the form of benches left at intertributary spaces in the main valley. If the portions cut away by side wash and tributary streams could be replaced, the continuous lateral moraines once present in this part of the valley would be reproduced." These older moraine remnants do not appear on the geologic map accompanying this bulletin (in pocket).

A glacier about three miles long did occupy the head of Mill Creek Canyon and was formed by small tongues of ice from four cirques nestled under the high divide between Mill Creek and Big Cottonwood. Atwood identified the moraines as belonging to his "younger epoch," although very probably deposits of the "older epoch" have been overridden and obscured by later deposits.

The situation in lower Mill Creek Canyon probably was similar to the conditions present in lower Big Cottonwood Canyon, where the ice in the main canyons came from tributaries entering from the south. The writer surmises that it was the Porters Fork glacier of the earlier ice epoch that entered and occupied the main canyon of Mill Creek for a limited distance, failing, however, to reach the mouth of the canyon.

The mudrock flow deposits of cloudburst origin at the mouth of the North Fork (Elbow Fork) of Mill Creek Canyon were mistaken by Atwood for glacial moraines, which they greatly resemble. Similarly, the prominent mudrock fans at the base of the Wasatch Range in Davis County were tentatively regarded as of glacial origin by the geologists of the Fortieth Parallel Survey (King, 1878). These early geologists could not visualize any transporting agent, other than ice, that could move such huge angular blocks of rock as are present on these debris deposits, yet they frankly admitted that the canyons from which these deposits came showed no evidence whatsoever of former occupancy by ice.

Atwood makes no mention of glaciation at the head of Lambs Canyon; but a greatly modified and subdued cirque lies at the north base of Murdock Peak (elev. 9,594 feet), and a marshy pond, Salimander Lake, occupies the basin floor. No morainal deposits associated with the ancient Lambs Canyon glacier have been shown on the geologic map, but careful search may discover, at least, some small obscure remnants of them.

GLACIERS AND LAKE BONNEVILLE

Since the late nineteenth century, investigators have surmised that a close relationship probably existed between the late Pleistocene lakes of the Great Basin and the glaciers in the adjoining mountain ranges -- both probably resulting from a common set of climatic conditions. Both Gilbert (1890) and Atwood (1909) reported at the mouth of Little Cottonwood Canyon an interfingering of till and outwash and overlapping by lacustrine deposits of Lake Bonneville. Blackwelder (1931) reported that he found the delta deposits of the Bonneville substage covering the lower part of the Little Cottonwood moraines; and Eardley et al. (1957, fig. 19) shows Bonneville sands lying on the outermost moraines at the mouth of Little Cottonwood Canyon and the head of Dry Cottonwood Creek. More recent and more detailed studies have amply verified these earlier conclusions.

A brief report by G. M. Richmond (1961), a member of the U.S. Geological Survey and a widely recognized authority on Rocky Mountain glaciations, describes the results of a recent survey of the glaciation in Little Cottonwood Canyon, in part, as follows:

> "The glacial deposits of Little Cottonwood Canyon in the Wasatch Mountains, Utah, represent three glaciations. Deposits of the oldest are probably of middle Pleistocene age and have been uplifted about 2,500 feet by normal faulting at the western margin of the mountains.
>
> Deposits of the next younger glaciation, correlated with deposits of the Bull Lake glaciation of Wyoming, comprise two sets of end moraines at the mouth of the canyon at altitudes of 4,980 and 5,090 feet, respectively. Till and outwash of the outer moraine interfinger with and are overlapped by deposits of the first rise of the lake -- the Alpine Formation of Hunt, Varnes, and Thomas (1953) -- and till and outwash of the inner moraine

interfinger with and are overlapped by deposits of the second rise of the lake -- the Bonneville Formation (Hunt, Varnes, and Thomas, 1953) -- or that which attained the Bonneville shoreline.

The third glaciation of the mountains -- correlated with the Pinedale glaciation of Wyoming -- comprises three sets of moraines in the middle and upper parts of Little Cottonwood Canyon and its tributaries at average altitudes of 6,570, 7,220, and 9,195 feet. These mark a maximum advance and two minor readvances or halts during recession of the ice that are believed to have been separated by only brief interstadial intervals."

MINERAL FORK TILLITE (the oldest glacial deposit in Salt Lake County)

Opposite page 80, Plate XIII "B", in Atwood's (1909) description of the glaciation at the head of Little Cottonwood Canyon, there appears an illustration of a smooth, polished bare rock outcrop, which he called "conglomerate" (Figure 29). The rock is rusty-weathering, but on freshly-fractured surfaces it is dark gray to black in color. In a fine-grained matrix lie scattered boulders, cobbles and pebbles of quartzite, limestone, or granitic rocks. Layers of seasonally-banded slate also occur.

John C. Fremont and his guide, Kit Carson, chisled a cross in 1843 on similar rock on a prominence on Fremont Island in Great Salt Lake. Fremont also called it a "pudding stone" or conglomerate. The late Professor Frederick J. Pack, former head of the Department of Geology, University of Utah, noted in 1904 a similar "conglomerate" on the north end of Antelope Island.

None of these early investigators recognized the true identity of the "black rock" and thereby missed an opportunity for world-wide fame. The correct origin of this unique rock unit was finally deciphered by F. F. Hintze in 1913, who recognized it as an extremely ancient glacial deposit. Subsequent studies have fully supported Professor Hintze's opinion, for the presence of striated cobbles and the general lack of sorting or bedding mark it as similar to late-Precambrian tillites in other parts of the world.

The known distribution of this ancient glacial deposit extends from southern Idaho, near Pocatello, southward through the Wasatch Range and thence westerly to the West Tintic Mountains. Evidently a vast ice sheet once spread over this region more than one-half billion years ago.

The name Mineral Fork Tillite was proposed for this rock unit in 1952 by Max D. Crittenden, who with Frank Calkins mapped its areal distribution in Salt Lake County, as shown on the Salt Lake County geologic map (in pocket).

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SECTION IV – LAKE BONNEVILLE

by A. J. Eardley[1]

BEACHES OF LAKE BONNEVILLE

Conspicuous terraces or beaches may be noted nearly everywhere along the lower slopes of the Wasatch Mountains in Salt Lake County. Most of these are the beaches of old Lake Bonneville, of which the present Great Salt Lake is a shrunken remnant. The terrace under the "U" on the mountain front east of Fort Douglas is one of the beaches. This may be traced northwestward to Ensign Peak, where several later benches or beaches are clearly visible. An exceptionally broad terrace around the Traverse Mountains, extending into a spit at the Jordan Narrows (Figure 31) between Salt Lake and Utah Valleys, can hardly escape the notice of travelers on the highway around the Point of the Mountain.

Terraces formed by the waves of the lake have several identifying characteristics. First, they are horizontal. A single terrace may be traced contour fashion for many miles with little variation in height above sea level. Fault or earthquake scarps or benches, on the other hand, pursue irregular courses, up hillsides and down across gullies. Beaches are marked commonly by cleanly washed sand and gravel. Where major streams entered the old lake, deltas were built; and the upper surface of the deltas matches the adjacent beach, because each was controlled by the same water level.

After a study of the entire Lake Bonneville basin, Gilbert (1890) recognized three main beaches and many lesser intermediate ones. He called the highest prominent beach the "Bonneville." It lies at an elevation of 5,135 feet above sea level along most of the Wasatch front east of Salt Lake City; however, at Corner Creek, southeast of Draper, it has been uplifted to about 5,185 feet on the east side of the Wasatch fault (Marsell, personal communication). The second and most prominent beach Gilbert called the "Provo." It is about 300 feet lower than the Bonneville and is easily the broadest in most places. It contains many fine sand and gravel deposits, and the Weber and Provo deltas are built largely up to this level. Elevations determined on this beach range from 4,800 to 4,830 feet in Salt Lake County.

The beach just below the "U" is the Bonneville, and the broad bench of Fort Douglas and the upper campus of the University of Utah is the Provo.

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Figure 31. Double Spits—Jordan Narrows. View looking south.

The exceptionally broad terrace around the Traverse Mountains is capped by the Bonneville, but the portion traversed by U.S. Highway 50 is a bar that was built at the Provo level. The low, flat-topped ridge that extends from Mount Olympus to Draper is a bar or spit built at the Provo level.

Evidence in Salt Lake and Utah Counties points to the conclusion that the lake stood at the Provo level on two occasions, because that level is marked by two sets of beach deposits separated by soil. The lake is thus supposed to have stood at the Provo level for some time, carved and built a broad beach with spits and bars, then dropped several hundred feet for a few thousand years while a soil formed on the beach deposits, and then rose to its former level, or approximately so, to result in a second sand and gravel deposit on the old (Eardley et al. 1957, fig. 20, p. 1198).

Approximately 400 feet lower than the Provo beach is the Stansbury. It is not nearly as prominent as the Provo, but in places in the Bonneville Basin it still is well developed and conspicuous. It may be seen along the west front of the Salt Lake Salient east of the oil refineries, and is the source of considerable sand and gravel in the pits along the mountain slope there. Since the lake withdrew from the Stansbury beach deposits, alluvial fans have been built across them, and the two types of deposits stand in marked contrast in the walls of some of the gravel pits. The poorly sorted, reddish alluvial fans rest on top of the crossbedded, gray, clean sand and gravel deposits. Movement on the Wasatch fault has since occurred and offset the apex parts of the alluvial fans 10 to 20 feet. This movement was prehistoric (see footnote, page 43), but, judging from the freshness of the scarps, it was only a few hundred years ago.

The lake stood at an elevation of 40 to 50 feet above its present level for some time, and prominent spits were built east and west of the north end of the Oquirrh Range. It is at this level that the tourist enters Salt Lake County from the west on U.S. Highway 40 at Black Rock. This beach and lake level has been called the "Gilbert" (Eardley, et al., 1957). The beach in Salt Lake County extends east of Magna for about three miles to McIntyre Lake. A number of other spits and beaches have been mapped on either side of the Jordan River Valley in southern Salt Lake County. These were formed as the lake receded. The Union Pacific Railroad tracks between Fourth and Fifth West Streets northward of the station are laid on a low bar, evidently at the Gilbert level.

Waves of Lake Bonneville, driven by prevailing winds, exerted tremendous force on the shores. As a result of the abrasive action of sand and boulders, terraces were cut into bedrock and beaches were built. Much of the debris was carried laterally by longshore currents and deposited nearby as wave-built terraces or offshore bars and spits. Longshore currents were highly effective in sorting and transporting the sand and gravel along the shoreline. Most headlands projecting into deeper portions of the lake deflected longshore currents into deep water and became the sites for spits and

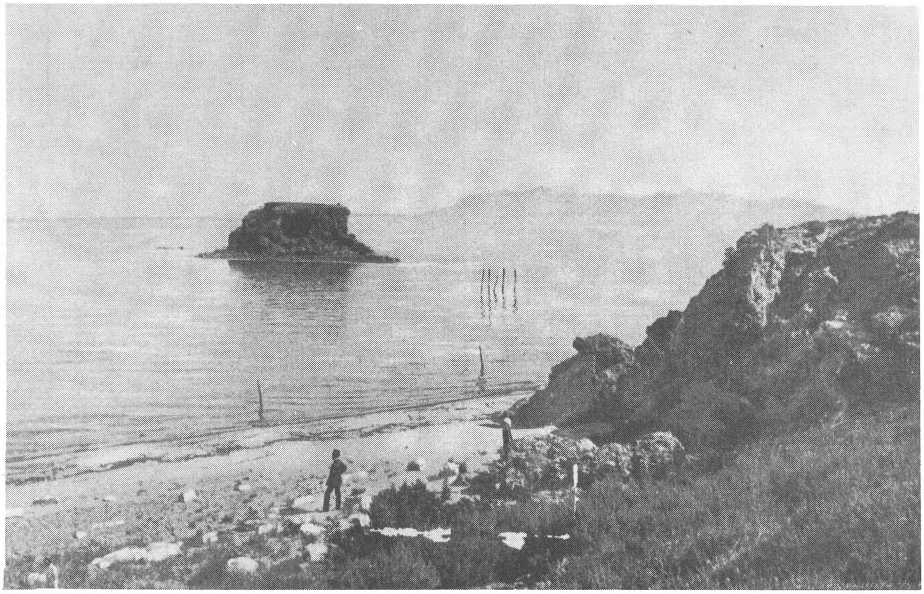

Figure 32a. The Great Salt Lake. Note beach line above the present U.S. Highway 40 (Photo from Talmage, circa 1890).

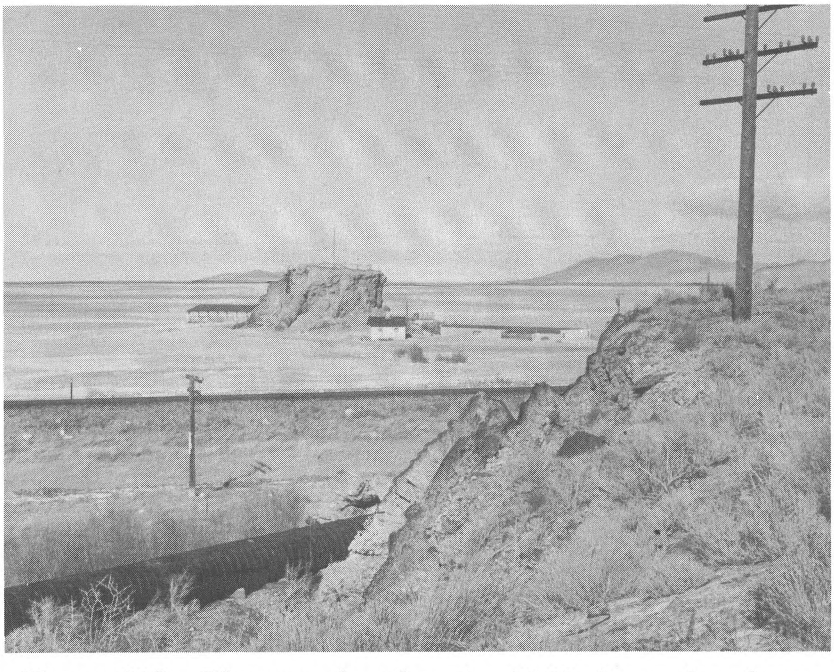

Figure 32b. Photograph taken in 1963 from site shown in Figure 32a. Note the recession of the shoreline.

bars. Most of the terraces which represent the different stages of Lake Bonneville are compound -- that is, they are the result of both erosion and deposition.

Terraces facing to the northwest usually are well-defined. At the base of Mount Olympus above Wasatch Boulevard, the terrace is wave-cut in hard quartzite. Wave-built terraces are generally in areas which contained more sheltered waters. The terrace exposed along the Traverse Mountains immediately above U.S. Highway 91 demonstrates two types of terraces. An earlier, older, wave-cut terrace is marked by a persistent line of vegetation which is supported by seeps of ground water along the base of the terrace. The upper portion of this terrace is depositional, or wave-built, and was constructed principally by longshore currents when the lake was deeper.

Some of the levels or terraces have been armoured by a fossilized calcareous reef material which is generally the result of biochemical deposition attendant with wave action. Such material forms greyish curtain-like deposits on some of the wave-cut terraces on the north slope of the Oquirrh Mountains (Figure 10) above the Garfield smelter at the western edge of the county and on the flank of the Wasatch Mountains where Victory Road leads into U.S. Highway 89. The building organisms were algae, similar to those in Great Salt Lake today, and through their photosynthesis calcium carbonate is precipitated.

JORDAN RIVER VALLEY

A bar was built at the Provo level at the Point of the Mountain. Extending from the East Traverse to the West Traverse Mountains east of the Oquirrhs, it served as a dam for Utah Valley. When the main body of water dropped on the Salt Lake Valley side, the lake in Utah Valley was sustained by the Provo River to overflowing across the dam, and the river (the Jordan) dissected the dam to form the Jordan Narrows (Figure 31).

The river ran across the lake bottom sediments of what is now the Jordan Valley and cut a valley in them marked by several prominent terraces on each side. The Jordan River changes from an erosional stream to a depositional stream at about 3300 South Street, and from this point northward has been engaged in flood plain and levee building for the past few thousands of years.

HISTORY OF THE LAKE

Lake Bonneville is most surely a result and accompaniment of the last glacial stage, which from many carbon-14 dates occurred in the period 25,000 to 11,000 years ago. Recently, Bright (1963) proposed that volcanic flows in southern Idaho north of Thatcher Valley diverted the Bear

Figure 33. Looking west down Little Cottonwood Canyon and across Salt Lake Valley shrouded in fog to a level slightly higher than the high-water line of old Lake Bonneville. The Oquirrh Mountains "island" is in the middle distance. The Stansbury Range, which formed another island in Lake Bonneville, can be seen along the left skyline. (Photograph courtesy Deseret News)

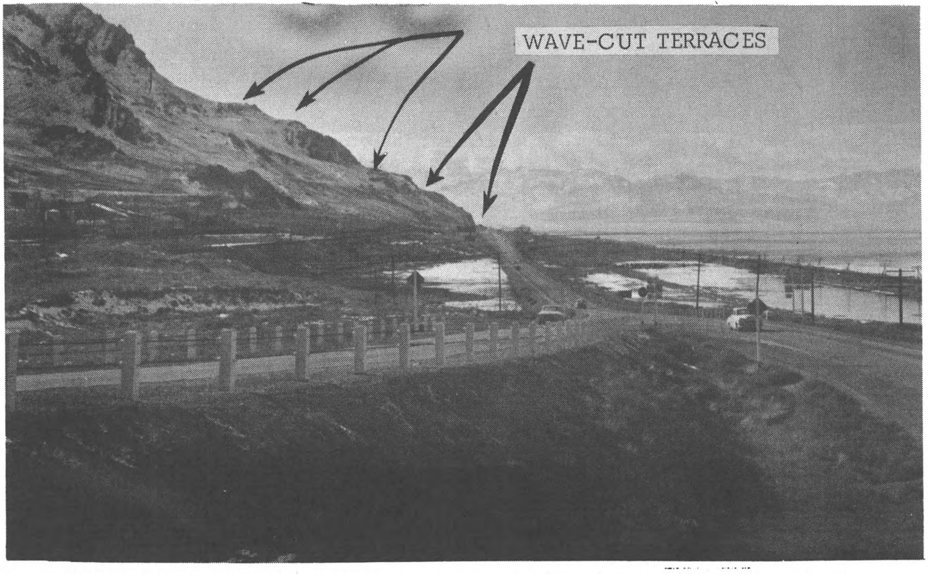

Figure 34. Wave-cut terraces on Oquirrh Mountains, looking south on U.S. Highway 40-50 from Black Rock.

River from a confluence with the Snake River about 20,000 years ago into the Bonneville Basin. The lake (Figure 33) was standing at and eroding the Bonneville beach at the time, and the additional inflow caused the lake to rise suddenly and to overflow at the north end of Cache Valley. There then resulted one of the earth's most catastrophic floods, for the overflow river quickly cut a passage 300 feet deep and drained the lake down to the Provo level. It is observed that the Snake River Canyon at Twin Falls was filled to overflowing, and from this it is calculated that the flood lasted about 300 years.

The lake held at the Provo level for a while, then fell, then rose again. By this time probably the climate was becoming more arid and the lake's history turned to one of shrinkage due to greater evaporation than precipitation and inflow. From this stage hence, the lake became one of increasing salinity and had reached the present Great Salt Lake stage about 11,000 years ago.

SEDIMENTS OF LAKE BONNEVILLE

Bonneville sediments range from shoreline boulder fields to deep-water clays. The most important economic deposits are the sands and gravels of the beaches. The silts and clays of the lake bottom are high in calcium carbonate and thus far have not proved to be of economic importance. In west-central Utah diatomaceous marl with some beds of pure diatomite occur in the surficial deposits of Lake Bonneville.

West of the Municipal Airport, the bottom silts and clays generally contain sufficient salt to render them unsuited for agriculture. If the salt could be flushed out, they should make good crop soils.

LAKE ALPINE

In the course of mapping the deposits of Lake Bonneville certain older and underlying deposits have become recognized. They are believed to have been deposited in a lake definitely older than Lake Bonneville, and one that disappeared before Lake Bonneville rose. They date generally beyond the limits of carbon-14 age determinations, but are thought to range from about 50,000 to 25,000 years ago. They are mostly of sand and silt, and in places are separated from the Bonneville sediments by a soil. They extend up the valley slopes to about 5,100 feet above sea level, and thus it is believed that the lake never quite attained the elevation of Lake Bonneville.

Alpine sediments are shown on the accompanying map (in pocket) as a belt forming the upper piedmont next to the old bedrock of the Wasatch, Traverse, and Oquirrh Mountains. Presumably, the episode of erosion that followed the demise of Lake Alpine and the erosional activity of the rising and falling Lake Bonneville have left no topographic shoreline forms of old Lake Alpine. Those that one sees are all of Lake Bonneville (see Jones, 1955; and Hunt, et al., 1953).

LIFE OF BONNEVILLE TIME

Very few invertebrate fossils have been found in association with Bonneville sediments; fresh water snails are the most abundant species identified.

Remains of large vertebrates, in particular the mammoth, have been found in deltaic deposits of the Provo stage of Lake Bonneville. Bones of musk oxen, camels, horses, deer, mountain sheep, and wildcats have been taken from local gravel pits. The Hardman gravel pits on Eleventh Avenue above the Salt Lake City Cemetery have yielded bones of many of these animals (Pack, 1939). In 1963 a tusk, probably from a mammoth, was found fifty feet below street level in silt beds underlying the City Creek alluvial fan on the west side of State Street between North Temple and South Temple Streets.

Recently (Stokes, Smith, and Horn, in press) disarticulate fish bones (of Bonneville Cisco, Utah Chub, and mottled Sculpin) were found near the intersection of Victory Road and U.S. Highway 89, a short distance northwest of the Utah State Capitol. They were in coarse sands and gravels fifty feet below the waterline of the Stansbury stage of the lake. Aside from these, no skeletal fish remains have been reported in lake sediments or in caves of the early Indians, but dwarf species found in isolated springs of the Bonneville basin could only have come from the waters of the lake that once spread across the terrain (Hubbs and Miller, 1949).

The lake had virtually shrunk to the Great Salt Lake level before the first humans apparently made their abode around its shores. Carbon-14 age determinations of debris of the earliest cultural level in Danger Cave near Wendover place the event some 11,000 years ago (Jennings, 1957).

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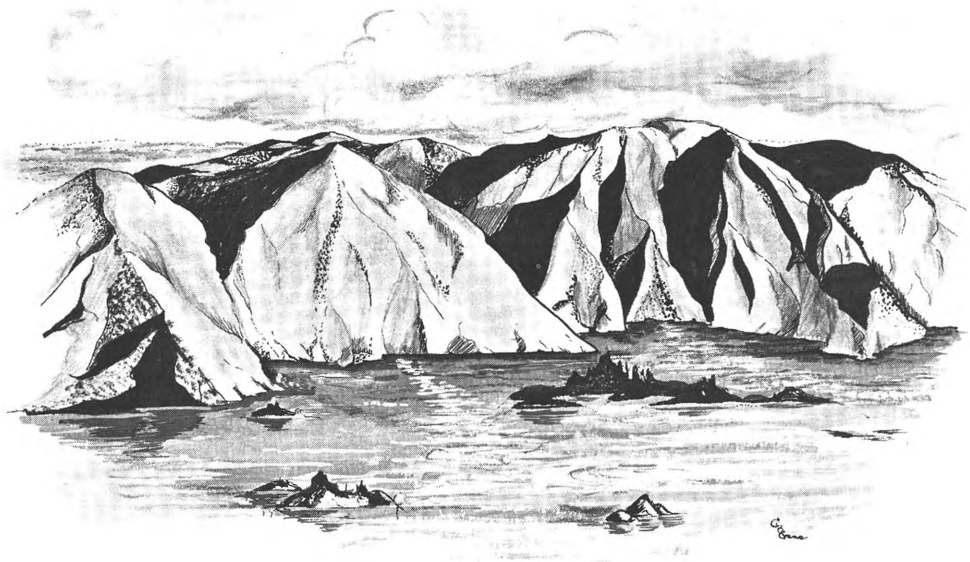

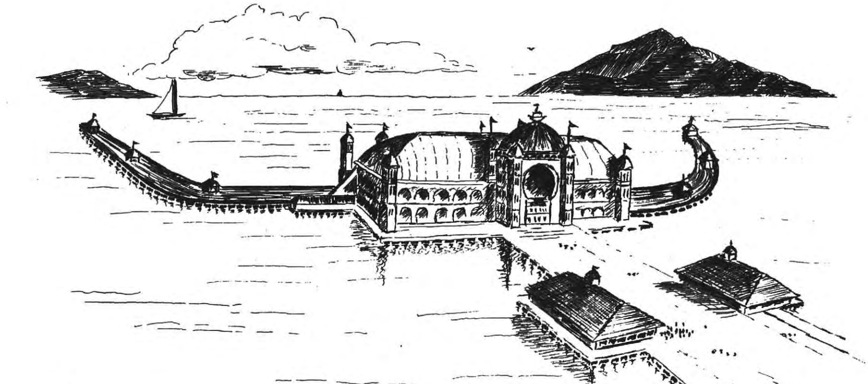

Evans

SECTION V – GREAT SALT LAKE

by A. J. Eardley[1] *and R. E. Cohenour*[2]

LOCATION AND ACCESSIBILITY

Great Salt Lake is a shallow saline remnant of Lake Bonneville. It lies in northwestern Utah, trends northwest, covers 940 square miles of area, is 72 miles long, 22 miles wide, and has a maximum depth of about 27 feet today. Approximately 22 miles of its southeastern shoreline lie in Salt Lake County.

DISCOVERERS AND EXPLORERS

Fathers Dominguez and Escalante entered Utah Valley on September 23, 1776 but did not visit Great Salt Lake, which the Indians reported as obnoxious and unattractive (Auerbach, 1943). Apparently the first explorer to see it was Jim Bridger, who, in the Fall of 1824, floated down the Bear River, entered Great Salt Lake west of the present site of Brigham City, and reported that the lake was an arm of the Pacific Ocean (Miller, 1949). Other "mountain men", including Etienne Provost, James Clyman, and J. R. Walker, also visited it.

Colonel John C. Fremont, the first to scientifically observe the lake, determined that the surface was about 4,201 feet above sea level, and that a gallon of lake water contained nearly three pints of salt (1845). Later, Captain Howard Stansbury (1852) mapped with remarkable accuracy the entire lake shore in 1849 and 1850, and Clarence King (1877), geologist of the Fortieth Parallel Survey, conducted a comprehensive examination of the lake in 1869-1870.

AREA AND VOLUME FLUCTATIONS

Since the discovery of Great Salt Lake in 1824, its recorded level has fluctuated through a range of 20 feet. James Clyman, circumnavigating the lake in 1825, revisited it in 1846 and noted in his journal, "This lake like all the rest of this widespread Sterility has nearly wasted away one half of its surface since 1825..." (Korns, 1951). In 1872 the lake rose

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TABLE III

DISSOLVED SOLIDS IN GREAT SALT LAKE NOVEMBER 8, 1961

(as compared to the Dead Sea)

	GREAT SALT LAKE * Parts Per Million	DEAD SEA Parts Per Million
Silica (SiO_2)	7.0	
Iron (Fe)	.11	
Calcium (Ca)	265.	
Magnesium (Mg)	9,390.	34,500.
Sodium (Na)	84,900.	33,500.
Potassium (K)	5,250.	
Lithium (Li)	Not determined for this sample, but ranges from 29.00 to 56.00.	
Bicarbonate (HCO_3)	398.	
Sulfate (SO_4)	22,100.	900.
Chloride (Cl)	147,000.	180,800.
Fluoride (F)	Not determined for this sample, but ranges from 4.20 to 7.40.	
Iodide (I)	Not determined for this sample, but ranges from .30 to .60.	
Nitrate (NO_3)	154.	
Boron (B)	Not determined for this sample, but ranges from 28.00 to 36.00.	
Dissolved Solids	280,000. (residue on evaporation at 180° C.)	273,408.
Dissolved Solids	269,000 (calculated)	
Density	1.210	

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* Analysis of Great Salt Lake by U.S. Geological Survey, Water Resources Division, reported in Utah Geological Survey Water Resources Bulletin 3.

to its highest historic level, and in 1961 it had again receded -- this time to its lowest historic level. The cause of the level fluctuations is now under intensive study.

The following indicates the lake's recorded fluctuations:

Date	Level	Elevation of Surface	Area (sq. miles)	Storage (acre feet)
June 1850	Stansbury's level	4,201	1,734	17,500,000
June 1872	Highest (historic)	4,211.7	2,187	30,000,000
Jan. 4, 1896	Statehood	4,200.8	1,720	17,065,000
Sept. 1961	Lowest (historic)	4,191.6	915.6	8,733,000
April 15, 1963	Approx. present level	4,192.55	940	9,300,000

If the lake should return to its 1872 level, it would, if unrestricted, again encroach upon the northern limits of Salt Lake City; wind tides resulting from northerly winds would inundate the city along the Jordan River as far south as the State Fairgrounds on North Temple Street; the waters would encroach in tongues close to the Salt Lake Municipal Airport, and the Interstate Highway near Saltair would be awash.

BRINE PROPERTIES AND SALT INVENTORY

Chemical and Physical Properties of Lake Water

The temperature of the lake has ranged in the past few years from 23 to 93 degrees Fahrenheit (D. R. Dickson, personal communication, 1962).

The density and salinity of the lake brines vary with changes of lake level. Historically, the density has ranged from 1.104 to 1.221 and the salinity from 151,300 to 288,000 parts per million, or from 15.1 to 28.8 per cent solids. Between February 1, 1961, and October 16, 1961, the salinity ranged from 25.6 to 28.7 per cent and the density from 1.192 to 1.217. As of April 15, 1963, the lake had an estimated 285,000 parts per million solids (28.5 per cent salinity) and a density of 1.215.

Samples taken six miles west of Promontory Point, south of the railroad crossing, on November 8, 1961, when the lake was at its lowest historic level (4191.6 feet), contained dissolved solids as shown in Table III (comparative determinations for the brines of the Dead Sea are given in the last column).

Mineral Inventory of Lake Brine

An estimate of the present salt inventory of Great Salt Lake is given in Table IV.

TABLE IV

SALT INVENTORY OF GREAT SALT LAKE

April 15, 1963 --

Elevation - 4,192.55 Density - 1.216
Salinity - 27.3% Area - 601,951
Storage - 9,300,145 acre feet
Lake water weighs 75.88 pounds / cubic foot and contains 20.72 pounds of salt.

Assumed Chemical Combinations	% of Total Dissolved Solids (approx.)	Salt Content of Brine			
		Pounds per cubic foot	Pounds per acre foot	Tons per acre foot	Tons in Lake (thousands)
Sodium Chloride NaCl	77	15.95	694,782	347.4	3,231,000
Sodium Sulfate Na_2SO_4	9	1.86	81,021	40.5	377,000
Magnesium Chloride $MgCl_2$	5	1.04	45,302	22.7	211,000
Magnesium Sulfate $MgSO_4$	4	0.83	36,155	18.1	168,000
Potassium Chloride KCl	4	0.83	36,155	18.1	168,000
Others	1	0.21	9,148	4.6	43,000
TOTALS	100	20.72	902,563	451.4	4,198,000

Origin of the Salt

The chemical composition of the Great Salt Lake brine, except for greater concentration, is about that of the oceans. This had led researchers to believe that the salts come from the Pacific Ocean, are carried in the atmosphere and dropped by rain and snow on the watershed of the lake. Others have noted that salt-bearing Jurassic strata crop out in the drainage basin, and may have yielded much of the salt.

Streams that empty into the lake introduce over 1,000,000 tons of salt each year (Hahl and Mitchell, 1963). At the present rate of salt introduction, there should be about three times as much as is known to exist. A proposed explanation of the discrepancy is that winds are effectively removing salt from Great Salt Lake and its surrounding flats (Eardley, et al., 1957).

THE SEDIMENTS OF GREAT SALT LAKE

The lake bottom consists mainly of four types of sediments: (1) calcareous clays and silts, (2) oolite sands, (3) algal reefs, and (4) saline precipitates.

Fine clays occupy part of the lake's bottom area, and are especially dominant in the deeper parts. Very fine and slippery, they range in color from light gray to black. The darker clays emit sulfurous odors, and on a calm day bubbles of gas, possibly hydrogen sulfide (H_2S), may be seen rising to the surface. During an attempt to recover an anchor buried five feet in clayey muck at the Salt Lake County Boat Harbor, sufficient methane gas was liberated to take fire. The mud adhering to the anchor was jet black and changed to a steel gray color when dry. The clays recovered in coring operations were unctuous and partly laminated. It has not yet been established whether the laminations are annual layers. One of the deeper cores, procured about twenty feet below the lake's floor, was black in color and emitted sulfurous odors. On drying, the outer aerated portion turned buff and showed thin laminae.

Oolite sands are the shallow water and shore deposits. They frame the lake except in areas of bioherm development. The oolites are small concretions of calcium carbonate encrusted on nuclei of mineral particles and fecal pellets of the brine shrimp, *Artemia gracilis*. The oolites are larger in areas of vigorous wave activity, where they often become cemented into crusts (Eardley, 1938).

Algal bioherms are a biochemical precipitate of calcium carbonate by the blue-green algae, *Aphanothece packardii*. The bioherms are reddish-brown if coated with living algal matter, and gray if barren. They are rounded pillow-like masses and are very extensive around the lake in shallow water (Figure 35).

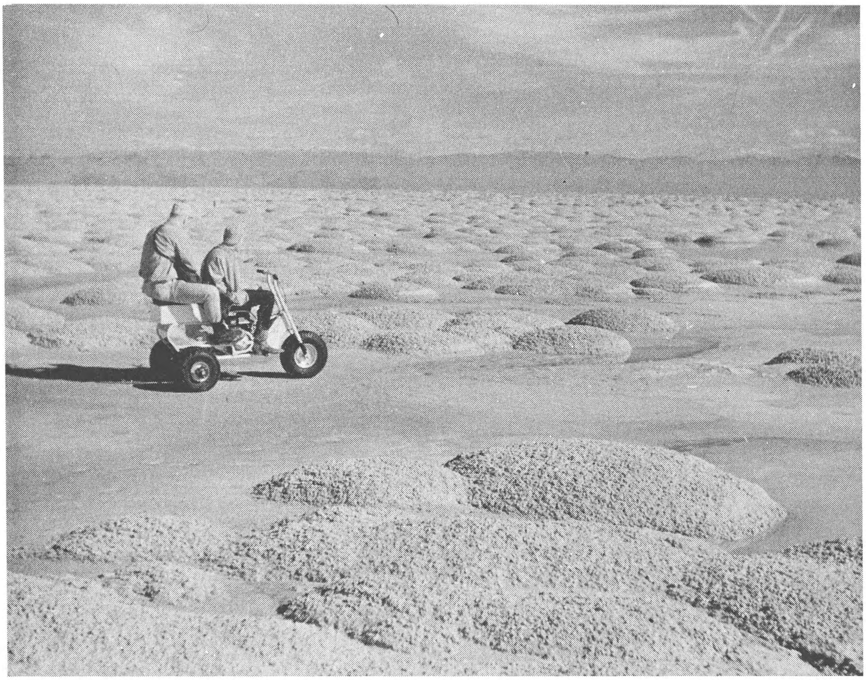

Figure 35. Mounds of porous calcium carbonate precipitated as reefs by blue-green algae that live prolifically in the lake. This photograph is on the southwest shore at an elevation of about 4,192 feet above sea level. The algal mounds have recently been exposed by the fall of the lake.

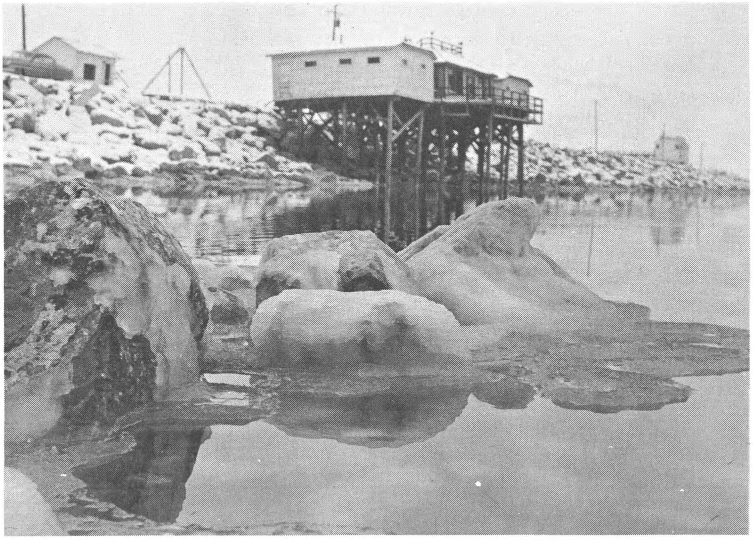

Figure 36. Mirabilite found on rocks at Great Salt Lake Boat Harbor (December, 1963).

Saline compounds in solution are principally the highly soluble sodium, potassium, and magnesium chlorides and sulfates and the relatively insoluble calcium and magnesium carbonates. The chlorides and sulfates have been precipitated in periods of low lake levels, but have been redissolved in response to salinity and temperature change. In recent years salt is being precipitated in the northwest end of the lake, north of the Southern Pacific causeway, and is not being redissolved, apparently.

Mirabilite, the hydrous sodium sulfate ($Na_2SO_4 \cdot 10\,H_2O$), is much less soluble in cold water than in warm. During the winter months mirabilite crystals coat objects along the shore (Figure 36), and in open water mirabilite blades grow to an inch in length (Crawford, 1949) and sink slowly to the bottom of the lake where they remain half suspended in the dense lake brine. Strong waves then may sweep them onto the shore in snow-white bars several feet deep, often scores of feet wide and almost continuous in length along the leeward side of the lake. These snow-white bars (Figure 37) soon become dirty, covered by wave-cast scum and wind-blown silt. Under favorable conditions oolite sand is washed over the mirabilite. In time the mirabilite deposit recrystallizes and cements the oolites with concrete-like tenacity. Beds of sodium sulfate are responsible for much of the foundation support of the rock fill which replaces the old trestle of the Lucin Cutoff of the Southern Pacific Railroad through the center of the lake (Eardley, 1962). It also constitutes the foundation into which the piles were sunk by means of steam jets for the old Saltair pavilion, west of Salt Lake City (Talmage, 1900).

Figure 37. Snow-white mirabilite bars around the south shore of the lake, looking easterly from Great Salt Lake Boat Harbor. (Courtesy Clyde Anderson)

LIFE IN THE LAKE

Great Salt Lake, though akin to a dead sea, is not lifeless. A few specialized types of plants and animals live and reproduce in great abundance in the lake (Eardley, 1938). Two animals and one plant comprise the visible forms: (1) the brine shrimp, *Artemia gracilis*, (2) the adult and pupa of the fly *Ephydra*, and (3) the blue-green colonial algae, *Aphanothece packardii*. The brine shrimp, less than a quarter of an inch in length, is rusty to colorless and is seldom recognized, although it exists by the billions in the brine. Recently the shrimp has been seived and packaged for tropical fish food. Pupae of the flies may be seen floating on the lake waters; but their presence is more readily apparent as fly-festooned smelly windrows of pupae and casts on and in scums on shallow pools. They frequent the beaches in warm weather. Colonial blue-green algae are actually reddish-brown in color and, when growing in the lake, form bioherms of stoney secretions which coalesce to form rough prickly reefs that are a hazard to boats and bathers. An extensive algal reef extends along the shore from near the Saltair pavilion southwestward, passing lakeward of the County Boat Harbor, to and beyond Black Rock at the westernmost edge of Salt Lake County.

ECONOMIC POTENTIAL

In 1963 the brines of Great Salt Lake contained more than four billion tons of salts. At present this potentially important mineral resource is only slightly developed. The salts are recovered by solar evaporation and represent but a fraction of the production which could be attained from the lake water under more favorable economic conditions. In present operations sodium chloride of all degrees of purity, from "butter" salt, table salt, to cattle salt-blocks, is refined at the Saltair plant of the Morton Salt Company, situated adjacent to U.S. Highway 40 about ten miles west of Salt Lake City. Although potash is recovered from brines from the clays beneath the salt crusts of the Great Salt Lake desert of western Utah, none is being harvested directly from the lake waters. Potassium, lithium, and magnesium salts represent a substantial portion of the economic mineral potential of Great Salt Lake.

Salt Lake County is the population center and the communication and transportation hub of the State. A major economic asset is the undeveloped tourist appeal of Great Salt Lake. Although long-neglected as a tourist recreation area, it has recently gained stature in the State's development programs. Neighboring counties have belatedly realized that it is one of the major tourist attractions. By legislation, the State is now seeking to develop this resource with the creation of a Great Salt Lake Authority.

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SECTION VI – FLOODS AND EARTHQUAKES

by R. E. Marsell[1]

Utah is fortunate in being relatively free of most of nature's disasters. Neither the violent hurricanes of the Atlantic seaboard nor the tornadoes and fierce electric storms of the Midwest and New England areas occur in Utah. Lacking large rivers with wide, heavily populated flood plains, Utah does not experience the recurring floods that inundate thousands of square miles, with attendant great loss of life and enormous damage to property.

The state does, however, suffer from the cloudburst floods that accompany the intense, heat-formed thunderstorms of the summer months. Salt Lake County has had fifty-four such damaging storms to date since the pioneers first settled in Salt Lake Valley in 1847. Typical of the more destructive of these storms was the one that struck the Salt Lake Airport and the north bench area on August 19, 1945.

Twice in the past forty years, Salt Lake County has experienced damaging spring snow-melt floods -- one in 1922 and the other in 1952. Both were caused by unusually cold and wet weather in late winter and spring, with deep snow cover at low elevations in the Wasatch Mountains. The absence of reservoirs and inadequate storm sewers offered no protection from the flooding. Larger and additional storm sewers have been constructed and a new reservoir in Mountain Dell Canyon (under consideration by the Metropolitan Water District of Salt Lake City) will tend to prevent or minimize future floods of the snow-melt type.

EARTHQUAKES

One dubious distinction that Utah shares with other western states, notably California, Nevada, and Montana, is that Utah is earthquake country; and of all natural disasters, earthquakes, and the fires which result when one strikes an urban area, are probably the worst -- for quakes give no warning and cannot be predicted!

An earthquake is a series of elastic waves or vibrations generated by a sudden rupturing of the earth's rocky crust, due to the sudden release of pent-up stresses in the earth. The vibrations travel at speeds of several miles per second and cause the earth to tremble or quake.

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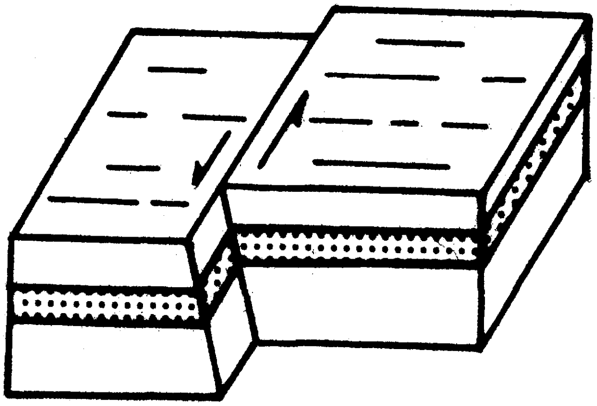

Figure 38. Diagrammatic sketch showing horizontal displacement along fault plane. This is similar to the displacement that caused the San Francisco earthquake of 1906.

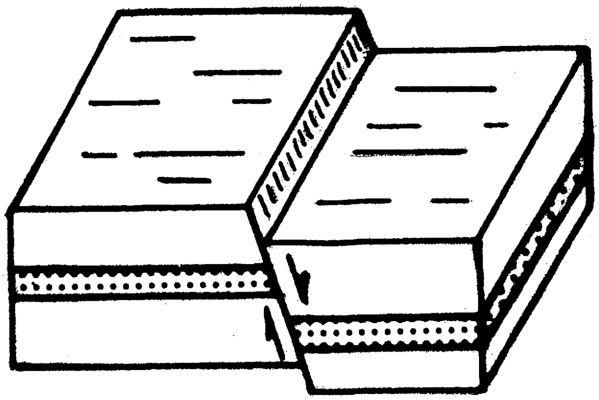

Figure 39. Diagrammatic sketch showing vertical displacement along fault plane. This is similar to the displacement that caused the Yakutat Bay earthquake of 1899.

The rupture or break, called by geologists a "fault", is usually accompanied by dislocation of the earth's blocks on opposite sides of the fracture. Faulting, as the movement along faults is called, is responsible for all destructive earthquakes. Fault zones often are many miles in length and generally extend downward into the earth for twenty-five miles or more. The exact locations and characteristics of faults in an earthquake belt are of vital concern to man, for faults are the mechanisms used by nature to adjust the earth's rigid crust to the unstable forces acting within the outer portion of the earth. Once a major fault zone is formed, it constitutes a weak structure in the crust and tends to localize further adjustments. In other words, faults experience recurrent movements from time to time, each one producing an earthquake! This is especially true of "active" faults, that is, those that have a historical record of earthquake "foci" along their courses or show evidence of geologically recent (last few hundred or few thousand years) movement. Any fault should be considered active which has displaced Recent[2] alluvium and whose surface effects have not been modified to any appreciable extent by erosion.

Faulting occurs in rocks of all kinds and the displacement of a single movement may be horizontal or vertical or a combination of both, and may vary from a fraction of an inch to many feet. The fault which produced the San Francisco earthquake of 1906 had a maximum horizontal displacement of 21 feet; that of the Yakutat Bay earthquake in Alaska in 1899 showed a 47-foot vertical displacement. A diagrammatic example of the former is shown in Figure 37; the latter in Figure 38.

Utah has an earthquake frequency only exceeded by California and Nevada (a dubious distinction to which our neighboring states are welcome). Utah has a record of 263 earthquakes in the 116 years that have elapsed since occupation began in 1847 -- 43 of them originated in Salt Lake County alone, a fact of which the great majority of our citizens are wholly unaware. For the state, this is an average of more than two earthquakes per year; for the county, one in three years. Based on compilations by Williams and Tapper (1953), the accompanying chart of historical earthquakes originating in Salt Lake County (Figure 40) shows none during the first two decades of record; then, for a period of 13 years, 10 quakes occurred; then again, after 14 years without an earthquake, 8 occurred during the next 17 year period, which was followed by 9 years of quiescence. Since 1925 Salt Lake County has experienced 25 quakes in the 38 year period.

Utah has several well-known, major, active fault zones that are responsible for the majority of its recorded earthquakes. Their locations and names are shown on the accompanying map (Figure 41). Movements along the Wasatch Fault zone have accounted for more earthquakes than any of the other zones.

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[2] Recent, the geologic epoch in which we live, dates from the last ice age of the Pleistocene, which in this area correlates with the last stage of Lake Bonneville.

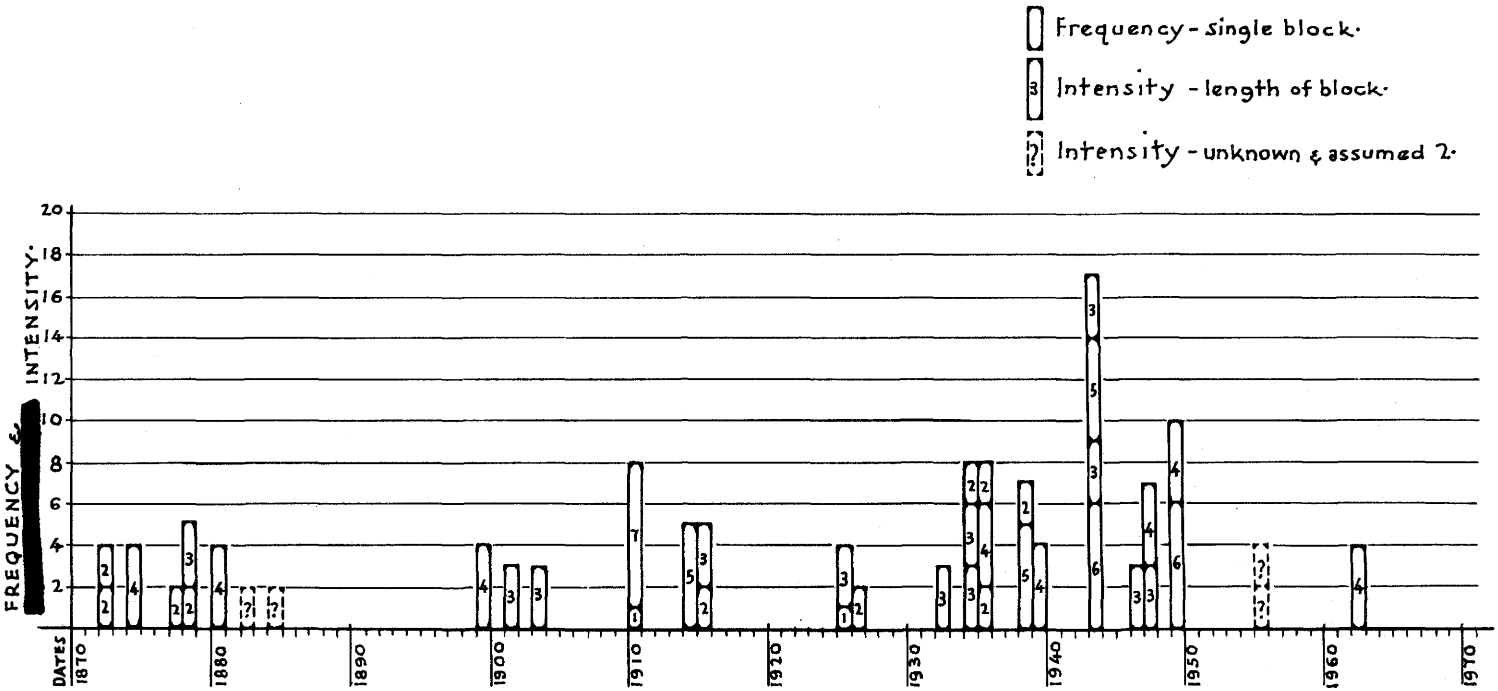

Figure 40. Earthquake frequency chart for Salt Lake County, 1850-1963.

TABLE V

EARTHQUAKES — SALT LAKE COUNTY

te	Time	Location	Intensity	Fault Source	Felt Area (sq. miles
72-Mar. 27	12:52 a.m.	Salt Lake City	II	Wasatch	local only
72-Mar. 28	1:00 p.m.	Salt Lake City	II	Wasatch	local only
74-June 17	11:00 p.m.	Salt Lake City	IV	Wasatch	local only
77-Mar. 5	2:00 a.m.	Salt Lake City	II	Wasatch	local only
78-July 21	5:00 a.m.	Salt Lake City	II	Wasatch	local only
78-Aug. 21	5:00 a.m.	Salt Lake City	III	Wasatch	local only
78-Sept. 7	12:00 p.m.	Salt Lake City	III	Wasatch	local only
30-Sept. 16	11:37 p.m.	Salt Lake City	IV	Wasatch	3,000
32-Nov. 7	6:25 p.m.	Salt Lake City	?	Wasatch	100,000
34-Nov. 9	2:00 a.m.	Salt Lake City	?	Wasatch	6 shocks
39-Dec. 13	6:50 a.m.	Salt Lake City	IV	Warm Sprs.	1,000
01-Aug. 11	9:00 a.m.	Salt Lake City	III	East Bench	local
03-July 23	1:34 a.m.	Salt Lake City	III	Wasatch	1,000
10-May 2	5:10 p.m.	Salt Lake City	I	Wasatch	local
10-May 22	7:28 a.m.	Salt Lake City	VII	Wasatch	local 3 shocks
14-Apr. 8	9:06 a.m.	Salt Lake City	V	Wasatch	1,000
15-Oct. 2	4:41 p.m.	Salt Lake City	II	Wasatch	local
	6:50 p.m.	Salt Lake City	III	Wasatch	local
25-June 27	5:21 p.m.	Salt Lake City	I	Wasatch	local
25-Dec. 1	12:30 a.m.	Salt Lake City	III	Wasatch	local
26-May 3	(late)	Salt Lake City	II	Wasatch	local
32-Dec. 20	11:13 p.m.	Salt Lake City	III	Wasatch	local
34-Jan. 30	1:21 p.m.	Salt Lake City	III	Wasatch	local
34-Apr. 6	7:16 p.m.	Salt Lake City	III	Wasatch	local
34-June 2	5:49 a.m.	Salt Lake City	II	Wasatch	local
35-June 4	10:09 a.m.	Salt Lake City	II	Wasatch	local
35-July 9	3:59 a.m.	Salt Lake City	IV	Wasatch	local
35-Nov. 6	1:12 a.m.	Salt Lake City	II	Wasatch	local
38-June 30	6:37 a.m.	Salt Lake City	V	Wasatch	local
38-Dec. 3	3:00 p.m.	Salt Lake City	II	Wasatch	local
39-Mar. 30	11:40 p.m.	Salt Lake City	IV	Wasatch	local
43-Feb. 22	7:20 a.m.	Salt Lake City	VI	Wasatch	1,000
	9:50 p.m.	Salt Lake City	III	Wasatch	local (Magna)
43-Apr. 10	4:42 p.m.	Salt Lake City	V	Wasatch	local (Magna)
43-Apr. 11	1:32 p.m.	Salt Lake City	III	Wasatch	local
46-Oct. 25	9:53 a.m.	Magna	III	Magna	local
47-Mar. 7	7:14 a.m.	Salt Lake City	III	Wasatch	local
47-Mar. 28	4:02 a.m.	Murray	IV	East Bench	local
49-Mar. 6	11:50 p.m.	Salt Lake City	VI	East Bench	local
49-Mar. 7	12:09 p.m. 1:06 p.m. 1:16 p.m.	Salt Lake City	IV	East Bench	local
55-Feb. 4	12:23 p.m.	Salt Lake City	?	East Bench	local
55-May 12	?	Salt Lake City	?	East Bench	local
62-Sept. 5	8:11 a.m.	Magna	?	Magna-Granger	local

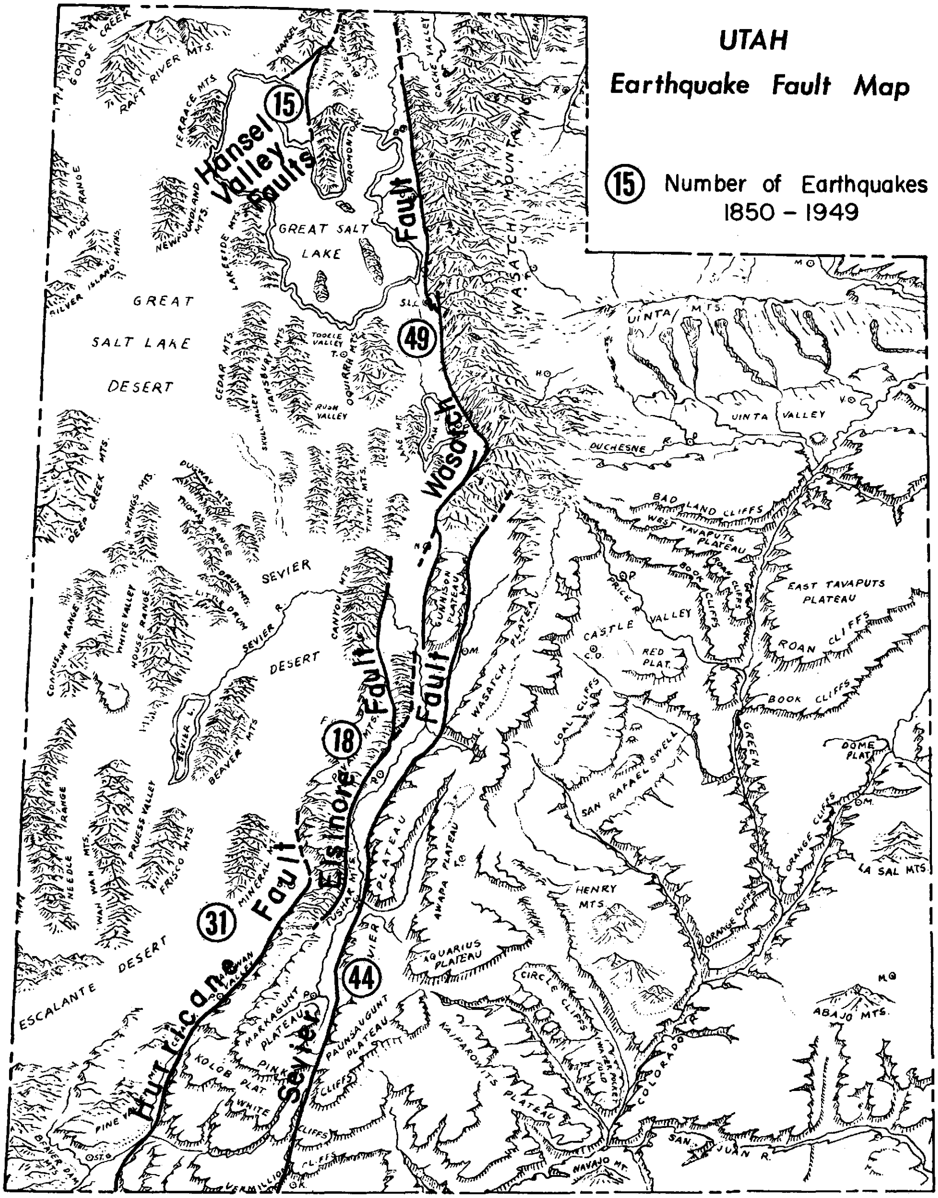
UTAH
Earthquake Fault Map
15 Number of Earthquakes 1850 - 1949
Hansel Valley Faults
15
Wasatch Fault
49
Sevier Fault
44
Elsinore Fault
18
Hurricane Fault
31
GREAT SALT LAKE
GREAT SALT LAKE DESERT
SEVIER DESERT
ESCALANTE DESERT
WASATCH MOUNTAINS
UINTA MTS.
UINTA VALLEY
DUCHESNE R.
BAD LAND CLIFFS
WEST TAVAPUTS PLATEAU
EAST TAVAPUTS PLATEAU
BOOK CLIFFS
ROAN CLIFFS
CASTLE VALLEY
SAN RAFAEL SWELL
HENRY MTS.
AQUARIUS PLATEAU
KAIPAROWITS PLATEAU
PAUNSAUGUNT PLATEAU
MARKAGUNT PLATEAU
KOLOB PLAT.
ORANGE CLIFFS
LA SAL MTS.
ABAJO MTS.
COLORADO R.
SAN JUAN R.
GREEN R.
NAVAJO MT.
SEVIER L.
RAFT RIVER MTS.
GOOSE CREEK
PROMONTORY
CACHE VALLEY
TOOELE VALLEY
RUSH VALLEY
UTAH L.
GUNNISON PLATEAU
WASATCH PLATEAU
TUSHAR MTS.
PINE VALLEY
BEAVER DAM MTS.

Figure 41.

Due to an accidental combination of physical geography and climate, the first settlers located at the western foot of the lofty Wasatch Range, because here they found tillable soil and water which could be diverted for irrigation from the streams debouching from the mountain front. Thus, from these circumstances the population grew, quite unaware of the great earthquake hazard posed by the presence of the Wasatch Fault zone that traversed the eastern margin of the growing community, at the junction of the valley floor and the base of the abrupt, bold mountain front. The known active faults in the eastern part of Salt Lake County are shown on Figure 42. Table V shows the recorded earthquakes that have originated in Salt Lake County since 1849.

Earthquakes are measured on two quite unlike scales: one type, long in use, is based upon the actual, observed effects of a quake by people in the area over which it was felt. This is called an "intensity" scale, and the historical record of earthquakes in Salt Lake County is computed on such a scale, a copy of which follows:

Modified Mercalli Intensity Scale
(Condensed)

I. Not felt except by a few under especially favorable conditions.

II. Felt only by a few persons at rest. Delicately suspended objects may swing.

III. Felt quite noticeably under favorable circumstances, but many people do not recognize seismic nature of the disturbance and many do not notice it. Standing automobiles may rock slightly. Like passing of a truck. Duration estimated.

IV. Felt by many or most. Some awakened. Dishes, windows, doors disturbed, walls crack. Sensation like heavy truck striking building.

V. Felt by nearly everyone; many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbance of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop.

VI. Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

VII. Everybody runs outdoors. Damage negligible in buildings of good construction and design; slight to moderate in well-built ordinary structures; considerable in poorly built or

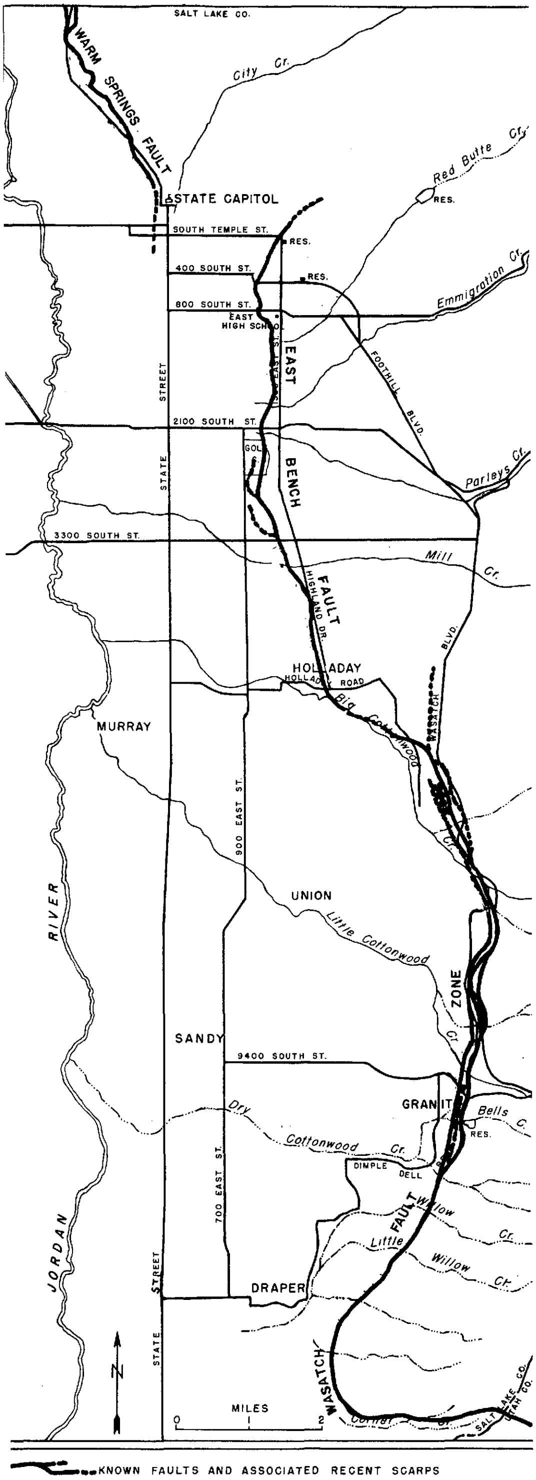

Figure 42. Earthquake fault map of a portion of Salt Lake County (prepared by the College of Mines and Mineral Industries, University of Utah)

badly designed structures; some chimneys broken. Noticed by persons driving motor cars.

VIII. Damage slight in specially designed (brick) structures; considerable in ordinary substantial buildings with partial collapse; great in poorly-built structures. Panel walls thrown out of frame walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motor cars disturbed.

IX. Damage considerable in specially designed (masonry) structures; well-designed frame structures thrown out of plumb; great in substantial (masonry) buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

X. Some well-built wooden structures destroyed; most masonry and frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and water. Water splashed (slopped) over banks.

XI. Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly.

XII. Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown into the air.

The other scale is one computed from instrumental recordings on seismographs, and was first used in 1935 by C. F. Richter, a seismologist, to express the energy released by a given earthquake. This is referred to as the "magnitude" scale. Each earthquake is given a number which represents its magnitude in terms of energy involved. On this scale a magnitude of 2.5 is usually just large enough to be felt. A magnitude of 7 or over represents a major earthquake. The largest magnitude recorded thus far in the twentieth century is 8.6, which represents three million times the energy released by the first atomic bomb. On this same scale, the San Francisco earthquake in 1906 rated 8.2; whereas the Hebgen earthquake in Montana, on August 17, 1959, was computed to be 7.1 on the Richter magnitude scale. A comparison of the disturbances of the earth's surface produced by the Hebgen Lake quake with similar features well displayed at the base of the Wasatch Range in Salt Lake County, resulting from the last movement along the Wasatch Fault zone (Figures 43-45), would lead one to believe that the last movement in Salt Lake County was as great or greater than the recent Montana quake.

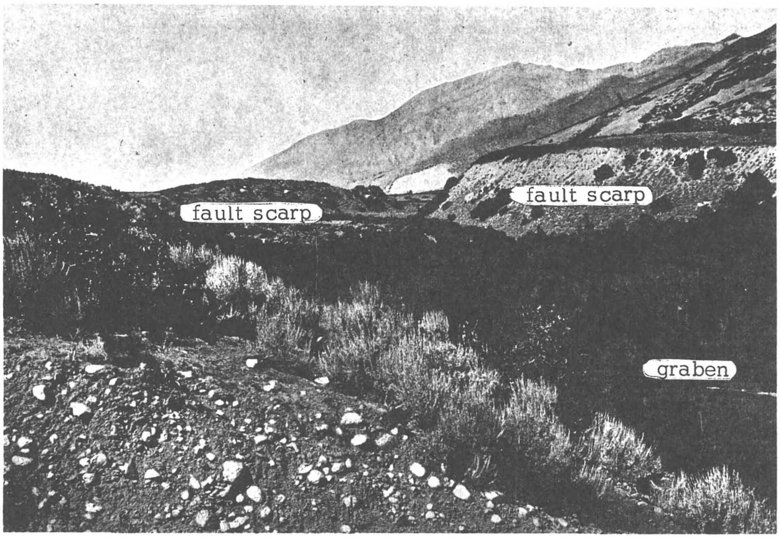

Figure 43. View near mouth of Little Cottonwood Canyon, showing two postglacial fault scarps and an intervening depression. (Taken from Atwood, 1909, U.S. Geol. Survey Prof. Paper 61.)

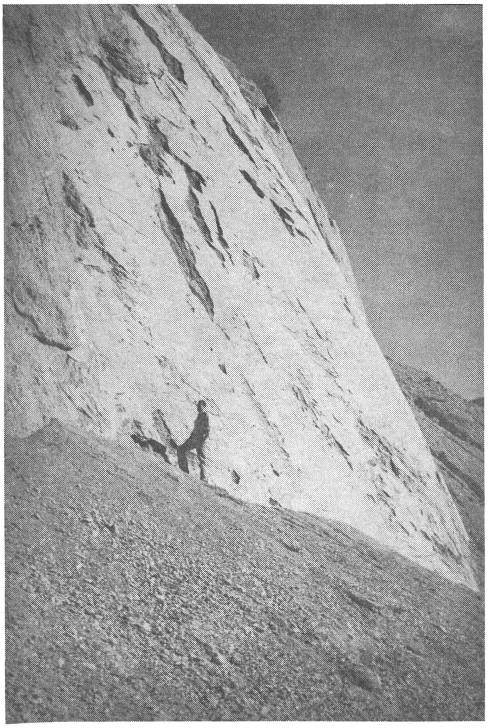

Figure 44. Fault surface at Warm Spring fault, North Beck Street, North Salt Lake, exposed by recent gravel excavations.

Someone has aptly pointed out that "Earthquakes are dangerous solely because we make them so by erecting buildings and houses which can be shattered or shaken down." Salt Lake County is a case in point: with a surface area of only 764 square miles, 44 per cent of the population of the state, nearly 400,000 people (1960 census) are crowded into less than one-third of the county. And here, too, is the greatest concentration of office buildings, schools, churches, industrial buildings, apartments and family dwellings -- the greatest concentration in the state of taxable wealth.

This is indeed a gloomy prospect for residents of Salt Lake Valley. The earthquake history of the western states indicates clearly that if you live near fault zones that have given rise to earthquakes before, you must expect they will do it again! Once we recognize this fact, we can either ignore it, as we have done in the past, or we can do something about it. For one thing, we could adopt the earthquake-resistant provisions of the Pacific Coast Building Code, where all public buildings and multiple dwellings are concerned. Ordinances could be passed that would prevent the erection of such structures astride any of the known active faults, as is the case in California. However well a structure survives the actual earthquake shocks, few can be saved from destruction by the fires that break out everywhere due to broken gas mains, electrical connections, wrecked chimneys and fireplaces. In the San Francisco quake of 1906, four-fifths of the city was destroyed by the fires that raced through the city, unchecked from lack of water and adequate fire-fighting equipment. As far as Salt Lake City proper is concerned, this lack of water is the most vital factor that would make the destruction of the city by fire inevitable -- for every one of the conduits that supply the city (with the possible exception of that of City Creek) crosses the fault zones. In a matter of minutes the water supply would be cut off and the city would be at the mercy of the rapidly spreading conflagration[3/].

A building, especially a one-story dwelling, may ride out a quake but little harmed if it is built on bedrock or dry, compact ground and is properly braced -- unless, of course, it should be directly over the place where the fault fracture breaches the ground surface. Experience has shown that far more important than proximity to a fault zone is the type of ground on which a given structure is built! Careful studies of earthquakes in heavily populated areas have consistently shown that the intensity of the shock is directly related to the type of ground supporting the building. Buildings on solid rock near the fault often suffer less damage than similar distant buildings on loose ground. Areas of water-saturated alluvium, such as constitute the floor of Salt Lake Valley, transmit with greatly amplified

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3. Editor's comment: It has been suggested that fire hazards might be minimized by building twin reservoirs, one on either side of known faults: then, assuming the ancient water mains would remain intact, the downgrade reservoir would supply essential water while the ruptured line is repaired by portable piping; by equipping power and utility lines above active faults with flexible joints and adequate slack.

intensity the motion of the passing earthquake waves. We are told to "Build our house upon the rock, and not upon the sand." Few buildings in Salt Lake Valley, however, are built "upon the rock." Architects can easily design buildings that are earthquake resistant, provided a suitable site is available. There is nothing mysterious as to the requirements. Their purpose is to insure that the structure will overcome inertia and move with the earth as a unit, not as an unrelated number of parts. The essential rigidity is obtained by adequate bracing, secure anchoring and bonding of all structural parts, so that the building is a monolithic unit able to withstand tensile, compressive, and shear stresses of short duration.

Figure 45. Fault scarps cutting glacial moraine on south wall of Little Cottonwood Canyon.

It is hard to tell how an individual will react to a major earthquake. No two people seem to respond alike. Some are immobilized with terror; some rush out of doors in panic; some, where the shaking motion is severe, are unable to stand; others report a rumbling sound like a freight train passing over a bridge. Nausea is common with many. It seems instinctive for most people to get into the open, but this is often a mistake, especially if you are in the business district of a metropolitan city. <u>Don't run into the streets</u>! In Long Beach, California, in the severe earthquake of March 10, 1933, the sidewalks and curbs were buried with thousands of tons of debris from falling parapet walls, electric signs and similar features of building fronts. Get into a doorway if possible, or dive under a heavy desk or table. One authority, when asked what one should do when the earth begins to quake, replied, "Count slowly to 40, and after that it doesn't matter much what you do."

REFERENCES

Williams, J. S., and Tapper, M. L., 1953, Earthquake History of Utah, 1870-1949: Seismol. Soc. Am. Bull., v. 43, no. 3, p. 191-218.

SECTION VII –
MINING IN SALT LAKE COUNTY

by M. P. Nackowski[1]

INTRODUCTION

A discussion of mining in Salt Lake County focuses attention on three mining districts (Figure 46) and several mineral processing plants. The three districts (West Mountain, Big Cottonwood, and Little Cottonwood) were discovered by soldier prospectors[2] of General P. E. Connor following their arrival in Salt Lake City in 1862. These districts are treated in detail by Boutwell (1905), Rickard (1918), Butler (1920), Beeson (1927), Gilully (1932), Calkins, et al. (1943), and Arrington (1963); and for recent developments in the Bingham district by authors James, Welsh, Smith, Roberts, Tooker, Hammond, Hansen, Bray, and editor Cook, of the symposium Utah Geological Society Guidebook to the Geology of Utah, no. 16. The reader is referred to their writings for greater background on the history, geology, and economic development of the mines.

The West Mountain or Bingham district in the Oquirrh Mountains west of Salt Lake City, continuously active since its discovery, has grown steadily in importance and is now a major producer of copper, silver, lead, zinc, gold, and molybdenum, in addition to by-product precious and rare metals and sulfuric acid. The Big and Little Cottonwood districts, also known as the Brighton and the Alta districts, high in the Wasatch Mountains, southeast of Salt Lake City were at one time important lead-silver camps.

The total value of mineral production in the West Mountain district approximates five billion dollars. That for the Big and Little Cottonwood districts exceeds thirty-seven million dollars. About one-third of the state's mineral production is currently from Salt Lake County, and largely from the Bingham district.

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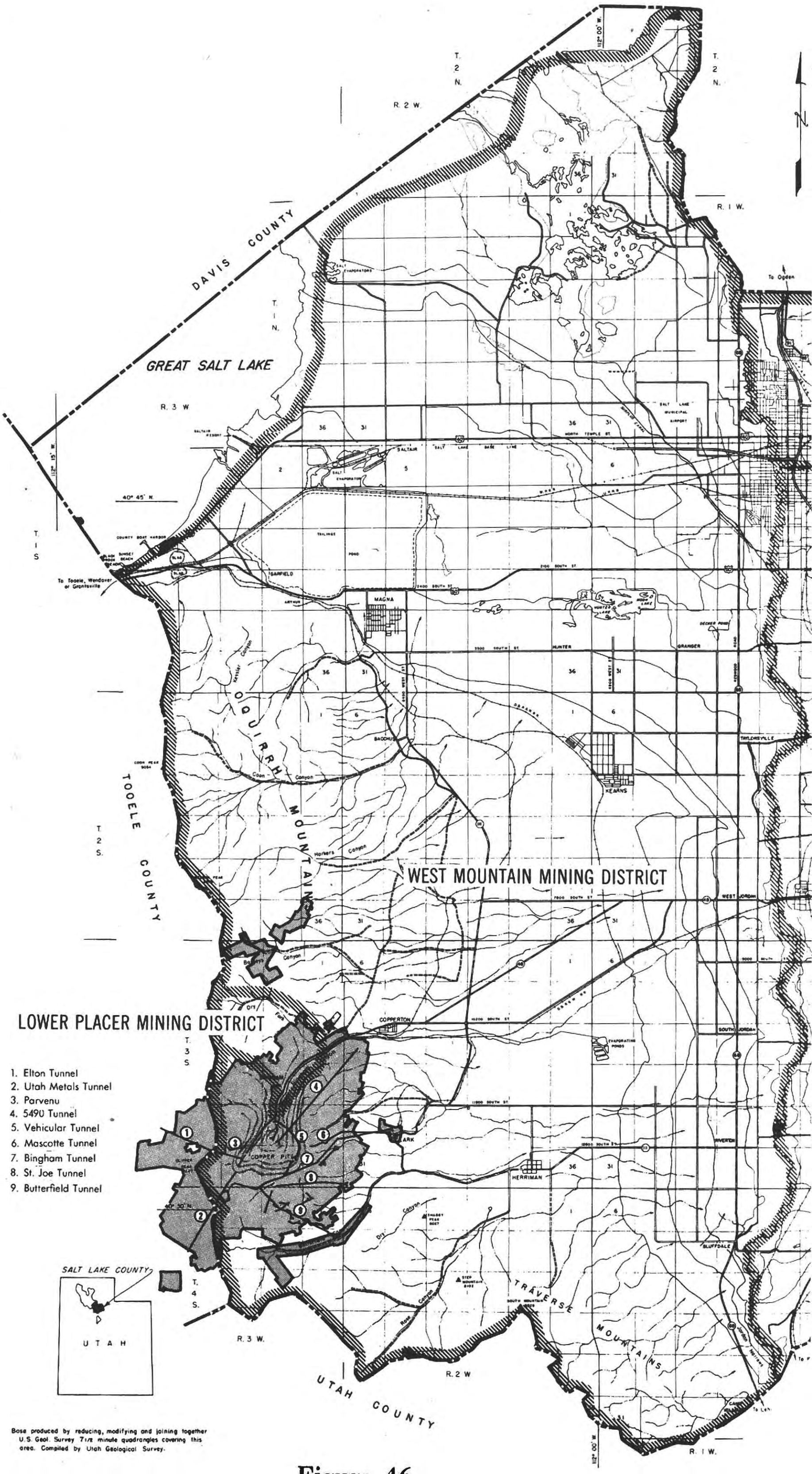
1. Professor of Mining and Geological Engineering, College of Mines and Mineral Industries, University of Utah.

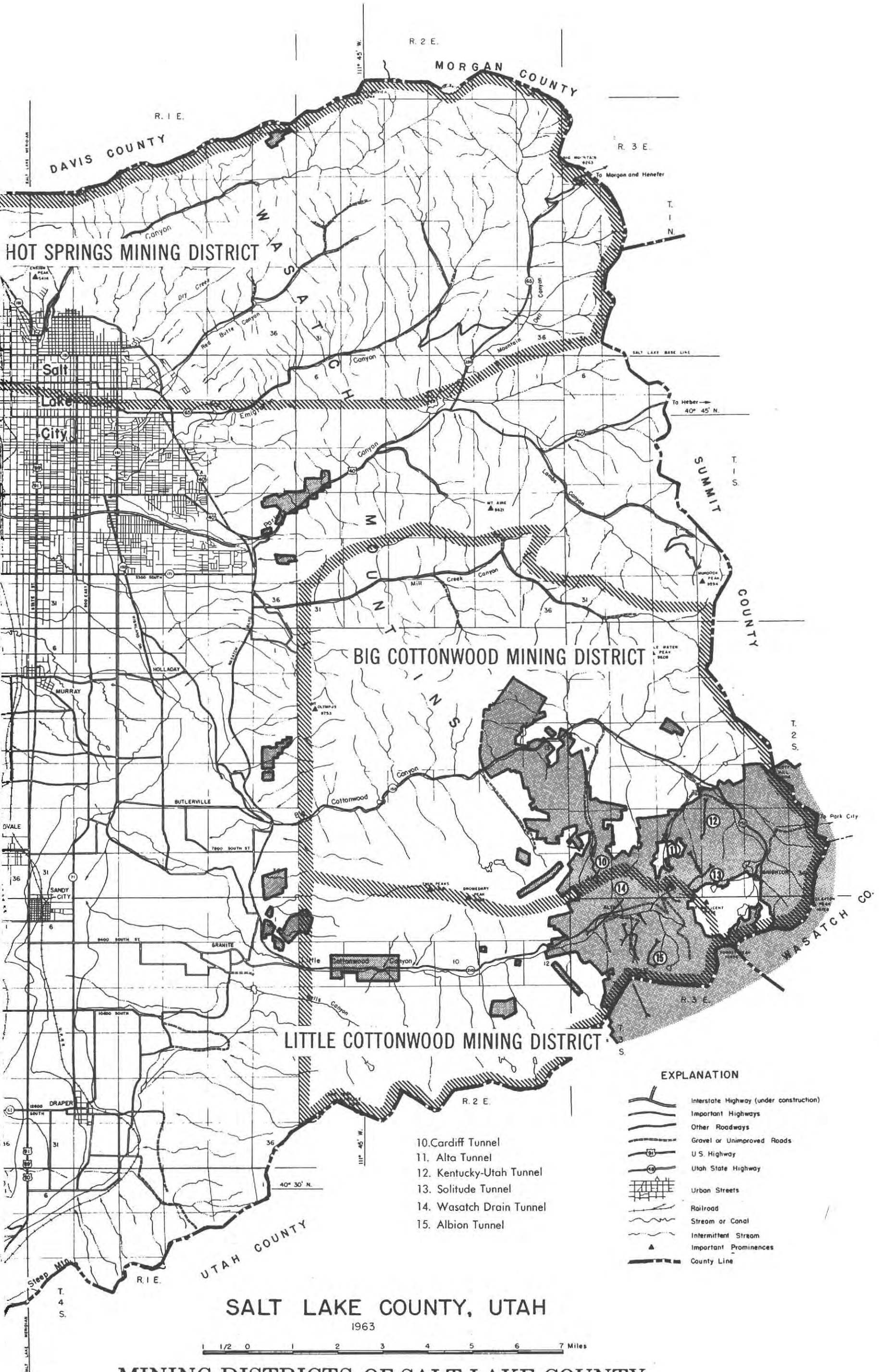
2. Even before Connor's time it is claimed by the Daily Alta California (San Francisco) (February 9, 1873) that the soldier prospectors of Colonel Albert S. Johnston discovered silver ore near Cedar Valley while they were stationed at Camp Floyd south of the Oquirrh Range.



1. Elton Tunnel
2. Utah Metals Tunnel
3. Parvenu
4. 5490 Tunnel
5. Vehicular Tunnel
6. Mascotte Tunnel
7. Bingham Tunnel
8. St. Joe Tunnel
9. Butterfield Tunnel

Base produced by reducing, modifying and joining together U.S. Geol. Survey 7 1/2 minute quadrangles covering this area. Compiled by Utah Geological Survey.

Figure 46



MINING DISTRICTS OF SALT LAKE COUNTY
Showing Patented Areas

Compiled from various sources.

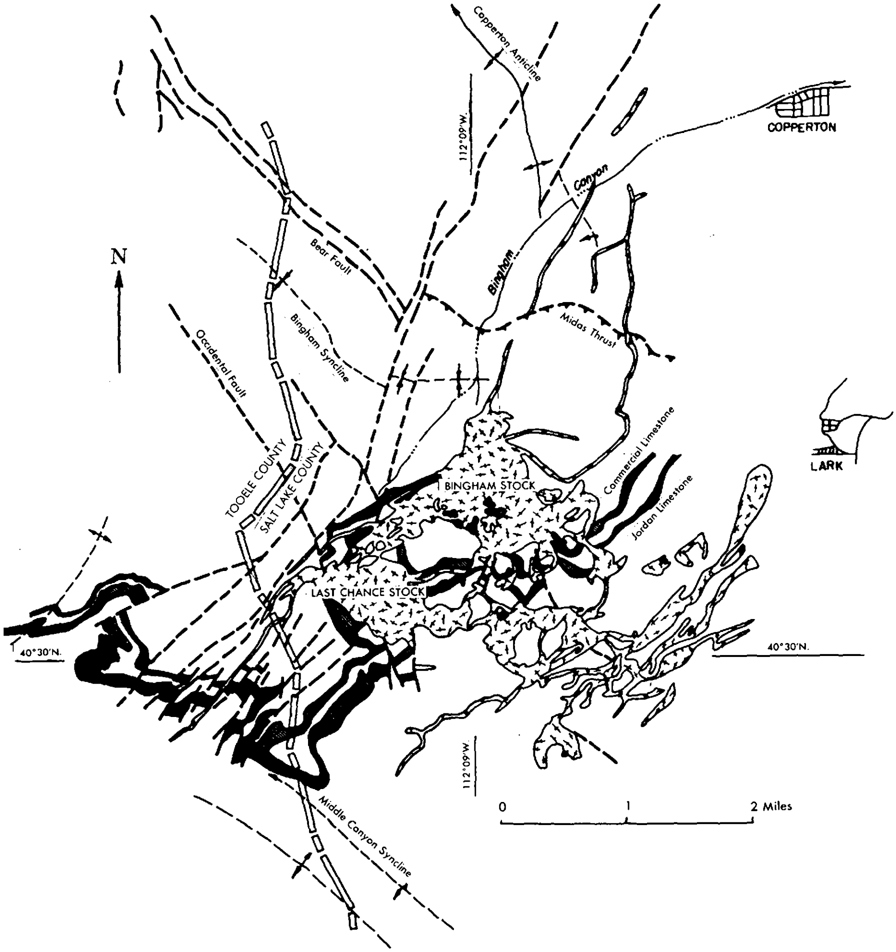


Figure 47. Generalized Geologic Map of the Bingham Area.

THE WEST MOUNTAIN DISTRICT

Geologic Environment

Bingham is one of the world's major mining districts and is the site of the first successful open-pit copper operation. Its productive area, roughly four miles square, produces high grade, massive, lead-zinc-copper ores which are extracted in underground mines; and low-grade, disseminated copper ores that are mined at the Utah Copper pit. Permian and Pennsylvanian sandstones, intercalated with thin beds of limestone, calcareous shale, and calcareous sandstone, have been intruded by the Bingham and Last Chance stocks and related apophyses of granite, granite porphyry, and monzonite. The massive ores are confined to the Permian and Pennsylvanian sediments; whereas, the low-grade disseminated ores are related to the intimately fractured, altered and mineralized Bingham stock as well as adjacent sandstone and associated sediments. Latitic and andesitic flows, breccias, agglomerates and tuffs, non-mineralized and younger than the intrusive rocks, are exposed along the Oquirrh foothills.

Three major folds are recognized: the Middle Canyon syncline and the Bingham syncline, which trend northwest; and the Copperton anticline, which trends north. With the Utah Copper pit as a point of reference, the axis of the Middle Canyon syncline passes three miles to the southwest and its northeasterly flank grades into a poorly exposed unnamed anticline. This in turn leads to the Bingham syncline, central in the district and an important control of the Bingham stock. In turn, the northeastern flank of the Bingham syncline passes into the north-trending Copperton anticline, which occurs about a mile to the northeast.

The structural picture is further complicated by a series of faults. Prominent among them, the low angle Midas thrust fault strikes west-northwesterly and surfaces a mile northeast of the pit. Its upper plate contains the Bingham syncline; its lower plate, the Copperton anticline. This thrust fault dips 40° southwesterly beneath the Bingham syncline. Its relation to intrusion and mineralization is not known. However, it marks the northeast limit of lead-zinc mineralization in the district. Another important fault is the North Oquirrh thrust, which, probably older than the intrusives, strikes east across the axis of the Oquirrh Mountains. The Occidental and Bear faults roughly limit the Bingham and Last Chance stocks. The Bear fault, considered by some to be a continuation of the Midas fault, is a high angle thrust which strikes northwest and dips 75° southwest. The Occidental fault is normal, strikes N 25° W and dips 62° southwest. It marks the southwest limit of lead-zinc mineralization. A system of northeasterly trending high-angle reverse faults, including the Clipper Peak and the West Mountain faults, controls the northeast striking contacts of the intrusive stocks and has localized lead-zinc mineralization (Figure 47).

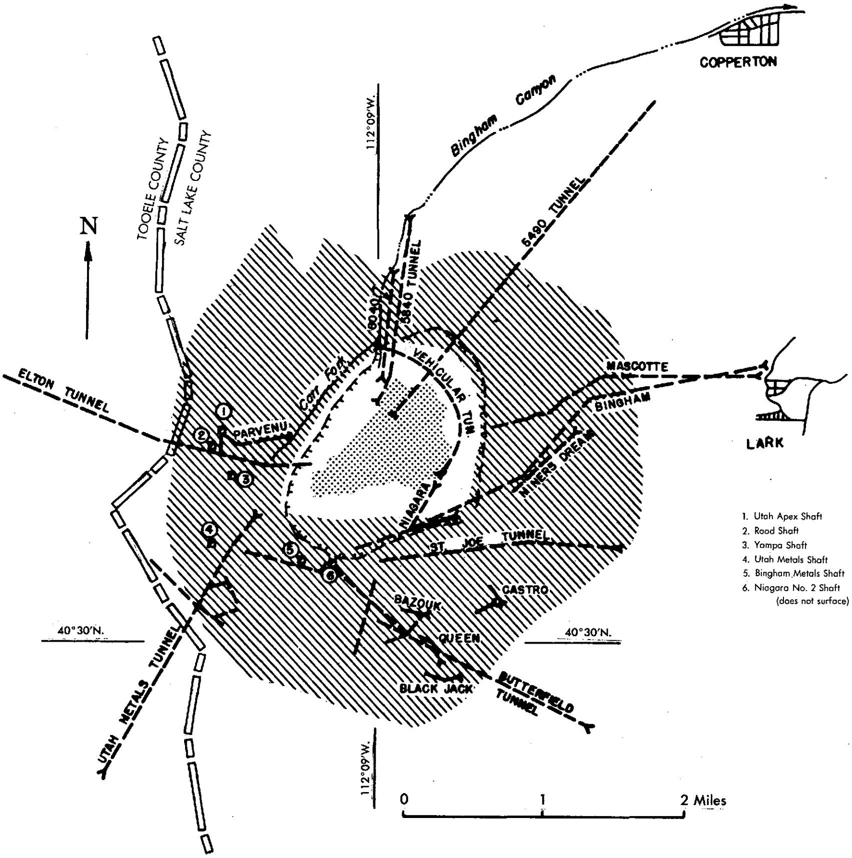


Figure 48. Principal Mine Workings and Mineralization Outline, Bingham Area.

Ore Deposits

Classification of Ore Deposits: The ores of the Bingham district form a zoned group of mineral deposits distributed within and around the Bingham stock (Figure 48). The central porphyry copper orebody, from which 85 per cent of the copper is produced, consists of disseminated sulfides and conforms roughly with the outline of a granite-porphyry which occupies the northern triangular portion of the Bingham stock. The principal primary ore minerals are chalcopyrite, bornite, and molybdenite, mixed with an abundance of waste pyrite.

The disseminated ore body is surrounded by two zones. The inner, sometimes in the Bingham stock, sometimes in surrounding sedimentaries, is 600 to 2,000 feet wide. It is rich in iron as pyrite and magnetite; but poor in copper, except to the northwest where, along its outer fringe, copper lode deposits of chalcopyrite-pyrite ore have been mined in the Highland Boy and Apex areas. The outer zone, from which 99 per cent of the lead-zinc production is derived, consists chiefly of replacement deposits in limestone intercalated in Pennsylvanian strata that range from sandstone to quartzite, and mineralized fissures which cut these beds and the Last Chance stock. Lead-zinc ores are progressively richer in silver values as they grade outward into the sedimentaries farther removed from the source of mineralization. The lead-zinc deposits are best developed east, south, and west of the central disseminated copper orebody, but they are practically nonexistent along the northern fringe.

Mineralogy of Ores: The minerals of the ore deposits include primary and secondary ore and gangue minerals.

The primary metallic minerals include the following, of which pyrite is the most abundant:

Pyrite	FeS_2	Galena	PbS
Chalcopyrite	$CuFeS_2$	Sphalerite	ZnS
Bornite	Cu_5FeS_4	Gold	Au
Tetrahedrite	$Cu_8Sb_2S_7$	Specularite	Fe_2O_3
Chalcocite	Cu_2S	Magnetite	Fe_3O_4
Enargite	Cu_3AsS_4	Molybdenite	MoS_2

The secondary minerals include:

Cuprite	Cu_2O	Cerussite	$PbCO_3$
Malachite	$Cu_2(OH)_2CO_3$	Anglesite	$PbSO_4$
Azurite	$Cu_3(OH)_2(CO_3)_2$	Hematite	Fe_2O_3
Chalcocite	Cu_2S	Limonite	$Fe_2(OH)_6 \cdot Fe_2O_3$
Chalcanthite	$CuSO_4 \cdot 5\ H_2O$	Covellite	CuS

Non-metallic gangue minerals include:

Quartz	SiO_2	Gypsum	$CaSO_4 \cdot 2H_2O$
Opal	$SiO_2 \cdot nH_2O$	Garnet	$Ca_3Al_2(SiO_4)_3$
Calcite	$CaCO_3$	Barite	$BaSO_4$
Sericite	$H_2(KNa)Al_3(SiO_4)_3$	Rhodochrosite	$MnCO_3$
Siderite	$FeCO_3$		

In the disseminated copper area, the primary minerals were overlain by an enriched blanket of secondary chalcocite and covellite, capped by 40 to 100 feet of leached rock barren of copper.

Grade of Ores: The copper content of Bingham's disseminated ore, as currently milled, averages about 0.76 per cent copper; whereas ore from the fissure and bedding replacement deposits was frequently as high as 6.6 per cent copper. The average grade of lead-zinc ore, produced over several decades, was about 7 per cent lead, 7 per cent zinc, less than 1 per cent copper, 7 ounces silver, and 0.10 ounces gold. The lead carbonate ores averaged 27.5 per cent lead and 57 ounces silver.

Size and Shape of Orebodies: The disseminated copper deposit is roughly triangular in plan and includes an area of 18,000,000 square feet. Its known vertical extent is still "classified" information, although the Salt Lake Tribune (Dec. 8, 1963, Sec. C, p. 1, R. W. Bernick) forecasts that

> "Utah copper and the people of Utah will be assured of at least 30 years more of good productive life at Bingham if the company and its managers are able to solve the very great mining and metallurgical problems ahead."

The vein or lode deposits are tabular in shape and have been mined down-dip well over a mile below the surface. The maximum known strike length of ore shoots is said to be 500 feet with a corresponding thickness of 150 feet. The orebodies in the sedimentary rocks generally parallel the bedding and range in dip from 15° to vertical.

History

On September 17, 1863, General Connor, George B. Ogilvie, Archibald Gardner and twenty-two others located the West Jordan claim in Bingham Canyon, the first mining claim located in Utah. In December the West Mountain Mining district, the first in the Territory, was organized. It included the entire Oquirrh Range. In 1864 it was subdivided, with the eastern slope of the range retaining the name West Mountain mining district, and the western slope becoming the Rush Valley district.

In 1864 the Jordan tunnel was started, but economic conditions curtailed development. Activity was renewed in anticipation of the completion of the Central Pacific and Union Pacific transcontinental railroads, and one week following their joining at Promontory Summit on May 10, 1869, construction was begun on the Utah Central Railroad from Ogden to Salt Lake City. By September 23, 1871, the Utah Southern Railroad had connected Salt Lake City to Sandy, and two years later a narrow gauge was extending into the West Mountain district.

Reduction Works

During the 1870's the Germania smelter, the Mingo or Mountain Chief furnaces and the Hanauer Smelting Works were built. Ores mined and shipped to these smelters were largely lead carbonates. By 1874 many surficial carbonate orebodies had been mined-out to the underlying sulfides, but in 1874 Nathan Kimball, Surveyor-General of Utah Territory reported[3], "At present there are 30 smelting works, ten quartz mills, one separating and refining and one concentrating work in successful operation in the Territory, and the number is constantly increasing."

In 1881 mines of Butterfield canyon were developed. Following exhaustion of lead carbonate ores in some Bingham canyon mines, attention turned to recovering gold from the near surface portion of oxidized ore shoots. Results were not encouraging, but successful argentiferous lead-sulfide mining developed and continued until 1892.

The Utah Copper Development

In 1896 about 5,000 tons of copper sulfide ore were shipped from the Highland Boy property and by this time Colonel Enos A. Wall, who had as early as 1887 become interested in the disseminated copper sulfides in the porphyry intrusive at Bingham, secured title to about 200 acres within the porphyry. After judicious exploration and evaluation, Colonel Wall optioned his property to Hartwig A. Cohen (who was acting secretly for D. C. Jackling). Cohen and Jackling submitted the "deal" to Charles M. MacNeill and the Penrose brothers, who exercised the option, and got it rewritten in the name of Spencer Penrose.

The Wall-Cohen-Jackling-MacNeill-Penrose disseminated copper claims became the nucleus of the Utah Copper Company, which was organized on June 4, 1903, by Charles M. MacNeill and associates under the laws of Colorado.

The first disseminated ore, averaging 2 per cent copper, was milled in August 1904 in a 300-ton per day capacity mill at Copperton. The Guggenheim Exploration Company underwrote a 3 million dollar bond issue to develop the Utah Copper disseminated ores. Also, foreseeing the probable

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[3] Report of the Commissioner of the General Land Office to the Secretary of the Interior for the year 1874, page 159.

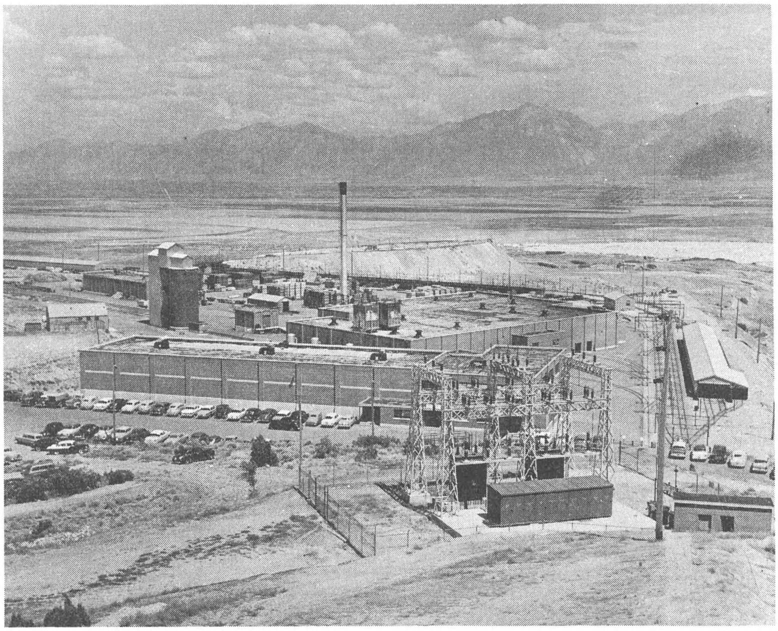

Figure 49. View facing easterly across the surface plant, U.S. and Lark Mine, United States Smelting, Refining, and Mining Company, Lark, Utah. Lead and zinc are the primary minerals mined.

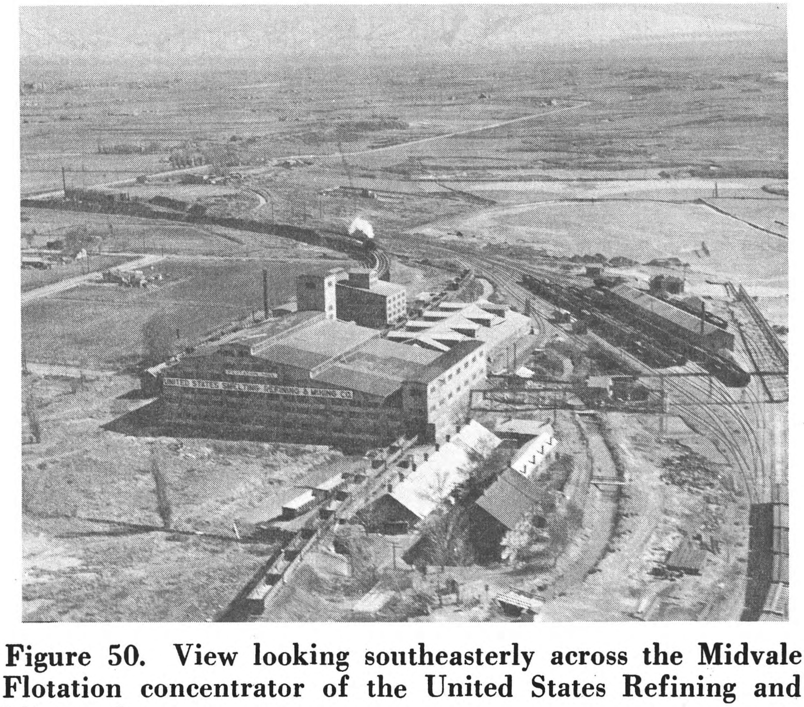

Figure 50. View looking southeasterly across the Midvale Flotation concentrator of the United States Refining and Mining Company.

court injunction against the release of fumes in agricultural areas, the American Smelting and Refining Company began construction of a smelter at Garfield to treat concentrates from a new 600-ton plant at Magna operated by the Utah Copper Company. The smelter started operating in 1907. In January 1910 the Utah Copper Company capitalization was increased to $25,000,000 and a merger with the Boston Consolidated Company, which had been formed in 1897, was effected. The Boston Company Mill was remodeled and renamed the Arthur Mill. The Utah Mill was renamed the Magna Mill. Over a period of years Kennecott Copper Corporation had acquired controlling stock in Utah Copper Company, and in 1936 the Utah Copper Company became an operating division of Kennecott.

The Anaconda Company

The Anaconda Company, through its acquisiton of National Tunnel and Mines Co., currently owns several old mines now idle on the west side of Carr Fork. Slightly less than 12 million tons of ore have been produced from them, chiefly from the Yampa and Highland Boy Limestones.

United States Smelting, Refining, and Mining Company

The Utah Consolidated Mining Company, formed in 1896, completed a 250-ton copper smelter at Midvale in 1899. In March 1899, it was consolidated with the Jordan, Galena, Utah, Niagara, and Telegraph mines as the United States Mining Company, later succeeded by the United States Smelting, Refining, and Mining Company, which has continued as a major operating company in the district and as one of the major lead-zinc producers in the United States (Grant, Ehrhorn, and Du Bois, 1948). Its holdings now include the mineral rights[4] on 8,100 acres, including outright ownership of 5,739 acres located north, east, and south of the Utah Copper pit. The company's main transportation tunnel, having its portal at Lark (Figures 48 and 49) is four miles long. The cumulative length of tunnels, adits, shafts, winzes, and raises exceeds 300 miles. Production entirely from underground operations at its Lark and U.S. mines in 1962 amounted to about 6,000 tons a week. The district's underground mines have produced over 4,000,000,000 pounds of lead and 1,500,000,000 pounds of zinc.

From 1902 to 1907 the United States Smelting, Refining, and Mining Company had operated a copper smelter as one unit of its complex of treatment plants. However, in 1907 because of the deleterious effects of sulfurous fumes on plant life, a Federal court injunction caused the discontinuance of all copper smelting near the crop lands of Salt Lake

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4. In 1962 the surface rights to much of this area were sold to Kennecott Copper Company for expansion of the open pit with a 30-year option to buy the mineral rights at depth.

Valley. Lead smelting, which was able to control its fumes[5], was not affected. In 1904 the United States Smelting, Refining, and Mining Co. added a gravity concentrator for the treatment of Bingham ores. This was replaced in 1926 by a 750-ton flotation mill, which is still operating in 1964, but with a capacity of 1,750 tons daily. It produces galena and sphalerite concentrates. The United States Smelting, Refining, and Mining Company's lead smelter was discontinued in 1958. However, through a cooperative agreement with Anaconda Company, ores for both companies are concentrated at Midvale by USSR & M, and concentrates are smelted by Anaconda -- the lead at International Smelting Company's custom smelter at Tooele, the zinc at the Anaconda zinc smelter at Great Falls, Montana. The Midvale concentrator (Wallace and Johnson, 1948) covering 640 acres is now the only base metal custom concentrator operating in the Salt Lake area (Figure 50).

Of the forty Utah smelters built since 1900 only four remained in 1948, and of these only the one at Tooele and the one at Garfield are in operation in 1964.

Kennecott

Since 1904 more than 2.28 billion tons of ore and waste have been removed from the Bingham open pit. During this interval more than 15,000,000,000 pounds of copper have been produced. The Bingham open pit (Figure 51) includes more than 1,000 acres; from east to west it measures more than two miles; its rim is 2,200 feet above the lowest bench; its benches are from 50 to 75 feet high and are up to 65 feet wide. From this pit about 90,000 tons of ore currently assaying 0.76 per cent copper and nearly 300,000 tons of waste rock are removed daily.

In 1963 the ore was being hauled by standard gauge electric railroads in 90-ton cars of 13- to 21-car trains downhill to the 5,490-foot haulage tunnel which emerges at Copperton, about seven miles from the pit. The cars are accumulated into 50- to 80-car trains for the remainder of the trip to the Arthur and Magna mills. Waste is loaded into 80-ton side-dump cars and hauled in trains of seven cars to disposal areas. Recently the upper portion of the pit has been converted to a truck-haulage operation.

In actual practice, mineralized rock containing 0.4 per cent copper or eight pounds of copper per ton of rock is considered ore. "Waste" is hauled to disposal areas for leaching.

As occasion demands, ore trains are powered by either two or three 125-ton electric locomotives. The electrified railroad system includes 175

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5. Personal communication of T. P. Billings, formerly General Manager of Mining Operations for the United States Smelting, Refining, and Mining Company, to Arthur L. Crawford.

miles of track in the mine and a 16-mile railroad from the mine to the Magna and Arthur flotation concentrators (Figures 52 and 53), each of which has a capacity of more than 50,000 tons daily. At these mills sulfide minerals are concentrated into a flotation product which in 1964 averaged 28 per cent copper, 25 per cent iron, 1.5 per cent molybdenum, and minor amounts of gold, silver, and other by-products. The molybdenite is removed from the copper concentrate through a combination of selective flotation and heat treatment. A 90 per cent molybdenite concentrate is sold.

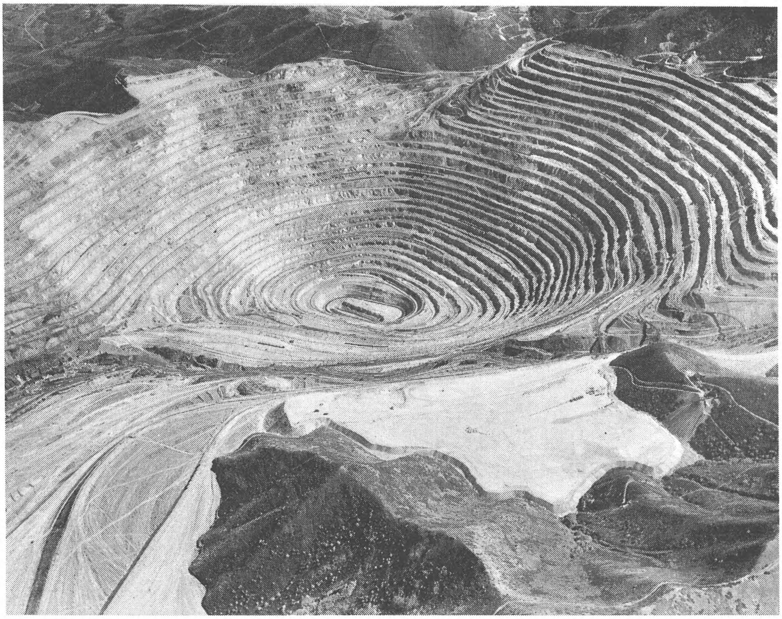

Figure 51. Bingham Open Pit Mine of the Kennecott Copper Corporation, Salt Lake County, Utah.

The cars of copper concentrates are moved by a diesel electric engine to the Garfield Smelter (Figure 54) which was purchased by Kennecott from the American Smelting and Refining Company in 1959. At the smelter is produced a 98 per cent metallic blister copper, from which oxygen is removed to produce 99 1/2 per cent copper anodes which are then shipped to an electrolytic refinery (Figure 55) where copper of 99.96 per cent purity is produced. The impurities recovered contain precious metals and other by-products.

metals and other by-products.

A sulfuric acid plant at Garfield, owned by the Garfield Chemical Company, formerly an affiliate of both the Kennecott Copper Corporation and the American Smelting and Refining Company but acquired in its entirety by Kennecott Copper Corporation in April 1964, converts stack gasses into sulfuric acid.

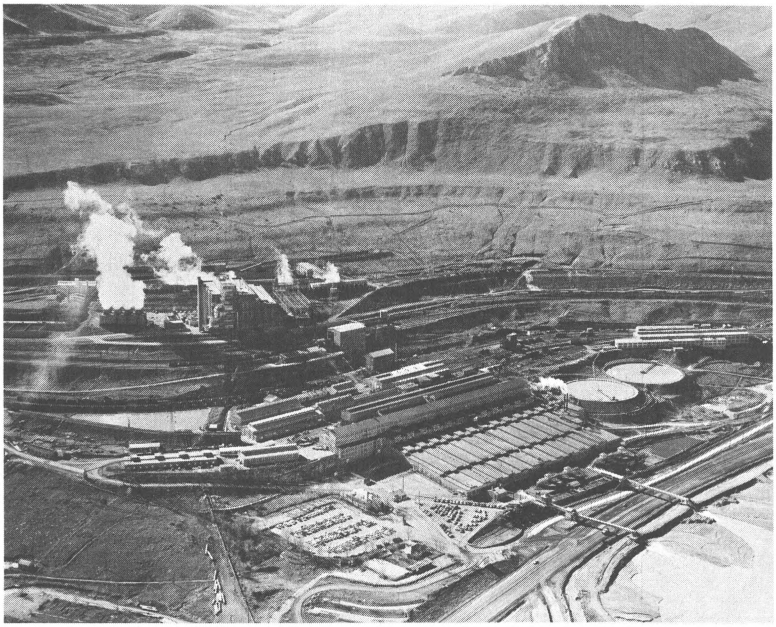

Figure 52. View looking westerly across the Magna concentrator of the Kennecott Copper Corporation, Salt Lake County, Utah. Note the prominent Lake Bonneville beach terraces in the middle and distant background.

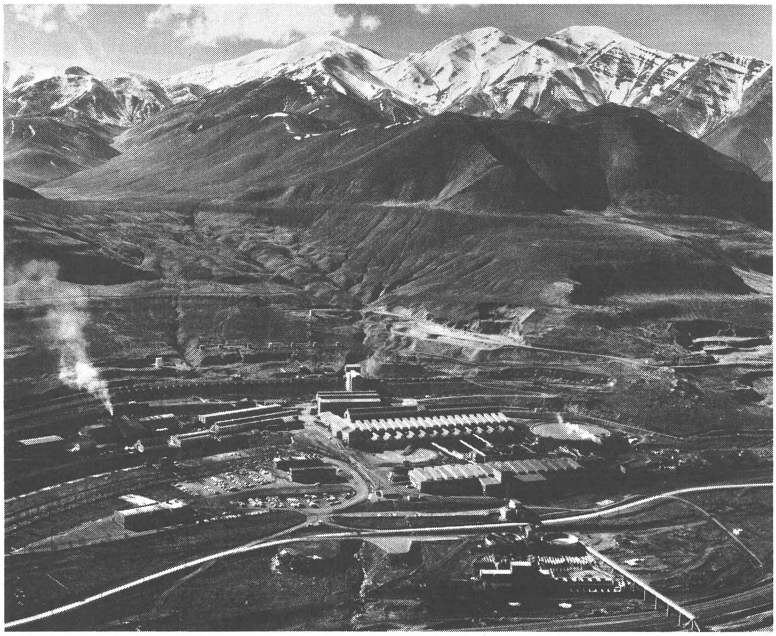

Figure 53. View looking westerly across the Arthur concentrator of the Kennecott Copper Corporation, Salt Lake County, Utah. Note the prominent Lake Bonneville beach terraces in the middle background.

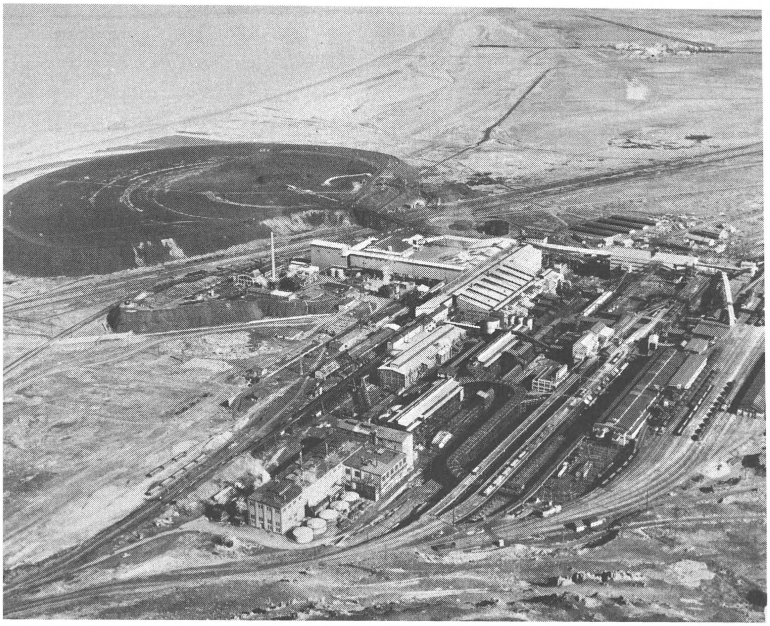

Figure 54. View looking northeasterly across the Garfield smelter, now known as the Utah Smelter of the Kennecott Copper Corporation, Salt Lake County, Utah. Note slag dump in left background and also the plant of Western Phosphates in upper right corner.

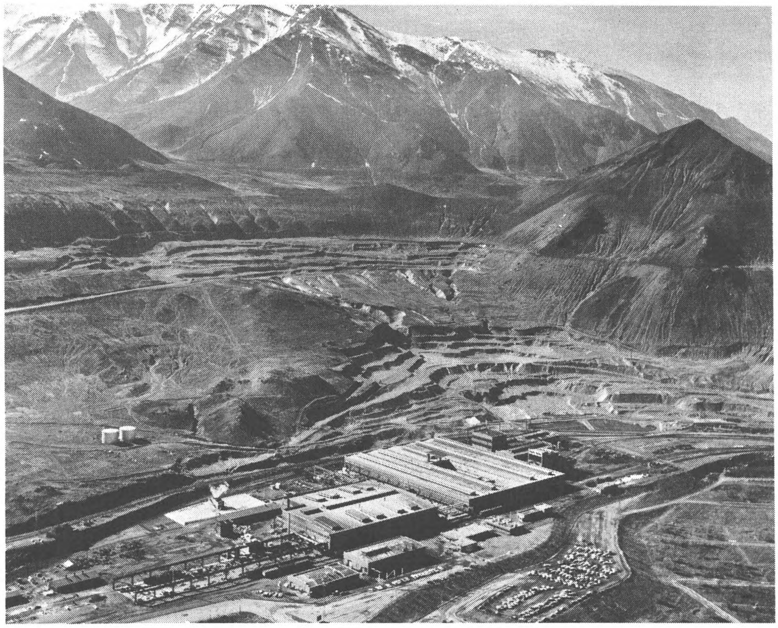

Figure 55. View looking westerly across the electrolytic copper refinery of the Kennecott Copper Corporation (near the Garfield smelter), Salt Lake County, Utah. Note the prominent Lake Bonneville beach terraces in the middle background.

Auxiliary facilities include a power plant with a rated output of 175,000 kilowatts. A foundry at Arthur produces grinding balls and castings. A kiln near Magna produces burned lime for use in the flotation concentrators.

Precipitate copper is produced at the precipitation plant located in Bingham canyon between the Bingham mine and Copperton. Preparatory to the precipitation process, leach water containing sulfuric acid, ferric sulfate, and varieties of bacteria which oxidize ferrous iron to ferric iron and sulfide to sulfate are pumped into prepared ponds on disposal dumps. As these waters percolate through the dumps, they dissolve copper from the waste. The water is collected below the dumps and diverted through the precipitation plant where the copper is removed by reaction with scrap iron. Precipitate copper production increased from 9,438 tons in 1961 to 16,678 tons in 1962. Expansion plans for the precipitation plants will increase production to 72,000 tons per year by 1967.

BIG AND LITTLE COTTONWOOD DISTRICTS

Geologic Environment

The Big and Little Cottonwood districts, near the summit of the Wasatch Mountains some twenty miles southeast of Salt Lake City, together extend five miles east-west, four miles north-south, and include an area of nearly twenty square miles. Alta is near the center of the area.

Folded Precambrian to Jurassic shales, quartzites, and limestones are intruded by the Little Cottonwood, Alta, and Clayton Peak granitoid stocks. These stocks lie along an easterly-trending domal anticline which passes near Alta, and pitches easterly under lavas that separate it from the Uinta Mountain fold with which it is in alignment. Subsidiary parallel folds occur on either flank.

The Alta thrust zone, the Reed and Benson thrust zone, the Grizzly thrust and others are deformed thrust faults that trend north-south and now dip east. These are older than the folding and also predate the intrusives. Several steeply dipping tear faults, normal in appearance and associated with emplacement of the intrusives, trend easterly and parallel the row of stocks. Most recent are nearby north-south Basin and Range faults which offset the ore deposits (Figure 56).

Ore Deposits

Classification of Ore Deposits: The ores are chiefly carbonate-sedimentary-rock-replacements, veins, and contact deposits. Most occur beneath the flat north-south thrust faults. Some are along the easterly-trending steeply-dipping tear faults. Others are adjacent to the intrusives; few occur within the stocks. The Maxfield Limestone and the limestone member of the Ophir Shale contain most of the orebodies.

Mineralogy of Ores: Primary metallic minerals of principal commercial importance include:

Galena	PbS	Argentite	Ag_2S
Sphalerite	ZnS	Chalcopyrite	$CuFeS_2$
Tetrahedrite	$(Cu,Fe)_{12}Sb_4S_{13}$		

Other metallic ore minerals are:

Bismuthinite	Bi_2S_3	Gold	Au
Bornite	Cu_5FeS_4	Jamesonite	$Pb_4FeSb_6S_{14}$
Bournonite	$PbCuSbS_3$	Molybdenite	MoS_2
Chalcocite	Cu_2S	Native silver	Ag
Covellite	CuS	Tungstenite	WS_2
Enargite	Cu_3AsS_4		

Scheelite (Crawford and Buranek, 1944) is also present. The following secondary mineral products of weathering have been reported:

Anglesite	$PbSO_4$	Limonite	$Fe_2O_3 \cdot 3H_2O$
Aurichalcite	$(Zn,Cu)_5(OH)_6(CO_3)_2$	Malachite	$Cu_2(OH)_2CO_3$
Azurite	$Cu_3(OH)_2(CO_3)_2$	Native silver	Ag
Cerussite	$PbCO_3$	Powellite	$Ca(Mo, WO_4)$
Covellite	CuS	Smithsonite	$ZnCO_3$
Hematite	Fe_2O_3	Stolzite	$PbWO_4$
Hydrozincite	$Zn_5(OH)_6(CO_3)_2$	Wulfenite	$PbMoO_4$

The principal metallic gangue minerals are pyrite and magnetite.

The chief nonmetallic gangue minerals include:

Quartz	SiO_2	Siderite	$FeCO_3$
Calcite	$CaCO_3$	Dolomite	$(Ca,Mg)CO_3$
Hematite	Fe_2O_3	Barite	$BaSO_4$
Rhodochrosite	$MnCO_3$		

Grade of Ore: Based on smelter returns for the years 1941 to 1962 inclusive, the ore mined averaged per ton:

Gold	0.018102 ozs.
Silver	10.14 ozs.
Lead	10.78 %
Zinc	7.07 %
Copper	1.02 %

Shape and Size of Deposits: The orebodies are tabular, cylindrical, pod-like or irregular in shape. They range from 50 feet to more than 1,000 feet in strike length; from 10 feet to more than 200 feet down dip, and from 10 feet to more than 100 feet in width.

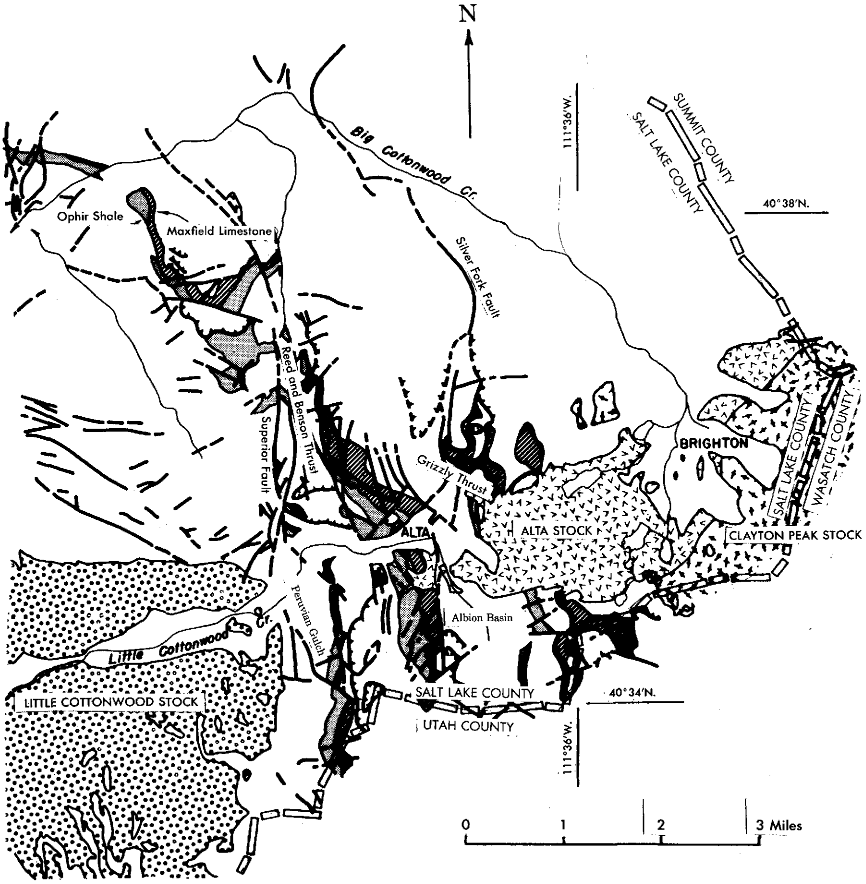

Figure 56. Generalized Geologic Map of the Big and Little Cottonwood Mining Districts.

History and Production

Following discovery of lead-silver veins in Bingham Canyon, prospecting activities were intensified and extended to the Wasatch Mountains, where the first discovery of silver-bearing ore in the Wasatch Range was made in the Little Cottonwood area and credited to soldiers of General Connor. Shortly thereafter the Wasatch mining district was formed. In July of 1864 it was renamed the Mountain Lake district, and in 1869 this district was subdivided. The western part became the Big Cottonwood, Little Cottonwood, and American Fork districts; the eastern part the Uinta, Snake Creek, and Blue Ledge districts.

The Big and Little Cottonwood districts produced principally lead and silver, with minor copper and zinc. A maximum was reached during the decade 1870 to 1880, with a secondary maximum during 1901-1910. Since then mining activity has been limited to minor exploration development and production.

The value of production through 1962 exceeds 37 million dollars, including:

Silver	$16,853,418
Lead	$15,478,932
Copper	$ 3,180,358
Zinc	$ 1,185,217
Gold	$ 670,909

In June 1870 the Woodhull Brothers built an eight-ton capacity cupola furnace at the mouth of Big Cottonwood Canyon, just east of what is now known as Wasatch Boulevard. Arrington, in his excellent summary, is believed to be mistaken (p. 207) when he indicates that this smelter was located "at what is now Murray" near what was then called the "State Road." In 1873 a jig mill was built to treat Emma ore. In 1884 a 10-stamp mill was set up at the mouth of Little Cottonwood Canyon to treat low grade ores from several mines. In 1905 the Columbus Consolidated and the Continental-Alta concentrators were installed, and in 1917 a jig mill was built at the Albion mine near Alta. None remains.

Transportation

The transportation of ores, concentrates, and bullion from the Little Cottonwood district was difficult. The narrow gauge Wasatch and Jordan Valley Railroad, completed in 1873 from the Sandy Station of the Utah Southern Railroad to Wasatch near the old Temple granite quarries, was soon extended from Wasatch to the Emma mine at Alta, and by 1876 snow sheds covered all of the snowslide areas and most of the remainder except the lower four miles. The excessively steep grades above Wasatch prevented normal operations. Shay engines were tried but they were not successful, and it was necessary to use horses operating from paths adjacent

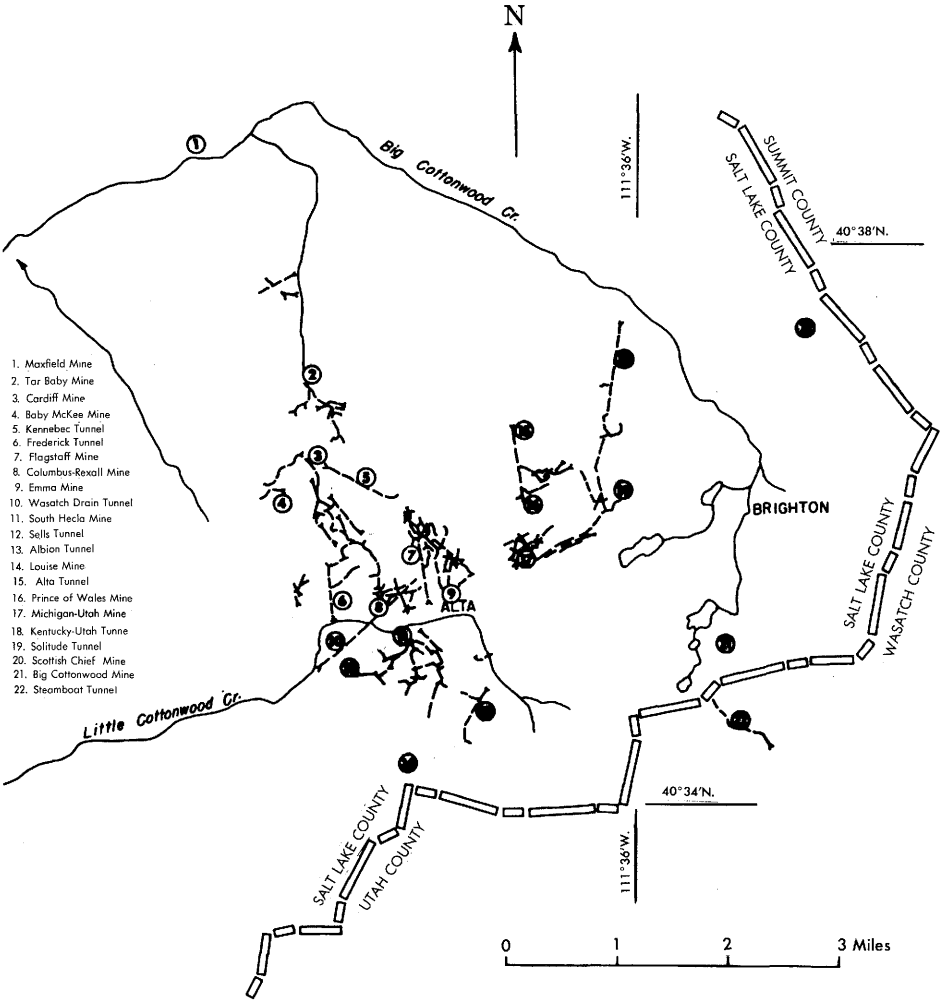

Figure 57. Principal Mine Workings, Big and Little Cottonwood Districts.

to the rails to pull up the empty cars[6]. Loaded cars were let down by gravity. With the aid of brake-clubs used as lever-arms on the staff-brake-wheels, one brakeman could control not more than two cars each trip. Snow in winter made "sanding" imperative. Five miles per hour was an excessive speed, and skidding occasionally caused the panic-striken brakemen to jump the cars and let the train wreck. Even the grade between Wasatch and Sandy was fraught with danger. A little coach and caboose broke loose from their engine about a mile west of the mouth of Little Cottonwood Canyon, and before brake-club leverage could be made effective, acceleration took a load of passengers on a hair-raising "Casey Jones" ride all the way to Midvale.

The road was purchased in 1881 by the Rio Grande Western Railway Co., and a few years later standard gauge tracks were put in from Sandy to Wasatch; but by 1893 the tracks were removed from Little Cottonwood Canyon. However, the lower portion of the road was maintained from Sandy to Sand Spur, about two miles east of Sandy, where abundant, well-graded sand from the old Lake Bonneville delta furnished a cheap supply of material for sanding tracks, stock cars, and stockyards along the whole railroad system and for the needs of industrial enterprises. In 1913 the old roadbed from Sand Spur to Wasatch was laid with standard gauge tracks and narrow-gauge tracks were relaid from Wasatch to Alta. Two shay engines were purchased to pull the cars up the canyon. Two and sometimes three 8-ton cars were let down by gravity. The engines were used as brake power, supplemented by man-operated brake clubs and staff-brake-wheels to retard the speed. About 1915 L. E. Despain, who had the stage and mail franchise, secured the right to transfer his passengers at Wasatch to a 2-ton GMC truck mounted on car wheels specially built for the narrow-gauge track. Since there was no turn-table at the upper end of the line, the seats were made reversible and the passengers faced valleyward as the gas-motor car, locally dubbed the "goose-bug," coasted down-canyon going backwards. The last car to use these tracks sped out of control in 1928 with Elbert G. Despain as "conductor," and was wrecked. The rails for this road were removed in 1935 and used for flux at the smelters.

During the operation of this railroad an important source of freight, in addition to ores and concentrates, was granite which was quarried at the mouth of Little Cottonwood Canyon and destined for Salt Lake City for the construction of both the Mormon Temple and the State Capitol Building.

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6. The history of this period of operations in Little Cottonwood Canyon is fragmentary and incomplete. Most helpful have been statements furnished Arthur L. Crawford by Robert W. Edwards, an authority on early pioneer railroads in Utah, and Elbert G. Despain, who with his father before him, was a contractor participating in many of the events that cannot be checked from other sources.

The Emma and the Flagstaff mines in the Little Cottonwood district were early producers. Unfortunately, the Emma became involved in an international scandal in 1872. The stock of the Emma Silver Mining Company, Limited, with a capitalization of £1,000,000 had been floated in London by Trenor W. Park with a coterie of associates he had skillfully assembled. In addition to three members of the British Parliament, Park had on his board of directors such prominent Americans as the U.S. Minister to the Court of St. James, Major General Robert C. Schenck; U.S. Senator from Nevada, William M. Stewart; and former president of the New York Central Railroad, General George Baxter. In his prospectus Park estimated a net yield of £800,000 per year for the Emma mine. The stock was subscribed immediately and within two days the shares with a par value of £20 were selling at a premium of £3 to £4 each.

"At the end of 1872, the company directors made the astounding discovery that their stock of available ore was exhausted." (Jackson, 1955). Glasgow shareholders held a "private indignation meeting." The prestige of the American Ministry and Americans in general was at a low ebb. Extensive court actions and a U.S. Congressional Investigation brought out most of the unsavory details, but failed to establish the extent of Minister Schenck's complicity.

Not all of the meteoric fall of the market value of the Emma stock was due to a manipulated market. The Emma bonanza ended abruptly against a post-mineral fault. Years of search failed to find the displaced segment until 1916 when Joseph J. Beeson, a young University of Utah and Stanford University geologist, solved the complicated fault riddle and discovered the lost ore body.

In the Big Cottonwood district the most famous mines were the Prince of Wales group on Silver Fork. The Maxfield mine was also one of the largest early producers, and the Cardiff has produced most of the ore since its discovery in 1910 (Figure 57).

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SECTION VIII –

NONMETALLIC MINING AND PROCESSING IN SALT LAKE COUNTY

by Arthur L. Crawford[1] *and Clarence F. Tuttle*[2]

In addition to base metal mining, and related processing activity, a large number of plants process nonmetallic minerals, rocks, and fuel, much of which originates outside Salt Lake County. However, cement rock from the Twin Creek Limestone (see page 25) is mined in Parleys Canyon, and salt (see page 81) is produced by solar evaporation in ponds adjacent to U.S. 40 between Salt Lake City and Great Salt Lake. These and other nonmetallics in Salt Lake County are here summarized. (For locality occurrences see Figure 58.)

SALT

There is now but one plant, that of the Morton Salt Company, producing salt within Salt Lake County. It, and its competitors in neighboring counties, are in a strong position to serve the entire market for all possible demands that can be made wherever freight-rates make their plants competitive. In 1963 there were produced 135,730 tons of salt from the 1,000 acres of ponds in Salt Lake County. Brochures on the solar evaporation process and the techniques of the industry may be obtained from the Morton Salt Company, Salt Lake City, Utah.

SODIUM SULFATE

Sodium sulfate, one of the abundant soluble constitutents that is being fed into Great Salt Lake, is relatively insoluble at low temperatures. Each winter it precipitates from the supersaturated brine as crystals of mirabilite (Glauber's salt, $Na_2SO_4 \cdot 10\ H_2O$) (see page 85). Widely used in industrial chemistry, much attention has been given to its recovery from the lake and to possible markets, but nothing commercial has developed.

In 1932 the Salt Lake Sodium Products Company was formed to extract and market the sodium sulfate cementing the sands beneath the lake shore immediately southeast of the pavilion grounds of the Saltair Beach Company and adjacent to U.S. Highway 40. A reconstruction finance loan was obtained. A plant was built. Rippers were used to break up the mirabilite-cemented oolite. Sodium sulfate was leached, concentrated, and precipitated to a marketable grade; but, the removal of the protective tariff

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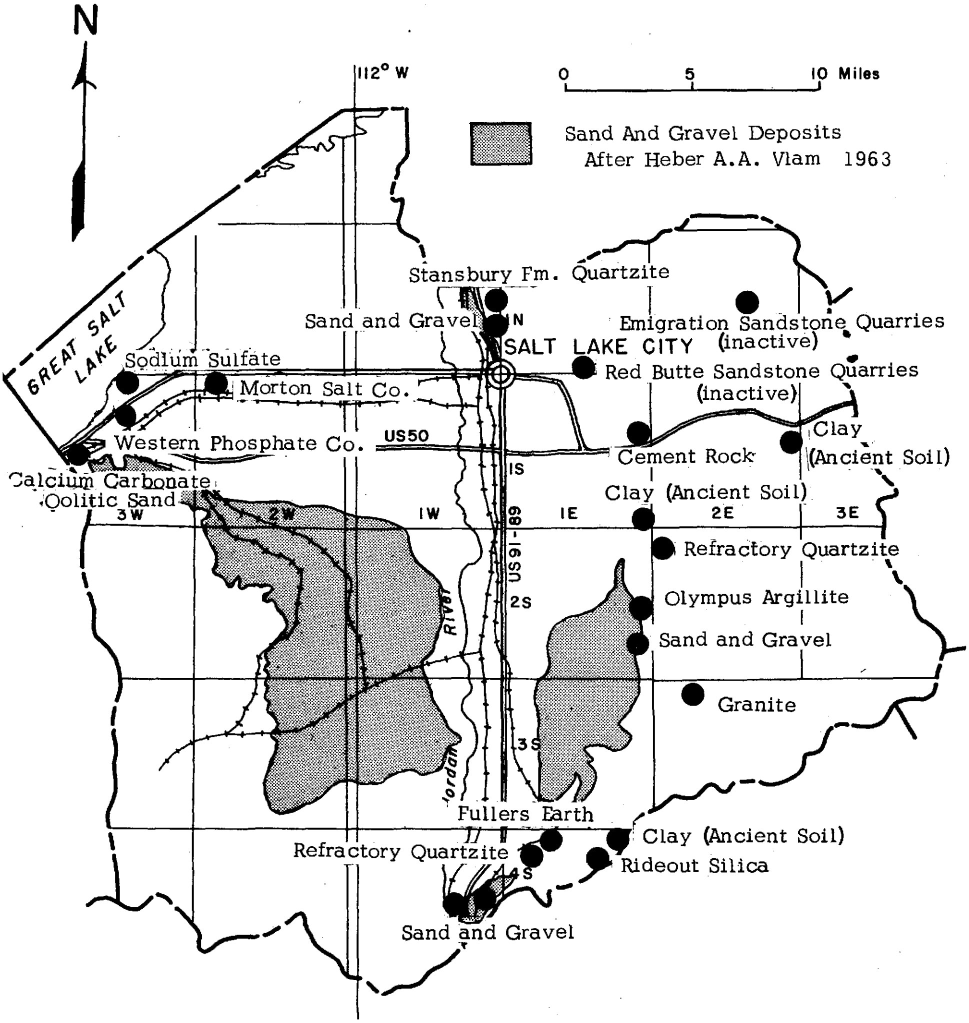

NONMETALLIC DEPOSITS AND PLANTS
of
SALT LAKE COUNTY

Figure 58.

permitted sodium sulfate from nearby Canada and the ocean-borne material from distant sources to capture the promising market in the Kraft paper industry of the Northwest.

Preceding the above and continuing long after it was a research venture sponsored by a syndicate[3] of University of Utah scientists headed by Junius J. Hayes. With hip boots and row-boats, these men studied the lake shores through several winters. The precipitation of the mirabilite crystals, their wind-concentration into bars, and the manner of burial of the undissolved residue was observed. Test-pits were dug into buried deposits. A special barge for gathering the newly-formed mirabilite crystals was designed.

Quantity samples of mirabilite crystals were harvested (Figure 59), centrifuged in ice-cold fresh water to remove the brine and its impurities, and the refined mirabilite stored for future research. Some twenty tons of clean but unwashed "crude" were warehoused for emergencies in case a warm winter might prevent the usual easy-to-harvest crop. One carload shipment was sent to the Midwest for testing in therapeutic cattle rations. Eight tons were installed in a Salt Lake home to capture solar heat (following the research at Massachusetts Institute of Technology on solar heating at the Peabody Estate near Boston using sodium sulfate as the heat reservoir). A rotor spray device, invented by Niels C. Christensen, Consulting Metallurgist, was designed to eject the saturated solution of Glauber's salt into a partial vacuum to produce a powder of the anhydrous salt that could be pressed into blocks for easy shipment. Since approximately half, by weight, of the mirabilite molecule is water of crystallization, cheap concentration to the anhydrous salt (the equivalent of nature's thenardite, Na_2SO_4) was deemed essential if the excessive freight costs were to be avoided.

Another outlet that initially was in prospect was the conversion of mirabilite to sodium carbonate through double decomposition with the oolitic calcium carbonate sand with which it could be strip-mined along the lake shore. However, the discovery of immense deposits of sodium carbonate in nearby southwestern Wyoming removed this outlet from consideration.

Early in the research program, negotiations were carried on with the Utah State Land Board for a lease that would protect the investment of the participants. Application No. 944 was filed February 24, 1934, and a 20—year lease No. 768 was granted March 29, 1934. The death in 1934 of

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[3] The original syndicate consisted of four men, all from the University of Utah: Dr. Thomas B. Brighton, Head of the Department of Metallurgy; Arthur L. Crawford, Director of the Cooperative Microscopic Research Laboratories; Junius J. Hayes, Head of the Department of Astronomy; and Dr. F. F. Hintze, Professor of Geology.

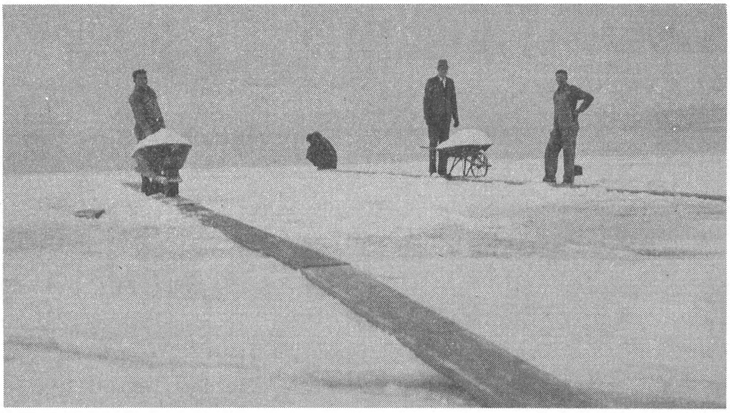

Figure 59. Gathering mirabilite from the shore of Great Salt Lake. Employees of Hayes Syndicate during the Winter of 1933-1934. The tall gentleman in the right center is Dr. Corliss R. Kinney, Chemistry Department, University of Utah. (Courtesy John K. Hayes)

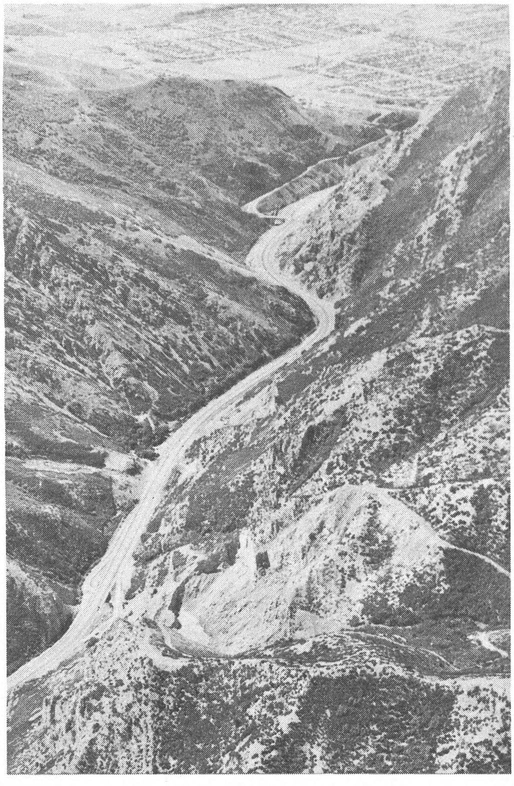

Figure 60. Quarry of the Portland Cement Company of Utah (lower right) in the Twin Creek Formation. View west along U.S. Highway 40 in Parleys Canyon with Salt Lake City in distance. (Courtesy Edwin S. Gallacher, President, Portland Cement Company)

Dr. Thomas B. Brighton, the "king-pin" of the research team, greatly dimmed the chances for the success of the project, and the removal of the protective tariff, which thwarted the efforts of the Salt Lake Sodium Products Co., likewise "pulled the props" from under the Hayes syndicate. Even so, research was continued until the death of Hayes in 1954. The new State Land Board declined to renew the old Hayes lease without modifications which the successors in interest would not accept. The lease was cancelled November 18, 1955.

Sodium sulfate is still a potential economic resource of Great Salt Lake.

SAND AND GRAVEL

Because it is the population and industrial center of the State, Salt Lake County is normally the greatest user of sand and gravel. Occasionally, as in 1962 when massive freeways and the Glen Canyon and Flaming Gorge dams were under construction, other counties in Utah may use more. In 1961 over 6,000,000 tons of sand and gravel, valued at $2,800,000, were produced in the county.

The county is particularly fortunate (Crawford, 1946) in being supplied with well-assorted gravels which fringe the Wasatch and protrude from it as two prominent spurs along the northern and southern boundaries of the county. The gravel deposit at "Point of the Mountain" between Utah and Salt Lake Valleys (see Figure 31) is an asset that will be more and more useful as the nearer deposits at North Salt Lake and along the Wasatch front east of Salt Lake City become more expensive to operate. Nackowski (this bulletin, page 121) has mentioned the importance of Sand Spur, between Sandy and the mouth of Little Cottonwood Canyon, in the history of the pioneer Denver and Rio Grande Western Railway Company. The deposit from which it drew is an extensive deltaic area of clean sand that within the foreseeable future is inexhaustible.

CEMENT

The Portland Cement Company of Utah, with a yearly production of approximately 750,000 barrels and a plant capacity of over twice that much, was founded in 1905 and has grown steadily with the expansion of construction in the state. Cement rock is quarried from the Twin Creek Formation on U.S. Highway 40, a short distance east of the mouth of Parleys Canyon (Figures 24 and 60). The shaly impurities of the Twin Creek Limestone give the formation an almost ideal composition for Portland cement. There is an inexhaustible supply with the only drawback to its production being the hazards and inconvenience of being immediately adjacent to a transcontinental highway. The stone is processed at the company's plant at Eighth South and Fifth West, Salt Lake City.

CLAYS

There are four "clays" in Salt Lake County that have had, or appear to have, industrial potential. Classified according to geologic occurrence, they are:

1. Shales and argillites;
2. Transported clays interbedded in Lake Bonneville sediments;
3. Residual deposits developed by weathering;
4. Hydrothermal deposits.

Of the four, the one having greatest promise was discovered in 1954 by the junior author of this section. It will be discussed first.

Shales and Argillites

The Olympus deposit[4] is not a true clay. It is an enormous lenticular mass of Precambrian shale incipiently metamorphosed almost to a phyllite, and herein is referred to as an argillite. It contains 20 to 40 per cent each of mica and pyrophyllite (Ehlmann, 1958), and, to the intimate mixture of these two microscopic constituents, with approximately an equal amount of fine-grained quartz, this argillite owes the satisfactory firing range, low shrinkage, and high structural strength which give it value as a ceramic raw material.

Five miles due east of Murray and in the NW 1/4 of Sec. 24, T. 2 S., R. 1 E., SLB&M, it is nestled under the south brow of Mt. Olympus, about one mile north of the mouth of Big Cottonwood Canyon. Bounded by ledge-forming quartzites of the Big Cottonwood Formation, it strikes N 80° E., dips 60° northerly, and forms a triangular outcrop just above the Bonneville terrace on the lower Wasatch front. Approximately 1,200 feet along the north-south base of the triangle, it extends eastward up the mountain face several thousand feet and gradually wedges down to an attenuated seam in the massive quartzite near the crest of the Wasatch. The best and most accessible material is covered by two parallel 600 feet by 1,500 feet patented mining claims. Their western end lines practically coincide with the western boundary of the Wasatch National Forest, and their length extends eastward up the mountain slope following the trend of the strata.

This massive relatively uniform argillite lens, originally a shale member, acted as a lubricant between rigid quartzite beds, and when the whole mass was buckled during mountain building it thickened into a vast lens within the massive nearly vertical quartzite strata that form Mt. Olympus. Dense, homogenous, hard, and with a somewhat slabby structure, the

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4. This deposit discussed as "Location 13: Murray Refractories pit" will be covered in a forthcoming publication on "The Refractory Clay Deposits of Utah" by Joel N. Van Sant, Supervising Mining Engineer, U.S. Bureau of Mines, Denver, Colorado.

argillite is gray to nearly black with a phyllitic sheen. Parallel to the rock cleavage are veinlets of quartz with limonite-rich cavities.

The character and worth of this deposit might have been overlooked indefinitely had not the Murray Refractories Company diligently searched for raw materials upon which to expand its productions. As an employee of Murray Refractories Company, the junior author of this paper investigated every reported occurrence of a refractory mineral within the freight range of the Murray plant. Andalusite, an aluminum silicate having the same formula as kyanite and sillimanite, minerals valuable for ceramic purposes, was known to occur in the Cottonwood district where a shale member of the Big Cottonwood Formation had been subjected to contact metamorphism by the intrusion of the Little Cottonwood stock. It was reasoned that the shale in which the andalusite had developed must have been rich in alumina to have developed andalusite and, therefore, this shale should be investigated in the hope that somewhere its quality, quantity, and geographic position would combine to form a deposit of commercial significance. The andalusite-bearing shale was traced valleyward from its contact with the granite. Where it crosses Big Cottonwood Canyon at Stair Gulch, it is still near enough to the intrusive to have been metamorphosed into hornfels (see page 14), but on the Wasatch front it thickens and changes from hornfels to an argillite. The size and apparent homogeneity of this wedge-shaped lens, combined with its location at the foot of the mountains, needed only industrial properties to give it commercial significance.

Preliminary analyses and firing tests were encouraging. Silica averaged 85 per cent; alumina 12 to 15 per cent; fusion between cone 14 (2,530° F) and cone 15 (2,595° F) (well within the fusion temperatures of most clays used in the structural industry). Several bars, fired in a laboratory furnace, were found to have a satisfactory maturing range. Some clays have to be fired near their fusion point, thus giving them a limited temperature tolerance and making them difficult to work; but this Precambrian "clay" can be fired between 1,950° and 2,000°F, well below its point of fusion, to a medium-red, dense body, with a low shrinkage and with high structural strength.

A systematic network of drill holes and sampling, correlated with chemical analyses and firing tests, proved the deposit to be relatively uniform with the exception that there is slightly more carbon in the material at depth. The material is low in plasticity, but sufficient plastic clay can be "pugged" with it to give it the desired properties. Higher alumina content would be desirable to make it more refractory. It has been found that the Olympus argillite adds greater strength to sewer pipe and similar heavy duty products than has hitherto been attainable with the use of competitive raw materials. Therefore, it is mixed with various clays to produce the structural products needed.

Two quarries have been opened in the deposit: a lower quarry, now operated under lease by the Interstate Brick Company; and an upper quarry being operated by the owners, Gladding McBean Company, successor in interest to Murray Refractories. The Olympus argillite is a cheap and adequate supply of structural ceramic material close to the industrial center of Utah.

Transported Clays Interbedded in Lake Bonneville Sediments

"Surface clays," found at various localities along the East Bench of Salt Lake Valley have been utilized by the Utah Fire Clay Company, the Interstate Brick Company, and the other brick companies that have operated since Utah was settled. These deposits are extensive, but all contain lime which limits their usefulness. Furthermore, the best areas have been improved for residential purposes, which removes them economically as a further source of ceramic material. They were deposited chiefly during the Alpine stage of Lake Bonneville (Hunt, Varnes, and Thomas, 1953) and are thought to have been derived from the widespread erosion of a mature soil that covered much of the drainage basin prior to the ice age with which Lake Bonneville is correlated. Clays exploited in Salt Lake County in pioneer times when requirements were less exacting belonged chiefly to this class.

Residual Deposits Developed by Weathering

Remnants of an ancient pre-Bonneville soil were first reported by Hunt, Creamer, and Fahey (1949). They have been further studied by the junior author of this article, and three remnants have been found in Salt Lake County: (1) along the Draper-Alpine road in Corner Canyon in the extreme southeastern corner of Salt Lake County; (2) along the Wasatch front above the Bonneville Terrace between Mill Creek and Days Canyon; and (3) in the road cuts along U.S. Highway 40 south of Mountain Dell Reservoir just west of the mouth of Lambs Canyon. In each of these occurrences the deposits are relatively shallow, but since they are surficial blankets over relatively wide areas, it is entirely possible they could be economically exploited for high-grade building brick and for tile or other structural products for which preliminary tests indicate that they would be suitable. Described by Hunt, Creamer, and Fahey (1949), "The clay comprising the upper layer of the old soil is practically free of lime but does contain considerable iron oxide." Hydromica, believed to be illite, is listed as the chief clay mineral, with minor amounts of montmorillonite.

Analyses of some of the remnants in Utah County of this old pre-Bonneville soil surface averaged:

SiO_2	66% to 69.6%	CaO	0.02%
Al_2O_3	12% to 15.5%	TiO_2	0.8%
Fe_2O_3	4.6% to 6.0%	MnO	0.003%
MgO	1.5% to 1.9%	Ig. loss	6.8%

In further prospecting for additional remnants of this ancient soil, it should be borne in mind that they will be "found only at those places where the land surface has been preserved since pre-Bonneville time without being eroded or buried by other sediments" (Hunt, Creamer, and Fahey, 1949).

Hydrothermal Deposits

The "Tallow Mine," or Fullers Earth of Draper, is a clay that may prove to belong to the hydrothermal deposits class, or it may be related in origin to the ancient soil remnants discussed under "Risidual Deposits Developed by Weathering." Observed by the writers to contain "ghost pebbles" of andesite and other material apparently altered to clay, it is buried just beneath the Bonneville terrace where Lake Bonneville lapped over an area presumed to have been completely mantled by the ancient soil to which the foregoing remnants belonged.

The deposit is on the north flank of the East Traverse Mountains about midway between the Utah State Prison and the town of Draper. The townsfolk of Draper had tried to use as a natural soap the peculiar "mineral tallow" that was exposed in a tunnel[5]. But it was not until about 1920 that the clay was developed commercially by the Refiners Clay Company (Figure 61) as Fullers Earth for the oil refining industry in California.

It was an underground operation. Mining was by shafts and drifts. There were three shifts per day with six men each shift during peak production[6]. High timbering costs, cave-ins, and the cost of freight to California eventually made the mine noncompetitive. It was never reopened after its shut-down in the late 1920's.

It is a nonswelling montmorillonite, high in magnesia. Listed in Table VI is an analysis of the best sample that could be hand-picked in 1963 from near the caved-in shaft. It is compared with standard montmorillonite and beidellite. The chemical and x-ray analyses were made through the courtesy of Ballard H. Clemmons, Research Director, Salt Lake City Station of the U.S. Bureau of Mines. An electron photomicrograph was taken by Mr. Gary Thornley, University of Utah Graduate Student; and the chemical analysis was recalculated into the following approximate formula by Dr. James A. Whelan, Assistant Professor of Mineralogy, University of Utah:

$$(Al_{1.33}, Mg_{1.00})Al_{0.39}, Si_{3.61}, O_{10}\,(OH)_{2.0} \cdot n\,H_2O$$

$$Ca/2_{\,0.36}, Na_{.02}, K_{.01} \text{ -- with 0.97 excess silica.}$$

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[5] As a 10-year-old boy John H. Boberg (oral communication with Arthur L. Crawford) examined the tunnel with lighted matches about 1882. This tunnel, near the old Charles Ellis Homestead, was probably driven to develop a spring seeping from the Bonneville gravels and brought to the surface by the bed of impervious Fullers Earth.

[6] Oral communication with the authors from Hall Walbeck, shift foreman during most of the active operation of the property.

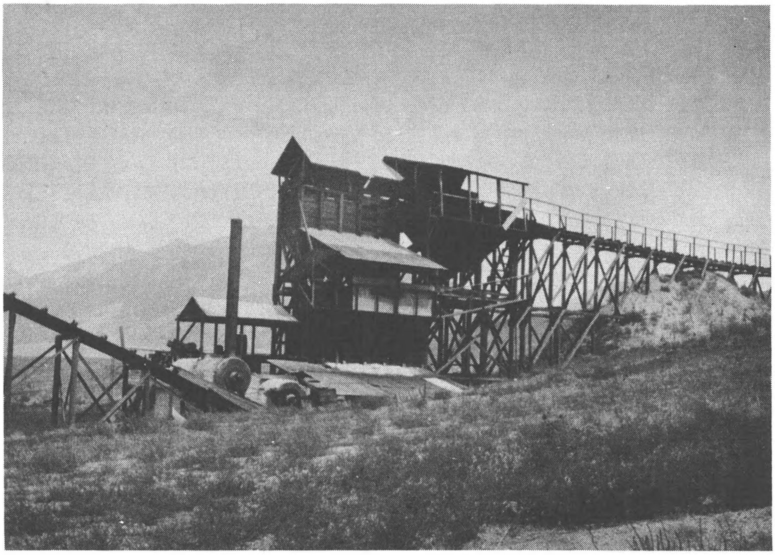

Figure 61. Shaft and tipple of the Fullers Earth Mine, Refiners Clay Company in the 1920's. (Photograph courtesy R. E. Marsell)

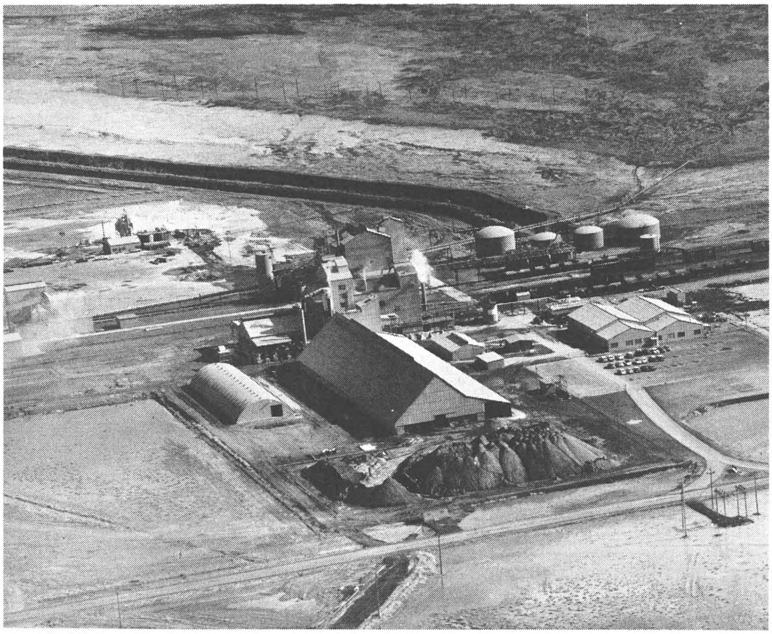

Figure 62. Plant of the Western Phosphate Company, fourteen miles west of Salt Lake City on U.S. Highway 40. (Courtesy Western Phosphate Company)

TABLE VI

ANALYSIS AND COMPARISON OF TALLOW MINE CLAY SAMPLE*

Determined	"Tallow Mine" Draper, Utah -325 Mesh Fraction	Beidellite Black Jack Idaho	Montmorillonite Montmorillon France
SiO_2	57.2	45.32	51.14
Al_2O_3	15.4	27.84	19.76
MgO	5.9	0.16	3.22
CaO	2.6	2.76	1.62
Na_2O	0.2	0.10	0.11
K_2O	0.1	0.12	0.04
H_2O (LOI)	19.8	22.64	22.80

* Chemical and x-ray analyses made through the courtesy of U.S. Bureau of Mines, Salt Lake City, Utah.

Mrs. Judy Montoya, mineralogical laboratory technician, who made the microscopic and x-ray studies of the purified fraction on which the chemical analyses were conducted, reports that the three major impurities remaining were: quartz -- not more than 5 per cent; calcite -- not more than 3 per cent; and biotite -- not more than 1 per cent. If the analysis were recalculated to eliminate these impurities, its composition would be even closer to the montmorillonite from the type locality. The optical properties and x-ray pattern were well within the range of typical montmorillonite. Ries (1935, p. 286), perhaps the best geologist of ceramic materials of the past generation, says:

> "We know that montmorillonite forms from the glassy particles of volcanic ash, sometimes under marine, occasionally by weathering, and, in one case at least, by hydrothermal waters. This might suggest that composition of the waters causing the change was important rather than the temperature."

From the foregoing, coupled with the geology discussed by Marsell (1932) and the cross-section[7] revealed in the Alpine-Draper tunnel through the Traverse Mountains driven for the Salt Lake Aquaduct, the writers believe that the Fullers Earth near Draper had its origin about as follows:

The Traverse Range, composed of a thick sequence of quartzites and intercalated limestones of the Oquirrh Formation, was covered with volcanic ash during the Tertiary Period when its form and relief were roughly comparable to that of the present. Swept down the slopes by wind and rain,

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[7] Unpublished data obtained from J. Neil Murdock, Chief, Geology Branch, U.S. Bureau of Reclamation, Region 4, Salt Lake City, Utah.

the ash draped the foot of the mountains with thicker beds than the original blanket. Before the ash could be eroded or greatly contaminated, volcanoes spewed out an impervious seal of lava which still covers most of the West Traverse Range. But as soon as erosion had exposed the central ridge and high eastern end of the Range, surface run-off gained ready access to the most elevated portions of the underlying beds; the porous, unconsolidated volcanic ash promptly filled with water which was held under artesian pressure by the lava seal to the west; and the CO_2 from the reaction of artesian water in contact with the underlying limestone may have been important in the hydrolysis (Dr. D. W. Thorne, quoted in Early, Osthaus, Milne, 1953, p. 707) of the ash to montmorillonite. On the other hand, dissolved constituents in ascending hydrothermal solutions from the Wasatch fault and the numerous shear zones described by Marsell (1932), between the Wasatch Fault and the Jordan Narrows, may have been even more important. Furthermore, surface weathering that developed the ancient soil a short distance to the east in Corner Canyon and northwest of Alpine, prior to the advent of Lake Bonneville may have further leached the montmorillonite of its impurities and left a unique Fullers Earth to be veneered by the gravels deposited during the Alpine stage of Lake Bonneville. There is little doubt that volcanic ash was the most important material from which the "Tallow Mine" Fullers Earth was derived.

The high quality of the Fullers Earth is unquestioned, but the extent of the reserves is unknown and all of it is covered.

REFRACTORY QUARTZITE

Crushed quartzite, consisting of more than 97 per cent SiO_2, less than 1 per cent Fe_2O_3 and less than 1/2 per cent combined Al_2O_3 and alkalies, is the preferred raw material in the manufacture of silica refractories. Salt Lake County has several fairly pure quartzites, but none yet known that meets desired specifications. The highly shattered Rideout quartzite deposit of the Oquirrh Formation east of the Utah State Prison, a similar deposit where the Wasatch shear-zone crosses the Traverse Range southeast of Draper, and a sheared quartzite north of Mt. Olympus near the Wasatch fault zone, have been used for lining reverberatory smelters and for structural clay products. Still another quartzite of high purity, with a sandy appearance at its outcrop and believed to belong to the Stansbury Formation of Devonian age, occurs on the Utah Sand and Gravel property in North Salt Lake where it has been beveled by the waves of Lake Bonneville and partially veneered by gravels. It and the other deposits mentioned have been considered for glass making. The ledge-forming quartzite in the Bonneville "sea-cliff" at the foot of Mt. Olympus is relatively pure and may find use in refractories. It crushes into flaky chips that make it highly desirable as a filter medium for swimming pools, laundries, etc. (Crawford and Thackwell, 1931).

NATURAL AND SYNTHETIC BUILDING STONE

The Nugget Formation, once widely used for building purposes in Salt Lake City and vicinity, was obtained from many pioneer quarries but none within the county is now in operation. The stone varied between a durable well-cemented, clean sandstone and a loosely cemented mudstone that weathered badly. Red to gray-buff in color, most of it came from Red Butte Canyon above Fort Douglas and some from one of the tributaries to Emigration Canyon. Much of the stone work in the early buildings is now hidden beneath protective plaster; but the best places to observe the stone are in the old City Hall Building, now reconstructed on Second North at State Street, across from the State Capitol Building, and in the administration buildings and officer's quarters, built facing the parade ground at Fort Douglas in 1876[8]. The latter are constructed of stone from the adjacent quarry at Red Butte. Several color varieties of the Nugget Sandstone as well as a light gray-lavender grit believed to be from the Shinarump Formation, are visible in the pillars of the Tabernacle Building in Temple Square.

Granite in Little Cottonwood Canyon was selected for the Temple Building and later for the Utah State Capitol, as well as for the Administration Building of the L.D.S. Church, just east of the Hotel Utah. Although it is a beautiful structural material equal in quality to imported stones, its use has been limited to local demands and the quarries are idle.

However, a rejuvenation of the granite industry is being effected by the Temple Granite Quarries, a company that now supplies chips for poultry grit and facing material for pre-cast "granite" facing slabs as well as granite itself for the occasional buyer. The new Salt Lake City Library and the new State Office Building have been constructed in part from this pre-cast material with pleasing effect. Local firms that have pioneered in this endeavor have shipped their pre-cast stone as far east as Chicago and Detroit.

Salt Lake City is said to have the most fully automated block company in the United States. The block companies use county-derived sand and gravel, porous slag from the steam electric plants in the county, and scoria, pumice, pumicite, and expanded shale that are brought in from outside the county to provide raw material for a three million dollar industry.

LIME FLUX AND QUICKLIME

Calcium carbonate sand from the shores of Great Salt Lake is produced by the Kennecott Copper Corporation for flux in its smelter at Garfield. Quicklime for use in mineral concentrators and for sugar refining and lesser purposes is either imported, ready for use, or is processed from lime-

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8. Personal communication to Arthur L. Crawford by James R. Otis, Resident Engineer, Fort Douglas Military Reservation.

stone shipped in from adjacent counties. Of the kilns that utilized local stone for quicklime for mortar in the construction of pioneer homes, none now remains.

PHOSPHATE

The Western Phosphate plant is located on U.S. Highway 40, fourteen miles west of Salt Lake City at the Garfield cut-off and is shown in Figure 62. Its supply of sulfuric acid is received by pipeline from the nearby plant of the Garfield Chemical Company. Its other basic raw materials are (1) phosphate concentrate which is brought in by truck from the San Francisco Chemical Company's open pit mines located near Vernal, Utah, and by rail from open pit and underground mines near Leefe, Wyoming; (2) ammonia, ammonium sulfate and ammonium nitrate which are brought by rail and truck from U.S. Steel's Geneva plant at Orem, Utah.

This modern plant manufactures phosphoric acid and concentrated phosphate fertilizers, including treble superphosphate and various grades of ammonium phosphate. In excess of 130,000 tons of these products are distributed annually.

Until recently Western Phosphates Inc. was owned 25 per cent by the Kennecott Copper Corporation, 25 per cent by the American Smelting and Refining Company, and 50 per cent by the Stauffer Chemical Company. Now it is owned 100 per cent by the Stauffer Chemical Company, and in the future it will be operated by the Fertilizer Division of this concern.

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SECTION IX – WATER SUPPLY

by R. E. Marsell[1]

When the first settlers arrived in the Valley of the Great Salt Lake on July 24, 1847, their first concern was water; and 116 years later water is still a major problem, for the continued growth of population and industry depends upon an adequate water supply. Two days before the main body of Mormon pioneers under the leadership of Brigham Young arrived, an advance company under Orson Pratt "camped on City Creek, near a spot where the City and County Building now stands... The camp was organized for work and the ground was broken by William Carter, George W. Brown, and Shadrach Roundy, who plowed a number of furrows for the planting of potatoes. A few men were directed to the stream where they dug a ditch and ran the water on the soil. Thus began the first practice by Anglo Saxons of irrigation." (Harris, 1942)

By the following spring over 5,000 acres were under cultivation, for the new settlement had to become self-sustaining, especially in food, being isolated so far from railhead. Within two years flourishing farming communities had been established throughout the county along Emigration Creek, Parleys Creek, Mill Creek, and Big and Little Cottonwood Creeks, in the area between the mountain front and Jordan River.

This early development involved the construction of the various "ditches," as these irrigation canals were called, from the several mountain streams which enter the valley floor from the east. Some of these early-built canals still survive. They were all built by the hand labor of the people themselves. Examples are: "The Big Ditch," on which work was begun in 1848; "The Big Cottonwood-Tanner Ditch" and "Green Ditch," also in the same year; "The Walker Ditch," during the following year, and the "Hill Ditch" in 1851. By means of these "ditches" and their laterals, water could be conveyed to land not adjacent to the stream channels.

The ensuing problems of "water turns," quantities to be allowed each user, etc., soon led to the need of more formal cooperation between the water users, and the formation of irrigation companies resulted. Thus by diverting the water of the mountain streams to beneficial use for agricultural purposes, the irrigation companies established rights to the permanent use of these waters, their rights being confirmed later by court adjudication and decree.

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1. Consultant, Utah Water and Power Board, Salt Lake City, Utah.

Then, as now, these early users of the water resources of the county were plagued by the irregular flow of the mountain streams, which have a high runoff for a few weeks in late spring and early summer, due to melting snow on the mountain watershed. These annual flood waters soon dwindle to a small base flow for the remainder of the year. Such uncontrolled floods, then as now, destroyed diversion dams and ditch headgates regularly. The pioneer water users realized that they had plenty of water, but in the absence of storage dams to hold the peak flows back, they were forced to allow this precious resource to join Jordan River and discharge into Great Salt Lake to be lost by evaporation.

The problem is still with us!

One might logically expect after an elapsed period of 116 years that this problem of the control of the seasonal flood flows would have been solved. But the fact remains that only one small storage reservoir is available in Parleys Canyon with a capacity of but 3,000 acre-feet.

By 1860 the municipality of "Great Salt Lake City," as it was then called, was already faced with a serious water shortage. Since practically all of the mountain streams were fully appropriated for agricultural use, the city was almost entirely dependent upon City Creek, and its supply was inadequate, especially in the dry years.

In the minutes of the Board of Alderman, under date of August 9, 1864, it is recorded that "Alderman Sheets reported that he had inquired into the propriety and practicability of introducing a greater supply of water to meet the pressing wants of the citizens in watering their lots." Alderman Sheets, who had evidently given the problem serious study, suggested the possibility of boring artesian wells -- untried in the valley up to this time. He also pointed out that due to its low elevation in the bottom of the valley, the waters of Jordan River were inaccessible for irrigation, and further were unfit for municipal use. He also suggested that Jordan River waters might be rendered available for irrigation purposes by erecting a dam in the Jordan Narrows, where the river first enters the valley, and by bringing additional water into the area by means of a canal constructed along the eastern margin of the bench-lands.

Early in January in the following year, Brigham Young endorsed the proposal of Alderman Sheets, and said, "the bringing of the waters of Utah Lake would be the means of sustaining a population in Great Salt Lake County of one-hundred thousand inhabitants." (Harris, 1942)

Typical of the delay in getting action in such a public matter, it was not until the year 1879 that actual construction began on "the Jordan and Salt Lake City Canal," which was finally completed in 1882. The builders took advantage for part of its course by using an older canal that many years before had been constructed to raft granite blocks from a quarry in Little Cottonwood Canyon for construction of the Mormon Temple.

In the decade 1880-90 the population of Salt Lake City more than doubled from 20,000 to approximately 44,000; and it was too apparent that the ever present shortage of water was not merely one affecting gardens, trees, and shrubbery, but the actual culinary needs of the citizens. The potable mountain water was owned by the farmers of the county, while the additional Utah Lake water brought in by the newly-completed Jordan and Salt Lake City Canal was unsuitable for domestic use.

The solution of this problem was the making of the first "Exchange Agreements" between the City and certain users of water from Emigration Creek and most of those of Parleys Creek whereby the City acquired the right to take and use for municipal purposes the mountain water and give in exchange "an equivalent quantity of water from the Jordan and Salt Lake Canal." (Harris, 1942).

In order to make the newly acquired water available, the City built the Parleys low-line conduit (capacity twenty-six cubic feet per second) and the small "Suicide Rock" diversion reservoir at the mouth of Parleys Canyon. This was a beginning to a solution of the short municipal water supply.

The year 1890 was a drought year, which further served to emphasize the growing demand for more water. As an emergency measure, over 100 small-diameter wells were driven along Jordan River in Utah County, northwest of Lehi. These wells were judged to interfere with a nearby small spring, and the resulting litigation forced the City to abandon the well supply.

At about the time when the Lehi wells were drilled, several artesian wells were developed in various parts of the city; some of these were capped in Liberty Park and in a nearby public ball ground. One at the southwest corner of Eighth South and Fifth East Streets still flows a tiny stream, but it is very popular with the public in the mistaken belief that the water is of superior quality to that supplied by the city mains.

Early in the decade 1890-1900, the Jordan and Salt Lake City Canal was enlarged, improved, and extended. In 1892 City Engineer, A. F. Doremus, recommended the construction of "a high line conduit extending along the base of the mountains from the mouth of one canyon to another in which to transport the water of the respective mountain streams into the city." (Harris, 1942) After carefully analyzing the alternatives, Mr. Doremus clearly recognized that the further exchange of lake water for mountain water was the most practical and least expensive means of securing potable water for the city and satisfactory water for the irrigators. Also, in 1892, a suggestion was made by "Water Master" J. M. Harvey that Congress be asked to appropriate $100,000.00 for the improvement of Utah Lake as a storage reservoir. But forty years were to elapse before that idea bore fruit with the initiation of the Utah Lake Division of the Provo River Project by the U.S. Bureau of Reclamation. It is sad to relate, at present writing (July 1963), that this phase of the project has not yet begun.

The Big Cottonwood conduit was finally commenced in 1904, twelve years after it was proposed, and completed in 1905, with a capacity of 62 cubic feet per second. And also during those years exchange agreements were perfected for part of the flow of Big Cottonwood Creek.

During the next two decades very little additional water was obtained, but small dams erected on mountain lakes at the head of Big Cottonwood Canyon helped store and regulate some of the snow-melt runoff. Twin Lakes reservoir (capacity 934 acre-feet) and Lake Phoebe-Lake Mary reservoir (742 acre-feet) were completed during 1915-1916; the Mountain Dell reservoir (955 acre-feet) was constructed in 1917, and later in 1925 was raised to a crest height of 98 feet, which increased its capacity to 3,514 acre-feet. Silt deposition has subsequently reduced the capacity to a little more than 3,000 acre-feet.

By condemnation proceedings, the City obtained the right to enlarge and extend a canal built earlier and higher up on the benchlands by the East Jordan Irrigation Company. This arrangement made it possible for the City to fulfill the "Exchange Agreements" with the several "ditches" on Big and Little Cottonwood Creeks and thus obtain a vital part of the present City water supply.

Both 1924 and 1928 were years of deficient precipitation and a need for a long-range plan to develop additional water supplies was more apparent than ever. During 1928, Mayor John F. Bowman and the City Board of Commissioners appointed an Advisory Board composed of Sylvester Q. Cannon, William Peterson, A. Z. Richards, and Harry C. Jessen. In March 1929, the Board submitted its report, which considered both "Local Sources" and "Outside Sources."

Among the "Local Sources," the Board advised the early construction of the "Argenta Dam," perhaps the only truly feasible site in Big Cottonwood Canyon. The one "Outside Sources" project favored at this time by the Board was the acquisition of some of the spring runoff waters of the upper Duchesne River, to be conveyed by means of a long tunnel to the upper Provo River and stored in the then-proposed Deer Creek reservoir to be built in Provo Canyon. To make this newly proposed water source available to Salt Lake City, a long conduit with necessary tunnels would have to be constructed from Deer Creek reservoir to the mouth of Provo Canyon, thence northerly along the base of the Wasatch Range to the mouth of Big Cottonwood Canyon.

This was indeed a far-sighted and far-reaching plan, but before anything actually came of it the prolonged drought of 1931-34 created another emergency that demanded immediate relief; more citizen advisory committees were appointed, for public concern was aroused to a fever pitch. Heated controversy arose and several alternate plans were debated. One that was favored by many was the immediate construction of the Argenta Reservoir in Big Cottonwood Canyon, as previously recommended by the 1929 Advisory

Board report. However, the bond proposal to finance the building of the dam was defeated by the electorate, and the dam has not yet been built. This was a tragic set-back in the long-range development of the City's "Local Sources" of supply. Some day the Argenta Dam will be constructed, but at a cost several times as much as it would have cost had it been built in 1931.

During 1931 and 1932 a conduit was completed to bring some Little Cottonwood Creek water northward into the Big Cottonwood Creek conduit, thus making an additional supply of water of high quality available to the City.

To meet the 1931 drought emergency and part of future needs, the sum of $2,000,000.00 was spent in acquiring several flowing well fields in the southeast part of the county. Under the doctrine of "correlative rights" prevailing at the time, the "supposed" underground rights of thousands of acres of land in the "artesian basins" were bought up and other large acreages were purchased outright. To make this newly-acquired water available, water mains were laid and a small collecting reservoir and pumping plant, east of Murray City, were constructed, now known as the Marcus Reservoir and the Third East Pumping Plant, respectively.

Perhaps the most forward step in furthering the recommendations of the 1929 Advisory Board report on long-range water development was the creation, during the term of Mayor Louis Marcus (1932-36), of the Metropolitan Water District of Salt Lake City, which insured the construction of the Deer Creek Reservoir under the Provo River Project of the U.S. Bureau of Reclamation.

The drought cycle begun in 1931 in Salt Lake County, and for that matter the whole State of Utah, reached its climax in 1934, the driest year of record up to that time. By February 1934 it seemed certain that Utah Lake would reach an all-time low and thus force Salt Lake City to meet its "Exchange Agreements" in part, at least, with water from some other source. If possible, a new water supply had to be found and made available by midsummer of 1934.

Beginning in 1931, the ground-water division of the U. S. Geological Survey started a ground-water investigation in Salt Lake Valley (Jordan Valley, they called it) and in July 1932 George H. Taylor and R. H. Leggette, of the Survey, released a mimeographed report, later published in 1946. With the findings of this report as a guide, G. D. Keyser, Water Dept. Commissioner of Salt Lake City, authorized an emergency well-drilling program on a "No water, no pay basis." By July 1, six well rigs were drilling and already 15 second feet of new well water was being delivered into the City's mains. When the program was completed, 17 wells around the eastern margin of the valley had been drilled, and 14 of them were producing 46 second feet (about 30,000,000 gallons a day). The cost of this emergency program was high (about $250,000.00), but it carried the City through the crisis. Sixty per cent of the City's total municipal supply in the summer of 1934 came from wells. Six of the fourteen emergency wells drilled in 1934 are still used each summer as a supplemental supply.

Commenting on the 1934 experience, the Salt Lake Tribune (as reported by Harris, 1942) said in part: "Salt Lake City has just passed through the greatest water crisis in history. ... This... should teach that Salt Lake City must at once look into the future of its water supply and development with the idea of some permanent plan and operation."

At last it seemed time to seriously consider "Outside Sources," and the suggestion made by the Advisory Board in their 1929 report seemed to point the way.

The Provo River Project of the U.S. Bureau of Reclamation provided the answer. Included in the project was a 6.5 mile tunnel from the upper Duchesne River to the upper Provo River, thus diverting some Colorado River water during the late spring snow-melt run-off into the Great Basin. The plan also contemplated a 9-mile diversion canal in Kamas Valley to convey flood flows from Weber River to the Provo River. The key unit of the project was the Deer Creek dam and reservoir in Provo Canyon. The dam was to be an earth-fill structure with a crest height of 155 feet above stream bed and the reservoir capacity was to be 155,000 acre-feet.

Another phase was the diking of a western arm of Utah Lake to save many thousands of acre-feet of water lost each year by evaporation.

According to Harris (1942), the Metropolitan Water District board sought an outside expert opinion on a water-development program, and on August 8, 1936, the firm of Alvord, Burdick and Howson, of Chicago, submitted its report. Its findings and conclusions confirmed the wisdom of the 1929 Advisory Board and endorsed the acquisition of "Deer Creek" storage. The "Burdick Report" further stated:

> "In our opinion it will supply Salt Lake City (with water) at less annual cost than any other project . . . . It insures an adequate supply of water for Salt Lake City for the indefinite future. . . . It will provide a storage reservoir capacity about twice the present yearly consumption of the city; thus permitting storage in wet years to be used in dry years. . . . The City's participation probably insures the construction of the Deer Creek Project, thereby tending to benefit the City, County, and State by increasing the opportunity to grow."

The report further emphasized the fact that in a semi-arid state, like Utah, the water supply, more than any other factor, will determine the region's growth in population and industry.

There still remained the problem of getting the water from the proposed Deer Creek reservoir to Salt Lake City by means of a costly 40-mile-long conduit and two tunnels, as was pointed out by the 1929 report. Such an aqueduct was not a part of the original Provo River Project; in fact, at one time the Chief Engineer of the Bureau of Reclamation expressed the Bureau's attitude when he stated: "We are not building aqueducts for cities."

The financing of such a conduit seemed at first an insurmountable obstacle, but greatly to the credit of a delegation consisting of Governor H. H. Blood, Congressman J.W. Robinson, and Attorney Fisher Harris, who went to Washington D.C., in June 1937, where they presented in person the problem to the Secretary of the Interior, with the result that several days later the Secretary, in writing, endorsed the Deer Creek-Salt Lake Aqueduct as a desirable unit of the Provo River Project. The enlarged project was ultimately arranged with a savings for the tax-payers of $150,000.00 annual interest charge.

Limitations of space preclude even a summary of the details of the developments of the Provo River Project over the ensuing decade-and-a-half, but in 1941, the Deer Creek dam and reservoir were completed at a total cost of approximately $4,000,000.00. The 40.8 mile Salt Lake Aqueduct was finished in 1952 and turned over to the Metropolitan Water District of Salt Lake City for operation. The Aqueduct project includes the 3 mile Alpine-Draper tunnel through the East Traverse Range and the 0.7 mile Olmstead tunnel near the mouth of Provo Canyon. The total cost of the aqueduct was near $5,500,000.00.

The conduit pipe, which is buried throughout its 37.1 miles of length, is constructed of reinforced, pre-cast concrete in 20 foot lengths, each segment weighing 22 to 23 tons. The inside diameter is 69 inches, and the walls are 7 1/2 inches thick. The conduit has a capacity of 150 cubic feet per second.

In 1962 this water from "Outside Sources" amounted to nearly 15 per cent of the Salt Lake City municipal supply. Table VII shows the various sources from which the City obtained its water in 1962.

TABLE VII

1962 SALT LAKE CITY WATER SUPPLY SOURCES

Source	City Creek	Emig. Tunnel	Parleys & Mtn. Dell	Big Cottonwood	Little Cottonwood	Deer Creek	Wells
% Total Supply	10.9	2.0	10.3	30.0	19.8	14.5	12.5
Total Dissolved Solids in Parts Per Million	213	582	291	177	102	227	184-932
Hardness -- $CaCO_3$	209	455	240	149	95	201	Ave. 507
Production in Million of Gals.	2,368.2	450.2	2,253.9	6,522.9	4,312.5	3,155.4	2,655.9

INCREASE OF IMPORTANCE OF GROUND WATER

From Table VII it is clearly evident that ground water is becoming more important among the "Local Sources" considered by the 1929 Citizen's Committee. Salt Lake City in 1962 obtained more water from wells than from either City Creek or Parleys Creek. Since surface waters in Salt Lake County are fully appropriated, the Salt Lake Valley ground water reservoir is the last remaining "local" water supply. Its potential was amptly demonstrated in the emergency well-drilling program by Salt Lake City in 1934.

THE STATE ENGINEER'S NEW WATER POLICY

In recognition of the rapid increase in demand in Salt Lake County for ground water, the only source still available for further appropriation, by both industries and municipalities, the State Engineer undertook in 1959 to examine the present use and probable future need for ground water by the various municipal water distributors in the county. His survey disclosed that in 1958 there were 28 municipal-type water distributors in Salt Lake County, with a total of 85,322 service connections. The annual total water use, from all sources, by these 28 distributors was found to be 93,592 acre-feet for the year 1958. The maximum "peak-day" demand was 277.57 cubic feet per second.

Following the completion of the study by the State Engineer's staff, a public meeting of representatives of all of the municipal water service agencies in the county was held July 6, 1959, at which the State Engineer announced a new policy with reference to appropriations of ground water for future municipal needs. On the basis of a population projection to the year 1975, the additional ground water needed by that time was estimated for each individual water distributor, and if his applications to appropriate ground water were insufficient to meet this projected demand, he was urged to file additional applications as soon as possible!

The projected total annual water use in 1975 was 198,165 acre-feet, as compared with an actual total water use in 1958 of 93,592 acre-feet -- more than double in less than twenty years!

This far-sighted move in future water planning by the State Engineer was both timely and commendable for it focused attention on the ever-increasing demand for water of good quality and also raised the important question as to the safe annual productive capacity of the Salt Lake Valley ground-water reservoir.

The water supply in a ground-water reservoir may be likened to a bank account, and the water administrator, like the banker, must know: (1) the capacity of the reservoir; (2) the amount of useable water in storage (our water "bank balance" from which safe withdrawals can be made ;

(3) pumpage by wells, and natural losses by discharge and by evaporation and transpiration (withdrawals from our water "bank account"); and (4) the most difficult generally of all hydrologic factors to determine is the annual recharge to the underground reservoir (the deposits in our water "bank account").

The next logical step, obviously was to provide the essential hydrologic data as quickly as possible so that the accelerated ground-water development might proceed both expeditiously and efficiently. A preliminary start in the effort to provide such information was made as early as 1931 by the ground-water division of the U.S. Geological Survey. Due to the Second World War, the publication of the results of this early study was delayed until 1949. It appeared as Water Supply Paper 1029 by Leggette and Taylor. A more comprehensive and detailed investigation was completed by J. Wendell Marine in 1961 as a Ph.D. Thesis at the University of Utah; it will probably appear as a Water Resource Bulletin, published by the Utah Geological and Mineralogical Survey. A copy may be placed on "open file" for public examination early in 1964.

Although one of the smallest counties in Utah in area, Salt Lake County has the densest population and also the largest concentration of water wells -- about one-third of the state total. Over 60 per cent of the nearly 10,000 wells in the county are less than 3 inches in diameter; 25 per cent between 3 inches and 8 inches; 1 1/2 per cent between 8 inches and 20 inches. Most of the small diameter wells are for domestic or individual use -- many still flow above ground surface.

Marine's inventory of ground-water use in Jordan Valley (Salt Lake Valley) for 1957 is shown in Table VIII.

TABLE VIII

GROUND-WATER DISCHARGE—1957 JORDAN VALLEY

(in acre feet)

From Wells:	(a)	From 100 wells 6" to 24" in diameter	
		1. Industrial Use	36,000
		2. Municipal Use	15,400
		3. "Public Supply" (non-municipal) Hotels, schools, hospitals, etc.	1,900
		4. Irrigation	1,900
		5. Air Conditioning	760
	(b)	From wells under 6" in diameter: (mainly flowing wells for domestic stock and fish culture)	34,000
		TOTAL	89,960

The ground-water produced from wells in Salt Lake County in 1962 was enough to fill the Parleys Canyon reservoir more than 33 times! This fact emphasizes the growing importance of ground water as a vital supplementary water source for the county.

THE 1963 WATER SUPPLY STUDY

The interest developed by the new policy of the State Engineer's office dealing with ground water led to the recognition of the need for supplying the hydrologic data essential for the controlled development of the ground-water reservoir. At a meeting held on December 20, 1961, in the Governor's Board Room at the State Capitol, representatives of both Federal and State agencies met with officers of the principal water-distributing organizations in the county. The conclusion reached was that a more comprehensive, over-all study of the water resources of Salt Lake County was needed; one that included both surface as well as underground supplies.

The local council of the U.S. Geological Survey was authorized to draft a "preliminary plan of investigation," which was completed and circulated in October 1962. The plan proposed an eight year study -- six years of field and laboratory investigation and two years for preparation of the final report. The total cost was estimated at approximately $500,000.00, to be borne on a cooperative basis by Federal and State agencies and by the water users.

This latest study of the water supply of Salt Lake County was begun July 1, 1963, under the direction of Dr. W. Vaughn Iorns, of the U.S. Geological Survey.

QUALITY OF WATER SUPPLIES

In 1962, 70 per cent of Salt Lake City's total municipal water supply came from the four principal streams entering Salt Lake Valley from the Wasatch Mountains in the eastern half of Salt Lake County. From north to south these streams are: City Creek (10.9 per cent), Parleys Creek (10.3 per cent), Big Cottonwood (30.0 per cent), and Little Cottonwood (19.8 per cent), respectively. For several decades these waters have been chlorinated to insure their safe use, but, in spite of the attempt to enforce strict sanitary regulations on the watersheds of these streams, the rapidly increasing use of the Wasatch Mountains, both in summer and in winter, has greatly magnified the problem of maintaining adequate quality to meet public health standards.

Two steps have been taken both by Salt Lake City and the Metropolitan Water District to improve the quality of surface water supplies: first, the small capacity distributing reservoirs around the northern and eastern margins of the valley have been covered to eliminate air-borne surface pollution and retard algal growth; second, costly treatment plants have been built in City Creek, Big Cottonwood, and Little Cottonwood, and a fourth is under construction (1963) in Parleys Canyon, just below the Mountain Dell reservoir. These plants control turbidity, improve color and taste, but they do not remove detergents and other liquid and chemical wastes that are in solution in the water!

RESERVOIR SITES

As mentioned earlier in this section, the need for storage reservoirs to hold back the snow-melt flood waters from the mountain streams was early recognized by the pioneer irrigators in Salt Lake County. But after an elapsed time of 116 years only one small reservoir exists in Parleys Canyon -- none in any of the others! One favorable site in Big Cottonwood Canyon, the Argenta site, as previously noted, was recommended by the 1929 Advisory Board Report, but it failed to materialize when the bond issue to finance its construction was defeated at the polls.

As early as 1916 a site at the mouth of Little Cottonwood Canyon, called the Beaver Pond Site, was studied and discussed. In the summer of 1959, Black and Veatch, engineering consultants from Kansas City, Missouri, at the request of the Metropolitan Water District, investigated the Beaver Pond Site and two others in the vicinity. In their final report, submitted in March 1960, the three sites were designated as "A", "B", and "C". Site "A" was the Beaver Pond Site; Site "B" was one selected on lower Little Cottonwood Creek, 2,000 feet upstream from the Beaver Pond Site; Site "C" was tentatively located on Dry Cottonwood Creek (Dimple Dell), two miles southwest from Site "B".

The Black and Veatch report recommended that Site "A" "be excluded from further consideration." The reservoir would lie astride the Wasatch Fault zone, which creates a hazard to be avoided if at all possible. The storage potential is low (1,485 acre-feet) and the unit construction cost of $910.00 per acre-foot of storage, too high.

The report, however, did recommend a high, earth-fill dam at Site "B", with a crest height of 190 feet (5,410 feet) above stream bed and a maximum capacity of 8,900 acre-feet. Since test holes drilled at Site "B" disclosed bedrock at a maximum depth of 180 feet below ground surface in the center of the proposed dam, a cut-off trench would be impracticable. Therefore, the entire reservoir basin would have to be lined with an impermeable cover to prevent excessive leakage. The estimated cost of such a reservoir at Site "B" is $6,287,000.00 (1960).

"As field exploration at Sites 'A' and 'B' indicated a trend toward high development costs, attention was directed to Site "C" in Dimple Dell Canyon (Dry Cottonwood Creek) and test hole C-1 was drilled in this area." Doubts raised by the findings in this one test hole indicated that an adequate analysis of Site "C" would require several additional test holes. Since the filing of the Black and Veatch report, no additional drilling and study has been given Site "C".

Since the Parleys Creek watershed has produced an average annual discharge of 18,800 acre-feet since 1898 to date (1962), it has long been evident that the Mountain Dell Reservoir, with a storage capacity of approximately 3,000 acre-feet, was inadequate to control and store the water available from this source.

From time to time, consideration has been given to raising the crest of the Mountain Dell dam still higher. The matter was brought to a head in 1951 when the State Department of Highways planned to build a new six-lane highway through Parleys Canyon, using, in part, a portion of the abandoned Denver and Rio Grande Railroad right-of-way opposite the Mountain Dell dam. Investigations showed that, because of a rapid flaring-out of the canyon cross section above the top of the dam as presently constructed, it would be impracticable and uneconomical to raise the dam any higher.

The disastrous snow-melt flood of the following spring (1952) cruelly emphasized the need for more reservoir capacity in the Parleys Canyon Watershed, both to control such floods and to conserve the valuable water that was being wasted.

Another dam site in Mountain Dell Canyon, a major tributary to Parleys Creek, had been suggested as early as 1947 for the erection of a second storage dam on the Parleys Creek watershed.

The Corps of Army Engineers, who were called in to assist the City and County officials in dealing with the flood emergency, became interested in the proposed "second" dam on the Parleys Creek drainage as a flood control project. During the succeeding 9-year period, the Congress from time to time appropriated funds to support the preliminary investigation by the Corps. Plans and cost estimates were prepared on the basis of a cooperative program, where the City would pay about 30 per cent of the construction cost and the Federal Government would pay the rest.

By the early summer of 1961, the Corps of Engineers had revised upward the cost estimate to over $7,000,000.00, and the Congress had by then raised the percentage that the City must bear of the total cost to about 47 per cent. This seemed definitely to place the project far beyond the City's financial capacity to pay its share.

In seeking a possible alternative solution to this dilemma, City Commissioner Conrad Harrison, in charge of the City Department of Water Works and Water Supply, requested Mr. Jay R. Bingham, Director of the Utah Water and Power Board, to make a limited study and estimate on the proposed Little Dell Dam (the name "Little Dell" was chosen to avoid confusion with the already existing "Mountain Dell" dam). The Water and Power Board had three similar earth-fill dams under construction at the time.

On February 5, 1962, the Water and Power Board report was submitted to the City Commission. The estimated cost for the Little Dell project was only $1,500,000.00, with the same reservoir capacity and annual yield as that proposed by the Corps of Engineers.

The wide difference in the two cost estimates led at once to something of a public furor. The Army Corps dropped their estimate at once to $5,880,000.00, but the City Commission was confused and hesitated to proceed further with the project.

The matter was finally resolved by turning the problem over to the Metropolitan Water District, who was given the responsibility of taking definite action as to the adoption of a feasible project plan for proceeding with further storage development on the Parleys Creek Watershed. The District concluded that more detailed information should be obtained, as suggested in the Utah Water and Power Board report, and that an independent study should be made. The engineering firm of Berger Associates, Inc., was employed and the study was directed by the firm's vice president, Mr. E. O. Larson, former Director of Region 4, U.S. Bureau of Reclamation, and a nationally and internationally recognized authority on water storage projects.

The "Larson Report" was completed in late 1962 and submitted to the Board of the Metropolitan Water District on January 25, 1963.

As the study got under way, the scope of the investigation was increased to include diverting flood waters from both Emigration Creek and Mill Creek by means of tunnels, and the whole discharge of Lambs Canyon drainage by means of a covered conduit, to a greatly enlarged Little Dell dam. This far-seeing plan greatly expanded the program for developing long unused "Local Sources" and would finally make "new water" available from Emigration Creek and Mill Creek as an important addition of "mountain water" to the City's municipal supply.

The estimated cost by Berger Associates, Inc., of the expanded Little Dell Project is as follows:

Dam and reservoir	$13,805,000
Lambs Canyon conduit.....................	600,000
Emigration Creek tunnel	980,000
Mill Creek tunnel to Lambs Canyon	1,515,000
TOTAL	$16,900,000

The dam as proposed by Berger engineers would be 183 feet in height above stream bed and would have a maximum capacity of 50,000 acre-feet -- over six times that proposed by the Corps of Engineers. The crest length would be 2,600 feet and the width, 40 feet. The earth-and-rock fill embankment would contain 10,500,000 cubic yards of earth material.

The "Larson Report" also presents an analysis of the projected needs for water in the Salt Lake Metropolitan area by 1980, and their conclusion is that by that date (only 17 years hence) the area will be seriously short of water, even if the Little Dell Project is promptly constructed.

At present writing, the Metropolitan Water District is conferring with the Corps of Engineers on the latter's possible participation, financially, on the flood control phase of the project.

The Little Dell Project, when built, will permanently prevent a recurrence of the 1922 and 1952 snow-melt type floods!

THE CENTRAL UTAH PROJECT

As pointed out in the Larson report, the "last water hole" for the Metropolitan area in Salt Lake County may well be additional Colorado River water to be made available about twenty years hence from the Bonneville Basin Project, a part of the initial phase of the Bureau of Reclamation's "Central Utah Project."

Water from the southern slopes of the Uinta Mountains in the Uinta Basin will be diverted to the Bonneville Basin. The Strawberry Aqueduct will be built to take water from the headwater tributaries of the Duchesne River. Strawberry Reservoir will be enlarged by downstream Soldier Creek Dam and will regulate the diversion of water from the Uinta to the Bonneville Basin. As planned at present 135,000 acre-feet of new water will be brought by trans-mountain diversion into Utah, Juab, and Salt Lake Counties; of this amount 29,000 to as much as 50,000 acre-feet (1961 report) will be available for municipal and industrial use in Salt Lake County.

If the Little Dell storage project, as proposed by the Larson Report, fails to materialize before Central Utah Project water is available, then the City will again face another shortage of water crisis.

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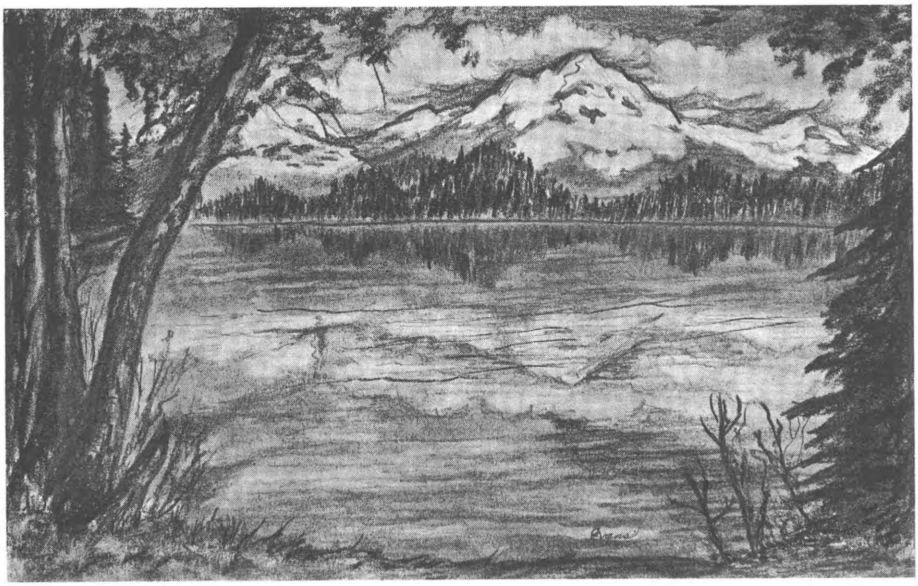

SECTION X – SALT LAKE COUNTY GEOLOGIC ROAD GUIDE

by Hubert C. Lambert[1]

U.S. Highway 40 — 37.5 miles: Black Rock to Parleys Canyon Summit	Miles from		Refer to Page
	East End	West End	
Summit—Salt Lake County line on Parley's Canyon Summit in Preuss Formation (Jurassic).	0.0	37.5	23-25
Abandoned Park City Branch Railroad to north in Preuss, Morrison, and Kelvin Formations.	0.2	37.3	23-25, 33, 34
High level alluvium on Preuss Formation (Jurassic) on south side canyon.	0.4	37.1	23-25
Morrison Formation (Jurassic) outcrops to north.	1.7	35.8	23-25
Ceramic clay west of highway at entrance to Lamb's Canyon.	2.0	35.5	132-133
Frontier Formation (Cretaceous) and Kelvin Formation (Cretaceous) at mouth of Alexander Fork to north.	3.8	33.7	23, 33, 34
Mountain Dell Canyon road to east (State 239) along fault in Twin Creek Limestone (Jurassic) and Nugget Sandstone (Jurassic).	4.3	33.2	23-25, 53
Mountain Dell Reservoir to north.	4.7	32.8	23, 26, 33, 34, 142, 144, 151
Cross Parley's Creek with outcrop of Twin Creek Limestone (Jurassic) on both sides of canyon.	5.2	32.3	24, 26, 53, 141, 150
Cement Quarry and plant securing raw material from Twin Creek Limestone (Jurassic)	8.1	29.4	24, 53, 125, 129

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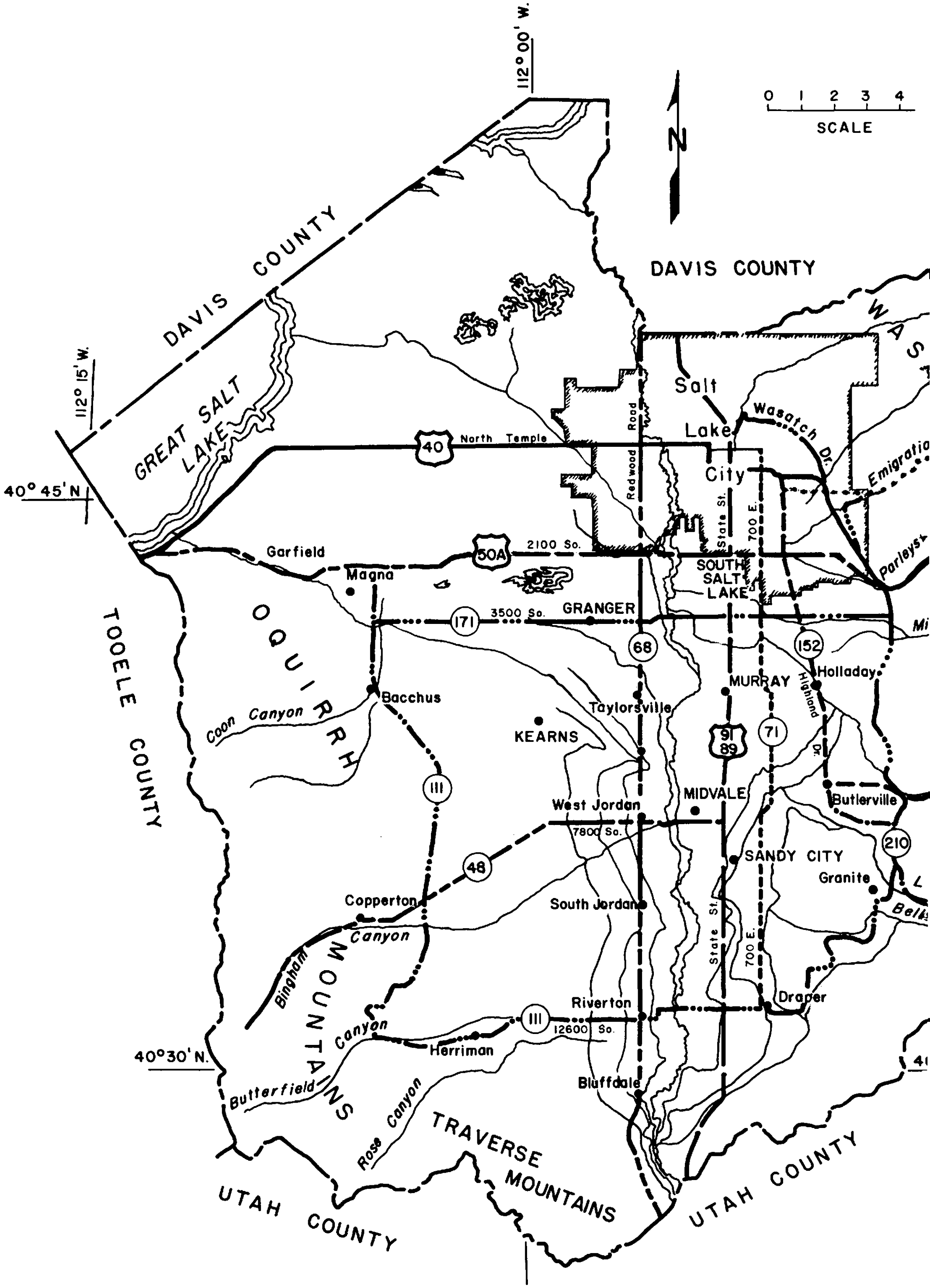
[1] Deputy State Engineer, State of Utah

U.S. Highway 40 Black Rock to Parleys Canyon Summit (continued)	Miles from		Refer to Page
	East End	West End	
Contact between Twin Creek Limestone (Jurassic) and Nugget Sandstone (Jurassic) on north side of canyon.	8.9	28.6	23, 24-25, 53
Ripple marked slab of Chinle Formation (Triassic) south of road with small exposed faults.	9.8	27.7	22-23, 94
Mouth of Parleys Canyon with Wasatch Fault zone cutting east-west trending overturned Parleys Canyon syncline to east.	10.4	27.1	22-24, 94
Junction with U. S. 40A at Interchange with Wasatch Boulevard near mouth of Parleys Canyon.	10.7	26.8	23-24
Hogback of Nugget Sandstone (Jurassic) to east.	11.3	26.2	23-24
Carrigan Canyon to east is a subsequent or strike valley.	11.5	26.0	22-23
Crest of Spring Canyon anticline to east with Thaynes Limestone (Triassic) exposed in center.	11.8	25.7	22-23, 53
Road on buried Emigration pediment covered with fossil soil of pre-Provo age.	12.9	24.6	22-23
Cross Emigration Creek with Emigration Canyon syncline to east.	13.1	24.4	141, 150
Trough of Emigration syncline in Twin Creek Limestone (Jurassic) to east.	13.6	23.9	23-24, 53
Cross East Bench Fault scarp.	15.2	22.3	94
Southwest edge of alluvial fan and delta deposits of City Creek.	16.9	20.6	73, 75
Cross Jordan River with its natural levees.	19.9	17.6	28, 79
Cross Surplus Canal used to drain Jordan River water directly into Great Salt Lake.	22.7	14.8	
Kennecott Copper tailings pond to south.	28.2	9.3	34, 35, 45

U.S. Highway 40 Black Rock to Parleys Canyon Summit (continued)	Miles from		Refer to Page
	East End	West End	
Western edge of the Jordan River delta deposits.	29.2	8.3	73
Morton Salt Company Saltair plant to south and salt evaporating ponds to southwest.	29.7	7.8	125
Old Saltair Resort to northwest and dump of abandoned sodium sulfate plant to west.	32.9	4.6	79-87 125-129
Arthur and Magna Concentrating Mills to southeast.	33.6	3.9	111-112, 138
Western Phosphate plant to south.	34.9	2.6	138
Garfield Smelter to south with Oquirrh Formation on north end Oquirrh Mountains.	35.8	1.7	21, 22, 52, 111-113
Boat Harbor to north with Oquirrh Formation to southeast.	36.8	0.7	21, 22, 52, 79-87
Sunset Beach on Great Salt Lake.	37.3	0.2	79-87
Black Rock on edge Great Salt Lake showing Gilbert level of Lake Bonneville at Tooele County line.	37.5	0.0	71, 79-87

State Highway 48 — 18.3 miles: Bingham east to Midvale at State Street (U.S. 89-91)	Miles from		Refer to Page
	East End	West End	
Midvale Junction on US 89-91.	0.0	18.3	
Old Midvale Smelter to south with slag pile to north.	1.6	16.7	111
Cross Jordan River.	1.8	16.5	28, 79
West Jordan, Utah at contact of Provo series sediments to west and bottom sediments to east.	2.7	15.6	69-71, 75
Contact Provo series Bonneville sediments to east and Alpine sediments to west.	7.6	10.7	69-71


112° 00' W.
N
0 1 2 3 4
SCALE
DAVIS COUNTY
DAVIS COUNTY
112° 15' W.
GREAT SALT LAKE
40° 45' N
Salt Lake City
Redwood Road
Wasatch Dr.
Emigratio
40
North Temple
State St.
700 E.
Garfield
50A
2100 So.
Parleys
Magna
SOUTH SALT LAKE
OQUIRRH
171
3500 So.
GRANGER
Mi
68
152
Holladay
MURRAY
Highland Dr.
Bacchus
Taylorsville
TOOELE COUNTY
Coon Canyon
KEARNS
91
89
71
111
West Jordan
MIDVALE
Butlerville
7800 So.
SANDY CITY
210
48
Granite
Copperton
South Jordan
Bingham Canyon
State St.
700 E.
Bell
MOUNTAINS
Riverton
Draper
Canyon
111
12600 So.
40°30' N.
Herriman
Butterfield
Bluffdale
Rose Canyon
TRAVERSE MOUNTAINS
UTAH COUNTY
UTAH COUNTY
WAS

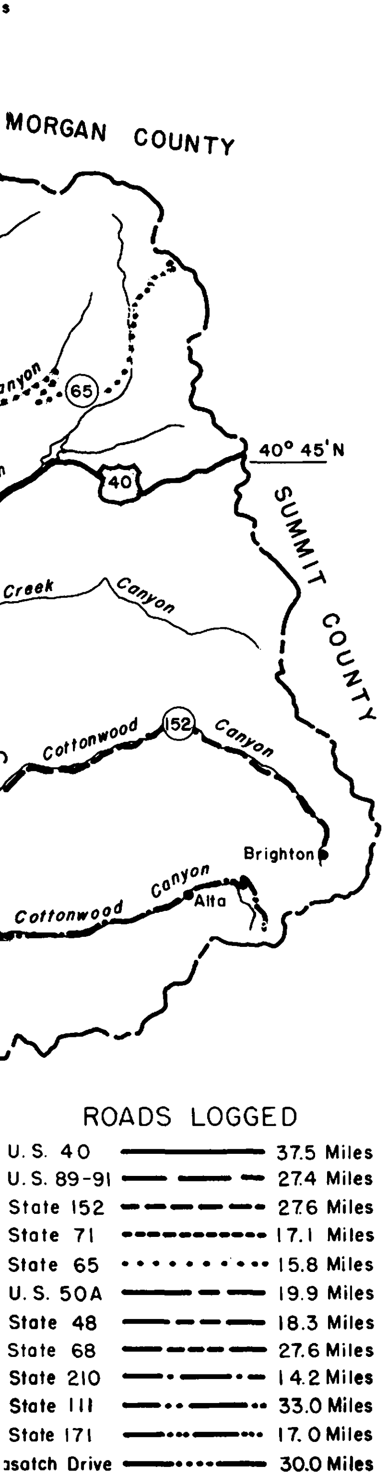


Figure 63. Index to Geologic Road Guides.

State Highway 48 Bingham east to Midvale (continued)	Miles from		Refer to Page
	East End	West End	
Contact Harkers Fanglomerate to west and Alpine sediments on the Oquirrh pediment to east.	10.4	7.9	28, 69-71
Bingham Creek is entrenched in Oquirrh pediment to south.	11.5	6.8	27
Copperton, a residential area for Kennecott Copper Co. employees.	12.2	6.1	109, 119
Contact Harkers Fanglomerate to east and Oquirrh formation in Bingham Canyon.	13.2	5.1	21, 22, 28, 52
Pink porphyry dike from Bingham Stock intruded in axis of Copperton Anticline to west.	14.7	3.6	29
Lower Bingham or old Frogtown at lower portal of Copper Pit railroad.	15.4	2.9	101, 105, 107-108, 111-112, 117, 119
Curry Formation (Permian) exposed to north.	15.8	2.5	22
Normal fault straightens Bingham Canyon at old Bingham High School with Lower Bingham Mine Formation (Pennsylvanian).	16.0	2.3	21, 22, 52
Cross Midas Thrust Fault at Markham Gulch entrance to canyon.	16.1	2.2	21, 22
Desert varnish covered Lower Bingham Mine Formation (Pennsylvanian) faulted against tan Curry Formation (Permian) on Midas Thrust Fault at old Bingham Canyon post office.	16.3	2.0	21, 22, 52, 101, 105, 107-108, 111-112, 117, 119
North end copper pit automobile tunnel which is 6,700 feet long and cut through Lower Bingham Mine Formation.	16.5	1.8	21, 22, 52

State Highway 48 Bingham east to Midvale (continued)	Miles from East End	Miles from West End	Refer to Page
Observation Platform for the Utah Copper Pit.	17.7	0.6	
End of road above Highland Boy mine which worked underground.	18.3	0.0	101, 105, 107-108, 111-112, 117, 119

U. S. Highway 50A — 18.5 miles: West Segment, Black Rock to State Street at 21st South	Miles from East End	Miles from West End	Refer to Page
US 89-91 at 21st South.	0.0	18.5	141
Jordan River delta deposits to west and Lake Bonneville bottom sediments to east.	1.0	17.5	28, 73
Cross Jordan River with delta deposits exposed.	2.1	16.4	73, 79
West edge Jordan River flood plain.	3.9	14.6	73, 75
Kennecott Copper Company tailings pond to northwest with McIntyre Lake to south.	10.7	7.8	71
Magna Mill of Kennecott Copper Company to south.	12.6	5.9	111-112
Flagpole Peak composed of Oquirrh Formation (Pennsylvanian) to south in Oquirrh Mountains.	13.0	5.5	21, 22, 52
Arthur Mill of Kennecott Copper Company to south.	13.4	5.1	111-112, 116
Garfield fault to south and Rio Grande and Pony Express fault blocks to northwest and northwest exposed in Oquirrh Formation.	13.9	4.6	21, 22, 37-38, 52
Deadman Cave to north in Pony Express Fault Block.	14.4	4.1	21, 22
Deserted town of Garfield and Electolytic Refinery Kennecott to south with Garfield	15.1	3.4	21, 22, 37-38,

U.S. Highway 50A, West Segment Black Rock to State Street at 21st (continued)	Miles from		Refer to Page
	East End	West End	
tear fault exposed in Kessler Canyon to south.			111-112
Garfield Smelter and lime flux plant of Kennecott Copper Company to south with Oquirrh Formation (Pennsylvanian) exposed in Oquirrh Mountains in the background.	16.9	1.6	21, 22, 52, 111, 112, 113, 137-138
North-south trending fault passes through gap to south separating the Smelter Fault Block to southeast from the Black Rock Fault Block to west.	17.9	0.6	21, 22, 37-38
Tooele-Salt Lake County line with Black Rock on the edge of the Great Salt Lake to north showing the Gilbert Level of Lake Bonneville.	18.5	0.0	71, 79-87

State Highway 65 — 16.5 miles: Emigration - Big Mountain Road east from Foothill Drive to Morgan County Line	Miles from		Refer to Page
	West End	East End	
Emigration Canyon Road and Foothill Drive.	0.0	16.5	23
Red Butte on south of Red Butte Canyon to north composed of Nugget Sandstone (Jurassic). It was quarried extensively for pioneer building stone.	0.2	16.3	137
Trough of Emigration syncline at mouth of Emigration Canyon.	0.4	16.1	23, 31-33, 34, 35, 53
"This is the Place" Monument where the Mormon Pioneers entered Salt Lake Valley.	0.8	15.7	
Road cuts in Twin Creek Limestone (Jurassic).	1.2	15.3	11, 53
Contact gray Twin Creek Limestone	4.2	12.3	25, 53

State Highway 65 Emigration-Big Mountain Road (continued)	Miles from		Refer to Page
	West End	East End	
(Jurassic) and red-brown Preuss Formation (Jurassic) to north.			
Cross Emigration Creek.	4.6	11.9	141
Outcrops of algae limestone and shale of Morrison Formation (Jurassic).	4.8	11.7	23
Outcrops of Kelvin Formation (Cretaceous) at road junction with Pinecrest road (State 172) going north and along which can be crossed successively Morrison, Preuss, Twin Creek, Nugget, and Thaynes Formations.	7.1	9.4	22-23, 25, 26, 27, 31-33, 34, 35, 53
Cross Little Mountain thrust fault at road switchback.	8.4	8.1	31
Little Mountain Summit with view of unconformity between Mesozoic and Tertiary beds to north with beds of Twin Creek Limestone (Jurassic).	8.9	7.6	23, 53
Road cut in Morrison Formation (Jurassic).	9.7	6.8	23
Kelvin Formation (Cretaceous) at junction with Mountain Dell Reservoir road (State 239).	10.6	5.9	25, 33, 34
Contact between Kelvin Formation (Cretaceous) to west and the Wanship Formation (Cretaceous) to east.	12.0	4.5	25, 26, 33, 34
Cross Little Mountain thrust fault with Frontier Formation (Cretaceous) to south of fault.	13.1	3.4	25, 33, 34
Cross Little Mountain thrust fault at foot of Big Mountain grade.	14.0	2.5	26, 33, 34
Contact of Echo Canyon Formation (Cretaceous) to south and Knight Formation (Eocene) to north.	15.9	0.6	26, 27, 33
Big Mountain Pass cut in Knight Forma-	16.5	0.0	26

State Highway 65 Emigration-Big Mountain Road (continued)	Miles from		Refer to Page
	West End	East End	
tion (Eocene) on Morgan - Salt Lake County line. Historic Marker No. 24.			

State Highway 68 — 27.6 miles: Redwood Road	Miles from		Refer to Page
	North End	South End	
Davis-Salt Lake County line at west end of Salt Lake Salient (Beck's Spur).	0.0	27.6	
Wasatch fault zone (Hot Springs fault) at base of Salt Lake Salient to east.	0.6	27.0	39-43, 94
Cross old lake bed found on Jordan River delta.	1.4	26.2	73, 79
Ensign Peak (Elev. 5414) capped by Wanship and Echo Canyon Formations (Cretaceous) to east.	2.2	25.4	26
State Capitol Building on Stansbury delta of Lake Bonneville to east.	2.9	24.7	71
Cross Surplus Canal built to divert flood water directly into Great Salt Lake.	5.7	21.9	79
Cross contact between Jordan River delta deposits to north and Lake Bonneville Bottom deposits to south.	8.0	19.6	28, 73, 75
Cut bank on Jordan River and view of flood plain to east.	9.0	18.6	73, 79
Cross Granger Fault zone on west side of Jordan Valley graben.	9.9	17.7	41
Knoll to east at east side of Oquirrh Mountain pediment which is veneered by Lake Bonneville deposits.	12.1	15.5	31, 37, 39, 69-71, 73-75
High point on east end of Oquirrh Mountain pediment.	13.3	14.3	31, 37, 39
Cross Bingham Creek with Bingham Copper Mine in Oquirrh Mountains to west.	15.5	12.1	101, 105, 107-108, 111-112

State Highway 68 Redwood Road (continued)	Miles from		Refer to Page
	North End	South End	
Cross Utah and Salt Lake Canal which diverts water from the Jordan River for use in Kennecott Copper Company mills at Magna and Arthur.	23.7	3.9	111
Steep Mountain sea cliff to east with prominent Bonneville shoreline at base and two spits extending into Jordan Narrows to south.	25.1	2.5	28
Point of the Mountain Spit across Jordan Narrows to east.	26.4	1.2	69-71
Hot Spring terrace to east composed of Pliocene travertine.	27.1	0.5	28
Utah - Salt Lake county line located on Lake Bonneville Provo series sediments.	27.6	0.0	

State Highway 71 — 17.1 miles: Seventh East from South Temple to Draper	Miles from		Refer to Page
	North End	South End	
At Seventh East and South Temple on sediments of the Provo series of old Lake Bonneville.	0.0	17.1	69-71
West base of Stansbury delta built into old Lake Bonneville to east.	1.2	15.9	71
Some of first water wells drilled in Jordan Valley to west.	1.9	15.2	143
Alluvial fans of Emigration Creek and Parleys Creek to east.	2.5	14.6	73, 75, 141, 150
Cross Big Ditch which was constructed in 1848 to divert water from Big Cottonwood Creek.	5.9	11.2	141, 143, 144, 150
Cross Big Cottonwood Creek, the largest stream in the Salt Lake County portion of the Wasatch Mountains.	7.2	9.9	141, 150
North of 6100 South cross Spring Rim	8.5	8.6	141, 144,

State Highway 71 Seventh East and South Temple to Draper (continued)	Miles from		Refer to Page
	North End	South End	
Creek which is largely recharged by irrigation on delta benches to east.			150
Cross Little Cottonwood Creek.	8.9	8.2	141, 144, 150
Gravel pit in Stansbury delta material to south.	10.6	6.5	71
Site of former Sandy smelter to west.	12.8	4.3	
Cross Dry Cottonwood Creek, the abandoned channel of Little Cottonwood Creek.	14.1	3.0	
Sand dune area on the Stansbury delta built in old Lake Bonneville.	15.3	1.8	71, 75
Wind formed blowout in Stansbury delta to east.	16.4	0.7	71
Junction with State 111 at Draper on sediments deposited in Lake Bonneville since Provo time.	17.1	0.0	75

U. S. Highway 89-91 — 27.4 miles: Through County on State Street with connections on north and south	Miles from		Refer to Page
	North End	South End	
Davis-Salt Lake County line at west end of Salt Lake Salient (Beck's Spur). Standard Oil Refinery to north.	0.0	27.4	
Beck's Hot Spring on the Warm Springs Fault to west with Maxfield Limestone (Cambrian) at point of origin.	0.4	27.0	19-20, 41, 43, 94
Gravel pit activity to east has exposed surface of Wasatch Fault with Knight Formation (Eocene) above and the Stansbury Formation (Devonian) refractory quartzite below.	0.8	26.6	27, 69, 94, 129, 135
Madison Limestone (Mississippian) exposed east of Wasatch Fault scarp to east.	1.2	26.2	20, 50

U.S. Highway 89-91 Through County on State Street (continued)	Miles from		Refer to Page
	North End	South End	
Remnant of Jones Canyon alluvial fan to east with gravel excavation showing inner structures of fan with Mississippian beds exposed to east in canyon and Wasatch Fault scarp cutting fan at mouth of canyon.	1.7	25.7	20, 50
Utah Oil Refinery to west and outcrops of Great Blue Limestone (Mississippian) to east.	2.2	25.2	20-21, 51
Ensign Peak to east capped by Wanship Formation (Cretaceous) at Victory Road junction (State 181).	2.4	25.0	26, 33, 34
Wasatch Hot Springs emerge from Wasatch Fault zone to east.	2.8	24.6	41-43, 94
State Capitol Building on Stansbury delta of Lake Bonneville to east.	3.6	23.8	71
Southwest edge of City Creek alluvial fan and delta deposits.	4.6	22.8	71-73
East edge of Jordan River delta deposits built in Great Salt Lake.	6.1	21.3	28, 71-73
Spring Canyon anticline in Wasatch Mountain front to east with Thaynes Formation (Triassic) in center.	7.4	20.0	23, 33, 53
Trough of Parleys syncline to east in Wasatch Mountains.	9.0	18.4	33, 34, 35
Cross Mill Creek.	9.5	17.9	141
"V"-shaped Mill Creek Canyon cuts Wasatch Mountain front to east.	10.9	16.5	22
Cross Big Ditch.	11.0	16.4	141
Cross Big Cottonwood Creek with Murray laundry to west.	11.4	16.0	141, 144
Murray postoffice to east.	12.5	14.9	94, 107-108, 111, 117

U.S. Highway 89-91 Through County on State Street (continued)	Miles from		Refer to Page
	North End	South End	
Cross Little Cottonwood Creek with old Murray smelter to west.	12.9	14.5	141, 144, 107-108, 111, 117
Cross East Jordan Canal near northwest edge Stansbury level delta.	18.0	9.4	71
Cross Jordan and Salt Lake City Canal.	19.0	8.4	142-143
Knoll of Oquirrh Quartzite (Pennsylvanian) to east.	23.8	3.6	21, 22
Steep Mountain, a fossil sea cliff of old Lake Bonneville to south.	24.4	3.0	21, 22, 69
Rideout Quartzite quarries to east on East Traverse Mountains.	24.7	2.7	135
Road on Provo Level of Lake Bonneville with wave cut and wave built Bonneville terrace to east.	25.8	1.6	28, 69-71
Mount, (U.P.R.R. siding) gravel pit in Alpine sediments of Bonneville Spit to east.	26.9	0.5	69, 129
Utah-Salt Lake County line at the Jordan Narrows.	27.4	0.0	28, 69, 70, 79

State Highway 111 — 33 miles: Magna south to Lark, east to Draper plus 4.3 miles southeasterly along Alpine Road	Miles from		Refer to Page
	East End	West End	
Deer Creek and Salt Lake Aqueduct at base of fault facets in Wasatch Fault zone.	0.0	33.0	94, 147
Provo level of Old Lake Bonneville.	0.4	32.6	69-71
Lone Peak (El. 11,253 ft.) horn to east with arete ridge and "U"-shaped canyons.	2.1	30.9	29, 63
Gravel pit in Lake Bonneville spit to north. Fossil soil clay deposits in Corner Creek Canyon to southeast.	2.7	30.3	69-71, 129, 132-133

State Highway 111 Magna south to Lark, east to Draper, southeasterly on Alpine Road (continued)	Miles from		Refer to Page
	East End	West End	
Eastern terminus of State 111.	4.3	28.7	
Fuller's Earth deposit at "Tallow Mine" below Bonneville terrace on East Traverse Mountains to south.	5.0	28.0	133-135
Cross Jordan River which drains entire Jordan Valley.	6.5	26.5	73, 79
Cross Bonneville Level of old Lake Bonneville on Alpine sediments.	11.9	21.1	69
Step Mountain forms southeast brow of a volcanic neck with spectacular columnar jointing in Rose Canyon to south.	13.7	19.3	27
Shaggy Peak, a rhyolite plug forming the north prong of the divide between Rose Canyon and Butterfield Canyons, in West Traverse Mountains to south.	14.9	18.1	27
Andesite flows on sides of Butterfield Creek flood plain to north and south.	16.0	17.0	27
Lark, a mining center for underground operations around the Bingham Copper Pit.	17.4	15.6	29
Harkers Fanglomerate on Oquirrh Mountain front to west with Midas Thrust Fault on mountain face to west.	19.0	14.0	28, 37, 38
Cross Bingham Creek which has entrenched itself here into the Oquirrh Mountain pediment.	21.1	11.9	28, 31, 37, 39
Hills of Harkers Fanglomerate (Pliocene) with Bonneville Level at summit to west.	25.3	7.7	28
Type area for Harkers Fanglomerate in Harkers Canyon to west.	27.3	5.7	28
Oquirrh Formation to west from Bacchus, the seat of much of Hercules Powder Company operation.	29.0	4.0	21, 22, 52
North limit of Jordan Narrows Formation	30.7	2.3	28

State Highway 111 Magna south to Lark, east to Draper, southeasterly on Alpine Road (continued)	Miles from East End	Miles from West End	Refer to Page
(Oligocene) a major unit of the Salt Lake Group.			
Lake Bonneville bottom sediments to north and Provo series to south.	31.6	1.4	69
Junction with US 50A at corner of Kennecott Copper Company tailings pond and northeast edge of Oquirrh Mountains.	33.0	0.0	31, 37, 39

State Highway 152 — 27.6 miles: Brighton to junction with US 40 at 5th South & 11th East (23.9 miles on State 152 plus north extension of 3.7 miles).	Miles from North West End	Miles from South East End	Refer to Page
Junction with US 40 at 5th South and 11th East, in Salt Lake City on east side of East Bench Fault.	0.0	27.6	94
Cross East Bench Fault scarp.	0.3	27.3	69, 94
Nose of Spring Canyon anticline in Wasatch Front to east.	1.0	26.6	33
Intricate folding on the south side of the Parley's syncline in Thaynes Formation to east.	3.2	24.4	23, 53
North terminus of State 152 at intersection of 13th East and Highland Drive.	3.7	23.9	
Cross Big Cottonwood Creek south of Big Ditch which was built in 1848.	6.5	21.1	141, 145-146
Cross Jordan and Salt Lake City Canal.	7.5	20.1	
Cross East Jordan Canal.	8.6	19.0	
Cross proposed Freeway.	8.7	18.9	
Junction with State 210 at 70th South and 20th East.	9.4	18.2	
Gravel pit in Lake Bonneville delta to north.	10.6	17.0	69
View of flood plain of Big Cottonwood	11.3	16.3	70

State Highway 152 Brighton to U.S. 40 Junction (continued)	Miles from		Refer to Page
	NW End	SE End	
Creek excavated since Provo time from the Lake Bonneville delta.			
Cross Wasatch Fault zone at mouth of Big Cottonwood Canyon.	12.5	15.1	15, 94
Blue to purple argillites of Big Cottonwood Series to north.	13.1	14.5	15
Mudcracks and ripple marks on vertical dipping hornfels to west at crossing of Big Cottonwood Creek at base of lower (cat) stairs.	14.4	13.2	15
Mule Hollow to north forms subsequent valley along hornfel slate and quartzite contact.	15.2	12.4	15
Outcrops of Mineral Fork tillite on north wall of canyon opposite mouth of Mill B South Fork.	16.8	10.8	15, 61
Mineral Fork in which canyon is located the type area for the Mineral Fork Tillite enters Big Cottonwood Canyon from the south.	17.9	9.7	15, 63
Basal conglomerate of Mutual Quartzite exposed near Mutual mine—its type area to north.	18.3	9.3	17-18
Abandoned pot holes in Mutual Quartzite across Big Cottonwood Creek to south.	18.7	8.9	17-18
Contact Gulch to north is cut along contact between Mutual Quartzite to west and Tintic Quartzite to east.	18.8	8.8	17-18, 19, 41
Outcrops of Ophir Shale (Cambrian) to north.	19.0	8.6	20, 49
Old Maxfield mine to north is type area for the Maxfield Limestone (Mississippian)	19.2	8.4	20, 122
Apophysis of diorite exposed in bottom of	19.3	8.3	20

State Highway 152 Brighton to U.S. 40 Junction (continued)	Miles from		Refer to Page
	NW End	SE End	
Mill A. Gulch to north has marbelized and bleached Madison (Gardison) Formation (Mississippian).			
Gulch separates Humbug Formation (Mississippian) on east from Deseret Formation (Mississippian) on west.	19.8	7.8	22, 49
Cross contact of Morgan Formation (Pennsylvanian) to east and Doughnut Formation (Mississippian) to west near lower limit of glaciation in Big Cottonwood Canyon.	20.5	7.1	21
Contact Weber Formation (Pennsylvanian) to east and the Morgan Formation (Pennsylvanian) to west.	20.6	7.0	21
Argenta damsite at old Argenta is located at contact of Park City Formation (Permian) to east and Weber Quartzite (Pennsylvanian) to west.	21.0	6.6	22, 144-145, 151
North-south trending fault (throwing Deseret Formation against Park City Formation) extends north to east-west trending Mt. Raymond Thrust Fault to north at junction of Cardiff Mine road.	21.5	6.1	34, 51, 52, 116, 122
East edge of Reynolds Flat which is result of glacial erosion and later alluvial filling.	21.9	5.7	62
Greens Basin hanging valley to south perched 800 feet above canyon floor and exposures of Triassic beds on crest of Wasatch Mountains to east.	22.8	4.8	22-23, 62
Cliffs of Weber Quartzite to north.	23.1	4.5	21
Fitchville Formation (Mississippian) formerly called Jefferson Dolomite (Devonian) in Mats Basin hanging valley to south at mouth of Silver Fork.	23.6	4.0	20, 21, 107

State Highway 152 Brighton to U.S. 40 Junction (continued)	Miles from		Refer to Page
	NW End	SE End	
Scotts Hill to north is capped by Thaynes Limestone (Triassic).	25.0	2.6	22-23, 53
Brighton at base of loop road is now a mountain resort and ski center in a glaciated valley at base of glacial horn peaks. Brigham Young and pioneers were here celebrating the 10th anniversary of their arrival in Salt Lake Valley when they received the news that Johnston's Army was on its way to Utah.	26.4	1.2	101, 119
Foot of Lake Mary trail to glacial lakes, cirques, stairs, treads and rises to south with the base of Mt. Millicent (Elev. 10,452 ft.) to west.	27.1	0.5	61
End of loop at Brighton in a glacial valley near morainal Silver Lake.	27.6	0.0	

State Highway 171 — 17.0 miles: Mouth of Parleys Canyon west to State Highway 111 south of Magna	Miles from		Refer to Page
	East End	West End	
Junction with US 40 at mouth of Parleys Canyon. Orange Nugget Sandstone cliffs are exposed to north and red beds of Ankareh Formation (Triassic) at bottom of canyon.	0.0	17.0	23
Dike Gulch to east eroded in shale beds with a North-South keratophyre dike cutting beds a short distance up gulch.	0.1	16.9	23, 29
Suicide member (Shinarump) of Ankareh Formation (Triassic) in a vertical position forms Suicide Rock at mouth of Parleys Canyon to north on east side of Wasatch Fault zone.	0.4	16.6	23, 39-43, 94
Tight fold in Thaynes Formation (Triassic) to east on south flank of Parleys syncline.	0.6	16.4	23, 53

State Highway 171 Parleys Canyon to south of Magna (continued)	Miles from		Refer to Page
	East End	West End	
Cross Jordan and Salt Lake City Canal which supplies Jordan River water to the heart of Salt Lake City.	4.4	12.6	142, 143
To north—Vitro Chemical plant which processes uranium ores.	7.3	9.7	
Cross Jordan River near head of the Jordan River delta being built into Great Salt Lake.	8.3	8.7	73, 79
Cross approximate trace of the Charleston-Nebo overthrust fault now covered by Lake Bonneville alluvium.	13.5	3.5	34-35, 45, 71
Oquirrh Mountain pediment forms east sloping surface on skyline to south.	14.5	2.5	31, 37, 39
Junction with State 111 at 8400 West and 3500 South on sediments of Provo age.	17.0	0.0	69

State Highway 210 — 14.2 miles: Little Cottonwood Canyon road east from junction with Big Cottonwood (State 152) at 20th East and 70th South, Salt Lake City	Miles from		Refer to Page
	East End	West End	
Junction with Big Cottonwood road (State 152) at 70th South and 20th East.	14.2	0.0	
Cross Deer Creek and Salt Lake Aqueduct which carries water from Deer Creek Reservoir in Provo Canyon to Salt Lake City.	13.9	0.3	146
Wasatch Fault zone at west base of Wasatch Mountains, to east.	13.4	0.8	39-43, 94
Little Willow Formation outcrops across Wasatch Fault zone to east.	12.8	1.4	14
Quarry in quartz monzonite to northeast used to build Salt Lake Temple.	11.8	2.4	29
Steep contact of Little Cottonwood quartz monzonite stock crosses canyon with gla-	11.7	2.5	14, 29, 55

State Highway 210 Little Cottonwood Canyon to Big Cottonwood Canyon (continued)	Miles from East End	Miles from West End	Refer to Page
cial erratics of quartz monzonite on lateral moraines to south.			
Temple quarry in quartz monzonite stock to north.	11.0	3.2	29, 137
Canyon is 4,730 feet deep here with stock capped by Big Cottonwood series beds.	8.4	5.8	14
Scenic view of "U" shaped cross profile to west and hanging valley of Hogum Fork to south.	8.2	6.0	61
Waterfall from Maybird Gulch hanging valley to south.	7.8	6.4	57, 58-59
Riegel on quartz monzonite stock and steep rise of glacial stair.	7.6	6.6	61
Waterfall from Red Pine Fork hanging valley to south.	7.4	6.8	59
Tanner Flat formed on a glacial tread.	7.2	7.0	59
Waterfall and hanging valley of White Pine Fork which has cut canyon through Little Cottonwood stock to south.	6.7	7.5	29, 59
East contact of Little Cottonwood stock to north with terminal moraine and landslide material in canyon bottom.	5.8	8.4	29
East contact of Little Cottonwood stock crosses canyon here and is in contact with Big Cottonwood Series beds.	4.4	9.8	14, 29
Contact Mineral Fork Tillite and Tintic Quartzite on both sides of canyon.	3.7	10.5	15, 19-20
Alta overthrust on north canyon wall at old mining camp of Alta with Ophir Shale (Cambrian) and Madison Limestone (Mississippian) outcropping.	3.3	10.9	33-34, 49, 101, 116, 117, 119, 122
Emma Tunnel and outcrops of Maxfield Limestone to north.	2.9	11.3	20, 122

	Miles from		Refer to Page
	East End	West End	
Scenic view of Alta from top of switchbacks through granodiorite of Alta Stock.	0.9	13.3	29, 33, 62, 116
End of road in Albion Basin, a glacial cirque with Devils Castle, a cirque wall composed of Gardison Formation (Mississippian) to south.	0.0	14.2	20, 119

Wasatch Drive — 30 miles: From Seventh East and 12800 South at Draper along foot of Wasatch Mountains north to State Capitol	Miles from		Refer to Page
	North End	South End	
At 7th East and 12800 South (Draper Cross-Roads): Deposits are bottom sediments of old Lake Bonneville.	30.0	0.0	70
Gravel pit to north in the Draper spit built by Little Cottonwood Creek into Lake Bonneville.	28.8	1.2	41, 69, 70
Wasatch Fault triangular facets at end of spurs to east.	27.4	2.4	94
Blowout on the surface of the Little Cottonwood delta to west.	27.1	2.9	69
Glacial cirques at heads of canyons to east.	25.8	4.2	55, 57, 58
Cross Deer Creek and Salt Lake aqueduct near the site for the Dimple Dell Reservoir.	24.8	5.2	151
Bell Canyon terminal moraine to east.	24.0	6.0	55-57
Cross Dry Cottonwood Creek an abandoned channel for Little Cottonwood Creek.	23.3	6.7	35, 41, 154
Moraine viewpoint for Bells Canyon and Little Cottonwood glaciers with an 80 foot fault scarp of Wasatch Fault zone crossing both lateral moraines.	22.6	7.4	41-43, 55-58, 94

Wasatch Drive Draper to State Capitol (continued)	Miles from		Refer to Page
	North End	South End	
Good example of glacial erratic of quartz monzonite to north in field.	22.4	7.6	55-58
Crosses fault scarp of Wasatch Fault zone with good view of "U" shaped Little Cottonwood canyon to east.	22.3	7.7	41-43, 65, 94
West side of Beaver Pond graben with fault scarp crossing Little Cottonwood lateral moraine to south and an apophysis on the Little Cottonwood stock appearing as sharp peak to northeast.	22.1	7.9	15, 29, 41-43, 64, 94, 116
Cross Little Cottonwood Creek at the Beaver Pond Reservoir site in Beaver Pond graben.	21.8	8.2	94, 141 146
North end of Beaver Pond graben.	21.5	8.5	151
Little Willow Formation exposed in Wasatch Front to east.	21.4	8.6	14
Fresh piedmont fault scarps along Wasatch Fault zone to east.	21.0	9.0	39-43, 94
Slump valley along graben causing irrigation toward mountain; quartz monzonite apophysis to Little Cottonwood stock to east.	19.8	10.2	15, 29, 39-43, 94
View of Big Cottonwood flood plain cut through Provo level delta to north; a glacial cross section of Big Cottonwood canyon existing 40 feet above narrow stream formed notch, visible to east.	18.9	11.1	61, 69
Cross Ferguson Canyon Creek, the canyon of which is locale for phenocrysts of microcline and of extensive glaciation with a prominent Wasatch Fault scarp.	18.5	11.5	37, 39-43, 94
Cross Big Cottonwood Creek on Wasatch Fault zone.	18.1	11.9	60-62, 94, 145
Glacial outwash deposits of Alpine age can be seen to north in the Walker gravel pit.	17.5	12.5	60, 69, 73

Wasatch Drive Draper to State Capitol (continued)	Miles from		Refer to Page
	North End	South End	
Better sorted outwash deposits can be seen in the Huber and Davis gravel pit to east with the face of pit being a Wasatch Fault scarp.	17.1	12.9	39-43, 70
Olympus clay deposit on Wasatch Front to east.	17.0	13.0	17, 23, 130
Contact Mutual Quartzite and Tintic Quartzite on face of Mt. Olympus in Hughes Canyon to east.	16.4	13.6	17, 23
Prominent Bonneville Level sea cliff to east cut on face of Mt. Olympus in Tintic Quartzite (Cambrian).	14.7	15.3	23, 73
Dry Creek and Casto Springs at base of Wasatch Fault scarp to west recharge from Neffs Canyon through channels in soluble limestones. Refractory quartzite being processed on north slope of Mt. Olympus to east.	14.0	16.0	39-43, 94, 136
Trace of Mt. Raymond Thrust Fault can be seen in Neffs Canyon to east.	13.5	16.5	23, 24, 34
Glacial moraine of Neffs Canyon glacier to east with mud flow remnants at road level.	12.6	17.4	33, 34, 65
Stream formed Mill Creek Canyon to east with Weber Quartzite (Pennsylvanian) on south side and Park City Formation (Permian) on north side of canyon.	12.3	17.7	20, 21, 34
Cross Mill Creek which has cut a narrow "V" shaped stream-formed canyon.	12.0	18.0	22
Mule Hollow to east is a subsequent valley cut on weak Woodside Shale (Triassic) with Pre-Bonneville residual clays present above the Bonneville level.	11.9	18.1	23, 29-30, 130-136
Terminal Reservoirs of Deer Creek-Salt Lake Aqueduct to west.	11.4	18.6	135

Wasatch Drive Draper to State Capitol (continued)	Miles from		Refer to Page
	North End	South End	
Highly folded Thaynes Formation (Triassic) on south limb of Parleys syncline to east.	11.2	18.8	23, 31-33, 49, 53
Suicide rock to east is a member of the Ankareh Formation (Triassic) or an equivalent of the Shinarump Formation of the Colorado Plateau.	10.8	19.2	23
Cross Parleys Creek which has cut a "V" shaped stream-formed canyon to east.	10.7	19.3	143-144
Trough of overturned Parleys syncline with Twin Creek Limestone (Jurassic) across Wasatch Fault zone to east.	10.2	19.8	25, 39-43, 53, 94
Crest of Spring Canyon anticline to east with Thaynes Formation (Triassic) in crest.	9.0	21.0	23, 53
Emigration pediment to west cut on Ankareh Formation (Triassic).	8.1	21.9	23
Edge of Provo delta of Lake Bonneville with Emigration syncline floored with Twin Creek Limestone to east.	7.6	22.4	30-31, 44, 53
Cross Emigration Creek.	7.2	22.8	141-144
Cliff of Nugget Sandstone (Jurassic) on south side Red Butte Canyon to east is host to pioneer rock quarries.	5.9	24.1	31, 137
Red Butte canyon to cast is subsequent valley formed along Ankareh Shale (Triassic).	5.7	24.3	23, 25
Ft. Douglas Military Reservation.	5.3	24.7	101, 105
Cephalopod Gulch to east is locale for many Triassic cephalopods in the Thaynes Limestone.	4.6	25.4	23, 53
Dry Canyon to east is cut on weak Woodside Shale (Triassic).	4.4	25.6	23
Wind gap at head of Limekiln Gulch to	3.6	26.4	

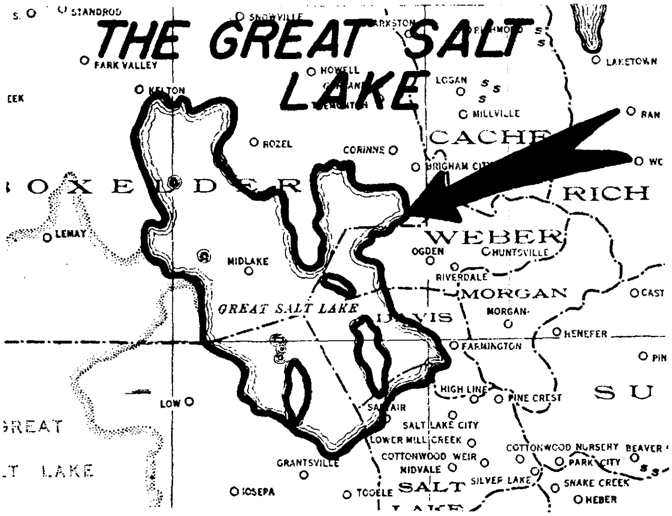
Wasatch Drive Draper to State Capitol (continued)	Miles from		Refer to Page
	North End	South End	
east due to stream piracy on Dry Creek through beds of Morgan Formation (Pennsylvanian).			
Perrys Hollow cut through Knight Conglomerate (Eocene) subject to extensive mud flow activity to east.	3.3	26.7	26, 27, 33
Edge of City Creek canyon cut through the Provo delta of Lake Bonneville and through relatively horizontal beds of Knight Conglomerate.	1.9	28.1	26, 27, 75
Road cuts in topset, foreset, and bottomset beds of Lake Bonneville delta.	1.7	28.3	70
Cross City Creek first utilized stream in Jordan Valley.	1.3	28.7	143
Outcrops of Tertiary volcanic tuff and breccia to north.	1.0	29.0	27-28
Junction with State 181 in front of State Capitol Building on Stansbury level delta of Lake Bonneville.	0.0	30.0	71

INDEX

OF SPECIAL INTEREST:

MAP OF THE GREAT SALT LAKE, UTAH

by Armand J. Eardley



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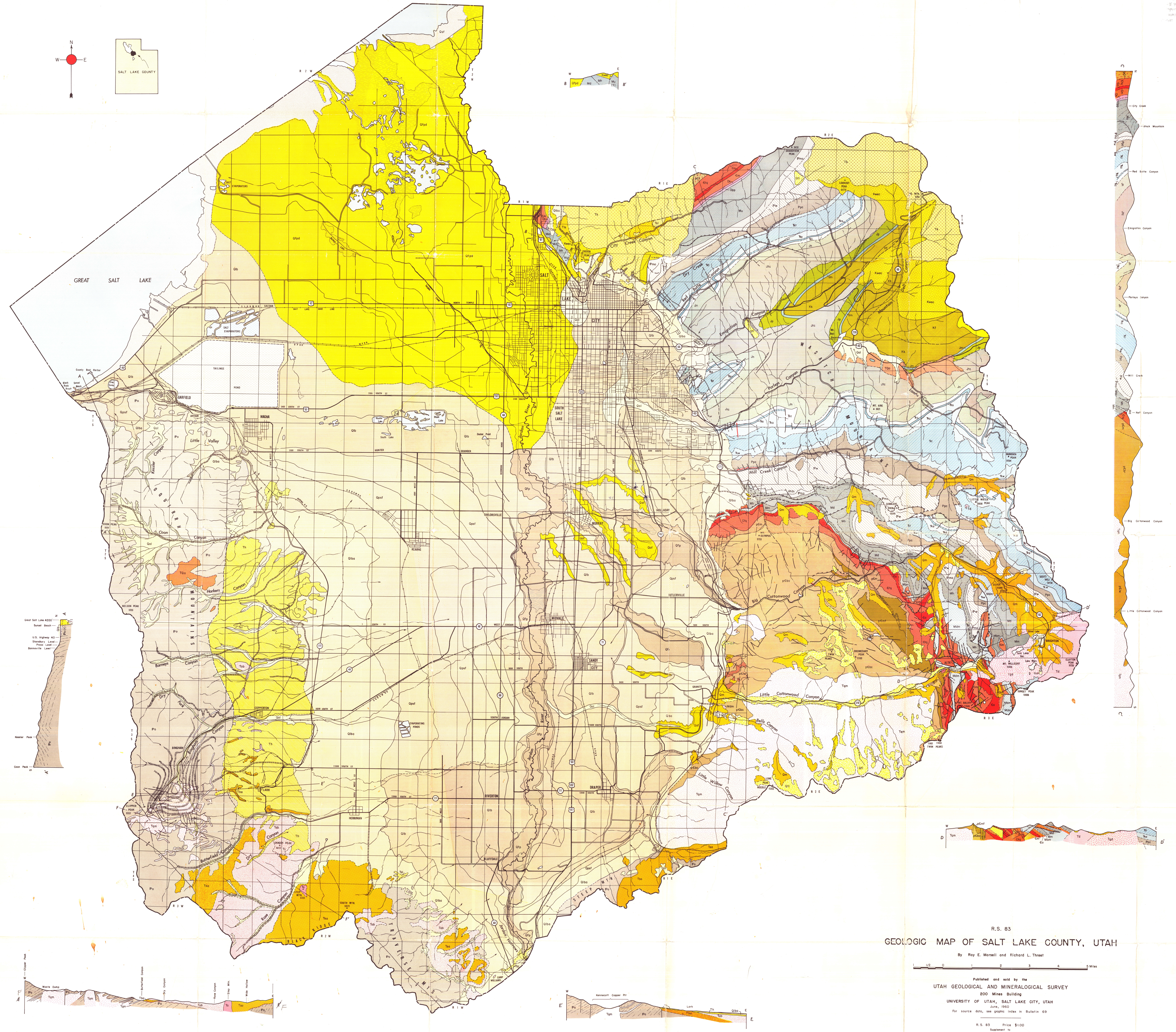

LEGEND

CENOZOIC ROCKS

Period	Epoch	Unit	Symbol
QUATERNARY	Post-Lake Bonneville	Salt flat	Qsf
		Alluvial fans & colluvial deposits	Qal
		Flood plain deposits along existing streams	Qfp
		Jordan River flood plain & delta complex	Qfpd
		Abandoned channel flood plain deposits	Qaf
		Provo & younger lake bottom silts & sands	Qlb
		Provo & younger shore facies of sand & gravel	Qpsf
		Lake Bonneville–Alpine deposits; chiefly shore facies of gravels & sands, & offshore silts	Qlba
		Glacial till, chiefly Wisconsin	Qm
		Talus & landslides	Qtl
		Older alluvium, high level remnants	TQa
TERTIARY	Pliocene	Harkers fanglomerate	Th
	Mio-Pliocene	Salt Lake group (Jordan Narrows & Camp Williams undifferentiated)	Tsl
	Oligocene	South Mountain andesite flows	Tsa
		Rose Canyon latite-andesite volcanics	Tab
		Butterfield andesite flows	Tba
	Eocene	Knight conglomerate	Tk
	Paleocene	Tertiary limestone	Tls

UNCONFORMITY

MESOZOIC ROCKS

Period	Unit	Symbol
CRETACEOUS	Wanship-Echo Canyon formation	Kwec
	UNCONFORMITY	
	Frontier formation	Kf
	Kelvin formation	Kk
?	Morrison formation	Jm
JURASSIC	Preuss formation	Jp
	Twin Creek limestone	Jtc
	Nugget sandstone	Jn
TRIASSIC	Chinle formation	₸c
	Shinarump formation	₸s
	Ankareh shale	₸a
	Thaynes limestone	₸t
	Woodside shale	₸w

PALEOZOIC ROCKS

Period	Unit	Symbol
PERMIAN	Park City formation	Ppc
?		
PENNSYLVANIAN	Weber quartzite	IPw
	Morgan formation	IPmo
	Oquirrh formation	IPo
MISSISSIPPIAN	Doughnut formation Great Blue limestone	Mdo Mgb
	Humbug formation	Mh
	Deseret limestone	Md
	Madison limestone	Mm
	Deseret & Madison undifferentiated	Mdm
	Basal Mississippian limestone	Mbm
	Undifferentiated Mississippian limestone	Mu
DEVONIAN	Pinyon Peak limestone	Dpp
	Stansbury formation	Ds
	UNCONFORMITY	
CAMBRIAN	Maxfield limestone	€m
	Ophir shale	€o
	Tintic quartzite	€tq

UNCONFORMITY

Sands, shale → (probable source = Antler orogenic belt)

PRECAMBRIAN ROCKS

Unit	Symbol
Mutual quartzite	p€m
UNCONFORMITY	
Mineral Fork tillite	p€mf
UNCONFORMITY	
Big Cottonwood complex	p€bc
UNCONFORMITY	
Little Willow series	p€lw
UNCONFORMITY	
Farmington complex	p€f

PLUTONIC ROCKS

Unit	Symbol
Shaggy Peak rhyolite plug	Tr
Step Mountain andesite neck	Ta
Bingham & Little Cottonwood stocks, quartz monzonite	Tqm
Alta stock, granodiorite	Tgd
Clayton Peak stock, diorite	Td
Acidic dikes & sills	
Tertiary volcanics undifferentiated	Tv

R.S. 83

GEOLOGIC MAP OF SALT LAKE COUNTY, UTAH

By Ray E. Marsell and Richard L. Threet

1 1/2 0 1 2 3 4 5 Miles

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