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GEOLOGY AND GROUND WATER RESOURCES OF NORTHERN CEDAR VALLEY UTAH COUNTY, UTAH

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GEOLOGY AND GROUND WATER RESOURCES OF NORTHERN CEDAR VALLEY, UTAH COUNTY, UTAH

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by

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ABSTRACT

Northern Cedar Valley lies in the extreme northwest corner of Utah County between the Oquirrh Mountains to the west, Lake Mountain to the east, and the Traverse Range to the north. The valley is 13 miles long and 8 miles wide, and is one of the basins of interior drainage in the extreme eastern portion of the Basin and Range Province. The maximum relief between the valley floor and the surrounding mountain tops is 5795 feet. West Canyon in the Oquirrh Mountains has the only permanent stream flowing into the valley.

The climate is semi-arid and temperate with an average precipitation of 10.44 inches per year on the valley floor. The Oquirrh Mountains receive 25 inches or more of precipitation per year. The valley supports about 300 residents, with agriculture as the major source of livelihood.

Sedimentary rocks of Paleozoic age supply most of the sediments which are shed into the valley. These rocks consist mainly of limestone, quartzite, and shale. The alluvial deposits in northern Cedar Valley are at least 1258 feet thick. The thickest sediments in the valley are the pre-Lake Bonneville deposits (Tertiary [?] and Pleistocene). These deposits are a series of interbedded fluviatile and lacustrine sediments. The Lake Bonneville group is represented in the valley by the Alpine and Bonneville formations.

The sedimentary conditions which have prevailed in the valley since the beginning of Lake Bonneville time are considerably different than those in the larger valleys that were occupied by the lake. The history of the lake in Cedar Valley varies from the general history of the main body of the lake in the larger valleys. These differences were the result of such factors as: position of the mountain area, elevation of the valley, size of streams entering the valley, distance of the lake from the base of the mountains, and the size of the valley.

Because of the elevation of the valley, Lake Bonneville ceased to exist as a lake in northern Cedar Valley at the close of the Bonneville stage. This resulted in a large quantity of fluvial sediments being deposited in the valley during the Provo stage and continuing, with a decrease in volume, into Recent times. In addition the Provo stage is possibly represented by lake sediments in the lower portion of the valley.

Since 1884, a total of 51 wells have been dug or drilled in the valley. Twenty-six of these are still being used. No well in the valley discharges more than 562 gallons per minute, and most discharge considerably less. The water table varies throughout the valley depending on the fineness of the sediments. There are 12 flowing wells in the valley totaling no more than 150 gallons per minute. During the summer of 1959 only seven pump wells were operating in the valley, with a total discharge of 4 second-feet. In the area of these seven pump wells the piezometric surface has dropped 51 feet since 1951.

Four springs occur within or around the periphery of the valley. These springs have a total flow of 6 second-feet. The three springs near Cedar Fort are bedrock springs and the single spring west of Fairfield is located on the toe of an alluvial fan.

The Paleozoic rocks that plunge under the valley contribute ground water to the valley, but the quantity is unknown. The major source of ground water in the valley is the pre-Lake Bonneville sediments which are extremely thick and permeable in certain areas. A minor source of ground water is the Lake Bonneville and post-Lake Bonneville sediments.

Meltwater from the winter snows in the Oquirrh Mountains is the major source of ground-water recharge for northern Cedar Valley.

The most promising areas for maximum ground water development are the toes of the alluvial fans along the north and west sides of the valley. The least promising area is the flat floor of the valley.

INTRODUCTION

Purpose and Scope of the Investigation

This report was undertaken and completed during the spring and summer of 1959 in partial fulfillment of the requirements for the Master of Arts degree in Geology at the Brigham Young University.

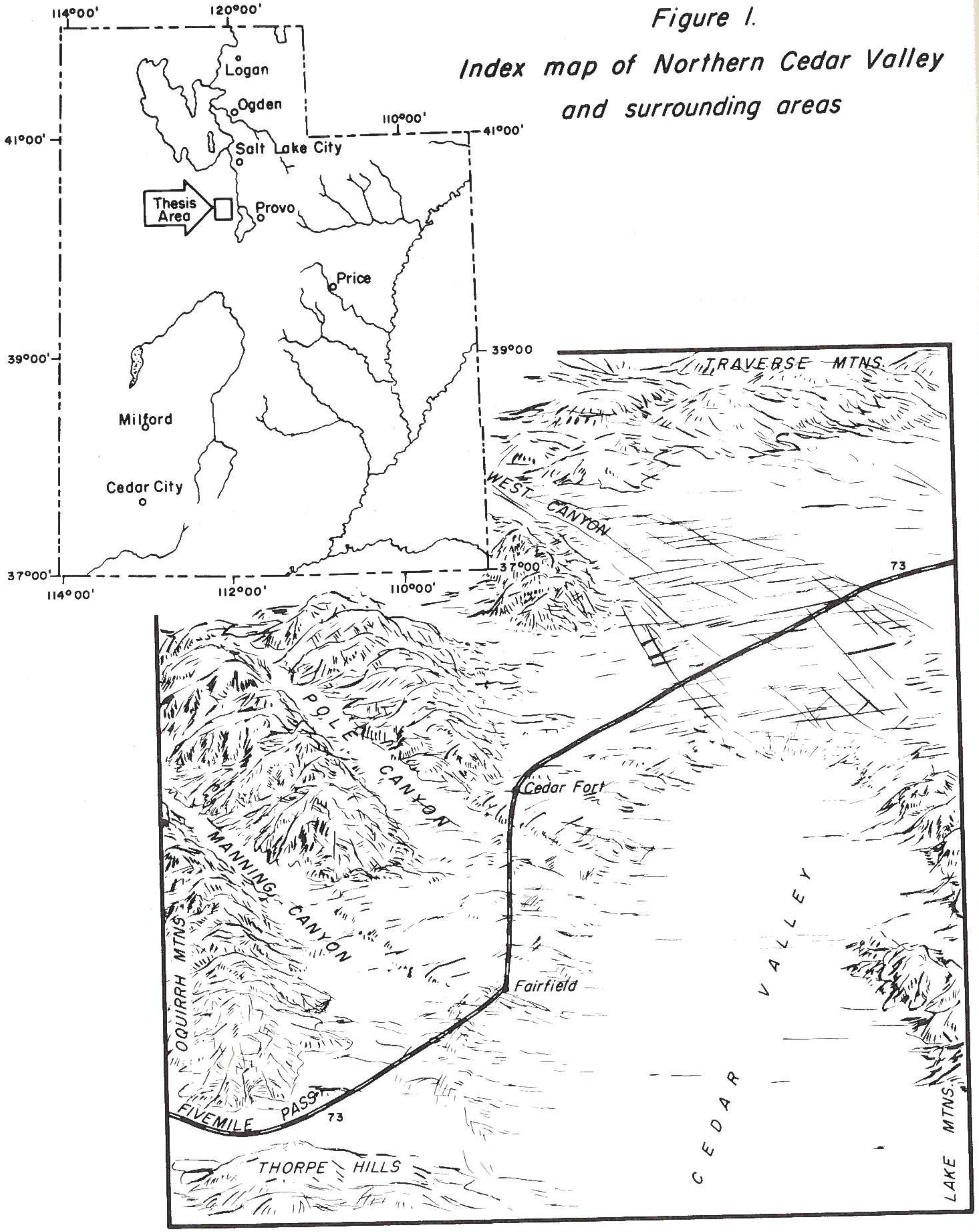
The purpose of the report is to interpret the geology of northern Cedar Valley and to determine its effect on the ground water supplies of the valley.

To accomplish this the unconsolidated sediments of the valley were mapped and the conditions of sedimentation which have prevailed in the valley were reconstructed. The bedrock geology and structure on the west side of the valley was taken from Bissell and Rigby (1959, pl. I), Bissell and Proctor (1959, pl. II), and McFarland (1955, table 1). A hydrologic study was made of the existing wells in the valley. In conjunction with this a hydrologic and geologic interpretation was undertaken of the well logs of all wells ever drilled in the valley. The geologic conditions controlling the flow of springs in the valley are interpreted and explained. The possibilities of future ground water development are discussed.

Location of Area

Some of the most interesting Quaternary geologic phenomena in the Basin and Range Province are located in Cedar Valley, an intermontane basin on the western border of Utah County in central Utah. The portion of the valley considered in this report occupies the northern 90 square miles of the valley and will be referred to in this report as northern Cedar Valley (Fig. 1). Northern Cedar Valley lies in the extreme northwest corner of Utah County about 25 miles northwest of Provo. The valley includes portions of Townships 5 and 7 south and all of Township 6 south. It includes portions of Ranges 1 and 3 west and all of Range 2 west. The datum lines in this area are the Salt Lake Base and Meridian lines.

Figure 1.
Index map of Northern Cedar Valley and surrounding areas



Previous Investigations

Up to the time of this report no detailed ground-water study had been undertaken in northern Cedar Valley. A reconnaissance report was compiled by Moulton (1951) but no conclusions were reached as to the ground water possibilities of the valley.

The bedrock surrounding the valley has been described in various geologic reports and the authors and titles of some of these reports are listed in the references cited at the end of this thesis. The effects of Lake Bonneville on this valley were studied by G. K. Gilbert whose monograph on this subject was published in 1890.

Methods of Investigation

During the spring and summer of 1959 the writer conducted geologic field mapping, canvassed wells, checked flow of springs, and studied the ground-water conditions in the northern Cedar Valley area. Water level measurements of all the accessible wells in the valley were made with a graduated rope during the month of July. Pump tests were conducted on eight selected wells from August 1-7. All of the accessible wells in the valley were visited by the writer during the course of the field work. The character and thickness of the water-bearing materials and the yields of wells were obtained from drillers' logs and from well owners in the area.

Lithologic units were mapped in the field on aerial photographs at a scale of 1 inch equals 660 feet. These data were transferred to the base map (scale, 1:12,000) which was enlarged from several United States Geological Survey quadrangles. Wells were located on the base map by measuring distances from section corners, section lines, and roads. Areas of high or low transmissibility were located by observation during field mapping and from well logs.

Well Numbering System

One well numbering system will be used in this report. The method used is a simple system in which each well has a number between 1 and 51. This system of numbering is used in the text and on Plates I-V. This method was found to be practical for numbering wells on maps where the spacing was extremely close.

Acknowledgment

Appreciation is expressed to Dr. George H. Hansen for the advice and assistance which he rendered in the preparation of this report. The writer is grateful to Dr. Harold J. Bissell for his guidance in interpreting the sediments of northern Cedar Valley.

Thanks are given to Donald Stewart of the State Engineers Office for his aid in obtaining well logs and other information on the valley. Clarence Shupe, consulting engineer, kindly provided information on certain wells. Art Cook, Cedar Fort resident, made it possible for the writer to visit the springs above Cedar Fort.

The writer acknowledges the help of Thomas Markland and Harry B. Young in the completion of the field work in the valley.

The writer is greatly indebted to Sherry Shipp and Barry Haskell for critically reading the manuscript.

GEOGRAPHY

Topography and Drainage

Northern Cedar Valley is in the extreme eastern portion of the Basin and Range Province. The general physiography of the valley is typical of numerous other basins to the west which give the Basin and Range Province its name.

The basin is fringed by mountain ranges, the north-south-trending Oquirrh Mountains on the west, the east-west-trending Traverse Range on the north, and north-south-trending Lake Mountain on the east. The southern half of Cedar Valley extends south for 20 miles before encountering the Tintic Mountains which fringe the southern part of the valley.

Northern Cedar Valley consists mainly of a series of bajadas and pediment slopes. The lowest point in the valley is near the southern boundary of the mapped area in the southwest corner of section 11. This is also the lowest point for the southern portion of Cedar Valley. The alluvial fans in the valley vary a great deal in volume of sediment contained, in steepness of slope, and in lateral extent. The largest fan in the valley is the fan at the mouth of West Canyon (Pl. I). This fan covers approximately 20 square miles with a maximum slope of 2 to 3 degrees. This fan, and those with which it coalesces, cover 30 square miles and occupy the northern one-third of the valley. No other fan or series of fans in the valley approaches this size. The next largest fans in the valley are the Pole and Manning Canyon fans, each of which covers about 4 square miles. These large fans are all located along the west and north sides of the valley.

Along the east side of the valley at the base of Lake Mountain the fans are smaller. These fans rarely reach more than one mile into the valley and provide only a small portion of the total volume of sediments entering the valley.

The flat center portion of the valley covers about 30 square miles and is a remnant of the floor of Lake Bonneville.

At the present time there is only one permanent stream which flows into northern Cedar Valley. This stream originates at various places in the upper reaches of West Canyon in the form of numerous small bedrock springs, most of which flow from the contact of the Manning Canyon shale with the overlying Oquirrh formation. The writer observed 10 of these springs and none flowed more than 30 gallons per minute. These springs flow all year, but the quantity of water depreciates noticeably in the late summer. This indicates that they are mainly meltwater springs.

The water from these springs goes underground within a few hundred yards upon reaching the main stream channel in West Canyon. The water again comes to the surface in the stream channel 2 miles above the mouth of the canyon. At this point the stream flows about 100 to 120 gallons per minute and appears to maintain this flow down to the point where it is used for irrigation east of Cedar Fort. The water is diverted from the main stream channel at the mouth of West Canyon by a man-made ditch which carries the water to Cedar Fort.

The remainder of the drainage coming into the valley is intermittent and unpredictable. Water is available for these intermittent streams when mountain snows melt in the spring; and heavy, local rains fall in the summer. As a result of the rapidity with which this water moves and the large volume which is available over a short period of time, a stream is able to carry a large amount of debris. This is especially evident on the fans along the front of the Oquirrh Mountains. These fans are characteristically deep-trenched with the stream channel having the typical flat-bottomed, vertical-walled shape resulting from flash flood erosion.

The fan in front of West Canyon has been trenched to a depth of 30 feet near the mouth and there is evidence of an older, higher alluvial terrace which has since been trenched by the further downcutting of the stream.

The Wells and Manning Canyon fans have both been trenched to a depth of 20 feet by these fast eroding intermittent streams. The Pole Canyon fan, which is a steeper fan than the Wells, Manning, or West Canyon fans, has not undergone the deep trenching that the latter three have.

All of the fans along the east side of the valley have undergone only a moderate trenching. They have generally been trenched only to a depth of 3 to 6 feet. This is probably due to the lack of flashfloods in the Lake Mountain which is the fan's source of sediment and water.

As a result of the interior drainage of the valley, water which falls on the mountains and in the basin itself must eventually reach the low part of the valley. When the surface water reaches this low playa

area, it stays on the surface longer than it would on the porous alluvial fans. The bottom of the valley is surfaced with fine clays and silts which puddle the surface water, and in many places very swampy conditions exist for several hours or days after a rain.

Climate

Since 1944 climatological data have been collected in northern Cedar Valley from two places. From 1944 until 1950 the weather station was located at the old Fairfield Airport which was 3 miles east and 1 $\frac{1}{2}$ miles north of Cedar Fort. This station was maintained by the Civil Aeronautics Association. From 1950 to the present time the weather station has been located in the town of Fairfield, 5 miles south and 3 miles west of the old station. There is an elevation difference of 87 feet between the two stations, but this difference is not noticable in the weather figures.

United States Weather Bureau figures for the years 1944 through 1957 indicate an average yearly precipitation of 10.44 inches. The wettest months of the year are December and May with 1.26 and 1.24 inches of precipitation respectively. The driest month of the year is September which receives on the average 0.52 inches of rainfall (TABLE 1).

TABLE 1

AVERAGE MONTHLY PRECIPITATION IN INCHES FOR NORTHERN CEDAR VALLEY, UTAH FROM 1944 to 1957

Month	Inches
January	0.92
February	0.63
March	0.91
April	0.78
May	1.24
June	0.63
July	0.94
August	0.88
September	0.52
October	0.97
November	0.83
December	1.26

There are no precipitation figures available for the mountains surrounding the valley, but it is likely that the Oquirrh Mountains would receive 25 inches or more of precipitation per year. These mountains have snow on their higher peaks until early May and this would indicate a precipitation figure somewhat similar but lower than in the Wasatch Range 25 miles to the east. In the summer months the Oquirrh Mountains are a center of thunderstorm activity. Summer storms originate over these mountains and then move eastward across the valley and into the Lake Mountain east of the valley. The Lake Mountain itself probably receives around 15 inches of precipitation per year.

During the normal growing season which extends from June 1 to September 15 the evaporation greatly exceeds the precipitation. Hunt, et al., (1953, table 3) shows that during the 3 ½ month growing season the evaporation on Utah Lake near Lehi was 36 inches. Fifteen miles to the west in northern Cedar Valley this evaporation rate is nearly the same. During the period of high evaporation there are only 2 ½ inches of rainfall. This probably evaporates completely without reaching the water table. As a result the total precipitation per year which might reach the underground water supply is limited to somewhat less than 8 inches. These figures indicate that the precipitation which falls on northern Cedar Valley is of minor importance as a contributor to the underground reservoir of water.

The present climate of northern Cedar Valley can be considered to be temperate and semi-arid. Although in the past, especially during the Pleistocene epoch, it differed considerably from the present.

The hottest month is July with an average temperature of 70.9 degrees Fahrenheit. This contrasts with the coldest month, January, which has an average temperature of 22.6 degrees. The highest temperatures of the year usually occur in July and very rarely exceed 100 degrees. The highest temperature ever recorded in northern Cedar Valley was 104 degrees in 1944 and the average high temperature for the summer is 98.3 degrees. The coldest temperature ever recorded in the valley was minus 31 degrees in January 1949, and average low over the years is minus 17.5 degrees.

Road Network

For the purpose of doing field work in northern Cedar Valley the road system is excellent. Not only are roads numerous; but because of the relative flatness of the valley, and the lack of restricting fences and cultivated fields, it is possible to drive nearly anywhere. Many parts of

the valley are brush free and devoid of deep gullies so that it is possible to ignore the road system and drive across the terrain. Even the alluvial fans along the sides of the valley are criss-crossed with roads and car trails. The fans in most cases are free of brush, and if it were not for the intervening gullies it would be possible to drive completely across most of them.

The valley contains one hard-surfaced road, State Highway 73, which is an all-weather, all-purpose road that follows the northern and western sides of the valley. This road passes through both Cedar Fort and Fairfield and leaves the valley by way of Fivemile Pass on the west and north of Lake Mountain on the east. The other main road in the valley is the Lehi Road. This graded and graveled road extends northeasterly from Fairfield and passes out of the valley through the low hills at the north end of the Lake Mountain. State Highway 73 connects with the Lehi Road, 1 ½ miles west of the Jordan River.

Population and Agriculture

Nearly all of the inhabitants of northern Cedar Valley live in the unincorporated towns in the valley, Cedar Fort and Fairfield. Cedar Fort, in the northwest portion of the valley and directly at the base of the Oquirrh Mountains, is the largest town with a population of about 200. Fairfield is a dwindling community of 100 residents. The greater part of the population of these two towns depends upon agriculture and cattle ranching for a living.

The only other people in the valley live on two Church of Jesus Christ of Latter-day Saints farms. The Hillsdale Stake Farm is 1 mile southeast of Fairfield and has one family living on it. The second farm is operated by the Church Welfare Department and is located 4 miles southeast of Cedar Fort. This farm has two families living on it permanently.

In the north end of the valley and extending as far south as Cedar Fort the main crop is winter wheat. This wheat is grown by dry-farming the surface of the West Canyon alluvial fan. These wheat fields cover approximately 20 square miles. Directly to the east of Cedar Fort for a distance of 1 ½ miles, and to the north for 1 mile are numerous small fields of alfalfa. These fields are irrigated by the ditch which transports the water from West Canyon.

The Church farm located southeast of Cedar Fort has several fields of hay, beans, and corn. These crops are all irrigated by water obtained from six wells on the church property.

There are also small fields of hay and other crops to the northeast, east, and southeast of Fairfield. All of the crops near Fairfield are supported by the spring a quarter of a mile west of Fairfield. This spring has a flow of 4 to 5 second-feet, and is more than adequate for the purposes of the people in this area.

On the Church farm southeast of Cedar Fort there is at present an active program of well-drilling underway in an attempt to provide enough irrigation water to enable 6000 acres to be put under cultivation. Up to the present time considerable difficulty has been experienced in attempting to obtain this water.

Other than the large West Canyon fan area the majority of the land in northern Cedar Valley is at present suitable only for sheep and cattle grazing. If adequate water from wells could be obtained, the lower flat reaches of the valley could become irrigated crop lands.

STRATIGRAPHY

Source Rock in Surrounding Mountains

The source rocks surrounding northern Cedar Valley consist almost entirely of sedimentary rocks of Upper Paleozoic age. In a few small scattered outcrops in the Oquirrh and Traverse Mountains, Tertiary intrusive and extrusive igneous rocks occur. These are of small extent in comparison to the tremendous thickness of the Paleozoic formations, and contribute very little to the unconsolidated sediments in northern Cedar Valley.

In the higher portions of the Oquirrh Mountains, mainly along the higher stream channels, are found small remnants of glacial moraines. These are depositional remnants of the Pleistocene glacial age, but are of small areal extent and contribute very little to the sedimentary record of the valley. These glacial deposits do not occur below the 7500 foot level. Apparently the glaciers in the Oquirrh Mountains did not extend as far valleyward as did those in the Wasatch Range to the east.

Since the Paleozoic rocks make up almost the entire sediment source for northern Cedar Valley, and they have all been described in detail by various writers, it will not be necessary for this writer to describe them further. It will suffice to include two stratigraphic sections which summarize both the sediment source to the east and to the west of the valley. The section (Fig. 2) in the Oquirrh Mountains is taken from McFarland (1955, table 1), and the section in the Lake Mountain to the east of the valley is taken from Bullock (1951, p. 13).

Cedar Valley Deposits

The sediments in northern Cedar Valley can be divided into three groups. The youngest of these, and the deposit which surfaces most of the valley, is the post-Lake Bonneville alluvium, clay, and silt. Underlying these deposits are the sediments which were laid down in the Pleistocene Lake Bonneville group. Beneath the Lake Bonneville group are several hundred feet of pre-Lake Bonneville interbedded alluvial and lacustrine sediments. There is no indication of any Tertiary sediments either around the edge of the valley or in the deepest drilled wells.

FIGURE 2
STRATIGRAPHIC COLUMNS
OF THE WEST CANYON AREA AND LAKE MOUNTAIN

West Canyon Area
(after McFarland, 1955)

Age	Formation	Thickness in feet	Lithology
Quaternary	Alluvium and glacial moraine	variable	Gravel, sand, silt, and clay
Tertiary	Quartz monzonite		
Pennsylvanian	Oquirrh fm.	3840	Quartzites and interbedded limestone
Mississippian	Manning Canyon sh.	2495	Black carbonaceous shale
	Great Blue ls.	2486	Light blue limestone, massive, fossiliferous near the base
	Humbug fm.	940	Ls., and interbedded ss. and qtzites.
	Deseret ls.	55	Blue-gray cherty limestone

Lake Mountain
(after Bullock, 1951)

Quaternary	Alluvium and lacustrine deposits	variable	Gravel, sand, silt, and clay
Tertiary	Salt Lake fm.	400	Limestone, marl, and sands
Pennsylvanian	Oquirrh fm.	6334	Alternating ss., ls., and orthoquartzite. Prominent basal ls. member 1303 feet
	Manning Canyon sh.	1121-1419	Black variegated shale
Mississippian	Great Blue ls.	2590	Massive to thin-bedded ls., 91 feet of shale near base
	Humbug fm.	1034	Alternating ss., ls., and qtzt.
	Pine Canyon ls.	751	Limestone with banded chert
	Gardner dolo.	574	Sugary dolomites, foss. ls. at top
Devonian	Pinyon Peak ls.	331	Mottled and sugary dolomites

Pre-Lake Bonneville Deposits

Due to the lack of available information concerning the character and exact age of the sediments encountered in the deep wells in the valley, it is impossible to differentiate the pre-Lake Bonneville Quaternary sediments from the pre-Lake Bonneville Tertiary sediments. Hunt, et al., (1953, p. 13) mentions that a well drilled at Cutler in Utah Valley near the center of sec. 5, T. 5 S., R. 1 E. appears to have penetrated 470 feet of Tertiary Salt Lake formation. The total depth of the well is 690 feet. Hunt, et al.,(1953, p. 14) in his paper takes the precaution of including a question mark following all Tertiary designations especially in his geologic sections based on well logs.

In northern Cedar Valley the pre-Lake Bonneville deposits occur in two settings: those that are exposed on the oldest fans surrounding the valley, and those that are concealed by the overlying post-Lake Bonneville and Lake Bonneville sediments.

Exposed deposits

On the geologic map accompanying this report (Pl. I) these exposed deposits have been given the designation Quaternary older alluvium. Gilluly (1932, p. 40), Hunt, et al., (1953, p. 15), and others have referred to these older alluvial deposits as fanglomerates. To this writer the term fanglomerate implies a cemented alluvial fan deposit, but during the course of this investigation this writer could find very little cemented alluvial fan deposits on any of these older alluvial areas. For this reason the designation older alluvium seems to be more acceptable for this material.

In general these older alluvial areas are all alike in being composed of poorly sorted materials, with both angular and subrounded boulders, cobbles, and pebbles included in a matrix of sand and silt. The degree of rounding on the individual particles is largely a function of the distance from the source area.

The pre-Lake Bonneville fans which make up most of this older alluvial material have lost their complete fan shape as a result of the Lake Bonneville shoreline terraces being cut into their lower portions. This is especially obvious on the east side of the valley where the wave action was most vigorous. North of Wiley Canyon the upper half of the old fans retain their convex downward shape in section and their typical fan shape in plan, but suddenly they lose these typical shapes where they have been cut by Lake Bonneville. From this point valleyward until they are overlapped by the post-Lake Bonneville deposits, the fans are cut by a series of shoreline terraces. This portion of the old fan still has some convex downward shape, but has lost the fan form entirely. This loss of the fan form in the lower reaches of the fan is the result of post-Lake Bonneville deposition. The post-Lake Bonneville drainage followed the low area where the old fans coalesced. Instead of the new alluvial material spreading out as it left the mountains as did the old fans, this new alluvium began to build new fans which started at the upper Lake Bonneville shoreline. By doing this the new alluvial fan tended to overlap the lower portions of the old fans, and the old fans now have a diamond shape with one point of the diamond being at the mouth of a canyon and the opposite point being toward the valley.

On the west and north sides of the valley any evidence of Lake Bonneville shoreline terraces on these huge fans has been destroyed. These shorelines which were probably only faintly impressed on the fans due to a lack of wave action on the north and west sides of the valley, were completely obliterated by the active growth of the fans following the Bonneville stage.

During the Provo stage these fans were acquiring a large volume of sediment because of the numerous streams depositing their sediment load upon the fans. The thickness of sediments which accumulated in Utah Valley during the Provo stage indicates that there was a generous supply of water to bring this sediment into the lake. The size of the deltas which were built at this time also indicates a constant supply of water over a fairly long period of time. Even though northern Cedar Valley is higher than the Provo level, there were no doubt tremendous quantities of water and sediments coming into the valley, especially in those areas adjacent to the Oquirrh Mountains. These sediments would actively increase the size of the fans in these areas and would wipe out any evidence of former shorelines.

The old fans in different portions of the valley are made up of various sediment types depending on the sediment source which is available to the fan. The Manning, Pole, and West Canyon fans are made up of limestone and quartzite detritus from the Oquirrh formation. The Manning Canyon fan appears to have more limestone than do the Pole and West Canyon fans. These limestones can be observed in a small gravel pit on the north side of Manning Canyon near its mouth with the gravel made up almost entirely of flat black limestone.

According to Hunt, et al., (1953, p. 11):

> "The total amount of valley sediment derived from any individual source is roughly proportional to the thickness of the formation."

On the east side of the valley, from Wiley Canyon north, the fans are composed of about 70 per cent quartzite, orthoquartzite, and sandstone; and about 30 per cent limestone. Individual fans vary somewhat from these rough percentages depending on the material that the individual stream passes through. From Wiley Canyon south the above percentages are nearly reversed, with 70 to 80 per cent limestone and 20 to 30 per cent orthoquartzite.

Concealed deposits

Deep wells (Pls. II, III, IV, V) drilled in northern Cedar Valley indicate that there are at least 1150 feet of pre-Lake Bonneville Tertiary (?) and Quaternary sediments present. All of the wells on the valley floor contain 70 per cent or more silts and clays. These silts and clays suggest that there were several ancient lakes which occupied the valley prior to Lake Bonneville. Between these old lake deposits there are varying thicknesses of gravel which seem to indicate periods of fluvial deposition between lake cycles. These ancient lakes probably coincided with the advances and retreats of the glaciers during the pre-Wisconsin Pleistocene time. Because of the poor quality of most of the well logs in the valley it is impossible to correlate or distinguish between these various units. Most of the fluvial sediments in the valley, both concealed and exposed, seem to be of such a lenticular nature that it makes it extremely difficult to attempt to correlate.

Lake Bonneville Group

Sedimentary conditions

The conditions of sedimentation which prevailed in northern Cedar Valley during the span of Lake Bonneville are considerably different than the conditions which prevailed in larger valleys such as Utah and Salt Lake.

Northern Cedar Valley, only 8 miles wide and bounded on the west and north by high mountains, was in Lake Bonneville time nothing more than a small embayment with a relatively shallow body of water in it. At no time during the entire span of Lake Bonneville did the shallow embayment in northern Cedar Valley exceed 300 feet in depth. This depth was only achieved for a very brief period during the Bonneville stage, and probably represents nothing more than a rapid rising and falling of the lake. According to Hunt, et al., (1953, p. 20) this stage is represented by not more than 15 feet of gravel in northern Utah Valley.

Because of the limiting size of the valley, the shallowness of the lake, and the high mountain range to the west which effectively blocked the prevailing westerly wind, the wave and current action in the embayment were minor compared to those in the Utah and Salt Lake Valleys. Because of the lack of this wave and current action the sorting of sediments is generally poor. In Utah and Salt Lake Valleys the large sediment-carrying streams descended from the snow-and-glacier covered Wasatch Mountains and deposited their loads into Lake Bonneville on the east side of the lake along which the wave and current action was the greatest. In these valleys there was a large sediment load entering constantly, and the sorting and working of the deposits were rapid and complete.

In northern Cedar Valley the opposite condition seemed to hold true. There were no large rivers as in the larger valleys; the main sediment source was from the Oquirrh Mountains to the west, and this material was being dumped into the calm protected side of the embayment. The sorting along this protected side of the valley was poor or non-existent. No large deltas were built up with a wave-cut top. Instead, the deposits entering the valley fanned out in the lake much as they would on an alluvial fan. Along the east side of the valley where the waves were the strongest, the sediment supply was so slight from the streams which drain the relatively small area of the Lake Mountain that the deposits along this side were very thin.

Along the front of the Wasatch Range the streams entering Lake Bonneville were emerging from deeply-cut, narrow gorges, directly into the lake, and were probably flowing at a rate of 1000 second-feet or more. This amount of water flowing down a fairly steep gradient can carry a tremendous volume of sediment in traction and larger-than-normal particles in suspension.

In northern Cedar Valley, however, the three major streams coming from the west side of the valley had to traverse large alluvial fan areas before reaching the lake. For example, the West Canyon stream had to traverse at least 2 miles of gently sloping alluvial fan before reaching the lake during the Bonneville stage. During the low water stages of Lake Bonneville this stream had to traverse at least 4 miles of fan before reaching the lake. Without a doubt these streams which were considerably smaller than those in the Wasatch Range lost much of their load, especially the larger particles, long before reaching the lake. It is little wonder then that almost all of the Lake Bonneville sediments in the valley are clays and silts.

History

Lake Bonneville was the last of several great lakes during the Pleistocene glacial ages, and marks the last advance of the glaciers in the northern hemisphere.

The earliest stage of Lake Bonneville was characterized by vast deposits of fine-grained sediments (Alpine formation) being laid down in the lake. In the larger valleys occupied by the lake these fine-grained sediments are still quite extensive, but in northern Cedar Valley they are completely absent except for those which are penetrated by wells in the center of the valley.

Gilbert (1890, pp. 141-146, 260) indicated that there is evidence to show that during the deposition of the Alpine formation the water level in the lake may have fluctuated and the stage may have been followed by a period of erosion. It is known that during the Alpine stage the high water level of the lake was somewhere between 4830 and 5135 feet. If it is assumed that the water level did fluctuate during the Alpine stage, then any time the water level dropped below 4830 feet this would expose all of the unconsolidated sediments in northern Cedar Valley to erosional processes. While the sediments were being stripped away, the sediments in such valleys as Utah and Salt Lake would continue to be deposited in bodies of water up to 700 feet deep. In Utah Valley, by far the greatest amount of Alpine sediments are found below the 4830 foot level.

As the water level fell at the end of the Alpine stage and before it rose to its highest level in the Bonneville stage, there would be another long interval in which the Alpine sediments in northern Cedar Valley would be exposed to erosion while the sediments in the deeper valleys were still under water.

Following the period of dessication at the end of the Alpine deposition the lake rose rapidly to its highest level during the Bonneville stage. This stage was apparently very short lived, because no appreciable sedimentary record can be found. In most areas a thin, discontinuous smattering of littoral gravels are found. Northern Cedar Valley has only two definite exposures of Bonneville gravel, the thickest of which is only 15 feet.

The Bonneville stage, short-lived as it may have been, did leave its mark. It left impressed on the alluvial fans and bedrock slopes on the sides of the valley excellent wave-cut shorelines. Along the east side of most of the valleys which Lake Bonneville occupied, this shoreline is still impressed. As the lake reached its highest level during the

Bonneville stage it overflowed into the Snake River by way of Red Rock Pass (Gilbert, 1890, pp. 173-175), and the lake fell rapidly to the level which it maintained during the Provo stage.

During the time of the Provo stage the final melting of the mountain glaciers in the Oquirrh, the Wasatch, and other mountain ranges surrounding Lake Bonneville was taking place. This melting was providing a vast supply of water and sediment, but because of the outlet which had been developed at Red Rock Pass the lake level did not rise appreciably. During this stage great deltaic deposits were being shed into the lake along the Wasatch front at the mouths of all major streams.

Northern Cedar Valley, whose lowest point was approximately 1 foot higher than the level of Lake Bonneville during the Provo stage was thus effectively eliminated from any connection with the main body of the lake in Utah Valley. Undoubtedly there was some sort of a lake in the lower portion of northern Cedar Valley, but it was probably no more than 50 feet deep at the greatest. As a result of the melting snows and glaciers in the mountains bordering the valley, the ample supply of water would allow rapid erosion of any exposed older lake sediments. This final period of erosion could well be the concluding factor in the removal of nearly all Alpine deposits from the sides of the valley. The abundance of water entering the valley would carry with it a tremendous amount of sediment, eliminating or burying most of the wave features impressed on the fans during the Bonneville stage. Because of the type of drainage that a melting glacier creates, it is probable that the gently sloping West Canyon fan carried on its surface a series of bifurcating drainage channels that deposited material rapidly as the glacial stream emerged from the confines of the canyon. It is conceivable that most of the pre-Lake Bonneville alluvial fan deposits could have been completely buried by this new deluge of sediment.

As the climate warmed and the glaciers disappeared the lake fell rapidly. As the climate became more semi-arid after the Provo stage, the streams flowing into the valley finally became intermittent and began to cut down into the fan surface across which they flowed. This is the condition that the streams are now in. They are cutting steep-sided, flat-bottomed channels with intermittent fluviatile sedimentation and erosion in the valley.

Alpine formation

The oldest formation in the Lake Bonneville group is the Alpine formation. Hunt, et al., (1953, p. 17) introduced the name Alpine. Prior to this time the name Intermediate had been used to refer to the lake stage in which these sediments were deposited. The name Intermediate, proposed by Gilbert (1890, pp. 135-154), was confusing because it applied to the height of the lake stage instead of to the age of the sediments laid down in that stage. Alpine as now used refers to those deposits now exposed at levels intermediate in altitude between the Provo and Bonneville levels.

The Alpine formation as defined by Hunt, et al., (1953, p. 17) contains:

> "a high proportion of fine-textured sediment, mostly silt. Sorting is excellent; the bedding is very distinct and in the fine-grained sediments individual beds commonly are only a fraction of an inch in thickness. The upper part of the formation is light gray but it is horizontally striped by thin beds that are rusty colored; the lower part of the formation is somber gray."

Gravel member----There are only two exposures of Alpine gravel in northern Cedar Valley. They are on opposite sides of the valley and both occur at the mouths of canyons. The exposure on the east side of the valley is in the form of two lake terraces which extend up the canyon on both sides for a distance of approximately 1700 feet. The canyon is just north of Webb Cedars (Pl. I) and is located in the southeast corner of sec. 31, T. 5S., R. 1 W. The gravel here is derived from the Oquirrh formation and is composed of approximately 70 per cent quartzite, and 30 per cent limestone. The gravel is fairly well-sorted near the mouth of the canyon but becomes poorly sorted up the canyon with the proportion of sand and silt increasing. There is no evidence of bedding or any sort of cementation. At the mouth of the canyon in the well-sorted material the largest particles are 6 inches in diameter with the average diameter being 3 inches. Also, the average particle size decreases up the canyon. All of the particles are subangular to subrounded with the subrounded the more abundant. The gravel has a total thickness of nearly 100 feet with the upper 10 feet considered to be Bonneville gravel. The gravel terrace on the south side of the canyon is the most extensive, as it is nearly 300 feet wide just inside the mouth of the canyon. The terrace on the north side is nearly this wide at the mouth but narrows rapidly up-canyon. As the gravel terraces emerge from the canyon and extend along the sides of the mountains to the north and south, they pinch out and become terraces cut directly into the bedrock.

On the west side of the valley the gravel exposure is on the north side of Clay Canyon in a small pocket backed by bedrock. This exposure is in the form of a small gravel pit containing nearly all limestone material. It is in the northeast corner of sec. 25, T. 6 S., R. 3 W. In this gravel pit there are about 10 feet of flat limestone particles with some bedding. The average size is about 2 to 4 inches with nothing larger than 6 inches, and the sorting is good. Directly below the gravel are 7 feet of well-bedded alternating gravel, sand, grit, and silt. Some of the sand beds show cross-bedding and numerous gastropod shells. All of the gravel material is subrounded with the particles decreasing in size in the lower 7 feet of the section.

Silt and clay member----Only one exposure of the silt and clay member of the Alpine formation was found in northern Cedar Valley. This one exposure was in a man-made sump 1300 feet north of the south-east corner of sec. 13, T. 6 S., R. 2 W. The sump was dug at the time well 10 was drilled at this site in 1953, and is about 10 feet deep. Of this 10 feet, probably the lower $7\frac{1}{2}$ feet is composed of Alpine silt and clay. The upper $2\frac{1}{2}$ feet are considered to be post-Lake Bonneville silt.

This Alpine clay and silt exposure consists of horizontal alternating red, tan, and gray beds of sandy silt, silt, and clay with the entire sequence being thinly bedded. The thinnest bed at this locality was 2 inches thick. Gastropod and Ostracod shells were found throughout the exposure, especially in the laminae of sandy silt. Iron staining of the laminated sediments is common. No other surface occurrences of the silt and clay member of the Alpine formation were found. However, in most of the well logs in the valley the Alpine silt and clay beds appear to be 50 to 90 feet thick.

Bonneville formation

Hunt, et al., (1953, p. 20) states:

> "The Bonneville formation includes those deposits that accumulated in the lake during its highest stage, the stage that Gilbert (1890, pp. 93-125) referred to as the Bonneville stage."

During the Bonneville stage the lake apparently rose very rapidly to a maximum height of around 5135 feet in northern Cedar Valley. It

remained at this elevation for a brief period, just long enough to etch a well-defined shoreline in the bedrock and the pre-Lake Bonneville fans. At this high level mark a few thin discontinuous gravels were deposited before the lake ebbed. As it receded, the lake cut a series of shorelines in the old fans below the high level mark. This series of shorelines can now be observed on the lower parts of the old fans which have not been covered or trenched by the post-Lake Bonneville alluvial material.

There are only two well-exposed occurrences of Bonneville gravel in northern Cedar Valley. Both of these exposures occur along the upper-most lake level at an elevation of 5135 feet along the eastern side of the valley. One deposit is in the mouth of the first large canyon south of Wiley Canyon along the front of the Cedar Valley Hills. This gravel is in the south central part of sec. 29, T. 6 S., R. 1 W. and is the thickest of the two deposits.

At this locality the gravel is a well-sorted, subrounded, open gravel somewhat cemented with most of the particles less than 7 inches in size. The gravel shows some bedding, with the beds lowest in the section having the largest percentage of "fines" and the poorest sorting. The bedding dips slightly valleyward; this gives the gravels the appearance of being deposited on the front slope of the terrace. Up-canyon the gravel grades into very poorly sorted gravel with high percentages of sand and silt.

To the south along the mountain front the terrace narrows and pinches out in 200 feet into a bedrock terrace. The gravel at this exposure is about 15 feet thick and is largely made up of limestone material.

One half mile south of where the Lehi Road leaves northern Cedar Valley the second Bonneville gravel exposure can be seen. This exposure lies on the south side of a small bowl-shaped depression, which opens to the west. The gravel here is subrounded and well-cemented. The average size is smaller than the Bonneville deposit farther south, around $1\frac{1}{2}$ inches with only fair sorting.

The source of these gravels is the low hills which surround the depression. The highest peaks of these hills were barely above water during the highest lake level and would have projected above the water as small islands. In between these small islands was the depression which collected most of the gravel that was shed off these islands as the waves battered their shores. As the gravels entered this depression they were sorted and bedded to some degree and came to rest along the south and east sides of the depression, where they are now exposed in the small stream which has cut into them. At this locality the gravels are derived from the Oquirrh formation and consist of nearly equal amounts of limestone and quartzite.

Post-Lake Bonneville Deposits

Because northern Cedar Valley was not a part of Lake Bonneville during the Provo stage, the sedimentary record is different than in the valleys which were occupied by Lake Bonneville at this time. In northern Cedar Valley four lithologies have been recognized as belonging to the post-Lake Bonneville deposits.

Recent fan number one

These fan deposits occur as interfluves between the present stream patterns. The alluvial gravels in these interfluves exhibit nearly all of the characteristics of normal alluvial gravels; angular particles poorly sorted, lenticular or indistinct bedding, and little or no cementing. These interfluve deposits differ from the normal alluvial fan deposits in that they contain a higher proportion of fine sands, silts, and clays than do the most recent fan deposits. This feature is a result of the reworking and redepositing of the fine Bonneville sediments along with the normal alluvial material brought down from the mountains.

Since Lake Bonneville during the Provo stage is considered to have been very shallow or absent from northern Cedar Valley, it can be seen that a portion of the alluvial fan material included in the designation, Recent fan number one, would include material deposited subaerially on the fans around the valley during the time of the Provo stage. This material deposited during the time of the Provo stage as alluvium can not be separated from the Recent material deposited on top of it prior to the development of the present stream patterns.

Recent fan number one will then contain the following materials: (1) Provo stage alluvial deposits; (2) Reworked Lake Bonneville deposits, mainly fines; (3) Recent alluvial deposits laid down prior to the development of the present stream patterns.

The thickness of these deposits is somewhat of a mute question. Because of the similarity of these deposits to the underlying pre-Lake Bonneville alluvium, and because of the lack of good exposures, it is only safe to say that the Recent fan number one deposits are at least 20 feet thick and probably considerably more. The Manning Canyon fan has been dissected to a depth of about 20 feet, with the entire exposure appearing to consist of Recent fan number one material.

Recent clays and silts

The silts and clays deposited since the Bonneville stage are overlapped by the edges of the alluvial fans extending into the valley, and cover the entire floor of the valley. This fine material is gray, contains almost no coarse material, and thickens toward the center of the valley. In sec. 13, T. 6 S., R. 2 W., at the sump where the only bedded Alpine lake beds are visible, these Recent clays and silts appear to be $2\frac{1}{2}$ feet thick. This location is nearly 65 feet above the lowest point in the valley and is not indicative of the true thickness of this deposit lower in the valley. It is impossible to distinguish from well logs the difference between this deposit and the underlying Alpine clays and silts.

These Recent clays and silts were undoubtedly laid down in part during the Provo stage of Lake Bonneville when the lake in northern Cedar Valley was extremely shallow. It is impossible to differentiate these Provo stage deposits from the more recent clay and silt deposits.

These Recent clays and silts are partly reworked Alpine clays brought in from the higher parts of the valley, and partly new material brought in from the mountains. The bedding of this material at the sump is fair to poor, and the bedded character of the deposit is partly destroyed by root systems and worm burrows. This clay is partly lacustrine and partly fluvial.

Recent fan number two

Recent fan number two refers to those deposits at the terminus of the present streams which are currently in the process of active alluvial fan development. These are the areas in which the present day streams begin to spread their debris laterally over Recent fan number one; hence the formation of small new fans.

Lithologically these deposits consist of completely unconsolidated fluvial material. The individual particles range in size from boulders to clay, the sorting is extremely poor, no bedding of any sort is evident, and the particles range from round to angular. The amount of fine material is considerably less than in the Recent fan number one deposit, which this deposit immediately overlies. The thickness is variable, measuring from a very thin covering, to 5 or 6 feet.

On the west side of the valley these deposits are found entirely along the toe areas of the older alluvial fans; while on the east side of the valley some of the Recent fan number two deposits are found directly along the face of the mountains, and well up on the Recent fan number one deposits. This feature results from the difference in carrying power of the streams on opposite sides of the valley. The streams emerging from the canyons in the Lake Mountain are small and can not carry their sediment load far from the mountain front. On the west side of the valley however, the streams have a larger supply of water and can carry a large volume of sediment a great distance. These streams on the west side of the valley have cut deep channels into the surfaces of the fans and have thus created narrow canyons across the gently sloping surface of the fans, enabling the streams to retain their velocity and carrying power to the outer limits of the old fans.

Recent gravel

These gravels occur in the present stream channels which transverse the fans along the sides of the valley. This gravel does not include the actively building fan areas, but is restricted to the narrow and incised channels of drainage which lead to these presently growing fans. On the Manning Canyon fan these narrow drainage channels completely transverse the fan and extend valleyward past the toe of the fan and onto the flat valley floor. The streams coming off of this fan do not spread out to form a Recent alluvial fan, but deposit their material in these narrow stream courses.

The Recent gravels high up on the old fans are extremely angular and coarse, with very few fines being mixed within the deposits. As the stream channels are followed valleyward the angularity of these particles decreases and the mixing of the coarse material with fines increases. The size of the individual particles decreases valleyward also, with boulders predominating near the mouths of the canyons; and pebbles and cobbles, mixed with sand and silt, being predominant where the gravels begin to spread out on the most recent fan surface.

These deposits vary in thickness from a few inches to 4 or 5 feet, the thickest deposits being near the mouths of the canyons and largely consisting of boulders and cobbles. These thickest deposits are apparently brought down from the mountains during times of storms and deposited rapidly near the mouth of the canyon where the water loses some of its velocity.

The type of rock detritus found in the individual stream channel depends entirely on the area of the mountains from which the stream has originated. Certain stream channels along the east side of the valley contain nearly 100 per cent limestone, while a stream channel a few hundred yards away would contain nearly all quartzite debris.

GEOLOGIC HISTORY

In most aspects the pre-Lake Bonneville geologic history of northern Cedar Valley is similar to other nearby areas in the Basin and Range Province. The history of the Precambrian eras must be inferred from other areas because of the deep burial of these rocks at this locality. In the Wasatch Range granitic rocks, metaquartzites, schists, and gneisses may be seen. These have been ascribed as of early Precambrian age by Stokes and Heylmun (1958, pp. 4-5). Unconformably overlying the former sequence in the Wasatch Range are 10,000 feet of quartzite, argillite, phyllite, and tillite. Many of these units are thought to correspond in time to the Belt series in Montana, or the Grand Canyon series of Arizona, and to have been deposited in a broad, shallow epicontinental sea.

At the dawn of the Cambrian this epicontinental sea transgressed eastward, and throughout the Paleozoic the site under investigation was a part of a huge subsiding trough known as the Millard miogeosyncline. Into this vast sea more than 60,000 feet of Paleozoic sediment accumulated. The stratigraphic sections (Fig. 2) may be used to compare the presently exposed Paleozoic rock units on each side of northern Cedar Valley.

After the deposition of basal Triassic red sediments and the inundation of the area by marine waters from the west during early Triassic time, the area was uplifted to become part of the Mesocordilleran Geanticline. This early Mesozoic positive barrier served as a source for the late Triassic and early Jurassic continental deposits of the Glen Canyon group. Middle and late Jurassic time was characterized by several episodes of marine and nonmarine conditions. These same conditions persisted during most of the Cretaceous Period. Toward the end of the Cretaceous Period the area under discussion was uplifted and marine conditions ceased.

After a gradual buildup in intensity the Laramide Revolution culminated its orogenic activity in late Cretaceous and early Tertiary time. Eardley (1951, pp. 284-290) and Bullock (1951, pp. 23-29) believe that in the vicinity of this particular study the major effects of Laramide activity occurred during late Cretaceous time. From circumstantial evidence Bullock (1951, pp. 23-29) deduced that the folds, most of the faults, and joints in the area under discussion were of this age.

Structural unrest, vulcanism, and regional uplift of the northern Cedar Valley area took place during the Oligocene, Miocene, and Pliocene epochs. According to Stokes and Heylmun (1958, p. 31) normal faulting and much volcanic activity occurred during and after the Oligocene. The prevailing direction of Tertiary folding and faulting was northerly, though there is also evidence of rejuvenation of older northwesterly and northeasterly trends.

During much of middle and late Tertiary time the interior basins created by Tertiary faulting were partially or completely filled with sedimentary cover. Well logs do not substantiate the presence of this Tertiary sequence in northern Cedar Valley. It is probable, however, that northern Cedar Valley was experiencing subaerial sedimentation at various times during middle and late Tertiary time.

During the early Pleistocene the climate of this area gradually cooled with the onset of continental and mountain glaciation. Well logs indicate several sequences of lacustrine sediments. These beds are tentatively correlated with pre-Lake Bonneville Pleistocene glacial lake stages.

STRUCTURE OF NORTHERN CEDAR VALLEY

Cedar Valley is a structurally controlled intermontane valley. Several large folds of Laramide origin plunge southeasterly into Cedar Valley from the Oquirrh Mountains. One example of this is Pole Canyon; the axis of the Pole Canyon syncline follows the canyon and plunges beneath the alluvium of the valley. Long Ridge, south of West Canyon, is an anticline and also plunges under the alluvium of Cedar Valley.

The writer observed no physical evidence of normal faulting along the margins of the valley. In a personal communication with Dr. Kenneth L. Cook, Chairman of the Department of Geophysics at the University of Utah, regarding geophysical studies that were conducted in northern Cedar Valley, it was learned by the writer that no evidence of normal faulting was detected during the course of the geophysical studies of the valley. Bullock (1951, p. 29) mentions a normal fault with a throw of 500 feet and a heave of 1500 feet in the bedrock on the west side of Lake Mountain. In the Oquirrh Mountains to the west of the valley Bissell and Rigby (1959, pl. I) show no faulting of any kind in the area covered by this report.

From the studies of this writer, Dr. Cook, Dr. Bissell, and Dr. Bullock, it is apparent that the valley is not controlled to any large measure by normal faulting, and with the exception of the normal fault found on the west side of Lake Mountain there is no evidence whatsoever of any major normal faulting in or around the mapped area. At best it could be said that the valley is possibly a half-graben, controlled in part by the normal fault on the west side of Lake Mountain.

Proctor (1959, p. 207, pl. III) cites both structural and stratigraphic evidence to indicate a right lateral strike-slip fault through the Fivemile Pass area (Pl. I). He concludes that this fault is of major magnitude and trends northeast across northern Cedar Valley. The effect of this fault (if any) on the movement of ground water in the valley is beyond the scope of this paper.

During the course of the University of Utah geophysical studies of the valley no estimations of the depth of the valley fill were undertaken. From wells drilled in the valley we can, however, get some indication of the fill depth. Well 10, located $1\frac{1}{2}$ miles west of the bedrock outcrop on the east side of northern Cedar Valley, encountered bedrock at a depth of 1070 feet. Well 14, which is $1\frac{1}{2}$ miles west of well 10, was drilled to a total depth of 1258 feet and did not reach bedrock.

WATER RESOURCES

Introduction

Throughout the Basin and Range Province the abundance and accessibility of water resources have been and will continue to be the most important factors in the development of an area.

The first Mormon pioneers settled in northern Cedar Valley shortly after 1849, and until 1951 the surface water supplies were adequate to support a few hundred people in the valley, and their crops. Since 1951 with the attempted development of new agriculture areas, the surface water supplies are not adequate.

In northern Cedar Valley there are approximately 23,000 acres of flat land which could be brought under cultivation if an adequate supply of irrigation water could be found. Until 1951 the large majority of the deep wells in the valley had been drilled in or around Fairfield. The rest of the valley contained a few scattered shallow wells for stock watering. At the present time there are no wells located in a position to adequately test the ground water potential of the valley, and most of the existing wells have been drilled in improbable places for obtaining a good ground-water supply.

Wells

History of wells

Since 1884 records show (Table 2) that 42 drilled and 9 dug wells have been put down in northern Cedar Valley. Of this total of 51 wells, 26 are still producing various quantities of water and are being used for domestic or agriculture purposes. Considering those wells drilled or dug before 1935, the records show that 13 out of the original 23 are still producing. All but one of these wells are in Fairfield, and they are all flowing wells. Of those wells completed since 1935, only 13 of the original 28 are still being used. It is interesting to note that all of the wells completed since 1935 have been pump wells, and that 25 of these have been drilled since 1950. This indicates a marked increase of interest in the ground water possibilities of the valley since the mid-century mark.

TABLE 2

WELL NUMBER, STATUS, DEPTH, AND METHOD OF WATER LIFT IN ALL WELLS IN NORTHERN CEDAR VALLEY

Thesis well number	Depth of well in feet	Pump or flow	Status of well
1	90	P	Abnd
2	464	P	Abnd
3	280	P	Abnd
4	265	P	In use
5	?	P	Abnd
6	250	P	Abnd
7	223	P	In use
8	283	P	Abnd
9	88	P	Abnd
10	1113	P	Abnd
11	1250	P	In use
12	1007	P	In use
13	1014	P	Abnd
14	1258	P	Abnd
15	890	P	In use
16	835	P	In use
17	457	P	In use
18	955	P	In use
19	505	P	In use
20	49	P	Abnd
21	300	P	Abnd
22	135	P	Abnd
23	?	P	In use
24	80	P	Abnd
25	80	P	Abnd
26	80	P	Abnd
27	80	P	Abnd
28	275	F	Abnd
29	(?)20	P	In use
30	(?)20	P	In use
31	180	F	In use
32	300	F	In use
33	189	F	In use
34	100	F	In use
35	235	F	Abnd
36	150	F	In use
37	502	F	In use

TABLE 2 continued

Thesis well number	Depth of well in feet	Pump or flow	Status of well
38	180	F	In use
39	450	F	In use
40	660	F	In use
41	824	F	In use
42	365	P	Abnd
43	365	P	Abnd
44	335	F	In use
45	525	F	In use
46	726	?	Abnd
47	(?)20	P	In use
48	(?)20	P	In use
49	?	P	Abnd
50	275	P	Abnd
51	?	P	In use

The majority of the deep wells drilled in the valley prior to 1935 were small diameter holes, generally less than 6 inches, and as a rule these small holes do not give a true picture of the formations penetrated. This element of error in the older logs makes their use for correlation extremely difficult. The largest hole drilled in this period before 1935 was 8 inches in diameter (Pl. I, well 2) from which an excellent log was obtained. Since 1935, of the 28 wells drilled, only two have been less than 6 inches in diameter, and nine have been 16 inches.

Discharge from wells

Flow wells----At the time of this study there were 12 flowing wells in northern Cedar Valley, all in the town of Fairfield. These wells, which are used mainly for domestic purposes and in some instances for stock watering, are small wells with a maximum flow of about 60 gallons per minute. The largest wells in this group are 33 and 34 in sec. 29, T 6 S., R. 2 W. and are 189 and 100 feet deep respectively. These wells have a combined flow of 50 or 60 gallons per minute. The pipes leading from these wells are connected together underground, so it was impossible to measure them individually.

The rest of the flowing wells in this area all maintain a constant flow of water considerably below the maximum flow mentioned above. All 12 of these flow wells together do not total more than 150 gallons per minute.

It was impossible to determine from the available well logs of these flow wells the depth to any single confined aquifer. According to the logs available, a well drilled to a depth of 160 feet flowed as freely as a well drilled to a depth of 824 feet. The rest of the flowing wells bottomed somewhere between 160 and 824 feet, which would indicate that there are several confined aquifers of unknown thickness and extent capable of producing flowing wells.

All of the flowing wells were completely free of any visible sand or silt particles. Since these wells have been flowing steadily for 47 years it is likely that all of the fine silt and sand material which was in the aquifer near the well has long since been transported out leaving only the coarse material in the immediate vicinity of the well bore.

Pump wells----During the time that this report was being compiled there were only seven wells in the valley which were being pumped. All of these are in sections 14, 15, and 16, T. 6 S., R. 2 W. Of these seven wells, five were being pumped constantly and two intermittently. Wells 15 and 19 were pumping only part of the time.

Since permission could not be obtained to perform controlled pump tests on the wells, the writer measured the gallons per minute then being pumped, at an unknown pump rate. The flow of the water was observed to determine if the well was pumping sand or silt, and the water level during pumping was recorded and compared with the normal static level to determine the drawdown.

Well 12 was pumping 552 gallons per minute with a drawdown of 171 feet which apparently remained constant. Only a very small amount of silt could be observed in the water. This was by far the cleanest pump well and also the most productive pump or flow well in the valley. Total depth was 1007 feet.

Well 11 was pumping 461 gallons per minute with a drawdown of 155 feet which apparently remained constant. The well was pumping a large quantity of silt and fine sand. This well had recently been worked on, and it was found that silt and sand had filled the 1250 foot well up to within 350 feet of the surface.

Well 18 was pumping 177 gallons per minute with a drawdown of 154 feet which remained constant. The well was dirty enough to give the water a brown color and make it opaque. Total depth was 455 feet.

Well 17 was pumping 135 gallons per minute with a drawdown of 169 feet which remained constant. This well was very dirty; it had recently been deepened from 460 to 955 feet with no increase in water.

Well 15 had been recently deepened from 500 to 890 feet, but with no increase in water. Since the deepening operation this well could not be pumped for more than 6 hours without its sucking air. This indicated that the well had a drawdown of greater than 200 feet in 6 hours. The well pumped so much air with the water that it was impossible to determine an accurate flow figure in gallons per minute. The well appeared to be pumping several second-feet when the pump was initially turned on, but at the end of a 6 hour pump period it was pumping only a small fraction of its original volume. The well did not appear to be extremely dirty, probably because of the several inches of gravelpack that were placed around the well during completion operations.

Well 19 was pumped once every ten days and pumped air in 50 minutes after the pump was started. When the well was first turned on it pumped 232 gallons per minute and in 50 minutes had slowed to 154 gallons per minute when it began to suck air. The water was very dirty initially, but began to clear up near the end of the 50 minute test.

Because of the lack of water encountered in the above mentioned wells, it was necessary to perforate the casing in these wells from about 100 feet below the surface to the total depth. By doing this it was felt that the entire length of the hole could be used as a producing zone. But this practice also allowed large amounts of the silt and fine sand to enter the wells and slowly fill them up, and this kept the water coming from the well constantly dirty. If too much of the sand and silt was pulled from directly around the casing and nothing came in to fill it up, a cavity was formed, until finally the surrounding material collapsed, crushed the casing, and ruined the well. This has happened in wells 13 and 14, sec. 14, T. 6 S., R. 2 W.; when the wells, 1014 and 1258 feet deep respectively, were produced too fast and the wells collapsed before proper completion methods could be employed.

The remainder of the pump wells in the valley are only used during part of the year for the watering of sheep and cattle, and produce a much smaller quantity of water than those mentioned above.

Depth to water

All of the wells in northern Cedar Valley that were drilled through the Lake Bonneville Alpine sediments are under some degree of hydrostatic pressure and water will rise in the well bore when encountered. In the area around Fairfield all of the wells which are deeper than 100 feet encounter water under hydrostatic pressure and flow to the surface.

Northeast of Fairfield in sections 14, 15, and 16, T. 6 S., R. 2 W., there are 10 wells deeper than 455 feet. In all of these wells water occurred in several small zones below the overlying Alpine formation, the deepest zone being at 950 feet in well 11 (Pl. III). Each of these thin aquifers adds to the total hydrostatic pressure, and the water level in the well slowly rises as the well is drilled and successive water zones are tapped. Due to the lenticular nature of these water-bearing zones they do not continue from well to well, but pinch out or undergo a facies change over a very short distance.

The piezometric surface in these 10 wells rises from east to west. In well 14 the piezometric surface is 133 feet below the ground surface, in 15 it is 121 feet, in 16 it is 120 feet, and in 19 it is only 70 feet below the surface (Pl. II).

Each of the drilled or dug wells south and east of Fairfield which fail to completely penetrate the Alpine formation obtain a small supply of water (25 gallons per minute) from a small perched zone at 15 to 35 feet. The water does not rise in the well bore. Directly on the toe of one of the larger fans emerging from Lake Mountain, water occurs in a confined zone at 229 feet (Pl. II) and rises in well 4 to within 10 feet of the surface.

Well 7, to the south 3 miles, struck confined water at 193 feet which rose only 8 feet in the well. This well was located a quarter of a mile above the toe of the fan. Apparently the difference in position of the two wells with relation to the alluvial fan makes a considerable difference in the hydrostatic pressure encountered. Where the well is located in such a position as to take advantage of the fine sediments covering the coarser alluvial fan material, the water is not only retarded in its lateral flow by the fine-grained material; but is also confined from moving upward, so that a hydrostatic head is developed.

On the West Canyon fan in well 2, water was encountered at 380 feet but did not rise in the well. About $1\frac{1}{2}$ miles south, well 3 encountered water at 280 feet, and the water rose 30 feet in the well. This again demonstrates that as the fines increase near the toe of the fan so does the hydrostatic pressure and the possibility of obtaining a flowing well.

Fluctuations of the water table

During the period in which this study was made no fluctuations in the water table were observed. The only fluctuations of the piezometric surface which could be determined were in sec. 14, 15, and 16, T. 6 S., R. 2 W.

In 1951 when well 11 was drilled the piezometric surface was 80 feet below the ground surface. At the time of this study the piezometric surface in this well was 131 feet below the ground surface. This would indicate a lowering of the piezometric surface of 51 feet as a result of the development of five additional wells since 1951. This would also demonstrate the inability of the fine sediments in this area to replenish the ground-water supply as rapidly as it is being removed.

Grant Smith, Cedar Valley land owner, stated that the water level in well 19 may rise as much as 30 feet following a wet season. This well, which is only three-quarters of a mile from the toe of the Pole Canyon fan, must be in fairly intimate contact with the recharge area high in the Oquirrh Mountains. This well has considerably more gravel present than do the neighboring wells to the east.

Springs

When the first settlers moved into northern Cedar Valley it was only natural that they would settle near the springs in the valley. These two spring areas, both on the west side of the valley, have, until recently, furnished nearly all of the water for the towns of Fairfield and Cedar Fort.

The spring directly west of Fairfield has a fairly constant flow of 4 to 5 second-feet. This spring supplies all of the irrigation water for the farms around Fairfield. The spring is directly in the path of the drainage from both Clay and Manning Canyons. According to the United States Geological Survey topographic map of the area, the spring is situated on the break in slope between the flat of the valley and the steeper sloping alluvial fan material. This would be the most likely place for the ground water, percolating valleyward through the coarse alluvium, to surface. As the water reaches the toe of the fan where the sediments abruptly become finer it is effectively dammed, backed up, and forced to the surface. Along the toe of this fan the spring surfaces at several points over a 200 yard area. This is to be expected in this type of spring where the water, being forced to the surface, has to seep through areas of varying permeability. In some places the sediments are permeable and allow the water free access to the surface while in other places the sediments are impermeable and force the water to find passage elsewhere.

West of Cedar Fort the three springs which furnish water for the inhabitants of the town are considerably different than the single spring at Fairfield. According to Art Cook, Secretary of the Cedar Fort Water Board, the three springs together flow about 450 gallons per minute.

Geologically, the three springs are all the same. They flow initially from fractured bedrock of the Oquirrh formation. The upper

spring, elevation 6350 feet, in Spring Creek Canyon flows directly out of a highly fractured dense black limestone striking N 42° W and dipping 49° SW. The limestone forms a "V" as it crosses the canyon, with the spring flowing from the apex of the "V" in the bottom of the canyon. In the canyon the water flows from bedding plane fractures in the lower 10 feet of exposed limestone. Directly below the 20 feet of black limestone is 6 feet of less fractured orthoquartzite. This acts as an impermeable layer through which the water can not percolate.

The spring apparently has originated here where the intermittent Spring Creek stream has cut down to the fractured, soluble, water-bearing limestone. The limestone and underlying quartzite beds form part of the northwest limb of the Pole Canyon syncline and plunge toward Cedar Valley.

Both the middle and lower springs are on strike with this upper spring (Pl. I). Because the middle and lower springs are at a lower elevation, the limestone bed from which they flow has been covered by alluvium. Although at the middle spring, elevation 5725 feet, in the first canyon south of Spring Creek the water-bearing limestone bed can be traced to within 10 feet of the floor of the canyon from which the spring issues. At this spring the water is flowing from a collapsed tunnel which has been dug into the alluvium on the south side of the canyon. The south canyon wall is very steep and has a 100 feet thick deposit of alluvium which completely covers the source bed from which the spring issues.

Downstream 100 feet and 10 feet lower than the spring, a second tunnel has been dug into the alluvium on the south side of the canyon. This tunnel was dug in the direction of the spring, but is below the impervious rock under the water-bearing strata and consequently is completely dry.

The lower spring, elevation 5180 feet, flows out of a small alluvial fan on the western edge of Cedar Fort. This spring probably flows from the same limestone bed as do the two other springs, but it appears to be off strike to the east a little because of its emergence from under the fan. This can be explained in the following manner. As the water flows out of the fractured limestone under this small fan, it tends to percolate valley-ward with the slope of the fan. It is allowed to percolate in this manner because of the coarseness of the material through which it flows. But shortly after it leaves the limestone bed, it begins to encounter finer sediments at the outer edge of this small fan. The flow of water is restricted by these fines, and the water is forced to the surface, much in the same manner as the water in the Fairfield spring. This assumption is supported by the United States Geological Survey topographic map of the area, which indicates that the lower spring is located on the break in slope, or toe of the small fan.

The individual flow of each of the three springs was difficult to estimate. It appeared that the upper spring was flowing the greatest amount, but would not exceed one-third of a second-foot. The middle spring appeared to be flowing about one-eighth to one-quarter of a second-foot. The lower spring has been cemented and the entire flow of water leaves the spring by a pipe, so it was not possible to determine the flow. This lower spring, however, according to Art Cook has the smallest flow of the three.

Sources of Ground Water

Paleozoic rocks

Along the west side of northern Cedar Valley the Oquirrh Mountains are folded into a series of anticlines and synclines which plunge southeastward under the valley. The rock units consist largely of interbedded limestone, sandstone, and orthoquartzite and represent a natural conduit down which the ground water percolates into the valley. That some water is percolating down through these beds is proven by the three springs above Cedar Fort, and by the numerous springs which occur at the contact of the Manning Canyon shale with the Oquirrh formation high up in West Canyon.

Permeability----Because of the age of the Paleozoic rocks they have long ago become well-consolidated and relatively dense. For this reason their permeability for ground water is nearly negative, but through the geologic processes of folding, faulting, and jointing, the rocks have been fractured. Along these fracture patterns ground water is allowed to move. The process of ground-water solution has been important in the development of these ground-water conduits, especially in fractured limestone.

Because of the great thickness of limestone in the area surrounding northern Cedar Valley, it should be assumed that a large volume of ground water is reaching the valley through solution-fracture conduits. Similarly, because of the fracturing that the Paleozoic sediments have experienced in the numerous disturbances since the close of the Paleozoic, it is assumable that a fracture system of ground-water conduits is leading into the valley from the recharge areas in the mountains.

Quantity of water----The volume of water flowing into the valley through these Paleozoic rocks is entirely undeterminable. The only surface expression of these features are a few small springs totaling no more than 2 or 3 second-feet of flow.

Pre-Lake Bonneville sediments

Throughout northern Cedar Valley the pre-Lake Bonneville lacustrine and fluvial sediments are the most prolific produces of ground water. All wells in the valley deeper than 100 feet are in the pre-Lake Bonneville material, and water will be encountered under artesian conditions with variable degrees of hydrostatic head. Of the 51 wells in the valley at least 36 are drilled in the pre-Lake Bonneville material.

Permeability----Taken as a group the pre-Lake Bonneville sediments below the floor of the valley contain such a high proportion of silts and clays that they have to be considered relatively impermeable. Even the gravels in the deep wells in the center of the valley (Pls. II, III, IV, V) generally contain such a high percentage of silts and clays that the permeability is diminished or ruined. There are a few thin, lenticular patches of gravel in these wells which have good permeability. However, these gravels are surrounded by an enclosing body of clay and silt which will not replenish the reservoir of water in the gravels as fast as it can be removed by the pump.

On the other hand, the pre-Lake Bonneville material in the alluvial fans around the valley is very permeable. All of the wells drilled into the pre-Lake Bonneville material in the fan areas contain more gravels than fines. The fans are characterized by lenticular deposits of sands, silts, clays, and gravels; but the overall percentage of coarse material is so much greater on the fans than under the valley floor that the fine material becomes a minor feature.

Well 2, for example, contained such a high percentage of coarse material and was so permeable that the water table was at 380 feet. This indicated that the water coming into the fan from West Canyon was able to percolate downward to at least 380 feet before being retarded by fine material. Wells 3 and 7, which are both located nearer the toe of a fan than well 2, have water depths of 185 and 250 feet respectively. This further indicates the lack of restricting fine material in the pre-Lake Bonneville fans.

The spring at Fairfield further indicates the general impermeability of the pre-Lake Bonneville sediments in the valley compared to sediments of the same age on the fans. It can be assumed that the underground water which percolates valleyward down the Manning and Clay Canyon fans is traveling through the pre-Lake Bonneville sediments. When this water encounters the less permeable pre-Lake Bonneville sediments of the valley floor, it is forced to the surface. This illustrates that in the fans all of the underground water can be transmitted readily by the permeable sediments, but that the fine valley sediment can only very slowly transmit this water.

Quantity of water----The wells drilled into the pre-Lake Bonneville sediments under the valley floor can not be expected to ever produce large quantities of water. The sediments are so fine that they will not transmit large quantities of water rapidly. Maximum production rates of 552 and 461 gallons per minute are now being obtained in wells 12 and 11 respectively. However, the large quantities of fine sand, silt, and clay produced with the water indicate future possibilities of caving and pump wear. These two wells which each produce over 1 second-foot are the exceptions rather than the rule, and wells between 100 and 200 gallons per minute should be expected in this vicinity if drilled.

On the alluvial fans around the valley a good flow of water could be obtained from the pre-Lake Bonneville sediments if the proper location near the toe of the fans were selected.

Lake Bonneville sediments

Five wells east of Fairfield, 24, 25, 26, 27, and 50 have produced water from the Alpine silts and clays of Lake Bonneville. Other than these five, no well in the valley produces any water from the Alpine sediments.

Permeability----The water in these clays apparently represents a perched water zone entering the clays from the spring at Fairfield or along the toes of the fans west of Fairfield. Part of the water may slowly seep downward from the irrigation water on the farm land east of Fairfield. None of the water penetrates the clays and silts more than 35 feet, for no mention has been made of water between the 35 foot level, and the bottom of the Alpine formation at 80 to 90 feet.

Quantity of water----Each of the five wells mentioned above initially pumped 25 gallons per minute with a 5 foot drawdown. These wells were drilled in 1953 and at the time of this report have all been abandoned. It appears that this perched zone was depleted very rapidly.

Post-Lake Bonneville sediments

Only in the area around Fairfield is there any indication of any water-bearing post-Lake Bonneville sediments. On the west side of the town, wells 29 and 30 might be obtaining water from these deposits. Both of these wells are shallow dug wells no more than 20 feet deep, and the owners of these wells report that the water begins to come into well at a depth of 6 feet. The water in both wells stands at 6 feet and

apparently comes into these clays from the Fairfield spring which is a few hundred yards to the south and west. At the Hillsdale Stake farm southeast of Fairfield, the water table in two shallow dug wells, 47 and 48, stands at 9 feet and is in the post-Lake Bonneville sediments.

Permeability----The sediments on the floor of the valley are silts and clays and tend to be fairly impermeable except in areas which have undergone intensive farming. This is the situation in and around Fairfield where the root systems of the plants and constant wetting of the sediments have created a more pervious upper clay layer. Through these upper soils the water is allowed to move freely. The spring at Fairfield and the yearly irrigation of farmlands and lawns have kept the upper 35 feet of sediment relatively saturated. On the fans around the valley the post-Lake Bonneville deposits consist of typical alluvial fan material and are very permeable.

Quantity of water----No water should be expected from the post-Lake Bonneville deposits in the fan areas and only enough water for domestic use could be expected for the area around Fairfield.

Recharge

The major source of recharge for the underground water supply in northern Cedar Valley is the meltwater from the winter snows in the Oquirrh Mountains to the west and Lake Mountain to the east.

Minor contributors to the ground-water supply are the rains which occur in the mountain areas and in the valley proper during the year. It is difficult to assume that the seepage from irrigation sources ever reaches the permanent underground water supply, partly because of the evaporation that is taking place during the months in which irrigation water is used, and partly because of the impermeable nature of the sediments underlying the irrigated areas.

The springs in the valley undoubtedly contribute some water through seepage to the ground-water supply in the valley, but the quantity is open to speculation.

McFarland (1955, pp. 18-19), stated that there may be a water loss as high as 40 per cent from the $5\frac{1}{2}$ mile ditch leading from West Canyon to Cedar Fort. He observed that this figure varies with the quantity of water in the ditch, and that the greater the volume of water the less the loss on a percentage basis. But because this ditch carries such a minor volume of water in comparison to that which runs off in the spring as meltwater, it is only a minor contributor.

The areal extent of the recharge area for northern Cedar Valley is about 190 square miles. Of this recharge area 65 square miles are in the Oquirrh Mountains from which most of the underground water supply is obtained. Only about 20 square miles of recharge are in the Lake Mountain, the rest are in the valley proper and the Traverse Mountains to the north of the valley.

Ground Water Development

Areas of maximum development

Up to the time of this report 51 known wells have been drilled or dug in the area under consideration. Of these 51 wells not one has been located in such a manner as to properly test the true ground water potential of the valley.

During the years since the first well was spudded in 1884 a total of 42 wells have been located and completed on the flat floor of the valley, and only nine wells have been located and completed on the alluvial fans surrounding the valley. Of these nine wells drilled on the alluvial fans, only two have been located in such a position as to take full advantage of the line of contact between the coarse alluvial material of the fans and the fine sediments encountered on the valley floor. These two wells, 33 and 34, are located just west of the spring at Fairfield, and on the contact of the Manning and Clay Canyon fans with the fine sediments of the valley floor. Both of these are shallow wells, well 33 is 189 feet and well 34 is 100 feet deep. These two wells are the best flowing wells in the Fairfield area.

The reason for the location of the majority of the wells on the valley floor has been to obtain water for either stock-watering or the irrigation of crops. The most recent examples of this mis-location of wells are the 10 deep wells drilled in sections 13, 14, 15, and 16 of T. 6 S., R. 2 W. (Pl. I). Of the 10 original wells drilled in these sections three have been abandoned (10, 13, and 14), and the seven remaining wells, all over 450 feet deep, produce a total of only 4 second-feet of water.

The most likely areas in northern Cedar Valley for the maximum development of ground-water resources would be just above the toes of the alluvial fans. On Plate I the toes of the fans are located approximately at the contact of the post-Lake Bonneville alluvial sediments and the Recent silt and clay. This break between the alluvial fan deposits and the finer sediments of the valley floor is shown on the United States Geological Survey topographic maps by a definite break in slope, but in

many cases this slope difference is difficult to detect in the field. Along the toe of the West Canyon fan this slope break can be easily detected in the field, and the difference in the lithology can be seen.

If a well is located properly above the toe of a fan, the water encountered should be backed up behind a dam of fine-grained sediments through which it is forced to percolate slowly as the particle size decreases valleyward. If the fine material has lapped up over the coarse fan material sufficiently it will create a confined stratum under which the water must pass because it is unable to seep upward. If these conditions are present the water will be under hydrostatic pressure and will rise in the well bore, or will flow to the surface if the pressure is great enough.

The alluvial fans in the valley which offer the greatest possibilities for ground water development are the following: (The first listed is judged to have the greatest potential.)

1. West Canyon fan----This fan covers an area of 30 square miles, or one-third of the entire valley. According to well logs and field studies it contains the thickest gravels in the valley. The canyon which feeds it is the major source of drainage into the valley, and drains the largest recharge area. There appears to be an abrupt break between the fan deposits and the finer sediments of the valley floor (this is at least true on the surface). The fan has good porosity and permeability.

2. Manning Canyon-Clay Canyon fans----These fans cover only 3 square miles, but have a good spring issuing from the toe which indicates that there is a good supply of water in the fans. The streams emerging on these fans cut through the Manning Canyon shale which has numerous springs along its contact with the Oquirrh formation. These fans have considerably less gravel than the West Canyon fan, but probably contain enough gravel to provide fair permeability.

3. Pole Canyon fan----This fan covers approximately 5 square miles and drains the highest recharge area in the valley. The recharge area is much smaller than the West Canyon recharge area but is equal to the Manning Canyon-Clay Canyon area. A shallow dug well on the fan surface indicates that the fan contains suitable gravels. The permeability is as good as the West Canyon fan.

4. Lake Mountain fans----These include all of the fans emerging from Lake Mountain. These fans are all small, the largest covers only one square mile. The recharge area for each fan is very small, and the fans are only capable of supporting stock wells or small irrigation wells.

Of all the areas in northern Cedar Valley, the most unlikely for ground water development is the flat floor of the valley.

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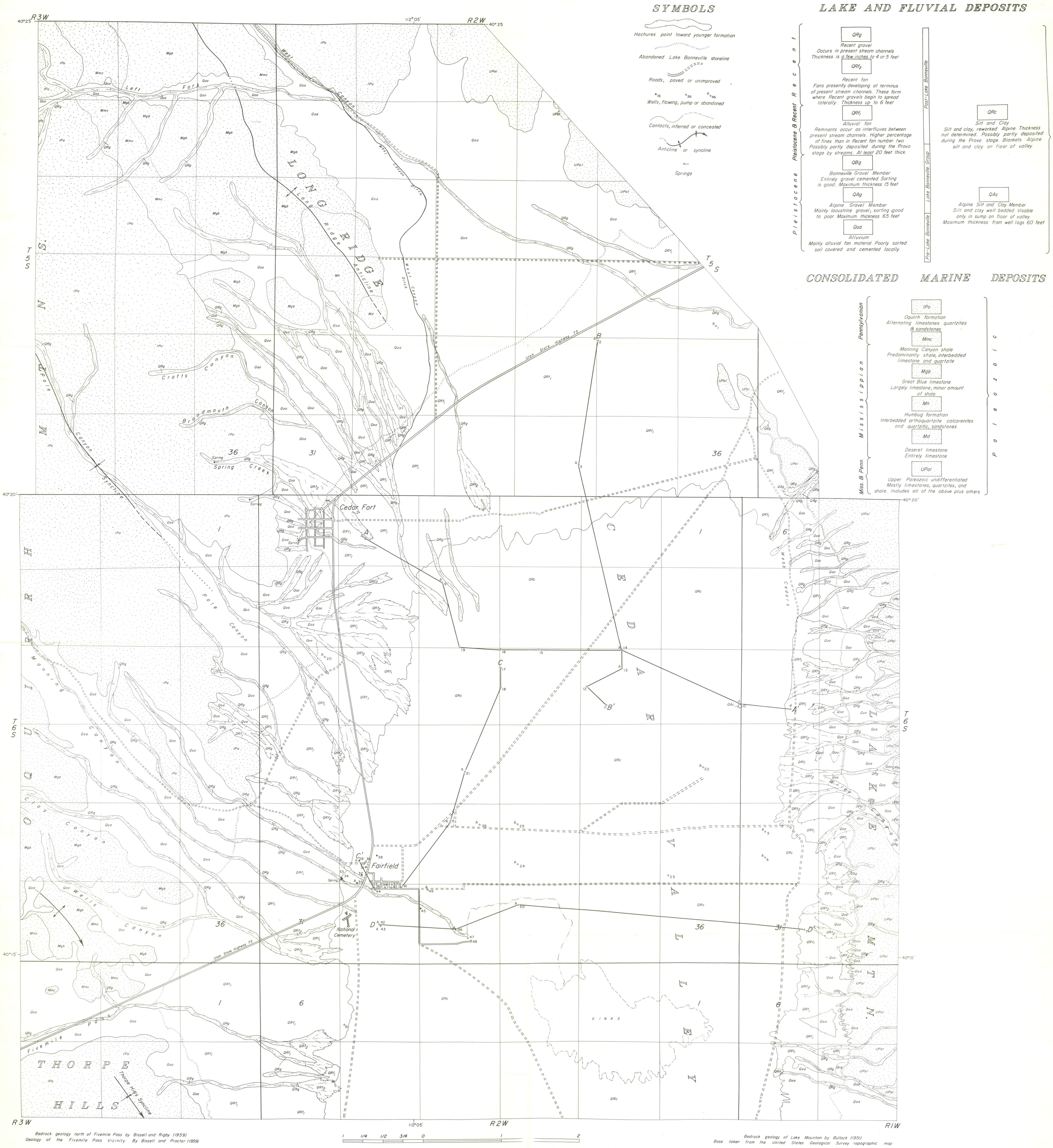
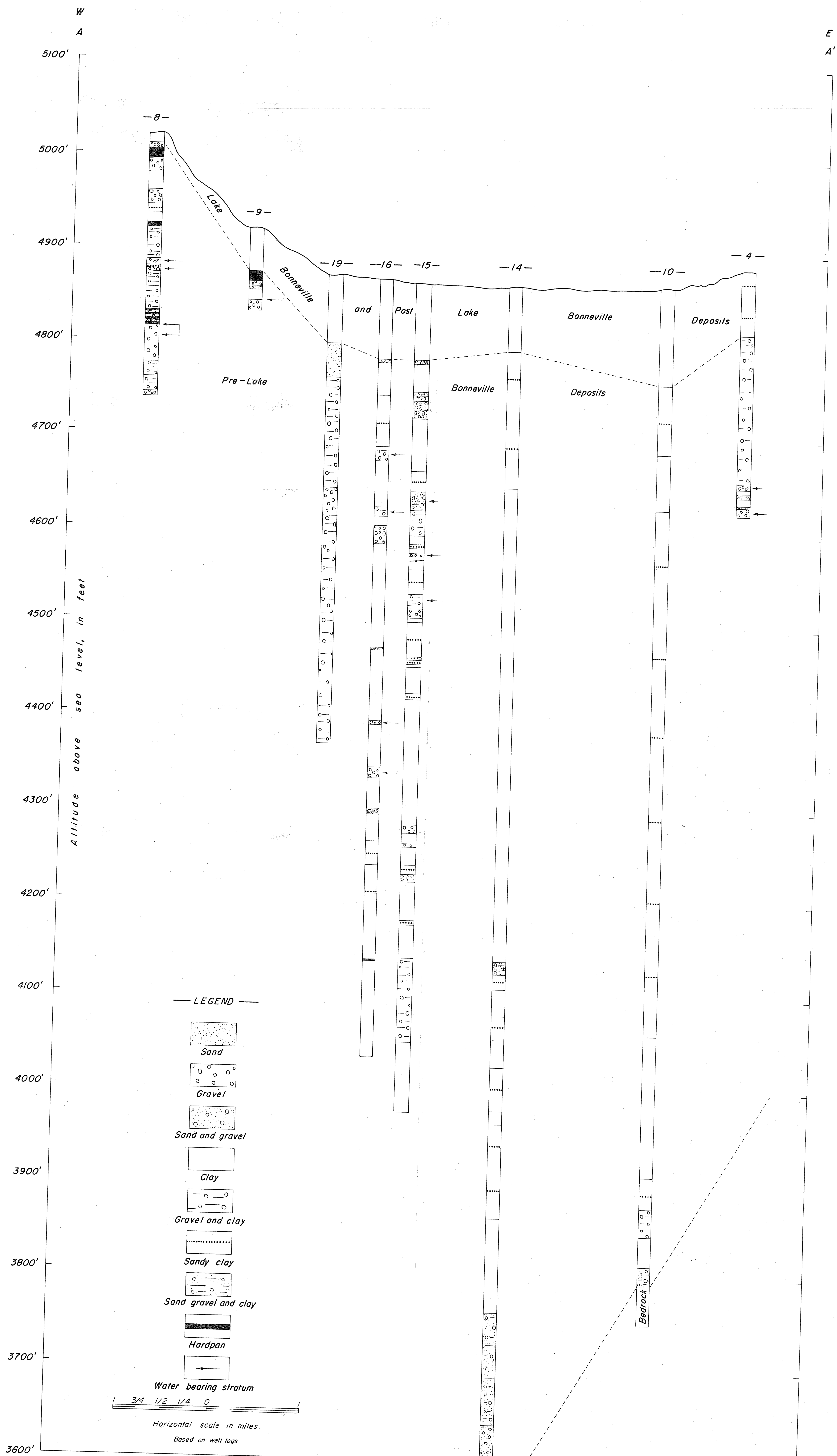


GROUND WATER GEOLOGY AND WELL LOCATION MAP OF NORTHERN CEDAR VALLEY, UTAH

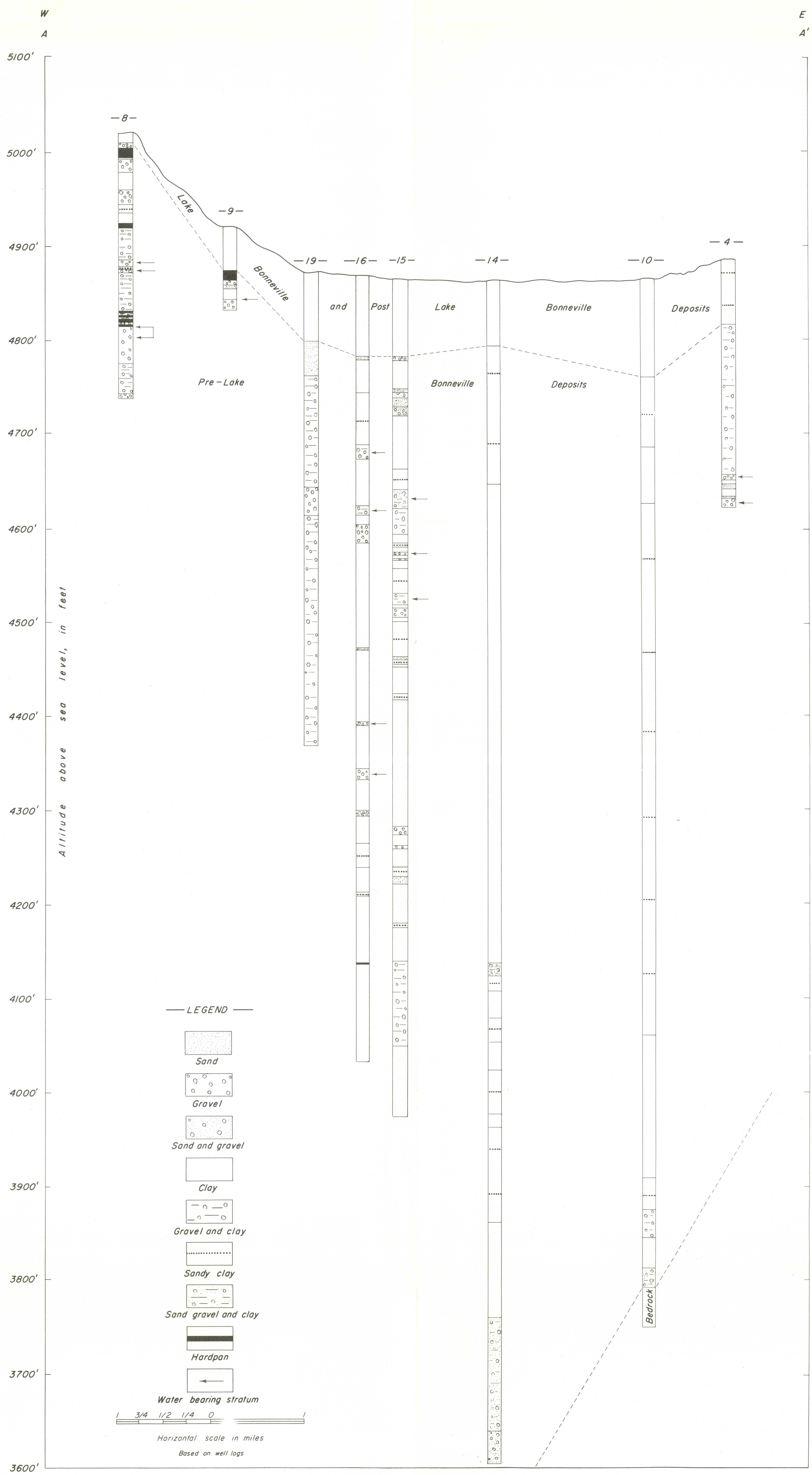
Norbert W. Larsen

1960

PLATE I

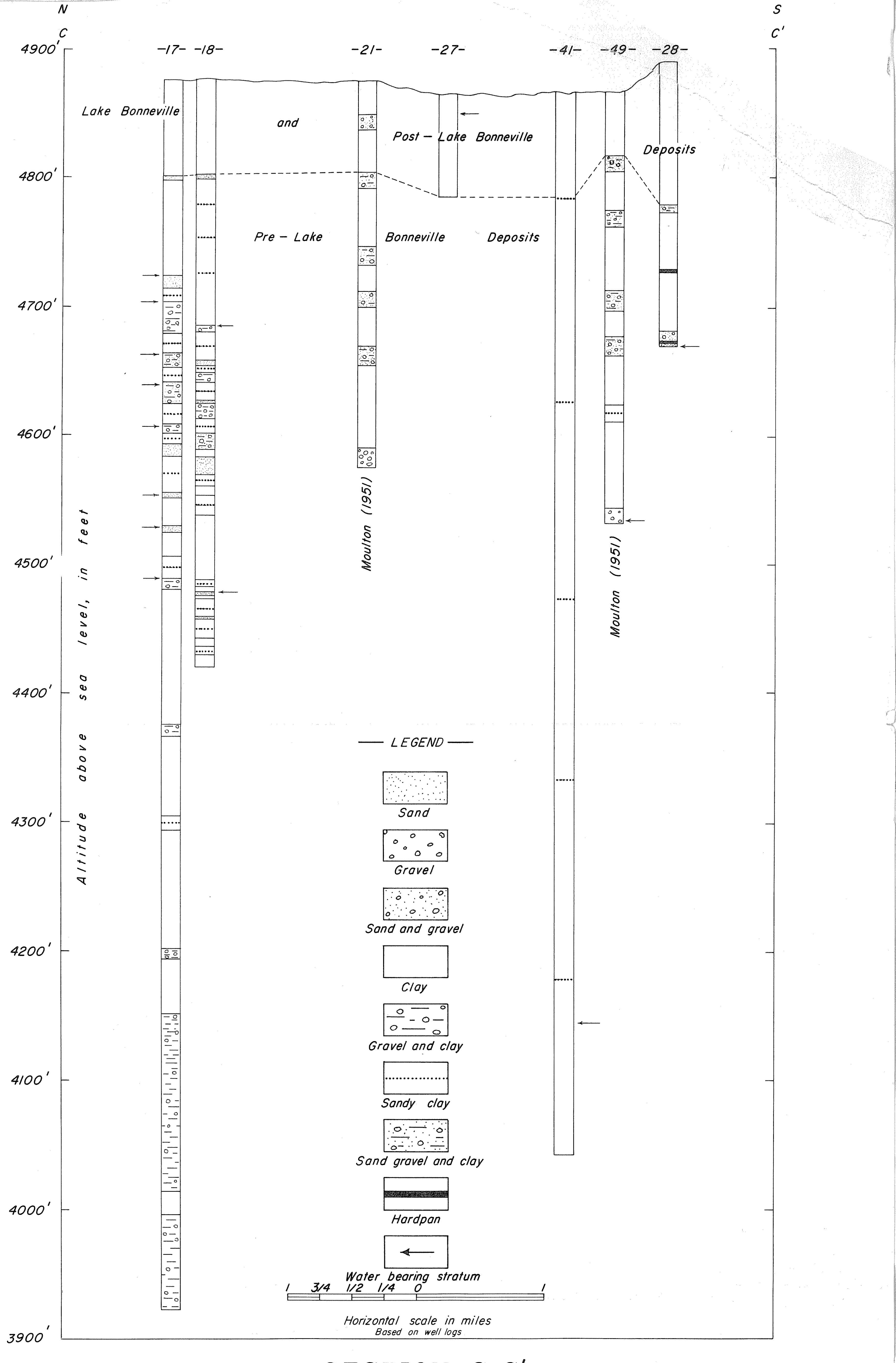


SECTION A-A'
PLATE II



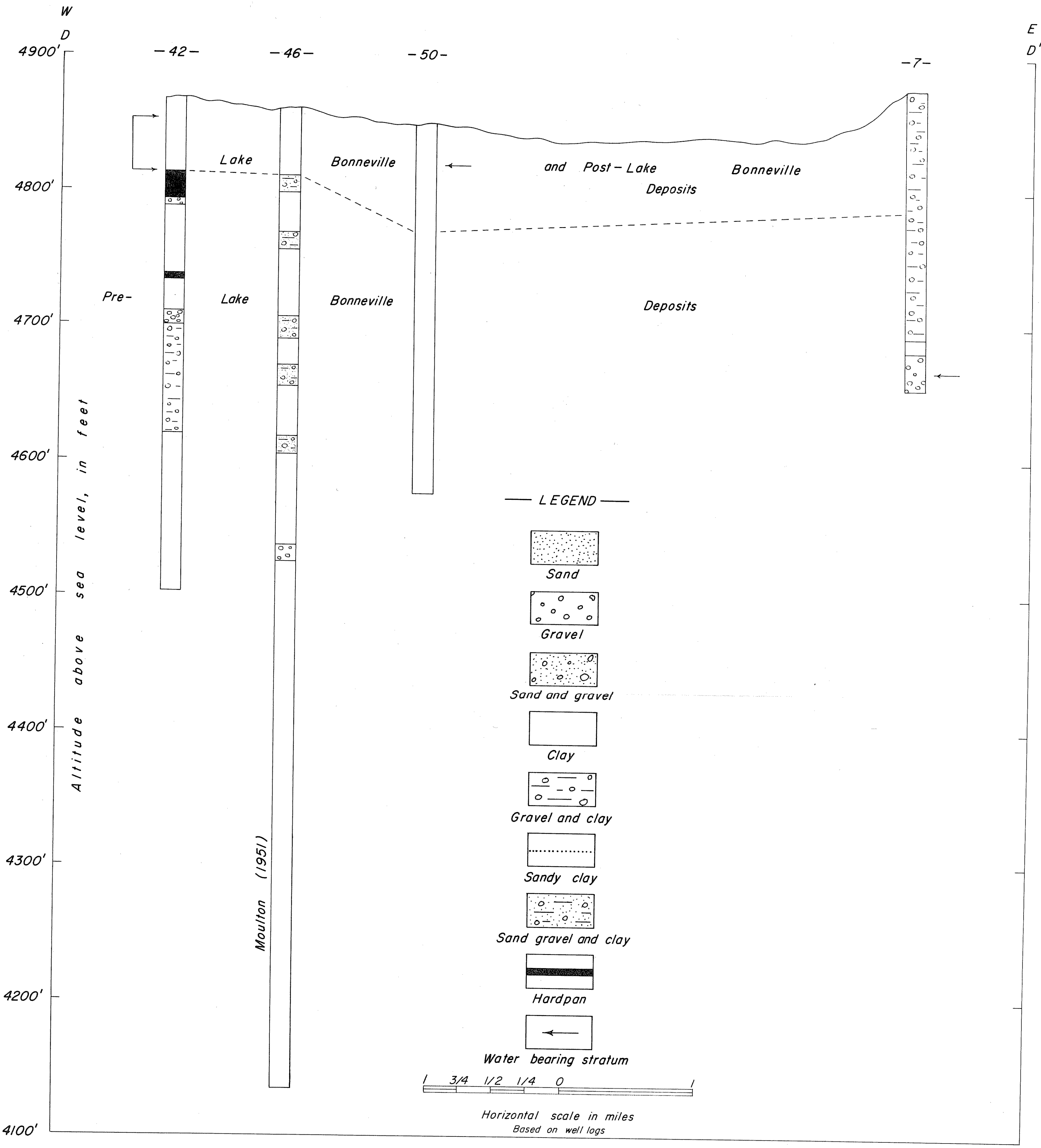
SECTION A-A'

PLATE II



SECTION C-C'

PLATE IV



SECTION D-D'

PLATE V