Lake Bonneville: Quaternary Stratigraphy of Eastern Jordan Valley, South of Salt Lake City, Utah

GEOLOGICAL SURVEY PROFESSIONAL PAPER 477

Lake Bonneville: Quaternary Stratigraphy of Eastern Jordan Valley, South of Salt Lake City, Utah

By ROGER B. MORRISON

GEOLOGICAL SURVEY PROFESSIONAL PAPER 477

A study of the stratigraphic record of the fluctuations of this late Pleistocene lake and a correlation with the record of contemporaneous glaciations in the Wasatch Mountains

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1965

UNITED STATES DEPARTMENT OF THE INTERIOR

STEWART L. UDALL, *Secretary*

GEOLOGICAL SURVEY

Thomas B. Nolan, ***Director***

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

ILLUSTRATIONS

[Plates are in pocket]

TABLES

LAKE BONNEVILLE: QUATERNARY STRATIGRAPHY OF EASTERN JORDAN VALLEY, SOUTH OF SALT LAKE CITY, UTAH

By Roger B. Morrison

ABSTRACT

Discussed in this report is the Quaternary stratigraphy, mainly of Lake Bonneville, in a 100-square-mile area in Jordan Valley, east of the Jordan River and south of Salt Lake City, Utah.

The oldest Quaternary deposits are colluvium and a few remnants of fan gravel and possible till of pre-Lake Bonneville age that are exposed mainly along the edge of the Wasatch Range. With increasing age these deposits are progressively more upfaulted—with respect to the basin to the west—by faults along the base of the range; the oldest deposits have been displaced more than 2,000 feet. The deposits bear a very mature soil, the Dimple Dell Soil [equivalent to the pre-Wisconsin paleosol and ancient soils of Hunt and Sokoloff (1950, p. 114–115) and Hunt (1953b, p. 43–44)], whose development is inferred to have shortly preceded the first rise of Lake Bonneville. This soil is at least 5 feet thick where well preserved; it has a coarse-textured brown B horizon and, a mile or more west of the mountain front, a dense C_{ca} (caliche) horizon.

The sediments of Lake Bonneville are designated, after Hunt (1953b), as the Lake Bonneville Group, but the units within this group are redefined. In eastern Jordan Valley this group is most feasibly divided into two formations, here named and defined as the Little Cottonwood Formation (older) and the Draper Formation. The Little Cottonwood is made up of lacustrine sediments that are divisible into at least three members, separated by diastems and local alluvium recording major lake recessions. The diastems and alluvium are discontinuous, however, and the members can be differentiated only locally. The members are, in ascending order, the Alpine, Bonneville, and Provo. The Alpine Member is approximately equivalent to the Alpine Formation of Hunt (1953b); it reaches a maximum altitude of about 5,110 feet west of the main Wasatch fault zone and is inferred to record the first two or more deep-lake cycles of Lake Bonneville. The upper part of the Little Cottonwood (Bonneville and Provo Members) extends as high as the Bonneville shoreline, which is at an altitude of about 5,135 feet west of the main Wasatch fault zone, and is inferred to record the third and highest lake cycle. The Bonneville Member lies at altitudes above the shoreward edge of the Provo terrace, which is at an altitude of about 4,800–4,825 feet, includes the Bonneville Formation of Hunt (1953b), and is here redefined as the Bonneville Member. The Provo Member lies at and below the altitude of the Provo terrace, includes most of the Provo Formation of Hunt (1953b), and is here redefined as the Provo Member.

The Little Cottonwood and Draper Formations are separated by a mature soil, local alluvium, and a pronounced disconformity that together record subaerial exposure at least as low as an altitude of 4,250 feet—or only 50 feet above the June 1951 level of Great Salt Lake. The soil, called the Graniteville Soil, is thinner (typically 3–4 ft thick) than the Dimple Dell Soil; its B horizon is distinctly less clayey, has much weaker structure, and is generally lighter brown; its C_{ca} horizon, present only in the western part of the area, has less calcium carbonate.

The Draper Formation comprises three tongues of lacustrine sediment that are separated by diastems which record subaerial exposure and hence are inferred to record the last three lake cycles of Lake Bonneville. The lower tongue reaches a maximum altitude of about 4,770 feet, not quite as high as the Provo shoreline. The middle and upper tongues extend as high as 4,470 and 4,410 feet, respectively, but these maxima are only faintly marked by shore features and shore deposits. The diastems between the tongues have been identified at altitudes as low as 4,450 and 4,360 feet, respectively, and probably extend lower.

Post-Lake Bonneville deposits include widespread loess and local eolian sand, alluvium, and colluvium. A submature soil, the Midvale Soil, is locally intercalated between the lower and upper parts of the eolian sand. This soil is correlated with the last part of the Altithermal age of Antevs. It is a Calcic to Noncalcic Brown soil that is about 2 feet thick and has a brown to brown-gray massive B horizon which locally grades downward into a weak C_{ca} horizon.

Thus, the stratigraphic record shows that Lake Bonneville had at least six lake cycles, whose maxima were at the following altitudes: at least as high as 4,925 feet (oldest, early Alpine), about 5,110 feet (late Alpine), 5,135 feet (Bonneville shoreline), 4,770 feet (early Draper), 4,470 feet (middle Draper), and 4,410 feet (late Draper). During the intervening recessions the lake level dropped below the level of the preceding maximum at least as much as 660, 720, 885, 320, and 110 feet, respectively. This record is in accord with the conclusions of Gilbert (1890), Antevs (1945, 1948), Ives (1951), Hunt (1953b), and Eardley, Gvosdetsky, and Marsell (1957) on the age relations and maximum altitude of the Alpine and Bonneville shorelines and lake cycles. It is in contrast with each of these interpretations, however, in that the longest and probably most complete lake desiccation seems to have followed rather than preceded the lake cycle that rose to the Bonneville shoreline. The long stillstand at the Provo level occurred during the recession of this lake cycle, as Gilbert and Hunt inferred, and not during the next younger lake cycle, as Antevs (1945, 1948, 1952, 1955), Ives (1951), and Eardley, Gvosdetsky, and Marsell (1957) concluded. The next lake maximum after the Provo stillstand (the early Draper maximum, at an altitude of about 4,770 ft) is equivalent to the Provo 2 maximum of Jones and Marsell (1955), Bissell (1952), Antevs (1952, 1955), and Eardley, Gvosdetsky, and

Marsell (1957). The next younger lake maximum (the middle Draper maximum, at an altitude of about 4,470 ft) was at the average altitude of the Stansbury shoreline of Gilbert (1890), of the Lake Stansbury II stillstand of Antevs (1945, 1948, 1952, 1955), and of the Stansbury stage of Ives (1951) and of Eardley, Gvosdetsky, and Marsell (1957). The last Draper lake maximum, at an altitude of about 4,410 feet, has not been identified previously.

Below the mouths of Bells and Little Cottonwood Canyons are two sets of bulky end moraines, representing two separate advances of glaciers from these canyons, which are correlated by Richmond (1961, 1964) with the early and late stades of the Bull Lake Glaciation in the Rocky Mountain region. Around the outer margins of the moraines, till and outwash of the early stade interfinger with high-shore sediments of the Alpine Member, and drift of the late stade likewise interfingers with high-shore sediments of the Bonneville Member. Furthermore, the higher shorelines of the Alpine lake cycle notch the end moraines of the early stade, and the Bonneville shoreline is carved into the end moraines of the late stade, contrary to the conclusions of Gilbert (1890) and Blackwelder (1931). The relations indicate that the highest (second) Alpine lake maximum was essentially contemporaneous with the maximum of the early stade of the Bull Lake Glaciation and that the Bonneville shoreline maximum occurred soon after the maximum of the late stade of this glaciation.

End moraines of post-Bull Lake age are far above the Bonneville shoreline in both canyons, and the intervening remnants of outwash gravel and stream terraces are too discontinuous to permit reliable direct correlation between the younger glacial and lacustrine sequences. These sequences can be indirectly correlated, however, on the basis of relative stratigraphic position of soils of similar maturity in each sequence. The drift of the Bull Lake Glaciation bears a mature soil, comparable in development to the Graniteville Soil. A submature soil, similar to the Midvale Soil, is present on three sets of end moraines in the middle and upper parts of the canyons that are correlated by Richmond (1961, 1964) with the early, middle, and late stades, respectively, of the Pinedale Glaciation. Consequently, the Draper Formation is correlated with the drift of this glaciation. The lower, middle, and upper tongues of this formation are matched by, and probably correlate with, deposits of the early, middle, and late stades, respectively, of the Pinedale Glaciation.

INTRODUCTION

OBJECTIVES OF THIS STUDY

Among the most intriguing of the younger geologic features of the Western United States are the deposits of former glaciers in the mountains and of pluvial lakes of the Great Basin, notably Lakes Bonneville and Lahontan. Both the glaciers and the lakes underwent numerous expansions and contractions in late Quaternary time. Detailed studies of these fluctuations have only recently commenced; glacial and lake histories still are imperfectly known in many areas, and even where best known, certain differences in interpretation by various students have yet to be reconciled. Furthermore, there has been rather wide disagreement on correlations between the lakes and glaciers. Lake Bonneville, the largest of the pluvial lakes, has been the most studied and has yielded the greatest variety of interpretations.

An area below the mouths of Little Cottonwood and Bells Canyons, on the eastern side of Jordan Valley south of Salt Lake City, has attracted more attention among geologists than has any other part of the Lake Bonneville region. This area is a particularly good site for such studies because of its accessibility, its conspicuous lacustrine features, its strikingly youthful fault scarps, and, mainly, because it is the only place where glaciers extended low enough to reach the higher lake shores, permitting direct correlation between parts of the lacustrine and glacial sequences.

The present study was undertaken to apply modern surficial stratigraphic techniques to this intriguing and controversial area. It was found desirable to extend the investigation into adjoining parts of Jordan Valley to obtain evidence on lake history. The research had several objectives:

1. To differentiate and map stratigraphically the surficial deposits—especially those of Lake Bonneville and the glacial deposits—in terms of units that would best portray the history of the lake and glacial oscillations.
2. To interpret the lacustrine, glacial, and alluvial history as recorded by the surficial deposits and Quaternary landforms.
3. To correlate the lacustrine, glacial, and alluvial sequences and their history.
4. To map the many faults that displace Quaternary deposits and to determine the age of their latest movement.

I spent 2½ weeks mapping in the area in September 1958, 6 weeks in the fall of 1959, and another week in September 1960. During 4 weeks of the second field season, G. M. Richmond concurrently mapped the glacial geology of the drainage area of Little Cottonwood Canyon. Together we studied the relations of the lacustrine and glacial deposits below the mouths of Little Cottonwood and Bells Canyons and are jointly responsible for the conclusions as to the interrelations and correlations of these deposits. Richmond's conclusions on the glacial stratigraphy, history, and correlation are given in a separate report (1964). I am indebted to Prof. R. E. Marsell of the University of Utah for showing various features of the Quaternary geology of this area to me in the field on several occasions between 1948 and 1960.

PREVIOUS STUDIES

The reports of the exploration of the 40th parallel briefly mention the Lake Bonneville shorelines and the evidence for glaciation in the Wasatch Range; they also show the maximum extent of Lake Bonneville and the glaciers on 1 : 900,000-scale maps. (See Hague and Emmons, 1877, p. 341, 353–355, 439; King, 1878, p. 473–474, 490–500, and analytic maps 5, 6.) G. K. Gilbert's classic monograph on Lake Bonneville (1890, p. 307–318, pl. 42) includes a map of the moraines and faults below the mouths of Little Cottonwood and Bells Canyons and a discussion of their relations to the Bonneville (highest) shoreline. Atwood (1909, p. 73–93, pl. 10), Blackwelder (1931, p. 914–916), Marsell (1946b), and Ives (1950) also discussed briefly the moraine and shoreline relations below the mouths of these canyons. Jones and Marsell (1955) and Marsell and Jones (1955) furnished general descriptions of Lake Bonneville stratigraphy and history in Jordan Valley, and Eardley, Gvosdetsky, and Marsell (1957) contributed valuable additional data in connection with a comprehensive study of many aspects of Lake Bonneville.

Antevs (1925, 1945, 1952, 1955), Ives (1948, 1951), Bissell (1952, 1963), Hunt, Varnes, and Thomas (1953), and Gvosdetsky and Hawkes (1953) also gave interpretations of Lake Bonneville history based on stratigraphic studies outside the area mapped for this report. Broecker and Orr (1958) recently published an interpretation, different from all previous ones, based entirely on radiocarbon dating of samples from the lake sediments.

The soils of the area were mapped and described from the agricultural standpoint by Jennings and others (1946). Their soil map shows little relation to the one resulting from the present study because the agronomic system of soil classification cannot readily be correlated with the stratigraphic units used in the present study.

LOCATION

The area mapped for the present study is in Salt Lake County, Utah, about 20 miles south of Salt Lake City (fig. 1). It is irregular in shape—about 11.7 miles from north to south (lat 40°41′25″–40°30′) and 8½ miles from east to west (long 111°46′–111°55′30″)—and has an area of about 100 square miles. The area is shown on the Salt Lake City South, Sugar House, Midvale, and Draper U.S. Geological Survey topographic quadrangle maps (7½-minute series, scale 1: 24,000) published in 1951 and 1952. The topographic base for the geologic map was compiled from these quadrangle maps.

TOPOGRAPHY

The area mapped is on the eastern side of Jordan Valley, which is a north-trending intermontane basin at the eastern edge of the Great Basin. The eastern margin of the area is the front of the Wasatch Range, and the western margin is the western edge of the flood plain of the Jordan River. This river flows northward along the axis of the valley and enters Great Salt Lake a few miles beyond the northern boundary of the area. Altitudes range from 4,235 feet where the Jordan River leaves the area to about 5,235 feet at the edge of the mountains and to about 7,400 feet on the high ridges of the mountain front. The highest shoreline of Lake Bonneville, known as the Bonneville shoreline, nearly coincides with the mountain front at altitudes that range from about 5,120 to 5,240 feet because of displacement by faults in the Wasatch fault zone.

Lacustrine landforms dominate the topography. These landforms include a huge compound delta, called the Cottonwood delta, below the mouths of Little Cottonwood and Big Cottonwood Creeks and many shore terraces, spits, and bars, as well as the extensive lake-bottom plain bordering the Jordan River. The Cottonwood delta is one of the largest formed in Lake Bonneville and has an unusually large proportion of gravel and sand, compared with the deltas of the Bear, Weber, Provo, and Sevier Rivers, although the drainage areas of Little Cottonwood and Big Cottonwood Creeks are relatively small. This anomalous situation was caused by the relatively large glaciers in the canyons tributary to the creeks (Blackwelder, 1948, p. 12).

Less dominant topographic features include the alluvial terraces of Little Cottonwood, Big Cottonwood, and Dry Creeks and the Jordan River. Along the mountain front are bulky terminal moraines at the mouths of Little Cottonwood and Bells Canyons, small alluvial fans at the mouths of other canyons, and a series of prominent young fault scarps that displace the moraines, fans, deltas, and other lake features. Relatively minor features are a few belts of sand dunes that veneer the sandy parts of the Cottonwood delta, notably north of Little Cottonwood and Dry Creeks and along the base of Draper spit.

The western edge of the Wasatch Range—the Wasatch Mountain front— is strikingly regular throughout the area; it forms a smooth curve and has no deeply embayed valleys or projecting ridges. To the east the front rises abruptly from about 5,200 feet to 10,000 feet above sea level within 2¼–3½ miles. The upper parts of the main ridges along the mountain front slope westward about 15°, but their lower parts steepen to about 30°–40°. These classic examples of faceted spurs and the regular alinement of the mountain front are presumably due to Quaternary high-angle normal faulting (King, 1878, p. 745; Gilbert, 1874, p. 50; 1875, p. 21–42; 1890, p. 340–360; 1928, p. 10–69; Davis, 1901, 1903, 1925; Blackwelder, 1910, 1928; Spurr, 1901; and Crittenden, Sharp, and Calkins, 1952, p. 25–31).

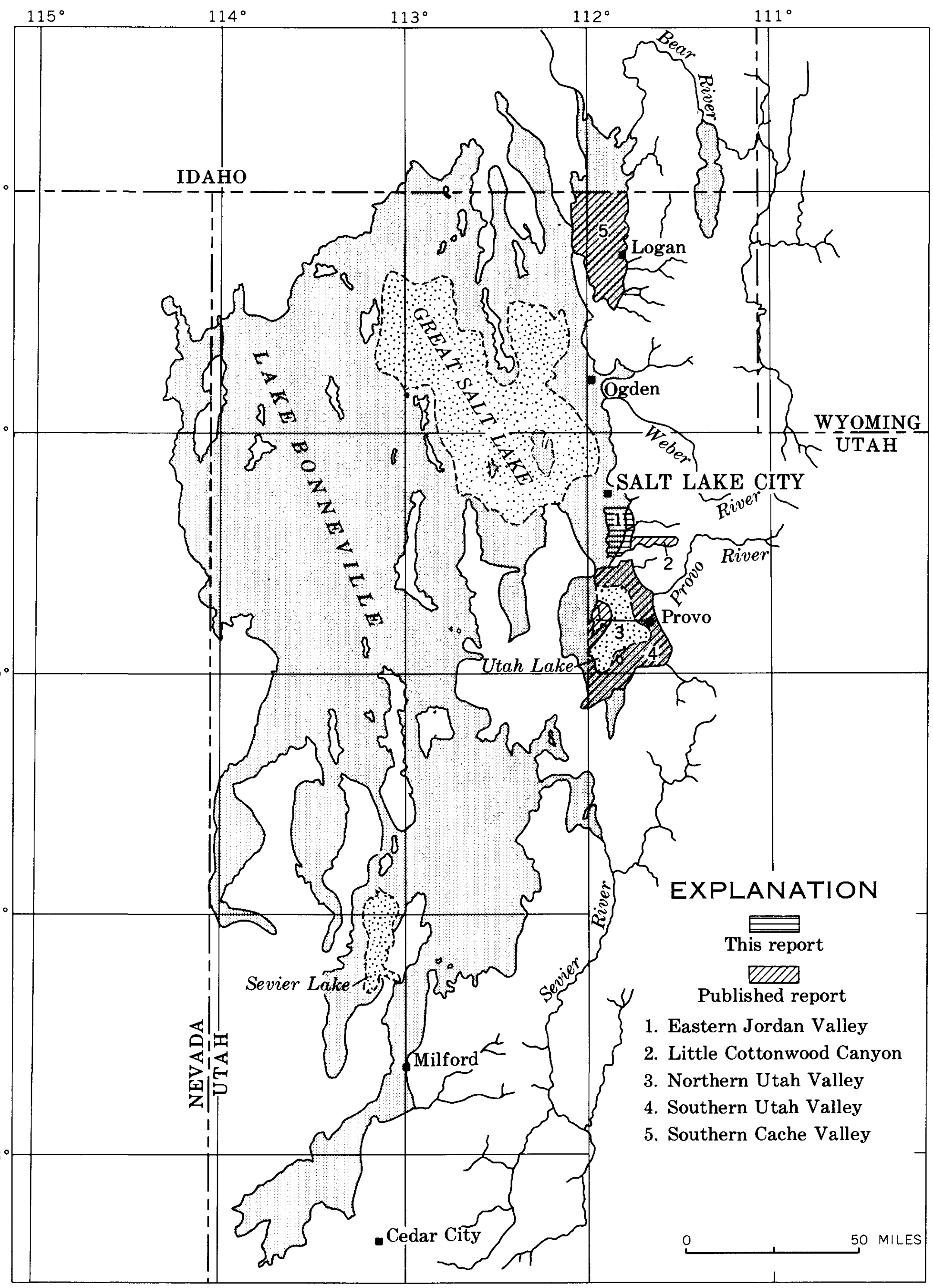

FIGURE 1.—Recent investigations of Lake Bonneville by the U.S. Geological Survey.

The unglaciated valley sides and ridges in the lower mountains along the range front, below an altitude of about 7,000 feet, are mostly smoothly rounded and are veneered by colluvial debris 1 foot to a few feet thick, but patches of bedrock are locally exposed; cliffs are comparatively uncommon considering the steepness of the terrain. With increase in altitude, the amount of colluvial veneer on the unglaciated valley sides generally decreases and steepness of cliffs increases.

Glaciers occupied two of the canyons, Little Cottonwood and Bells Canyons, and extended as much as 1 mile beyond their mouths. Little Cottonwood Canyon's spectacular U-shaped gorge as seen from the mountain front—sheer walls of granite rising more than 2,000 feet above the canyon floor—attests to the intensity of its glaciation, for nothing comparable occurs elsewhere in the region. Several other canyons that debouch at the mountain front—Ferguson, North Fork of Little Willow, Big Willow (Creek), Little Willow (Creek), and Bear—were glaciated in their upper parts but not to their mouths (contrary to the conclusions of Atwood, 1909). Big Cottonwood Canyon was glaciated in its upper part and, by a separate glacier that originated in Mill B South Fork, to within a third of a mile of its mouth, somewhat farther than Atwood (1909) inferred. All the unglaciated canyons and the unglaciated parts of the partly glaciated canyons have V-shaped cross sections, typical of normal streamcut valleys. Many of these canyons are strikingly youthful, owing to the high relief and recent uplift of the range.

CLIMATE

Jordan Valley has a semiarid temperate climate. The mean annual temperature ranges from about 51° F at Midvale and Murray to about 54° F at the edge of the Wasatch Mountains (table 1). The seasons are well defined, and daily temperatures vary considerably throughout the year. Summers are fairly hot, with many daily maxima above 90° F and occasional ones about 100° F. Winters are cold, with many daily minima below freezing and occasional ones below zero. Annual variation in the mean temperature is small: the warmest 5 years at Salt Lake City averaged 0.9° F above the 58-year average (1900–1959) and the coolest, 1.2° F below the 58-year average.

Precipitation is greater in Jordan Valley than in the extensive desert plains lying at comparable altitudes to the west because it is immediately windward of the Wasatch Range, which acts as a climatic barrier. Mean annual precipitation increases gradually from west to

TABLE 1.—*Climatic data from various stations within and near eastern Jordan Valley*

[Tr, trace; ------, not determined]

Station	Altitude (ft)	Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual: Maximum	Annual: Minimum	Annual: Mean	Annual: Average
Precipitation (inches) [1]																		
Alta	8,760	1931–51	7.68	5.28	8.91	5.26	------	------	1.10	3.23	------	------	7.52	8.73	------	------	[2] 54.37	------
Cottonwood Weir	4,961	Before 1931	1.56	1.99	2.46	2.85	2.20	0.91	1.05	1.16	1.62	1.96	1.70	1.58	27.49	12.99	20.83	------
		1931–51	1.94	1.92	2.65	2.36	2.10	1.33	.73	1.17	.76	1.98	2.01	1.99	------	------	20.94	------
Midvale	4,343	Before 1931	1.24	1.46	1.81	1.98	1.46	.76	.74	.80	1.12	1.56	1.35	1.22	24.49	11.35	14.82	------
		1931–51	1.20	1.31	1.70	1.57	1.37	.97	.68	.93	.48	1.35	1.39	1.34	------	------	14.29	------
Silver Lake (Brighton)	8,700	Before 1931	4.74	5.37	5.45	4.36	2.58	1.05	1.45	2.32	2.84	3.12	3.71	4.64	54.97	28.14	41.31	------
		1931–51	5.07	5.29	5.42	3.78	2.56	2.12	1.44	1.75	1.33	3.12	4.36	5.30	------	------	41.54	------
Salt Lake City (airport)	4,221	1901–58	1.20	1.23	1.66	1.76	1.56	.91	.61	.97	.74	1.34	1.42	1.34	------	------	14.74	------
Snowfall (depth in inches) [3]																		
Cottonwood Weir	4,961	Before 1931	22.9	23.0	18.9	13.1	0.1	0	0	0	Tr	2.3	10.0	22.1	------	------	------	112.4
		1931–51	25.4	19.2	18.7	5.9	1.3	Tr	0	0	Tr	1.5	12.1	20.3	------	------	------	104.4
Midvale	4,343	Before 1931	11.5	8.8	7.9	4.2	Tr	Tr	0	0	0	1.0	4.9	12.3	------	------	------	50.6
		1931–51	13.2	9.0	8.4	1.9	.3	Tr	0	Tr	Tr	.3	6.5	11.3	------	------	------	50.9
Silver Lake (Brighton)	8,700	Before 1931	51.6	54.1	60.4	47.2	14.2	3.2	0	Tr	5.5	16.0	43.7	50.1	------	------	------	346.0
		1931–51	64.2	63.0	64.2	38.2	12.8	3.8	Tr	0	2.3	19.4	47.1	61.4	------	------	------	376.4
Temperature (° F) [1]																		
Cottonwood Weir	4,961	1931–51	28.7	34.8	40.6	52.6	59.6	66.9	78.5	77.5	69.0	55.9	40.7	33.3	------	------	53.2	------
Midvale	4,343	Before 1931	27.5	34.2	41.0	49.1	58.4	67.0	74.8	72.8	62.7	51.0	39.6	29.1	------	------	51.0	------
		1931–51	27.2	33.2	40.6	50.5	58.6	66.6	76.1	74.3	64.5	53.2	39.0	31.9	------	------	51.3	------
Silver Lake (Brighton)	8,700	1931–51	17.8	19.8	24.1	33.2	41.4	48.7	57.4	56.5	49.0	39.2	27.2	21.8	------	------	36.3	------
Salt Lake City (airport)	4,221	1901–58	26.5	25.4	41.1	51.1	58.9	67.1	76.6	74.4	64.2	52.9	39.3	31.5	------	------	51.3	------
Maximum temperature (° F) [3]																		
Cottonwood Weir	4,961	1931–51	38.8	45.4	51.6	64.8	72.6	80.4	92.9	91.5	83.3	68.2	51.1	42.2	------	------	------	65.2
Midvale	4,343	Before 1931	38.8	44.8	53.5	63.4	74.3	85.0	92.5	90.4	80.3	66.8	52.4	39.8	------	------	------	65.2
		1931–51	37.0	43.1	52.3	64.2	73.2	82.4	92.8	90.6	81.2	68.0	50.6	41.5	------	------	------	64.7
Minimum temperature (° F) [3]																		
Cottonwood Weir	4,961	1931–51	18.5	24.2	29.7	40.4	46.7	53.4	64.1	63.5	54.7	43.6	30.2	24.4	------	------	------	41.1
Midvale	4,343	Before 1931	16.3	23.5	28.5	34.9	42.4	49.0	57.2	55.2	45.3	35.1	26.7	18.4	------	------	------	36.0
		1931–51	17.3	23.3	29.0	36.8	44.0	50.8	59.3	58.0	47.7	38.5	27.3	22.3	------	------	------	37.9

[1] Mean monthly.
[2] 1952 only.
[3] Average monthly.

east in the valley, from about 15 inches along the Jordan River to about 20 inches at the mountain front. June, July, and August are the driest months; March, April, and May, the wettest. Much of the winter precipitation is snow. Part of the summer precipitation occurs as torrential showers, but these heavy cloudbursts are rather infrequent. Mean annual evaporation is about 50–55 inches, considerably exceeding the precipitation. Annual precipitation varies greatly from year to year, much more than the temperature. At Salt Lake City the precipitation during the wettest consecutive 5 years of record was 118 percent of the 58-year average, and the precipitation during the driest 5 consecutive years of record was 88 percent of the long-time average.

The mean annual runoff from Big and Little Cottonwood Creeks into the Jordan River is about 55,000 acre-feet (Utah Univ. Bur. Econ. and Business Research, 1953, p. 11, 41).

METHODS OF STUDY

Mapping of the Quaternary surficial deposits was done on enlargements (× 2, about 1:24,000 scale) of aerial photographs taken for the U.S. Geological Survey in 1950 and then was transferred by visual inspection to the topographic base map. Emphasis in this study was stratigraphic rather than geomorphic. The surficial deposits were divided into rock-stratigraphic units, and these were mapped instead of landforms. Subaerial and lacustrine landforms such as alluvial fans, alluvial terraces, moraines, deltas, shore terraces, bars, and spits were noted but were studied less intensively. Such a procedure was followed because studies based on morphologic features alone generally have not yielded as complete and unambiguous information on lake fluctuations as have the stratigraphic studies.

The Quaternary stratigraphy was studied in exposures in valley and gully sides, road and canal banks, sewer trenches, cellar excavations, and the like. Across intervening areas where surficial materials are poorly exposed, the stratigraphic units were mapped on the basis of soil texture, and geomorphic expression, and, where needed, exposures in small dug pits a foot to several feet deep. Below the Bonneville shoreline, the uppermost stratigraphic unit was mapped if it was at least 18 inches thick and differed distinctively in texture, composition, or bedding from an underlying unit. Above the Bonneville shoreline, only deposits more than 3 feet thick were differentiated. Eolian sand of post-Lake Bonneville age was not mapped unless it was thicker than 5 feet. These rules were not followed slavishly, and, in places, deposits thinner than the minimum thickness were mapped if they were considered particularly significant.

Several dozen stratigraphic sections were measured to record the three-dimensional pattern of the stratigraphic units and their facies changes and overlaps. A like number of soil-profile sections also were measured. Selected stratigraphic sections are given on page 57, and soil-profile sections, on page 71.

The lake maxima were determined by mapping the upper altitude limits of the deposits of each lake cycle and observing the relations of these deposits to shore geomorphic features. The lake minima, which were much more difficult to determine, were found by noting subaerial features formed on or intercalated with lake sediments and by tracing subaerial features of a given age to their lowest altitude limit. These subaerial features include alluvial, colluvial, and eolian sediments; soils; and unconformities representing subaerial erosion. Tracing of subaerial features is more difficult toward the lower parts of the basin; so the lake minima were at least as low as determined for this paper but may have been still lower.

Soils were especially useful, both as stratigraphic markers in subdividing and correlating the various surficial deposits and as unambiguous indicators of lake recession. The term "soil" is restricted in this report to mean a profile of weathering, or soil profile, consisting of a layer of material that has been discernibly weathered by chemical and physical surficial agencies. Four soils, of different ages, were identified in this area. Each soil is a soil-stratigraphic unit—that is, a "soil," according to the revised stratigraphic code (American Comm. on Stratigraphic Nomenclature, 1961)—and three of the four soils are formally named. The four soils range in degree of development from very strong (very mature) to weak (immature), and each soil maintains the same degree of development relative to the others wherever it occurs. The more strongly developed soils have vertical zonation into soil horizons corresponding to the zonal and intrazonal soils proposed by soil scientists, but the weakly developed ones have only indistinct zonation. All the soils generally occur as relict soils—they have been continuously exposed at the land surface since they formed—although in local exposures they are buried by younger deposits.

The stratigraphic record shows that each soil is of a distinct geologic age and that it maintains a consistent age relation to the associated deposits; each soil is defined on the basis of this stratigraphic relationship. The geologic age of a soil is determined from that of the youngest deposit or erosion surface on which it is formed and from that of the oldest deposit which overlies it in as many different environments as possible.

All the soils change appreciably in their general profile characteristics from one part of the area to another, particularly in relation to altitude. For example, a given soil may be a Brown Podzolic soil, characterized by a bleached A_2 bleicherde subhorizon, in high mountains; a Noncalcic Brown soil in the lower mountain and higher piedmont belt; and a Calcic Brown soil, characterized by a calcareous (C_{ca}) horizon, at lower altitudes. These changes are considered to be changes in facies of a soil. The soil-facies terms used in this report differ somewhat from those used by Richmond (1964). Noncalcic Brown soil in this report is generally equivalent to Brown Podzolic soil as used by Richmond, and Calcic Brown soil is equivalent to the Brown soil of Richmond.

The three oldest soils are distinctive markers. They provide the chief means of subdividing and correlating the main rock-stratigraphic units in the lacustrine, alluvial, and glacial successions because none of these sequences has any other distinctive marker horizon or particularly distinctive lithology between its component units. Typical examples of how soils are used for these purposes are shown in figures 2, 9, 10, 14, 18, and 21.

The descriptive nomenclature used for soils in this report follows that adopted by the U.S. Department of Agriculture (1951). Color names are from the 1954 edition of the Munsell Soil Color Charts, which have been adopted by the U.S. Department of Agriculture. These commonly differ from standard Munsell color names although the symbols are the same.

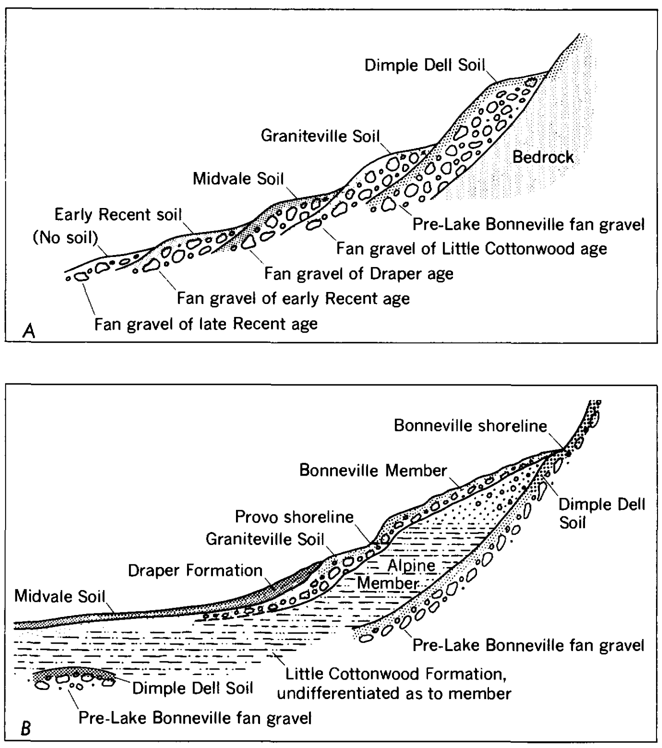

FIGURE 2.—The Dimple Dell, Graniteville, and Midvale Soils and the early Recent soil. *A*, Section showing how these soils are used to differentiate fan gravels of various ages. *B*, Section showing relations of the Dimple Dell, Graniteville, and Midvale Soils to various units in the Lake Bonneville Group. Darker shades of the soil colors are Pedalfer (Noncalcic Brown soil) facies; lighter shades are Pedocal (Calcic Brown soil) facies. Effects of post-soil erosion are not shown.

SPECIAL ADVANTAGES AND DISADVANTAGES OF STUDYING THE AREA

Among the advantages of this area for a stratigraphic surficial study, in addition to the above-mentioned moraine-high-lakeshore relations, are the fairly deep dissection (locally 100 ft or more) of the Quaternary deposits and the fairly continuous exposures along Dry Creek, along the north side of Little Cottonwood Creek for several miles below Wasatch Boulevard, and along the inner valley of the Jordan River. The exposures along the inner valley of the Jordan River—among the lowest in the Lake Bonneville area—extend to an altitude as low as 4,235 feet.

Chief among the disadvantages is the paucity of good exposures in most parts of the area. Most of the surficial deposits are poorly consolidated, and cuts slump quickly under the existing climate. Few exposures are deep and continuous enough to reveal more than small parts of the local succession or to permit reliable lateral tracings of units. This difficulty is compounded on the Cottonwood delta, where the lacustrine units are especially thick. Buried soils and other evidences of disconformity (recording subaerial exposure) between lacustrine units are rarely exposed—most of the best exposures are ephemeral ones such as cellar and sewer excavations. Especially complicating in the mapping and local correlation of units in parts of the area are the absence of any marker horizons except soils, the marked lateral and (or) vertical facies variability of some units, and the lithologic similarity of some units. Thus difference in relict soils is one of the few available criteria for stratigraphic classification and local correlation.

PRE-QUATERNARY GEOLOGY

Pre-Quaternary rocks are exposed extensively in the Wasatch Mountains as far west as the base of the mountain front but not in the interior of Jordan Valley except for several small outcrops of the Oquirrh Formation at the southern edge of the area mapped. Table 2 summarizes the characteristics of the principal pre-Quaternary units. Several units of distinctive lithology and limited occurrence (indicated by asterisks in table 2) give valuable clues to the provenance of the

TABLE 2.—*Pre-Quaternary stratigraphy of the Wasatch Mountains adjoining Jordan Valley*

[Includes the more resistant formations exposed on the western slope of the Wasatch Mountains from north of the area mapped to Parleys Canyon; based on Crittenden, Sharp, and Calkins (1952, p. 3-18). Units of Pennsylvanian through Jurassic age exposed only north of Little Cottonwood Canyon. Asterisk indicates units that furnish debris that is especially distinctive and useful for determining the provenance of alluvial, lacustrine, and glacial gravels]

Age	Stratigraphic unit	Character	Maximum thickness (ft)
		Sedimentary and metamorphic rocks	
Jurassic	*Nugget Sandstone	Sandstone, pale-terra-cotta; strongly crossbedded	800
Triassic	*Ankareh Formation	Sandstone and much shale, brilliant dark-red; contains a little red to pale-gray limestone. Divided near middle by a 50–100-ft bed of pale-purplish-red gritty quartzite.	1,575
Triassic	Thaynes Formation	Shale and fine-grained limy sandstone; generally pale drab or green; weathers tobacco brown; interbedded with some light-gray limestone.	1,000
Triassic	Woodside Formation	Shale and siltstone, dark-red (locally green owing to secondary alteration), poorly exposed	1,000
Permian	Park City Formation	Limestone, limy shale, and sandstone	600
Carboniferous: Pennsylvanian	*Weber Quartzite	Quartzite and quartzite sandstone, pale-gray, tawny-weathering; interbedded with limy and dolomitic quartzite and sandstone and buff to blue-gray cherty limestone and dolomite. Forms steep slopes and abundant talus.	1,500
Carboniferous: Pennsylvanian	Morgan(?) Formation	Limestone, pale-gray; interbedded with pink chert and minor green shale and quartzite	300
		Unconformity	
Carboniferous: Mississippian	Doughnut Formation	Limestone, dark-gray to black, fossiliferous; 50–100 ft of black limy shale at base	300
Carboniferous: Mississippian	Humbug Formation	Lower half alternate dark- to light-gray limestone, dolomite and subordinate (±25 percent) fine-grained gray (weathering light grayish brown) sandstone and a little shale; upper half, very fine grained, nearly black to blue-gray (weathering buff) limestone. Marine.	400±
Carboniferous: Mississippian	Deseret Limestone	At base, 25 ± ft nearly black shale and shaly limestone; remainder is blue-gray limestone and dolomite, darker in color, more cherty, and less fossiliferous than Madison Limestone.	850±
Carboniferous: Mississippian	Madison Limestone	Limestone, blue-gray, well-bedded; richly fossiliferous, especially in lowest 50 ft; minor cherty beds locally; naer Alta, locally bleached to light gray and white.	450±
Carboniferous: Mississippian	Dolomite	Jefferson(?) Dolomite of Calkins and Butler (1943). At base, 2–5 ft yellow limy sandstone and sandy shale; remainder is two thick layers of massive dolomite, the lower one pale gray, the upper one dark lead gray.	135±
		Angular unconformity; erosion surface	
Cambrian	Maxfield Limestone	Lower part, blue pisolitic limestone at base, then 15 ft very fine grained light-gray to black dolomite; middle part mainly nodules of white limestone imbedded in dark argillite, some dark shale; upper part pale gray to sooty-black dolomite.	1,000±
Cambrian	Ophir Shale	Lower 250 ft dull olive-green micaceous shale; middle member 80 ft blue-gray to white limestone with wavy brown laminae; upper part, limy shale weathering yellowish brown, with blocky fracture.	400±
Cambrian	*Tintic Quartzite	Quartzite, white to pink; weathers somewhat rusty; 1–4-ft pebble- to small cobble-conglomerate qaurtzite at base; greenish shale at top, transitional into Ophir Shale.	800±
Younger Precambrian	*Mutual Formation	Quartzite, red-purple, medium- to coarse-grained, and variegated red and green shale (brighter colored than the Big Cottonwood Formation). Exposed in Big Cottonwood (but not in Little Cottonwood) drainage area.	1,200
		Small angular unconformity; erosion surface	
Younger Precambrian	*Mineral Fork Tillite	Mainly black tillite—boulders, cobbles, and pebbles of quartzite, limestone, and granitic rocks in abundant black sandy matrix; some black and dark-gray varved slate and shale; local dark-gray quartzite and boulder conglomerate (channel fillings).	1,000±
		Unconformity; erosion surface	
Younger Precambrian	Big Cottonwood Formation	Quartzite, white, pink, and green, rusty-weathering; interbedded with red, green, and blue-purple shale and argillite; beds commonly show ripple marks, mud cracks, and minor crossbedding.	16,000±
		Unconformity	
Older Precambrian	Little Willow Series	Quartz-mica schist, gneissic quartzite, and stretched-pebble schists, cut by basic igneous rocks, which now are amphibolite or chlorite schist.	(?)
		Igneous rocks	
Tertiary(?): Eocene(?)	Dikes	Diorite, granodiorite porphyry, monzonite porphyry, lamprophyre, alaskite.	
Tertiary(?): Eocene(?)	*Quartz monzonite (Little Cottonwood stock).	Quartz monzonite coarsely porphyritic, coarse-grained, light-gray.	
Tertiary(?): Eocene(?)	*Granodiorite (Alta stock).	Granodiorite, medium-grained, gray; has granitic texture.	

lacustrine, alluvial, and glacial gravels. Debris from these units has commonly been traced 10–20 miles and more from its source areas.

The pre-Quaternary units in the vicinity of this area are mainly sedimentary rocks ranging in age from older Precambrian to Mississippian. They are intruded by two large stocks of quartz monzonite and granodiorite, respectively, and by numerous dikes, all of early Tertiary(?) age. A complex structural pattern has been produced by folds of several ages, as well as by numerous faults, both thrust and normal. The present Wasatch Mountains are essentially the core of an ancient mountain range that has been reelevated by Tertiary and Quaternary block faulting. The reports of Calkins and Butler (1943); Crittenden, Sharp, and Calkins (1952; written communication, 1960) contain the most comprehensive and up-to-date accounts of the pre-Quaternary stratigraphy, structure, and ore deposits, as well as geologic maps showing the distribution of the pre-Quaternary units.

QUATERNARY STRATIGRAPHY

PRE-LAKE BONNEVILLE FAN GRAVELS AND TILL

The oldest surficial deposits in the area are local remnants of ancient gravels along the Wasatch Mountain front. All bear the Dimple Dell Soil of pre-Lake Bonneville age. They have a heterogeneous lithology that bespeaks considerable transport, distinguishes them from pre-Lake Bonneville colluvium, and identifies them as either alluvial-fan gravel or till. They generally cannot be differentiated as to alluvium or till on the basis of lithology, and morphologic features diagnostic of origin generally have been removed by erosion. Most of the remnants are on ridges between fairly short canyons that neither were likely sites for, nor show evidence of, glaciation in pre-Lake Bonneville time to altitudes as low as those of the gravel patches; hence, such remnants are presumed to be ancient fan gravels. The origin of several remnants bordering Little Cottonwood Canyon is controversial, however, as will be explained later.

The topographic position of the high gravel remnants, perched far above the present beds of their source streams, and their position with respect to faceted spurs and known faults along the Wasatch Mountain front suggest that they have been faulted up with respect to Jordan Valley by intermittent Quaternary faulting. The highest remnants, being displaced the most, presumably are the oldest. On this basis, gravels of two ages are differentiated on the map: the older pre-Lake Bonneville fan gravel and till and the younger pre-Lake Bonneville fan gravel.

The highest gravel remnant lies between altitudes of 6,800 and 7,100 feet in a saddle on the ridge between Little Cottonwood and Bells Canyons, just east of the ridge's 6,928-foot summit; a part of the remnant extends down the side of Bells Canyon to an altitude of 6,600 feet. Richmond (1964) described the bipartite character of this remnant and gave reasons for inferring that one part is till from a glacier from Little Cottonwood Canyon and that the other part is till from a probably coeval glacier from Bells Canyon. He correlated these tills with the youngest of three pre-Bull Lake tills in the Rocky Mountain region.

Another high remnant, probably fan gravel, reportedly (M.D. Crittenden, Jr., written commun., 1960) mantles a bench at an altitude of about 6,800 feet on the south side of the canyon of the North Fork of Little Willow Canyon (north of Little Cottonwood Creek). This gravel includes 3- to 4-foot boulders of quartz monzonite from the Little Cottonwood stock.

The most complete and best preserved series of ancient gravels in the area is on the ridge just north of the mouth of Little Cottonwood Canyon. Here, patches of these gravels lie at four distinct levels. The three highest patches are problematic as to origin; they are either fan gravel or till. They are deeply eroded and weathered and lack any incontrovertible indications as to alluvial or glacial origin.

The highest gravel patch is at an altitude of 6,500–6,600 feet (more than 2,200 ft above the present bed of Little Cottonwood Creek) and consists of scattered small boulders and cobbles of quartzite, hornfels, Mineral Fork Tillite, and resistant metamorphics from the Little Cottonwood drainage area. The next lower remnant, at an altitude of 6,000–6,400 feet, is the largest and thickest exposure of ancient gravel in the area; it covers several acres and is at least 100 feet in maximum thickness. Richmond (1964) inferred that this deposit is probably till correlative with the second-oldest pre-Bull Lake glaciation in the Rocky Mountain region. I, however, consider that this deposit more likely is fan gravel and that it is younger than the above-mentioned ancient till on the south side of Little Cottonwood Canyon because it is several hundred feet lower. It underlies a prominent bench on a northward bend in the spur, almost directly in line with the unnamed gulch lying immediately north of Little Cottonwood Canyon, and consists of rocks typical of the drainage area of this gulch—quartzite and hornfels of the Big Cottonwood Formation, gneissic to schistose metamorphic rocks of the Little Willow Series, and various dike rocks peripheral to, and essentially congenetic with, the Little Cottonwood stock. No quartz monzonite typical of the main parts of the Little Cottonwood stock was seen, although this rock type is a major constituent of all the known tills, as well as the alluvial gravels, below the mouth of Little Cottonwood Canyon. The bulk of this deposit evidently came from the gulch, which shows no sign of having been glaciated, and hence is probably fan gravel. One pebble of Mineral Fork Tillite, found at the southern margin of this exposure, however, indicates minor contribution from Little Cottonwood Canyon, but whether it came as alluvium or till is impossible to determine.

The next lower occurrence on the ridge north of Little Cottonwood Creek is a band of scattered boulders and cobbles on the steep south slope of this ridge at an altitude of about 5,700–5,900 feet and directly above the lateral moraine of Bull Lake age. All the more resistant lithologies typical of the Little Cottonwood drainage area are represented, including quartz monzonite of the Little Cottonwood stock. Richmond interpreted this poorly preserved occurrence as till, but the evidence is inconclusive.

The lowest occurrence of gravel on this ridge, designated as younger pre-Lake Bonneville fan gravel, lies north of the Bull Lake lateral moraine between altitudes of 5,200 and 5,400 feet. It consists entirely of rocks from the drainage area of the unnamed gulch just north of Little Cottonwood Creek. Toward the mountain front it is overlain by several feet to perhaps 20 feet of finer colluvium that bears the Dimple Dell Soil. Both the colluvium and the fan gravel are overlain by the lateral moraine of Bull Lake age. The steep front of this fan gravel remnant and its position more than 100 feet above the present bed of the wash suggest that it was faulted up (with respect to Jordan Valley) at least this much prior to Lake Bonneville time.

Other fan gravel remnants, at comparable altitudes along the range front and probably of about the same age, border the mouths of a few of the smaller canyons north and south of Little Cottonwood Canyon. The remnants at the mouth of Little Willow Canyon are found as high as an altitude of 5,700 feet and contain many fairly well rounded boulders, cobbles, and pebbles. A patch south of the mouth of Middle Fork of Dry Creek at an altitude of about 5,200 feet bears the Dimple Dell Soil and is overlapped by till of the early stade of Bull Lake Glaciation in Bells Canyon. Another patch lies on the north side of the mouth of this canyon at an altitude of about 5,400 feet.

No till of pre-Lake Bonneville age has been identified at low altitudes along the base of the mountains. Both the moraines below the mouths of Little Cottonwood and Bells Canyons that Marsell (1946b) considered to be of pre-Lake Bonneville age and the oldest of the "Graniteville erratics" of Ives (1950) are correlated by Richmond (1964) and me with the Bull Lake Glaciation.

Two exposures of pre-Lake Bonneville fan gravel were noted below the Bonneville shoreline. One is in the south bank of Dry Creek, in the NE¼SE¼ sec. 15, T. 3 S., R. 1 E. (stratigraphic section 18), at an altitude of about 4,760 feet. It shows 5½ feet of well-rounded cobble-and-pebble gravel, either alluvial or lacustrine, overlain by several feet of poorly sorted pebbly and sandy silt, evidently a wash flood-plain deposit, bearing the Dimple Dell Soil (with both the C_{ca} horizon and lower part of the B horizon preserved); the soil in turn is overlain by a thick succession of sand, silt, and clay of the Alpine Member of the Little Cottonwood Formation. The other exposure is at an altitude of 4,425–4,440 feet on the western tip of a low ridge 1¼ miles southwest of Crescent and about ¾ mile east of the Jordan River (N½ sec. 25, T. 3 S., R. 1 W.). It is poorly bedded well-rounded pebble gravel but includes some cobbles, rarely as much as 8 inches in diameter. This occurrence now lies at least 100 feet too high to be accordant with the piedmont slopes on the western side of the basin, thus suggesting that it has been faulted up relative to the western piedmont. The fan gravel locally bears the Dimple Dell Soil—commonly several feet of very strong C_{ca} horizon and, in the least eroded areas, a few inches of the lower part of the B horizon (the B_{ca} subhorizon). Overlying both the gravel and the soil is the Alpine Member of the Little Cottonwood Formation.

All the deposits of ancient fan gravels and till are older than Lake Bonneville, but they probably differ greatly in age. The two lowest outcrops—the one west of Crescent and the one along Dry Creek— are presumed to be comparatively young by reason of their direct and apparently almost conformable overlap by the Alpine Member of the Little Cottonwood Formation. They are probably only a little older than the Dimple Dell Soil, which itself preceded the first rise of the lake by a comparatively short interval. The deposit at an altitude of 6,000–6,400 feet on the ridge north of the mouth of Little Cottonwood Canyon is approximately accordant with a lower broad-valley surface along this canyon that is recorded by bench remnants 300 feet above Little Cottonwood Creek near the head of the canyon and 1,000 feet above the creek near the canyon mouth (Richmond, 1964). Richmond believed this surface to be of middle Pleistocene age and correlative with a broad valley surface in Emmigration Canyon which Crittenden, Sharp, and Calkins (1952) correlated with the Weber Valley surface of Eardley (1944; 1952, p. 59–60; 1955, fig. 9, p. 39, 43). This broad-valley surface also is evident in Big Cottonwood Canyon.

The highest gravel on this ridge, as well as that high on the south side of the North Fork of Little Willow Canyon and the deposit on the south side of Little Cottonwood Canyon, is about 1,000 feet below the projected upper broad-valley surface that Richmond inferred from accordant crests of ridges between the principal tributaries of Little Cottonwood Canyon. Richmond considered this surface to be late Pliocene or early Pleistocene, hence these gravels likely are early or middle Pleistocene.

The pre-Lake Bonneville fan gravel probably is correlative with the upper artesian aquifer of the pre-Lake Bonneville deposits of Hunt and Thomas (in Hunt, Varnes, and Thomas, 1953, p. 14–17, 82–85) in northern Utah Valley, with the pre-Lake Bonneville fan gravel of Bissell (1963) in southern Utah Valley, and with the so-called basal fanglomerate member of the green clay series of Jones and Marsell (1955, p. 91–92) in Lower Jordan Valley.[1]

The few tiny exposures of ancient fan gravels in the mapped part of the Jordan Valley understate the significance of subsurface equivalents in the basin interior. Well logs and gravity measurements indicate that several hundred to several thousand feet of pre-Lake Bonneville Quaternary fill exist in various parts of the basin. Wells within several miles of the Wasatch Mountains penetrated—beneath sand, silt, and clay referable to the Little Cottonwood Formation—approximately 100 feet of gravel and sand that I tentatively correlate with the pre-Lake Bonneville fan gravel. Available data are insufficient, however, to permit correlation of deeper subsurface units with any of the older exposed gravels.

PRE-LAKE BONNEVILLE COLLUVIUM

Colluvium of pre-Lake Bonneville age is exposed in a belt along the lower slopes of the Wasatch Range. It extensively mantles the gentler slopes and is much more widespread than the ancient fan gravels. It diminishes in abundance with steepness of slope and increase in altitude because of reworking by younger mass wasting, and above altitudes of 7,000–8,000 feet it is generally absent. This colluvium is chiefly creep mantle and slope-wash mantle; locally it is solifluction mantle. It is mostly clay- to angular pebble-sized fragments, although large blocks occur locally. The lithology of the colluvium intimately reflects that of the bedrock a short distance directly upslope, indicating limited downslope transport. The Dimple Dell Soil is locally preserved on this colluvium and aids in differentiating it from younger deposits. On the upper surface of the lowest remnant of pre-Lake Bonneville fan gravel on the ridge north of the mouth of Little Cottonwood Canyon, the fan gravel is locally veneered by a few feet of colluvium bearing the Dimple Dell Soil (fig. 9). This colluvium attests to an interval of active mass wasting after the alluviation represented by the fan gravel and prior to the development of the soil.

[1] The green clay series described by Jones and Marsell (1955) is known primarily from well data, and its subsurface thickness is said to be 800–1,000 feet, far greater than the thickness of the Lake Bonneville Group. The subsurface section through eastern Jordan Valley given by Jones and Marsell (1955, fig. 25) together with well logs shows that the green clay series consists of gravel and sand from the east (the so-called basal fanglomerate member) that intertongues fairly regularly westward, top to bottom, with pre-Lake Bonneville silt and clay (the green clay facies). Only one good outcrop of the green clay facies was cited by Jones and Marsell; this is near "The Old Mill," below the mouth of Big Cottonwood Canyon. The series underlies terrace gravel coeval with the Provo Member and is lithologically typical of the Alpine Member of the Little Cottonwood Formation in the vicinity. In lieu of positive evidence of greater age, I therefore prefer to correlate this exposure with the Alpine Member.

DIMPLE DELL SOIL

All the deposits older than Lake Bonneville locally bear a characteristic and very strongly developed (very mature) soil, here named the Dimple Dell Soil after the Dimple Dell Road near its type locality. This soil is equivalent to the pre-Wisconsin paleosol of Hunt and Sokoloff (1950), the ancient soils of pre-Lake Bonneville Pleistocene age of Hunt (1953b, p. 43–44), the pre-Alpine soils of Eardley, Gvosdetsky, and Marsell (1957, p. 1191–1194), and the pre-Lake Bonneville soil of Morrison (1961a, b), and Richmond (1964). The Dimple Dell Soil, where its original profile is well preserved, is much more strongly developed than any of the younger soils, but because of its greater age it commonly is deeply eroded and is completely eroded in many places.

Nearly all exposures of the Dimple Dell Soil are on the western frontal slopes of the Wasatch Mountains close to the base of the mountains. Most of these exposures are relict occurrences with fairly full profiles locally preserved on the flatter surfaces of remnants of pre-Lake Bonneville fan gravel and colluvium. Especially well preserved relict profiles can be seen on pre-Lake Bonneville fan gravel just below the mouth of the canyon of Middle Fork of Dry Creek (vicinity of NW cor. SW¼ sec. 13, T. 3 S., R. 1 E.) and on pre-Lake Bonneville colluvium and the lowest patch of pre-Lake Bonneville fan gravel on the ridge north of the mouth of Little Cottonwood Canyon (soil-profile section S–5)—here the banks of a road built in 1961 afford superlative exposures.

Only two exposures of the Dimple Dell Soil were found in the area, and in both exposures the soil is developed on pre-Lake Bonneville alluvium and is overlain by the Little Cottonwood Formation. One exposure is several hundred feet long in the bank of Dry Creek about 1⅓ miles west of the mountain front and is the type locality (see below) for this soil. The other exposure covers several acres near the mouth of Willow Creek, about 1 mile east of the Jordan River, in the N½N½ sec. 25, T. 3 S., R. 1 W., at an altitude of about 4,400 feet.

The type locality for the Dimple Dell Soil is in the south bank of Dry Creek (the lower exposure described in stratigraphic section 18), in the NW¼SE¼ sec. 15, T. 3 S., R 1 E., at an altitude of about 4,770 feet (fig. 3). This exposure excellently shows the stratigraphic relations of this soil, which is developed in its Pedocal (Calcic Brown soil) facies. The B horizon is somewhat atypical for this facies, however. See p. 13.)

All exposures of the Dimple Dell Soil on the Wasatch Mountain front and along the base of the mountains are Pedalfers that lack a calcareous (C_{ca}) horizon. This soil facies seems to belong either to the Prairie soils

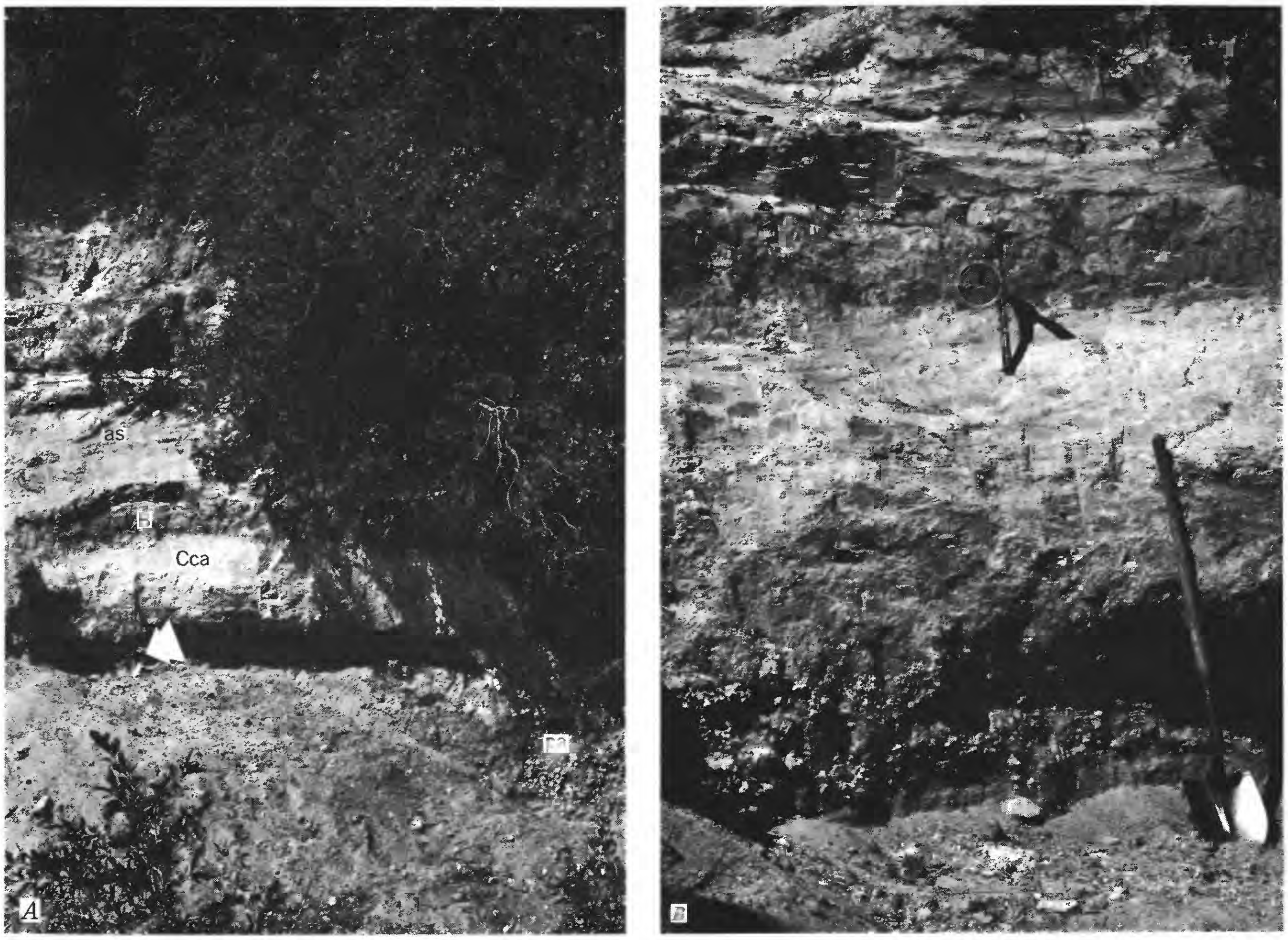

FIGURE 3.—Dimple Dell Soil at its type locality. *A*, Calcic Brown soil facies, with a calcareous horizon (C_{ca}) about 4 feet thick—the white band against which the shovel handle rests. The overlying B horizon (B) is partly eroded, with only 6–8 inches of the B_3 subhorizon remaining. The soil is developed on pre-Lake Bonneville alluvial gravel (pa) and it is overlain by sand and silt of the Alpine Member (as). Shovel is 4 feet long. *B*, Close-up. Pick point marks the top of the eroded B horizon; only the B_3 subhorizon remains. Pick handle is 18 inches long. Stratigraphic section 18 site (lower exposure), south bank of Dry Creek, NW¼SE¼ sec. 15, T. 3 S., R. 1 E.

of Marbut (1935), the Soil Survey Staff of the U.S. Department of Agriculture (1938, p. 1052), and Joffe (1949, p. 316–328), or to the Degraded Chernozem soils or Noncalcic Brown soils of Baldwin, Kellogg, and Thorp (1938, p. 993, 997). In this report this facies is designated as a Noncalcic Brown soil. Westward, because of decreasing precipitation due to decreasing altitude and increasing distance from the mountains, this soil changes facies in the usual manner and becomes a Pedocal (Calcic Brown soil) with a strongly developed calcareous (C_{ca}) horizon. The Pedocal facies is represented by the two aforementioned buried occurrences. The easternmost of these is only 1½ miles from the mountain front; so evidently the change from Pedalfer to Pedocal facies here lies within a mile west of the base of the mountains (see pl. 2).[2] Although the Pedocal facies looks quite different from the Pedalfer facies, this soil is so distinctive in its markedly stronger development relative to the younger soils that it can be unmistakably identified and correlated.

All exposures of the Dimple Dell Soil lack the original A horizon, probably because of erosion, though an A horizon of younger age is locally present in relict occurrences. No evidence of a bleached A_2 (podzolic) subhorizon was seen in any exposures. The B (argillic, or oxide) horizon is thicker in the Pedalfer than in the

[2] Hunt (1953b, p. 43–44) and Bissell (1963) described only the Pedocal facies of this soil in Utah Valley. Evidently in Utah Valley the Pedalfer-Pedocal facies boundary lies farther eastward in relation to the Wasatch Mountain front than it does in Jordan Valley.

Pedocal facies. In the Pedalfer (Noncalcic Brown soil) facies this horizon is commonly more than 5 feet thick and locally is as much as 8 feet thick, where least eroded. The upper 1–2 feet is generally moderate-reddish-brown (5*YR* 5/4 to 5*YR* 4/4) clay loam or clay that is very stony. Its structure is moderate to strong, medium to coarse prismatic to coarse to very coarse angular blocky; its consistence is hard to very hard, sticky, and plastic. Practically all the pebbles are quartzite and siliceous hornfels, though locally much-rotted quartz monzonite and granitic gneiss can be distinguished. In the next several feet downward this horizon very gradually becomes more yellowish brown (about 7.5*YR* 4/4), lighter colored, and less clayey, and has weaker structure and softer consistence; also, the proportion of granitic pebbles increases where the parent material contains such pebbles.

In the two exposures of the Pedocal (Calcic Brown soil) facies, the upper part of the B horizon has been partly eroded and only a few inches to about a foot of the B horizon is preserved; the overlying Alpine Member of the Little Cottonwood Formation is invariably somewhat disconformable. The exposure on Dry Creek is representative of this facies, except for the B horizon which is probably somewhat atypical. Here the B horizon is slightly less than a foot thick and, even allowing for minor erosion, seems to have been abnormally thin in its original development. It also is unusually light colored, grayish, and in the 10*YR* instead of the 7.5*YR* hue. B horizons of this type are typical of Calcic Brown soils that have formed in poorly drained locations, where a shallow water table and lush vegetation tended to cause a reducing environment and inhibit oxidation to reddish (ferric) iron oxides.[3]

The C_{ca} horizon is only about 4 feet thick at the Dry Creek exposure; there it consists of very strong white calcium carbonate (caliche) concentrations in the upper half and becomes somewhat weaker downward. The exposure near the Jordan River appears to have a comparable C_{ca} horizon, although here the base of this horizon is not exposed. There is no suggestion of a C_{ca} horizon as much as 12 to locally 20 feet thick, as reported from northern Utah Valley (Hunt, 1953b, p. 44). Possibly the occurrences of very thick C_{ca} horizons represent increments from more than one soil-forming interval in pre-Lake Bonneville Quaternary time.

Evidence of age.—The Dimple Dell Soil is overlain by the Alpine Member of the Little Cottonwood Formation, the earliest sediments of Lake Bonneville. It is also transgressed by the lower till of the Bull Lake Glaciation on the ridge north of the mouth of Little Cottonwood Canyon and below the mouth of the canyon of the Middle Fork of Dry Creek. This soil occurs locally on the youngest known fan gravel and colluvium of pre-Lake Bonneville age, and these occurrences have profiles essentially identical with those on older deposits. All occurrences are on land surfaces that, except locally, are only slightly eroded. From their reasonably close adjustment with present topography, the oldest of these surfaces are probably no older than middle Quaternary. Neither the character nor the stratigraphic relations of the soil signify that the main time of soil formation was early Miocene, Oligocene, or even late Eocene, as suggested by Eardley, Gvosdetsky, and Marsell (1957, p. 1194). All the available evidence points to a pre-Lake Bonneville Quaternary age, perhaps during one or more of the pre-Wisconsin (pre-Bull Lake) interglaciations, as Hunt (1953b, p. 42–44) and Hunt and Sokoloff (1950, p. 115) concluded. The last interval of its development was probably the last interglaciation prior to the first rise of Lake Bonneville and the first advance of Bull Lake Glaciation.

LAKE BONNEVILLE GROUP

STRATIGRAPHIC NOMENCLATURE

Hunt (1953b) pioneered the modern stratigraphic studies of Lake Bonneville by subdividing the lake deposits into formations and mapping them comprehensively over an extensive area. He designated the deposits as the Lake Bonneville group [4] and divided the

[3] The Pedocal facies of this soil in northern Utah Valley has a B horizon locally as much as 10 feet thick (Hunt, 1953b, p. 43). Recent reconnaissance and detailed studies in many other parts of the Lake Bonneville drainage area show that in this facies the B horizon generally is less than 3 ft thick, and rarely is as much as 5 or 6 ft thick. Greater apparent thicknesses commonly are measured, however, in shallow ravines or depressions where an upper zone of material derived from the original B horizon has been moved by solifluction or other mass-waste processes. This upper reworked zone obviously is not properly a part of the original soil profile, but in some places it is difficult to distinguish exactly between the two.

[4] Hunt (1953b, p. 17) defined the Lake Bonneville Group as follows: "The deposits that were laid down in Lake Bonneville in northern Utah Valley can be divided into three formations, each of which represents a different stage in the history of the old lake. These are the Alpine, Bonneville, and Provo formations, and they correspond respectively to what Gilbert (1890, p. 90–152) referred to as the Intermediate, Bonneville, and Provo stages of the lake. Around Great Salt Lake, Gilbert recognized a fourth stage that he named the Stansbury. This is the youngest stage and represents a lake level lower than the other three and approximately at the level of Utah Lake."

group into three formations, Alpine, Bonneville, and Provo. His methods and nomenclature served as a guide for further productive studies by Bissell (1952, 1963), J. S. Williams (1962), Varnes and Van Horn (1951, 1961), Jones and Marsell (1955), and Eardley Gvosdetsky, and Marsell (1957). These later workers generally adopted Hunt's formational names for units in their areas but made various significant changes in usage. Table 3 illustrates the principal differences in usage and the resulting ambiguity.

The principal problems posed by the Alpine, Bonneville, and Provo Formations as originally defined[5] are as follows:

1. These formations are defined mainly in terms of inferred lake history, not primarily on lithologic content, which is contrary to currently recommended stratigraphic procedure (Am. Comm. Stratigraphic Nomenclature, 1956, 1961).
2. Each formation is defined as the deposits of a given lake stage; the term "stage" is used principally to denote water level but is used also in a time sense.
3. The definitions of these formations are not tied to specific type localities and hence are susceptible to rather widely varying interpretations as to stratigraphic content.
4. Stratigraphic criteria for separating and correlating the formations, such as distinctive lithologies, contact relations, soils, and unconformities, are scarcely discussed.
5. By defining the formations as deposits of a given lake stage (lake level), the deposits laid down while the lake was rising to or receding from this level are ignored; yet later studies have shown them to be significant both volumetrically and as records of lake history.

These problems necessitate either expanding the formations by redefining them or adding new units to the Lake Bonneville Group to include the omitted deposits.

Hunt's interpretation (1953b) of the lake history was oversimplified, as shown by later studies—he essentially agreed with Gilbert's (1890) interpretation—and the formational units that Hunt set up require considerable modification to accommodate the more recent findings. The Provo Formation (as mapped by Hunt) presents the most difficulty. The present study shows that the Provo Formation is a multiple unit: one part is much younger than the other and is separated from the older part by the most pronounced disconformity within the Lake Bonneville Group; also, the younger part records three successive lake maxima.

[5] The original definitions (Hunt, 1953b, p. 17–21) are quoted on pages 17, 21, and 23 of this report.

In eastern Jordan Valley neither the Alpine, Bonneville, and Provo Formations, as defined by Hunt (1953b), nor my own modified units, which are approximately equivalent to those of Hunt, meet the mappability requirement for formational status. My 1:24,000-scale mapping showed that the Alpine could not be differentiated clearly from the Bonneville and Provo in at least two-thirds of the good exposures; hence these units merit only member rank. Other geologists—Jones and Marsell (1955), Eardley and others (1957), A. J. Eardley (oral commun., September 1960), J. Stewart Williams (1962)—working in other areas have likewise had difficulty in differentiating these units on other than a local basis.

Bissell, Williams, Jones, and Marsell, and Eardley, Gvosdetsky, and Marsell made various changes in stratigraphic nomenclature from Hunt's original definitions without resolving some of the more serious deficiencies. The present investigation provided the stratigraphic data for a workable redefinition of the Lake Bonneville Group. It showed that this group comprises two main units that can readily be differentiated in mapping on the basis of generally contrasting lithology, the separating Graniteville Soil, and a widespread disconformity that records a long interval of lake desiccation and subaerial erosion in the basin interior. (The units are not differentiated on the basis of inferred lake history or of morphologic position and features.) In this report, the Lake Bonneville Group is divided into two newly named and defined formations, the Little Cottonwood and the Draper. The Alpine, Bonneville,[6] and Provo, which were formerly formations, are redefined as members of the Little Cottonwood. The Little Cottonwood comprises deposits of the early oscillations of Lake Bonneville, including at least three major lake cycles (fig. 4). The Draper records at least three later lake cycles.

LITTLE COTTONWOOD FORMATION

The Little Cottonwood Formation, the oldest unit of the Lake Bonneville Group, is composed of lacustrine sediments—mainly gravel, sand, silt, and clay. It over-

[6] The Bonneville and Provo Formations were named after Gilbert's shoreline names. Such interchanging of geomorphic and rock-stratigraphic names is semantically unwise and has been responsible for much confusion in Quaternary research. Nevertheless, Bonneville and Provo are retained as rock-stratigraphic names in this report inasmuch as they already have become well established in this usage and as introduction of new names would be unnecessarily confusing. Gilbert himself was meticulously careful in using separate nomenclature for the morphologic features and for the deposits of Lake Bonneville: he applied names such as Intermediate, Bonneville, Provo, and Stansbury only to shorelines and shore morphologic features (shore terraces, spits, bars, and deltas) and never used them for deposits.

TABLE 3.—*Interpretation of usage of names for subdivisions of the Lake Bonneville Group*

[Glacial deposits excluded]

Hunt (1953b)	Jones and Marsell (1955)	Eardley, Gvosdetsky, and Marsell (1957)	Williams (1962)	Bissell (1963)	Morrison (this report)
Post-Provo alluvial and lacustrine deposits; modern soils	Post-Provo lacustrine, fluvial, and eolian sediments	Deposits of Great Salt Lake	Post-Lake Bonneville alluvium, slope wash, eolian sand, and spring tufa	Deposits of Utah Lake and alluvium of Utah Lake age	Recent alluvium
		Soil			Early Recent soil
		Gilbert deposits (lacustrine; max. alt. 4,245 ft)		Late- and post-Provo, pre-Utah Lake fan gravel; post-Provo eolian sand and silt	Post-Draper eolian sand and loess
		DISCONFORMITY			Midvale Soil
Provo formation (as mapped—mainly lacustrine, some alluvial)		Stansbury deposits (lacustrine; max. alt. 4,470± ft)			Lake Bonneville Group (lacustrine): Draper Formation: Upper tongue (max alt. 4,410 ft) (Local diastem above altitude of 4,360 ft)
		Disconformity; soil			Middle tongue (max. alt. 4,470 ft) (Local diastem above altitude of 4,450 ft)
	Provo formation (lacustrine): Provo 2 deposits (max alt 4,760 ft)	Provo 2 deposits (lacustrine; max. alt. 4,800 ft)	Lake Bonneville group: Provo formation (lacustrine)	Lake Bonneville group: Provo formation (lacustrine): Provo 2 deposits (max. alt. 4,770 ft)	Lower tongue (max. alt. 4,470 ft)
	DIASTEM	Diastem above altitude of 4,300 ft; soil		Diastem, loess, alluvium, volcanic ash, and weak soil at above altitude of 4,700 ft	Granteville soil Disconformity above altitude of 4,250 ft
					Alluvium of the middle-Lake Bonneville age
Lake Bonneville group (lacustrine): Provo formation (as defined, lacustrine)	Provo 1 deposits	Provo 1 deposits (lacustrine; max. alt. 4800–4820 ft)		Provo 1 deposits max. alt 4,800 ft	Little Cottonwood Formation: Provo Member; Bonneville Member (at altitudes between Provo and Bonneville shoreline)
Alpine formation (see below)	Disconformity above altitude of 4,390 ft	Bonneville deposits (lacustrine; max. alt. 5,135 ft)	Alpine and Bonneville formations, undifferentiated (lacustrine)	Bonneville formation (lacustrine; max. alt. 5,135± ft)	(at and below Provo shoreline, alt. 4825± ft)
Bonneville formation (max. alt. 5,135 ft)	Alpine formation (lacustrine, max. alt. 5,050 ft)				
UNCONFORMITY		Disconformity above altitude of 4,200 ft; 2 soils		Disconformity; loess, alluvium, and weak soil above altitude of 4840 ft	Local diastem above altitude of 4,305 ft
Alpine formation (partly younger than the Bonneville formation; as defined)		Alpine deposits (lacustrine; max. alt. 5,050 ft)		Alpine formation (lacustrine; max. alt. 5,100± ft)	Alpine Member (max. alt. 5,110± ft)
(Omitted lake deposits—those deposited at lake levels below the Provo level)					
Ancient soils (pre-Lake Bonneville)		Pre-Alpine lateritic soil (possibly Tertiary)		Pre-Lake Bonneville soil	Dimple Dell Soil
Pre-Lake Bonneville fanglomerate	Green clay series and basal fanglomerate	Old fanglomerate	Pre-Lake Bonneville *fan gravel and landslides*	Pre-Lake Bonneville *fan gravel*	Pre-Lake Bonneville fan gravel, till and *colluvium*

lies, and is therefore younger than, the Dimple Dell Soil and the pre-Lake Bonneville fan gravel and colluvium; and it bears, and is therefore older than, the Graniteville Soil. It is named after Little Cottonwood Creek, along whose course it is well exposed west of Wasatch Boulevard. The type locality comprises a series of exposures in the western bluff of Dry Creek 0.7 mile southwest of the Granite Latter-Day Saints Church. The section at the type locality is given at the end of this paper as stratigraphic section 17.

The Little Cottonwood Formation records the earlier fluctuations of Lake Bonneville—at least three deep-lake cycles (fig. 4) separated by major lake recessions. There was a long stillstand during the recession of the third cycle (the lake cycle that rose to the Bonneville shoreline) that has been called the Provo 1 lake "stage" (Jones and Marsell, 1955; Eardley, Gvosdetsky, and Marsell, 1957). The Alpine (lowermost), the Bonneville, and the Provo Members record these lake fluctuations as manifested by lithologic differences, unconformities, and, as with the Provo, topographic position. The Alpine Member includes most of Hunt's (1953b) Alpine Formation; the Bonneville Member includes Hunt's Bonneville Formation and the remainder of his Alpine; and the Provo Member includes most of Hunt's Provo Formation. The three members are generally differentiated in the gravel and sand facies but not in the silt-clay facies.

The Little Cottonwood is widely exposed between the Bonneville shoreline and the outer edge of the tread of the Provo terrace (p. 37) and is locally exposed below this terrace to altitudes as low as 4,235 feet (northwestern corner of the area mapped). The Bonneville shoreline, which has an average altitude of from 5,135 to 5,185 feet because of faulting and tilting, marks the upper limit of the Little Cottonwood Formation. On and near the Cottonwood delta this formation locally exceeds 200 feet in thickness, as shown by exposures and well logs, and it reaches a maximum thickness of about 280 feet along the northern and western sides of the valley of Dry Creek, 1–2 miles west of the mountain front. Away from the delta the formation commonly is only 50–100 feet thick.

The gravel, sand, and silt-clay facies of each member of the formation are differentiated on the map. The facies laterally intergrade and intertongue with each other from coarser near shore to finer offshore; consequently, their boundaries are indistinct and gradational and generally must be drawn rather arbitrarily in mapping. The lower boundary of the Little Cottonwood Formation is readily identifiable by lithologic difference from the underlying Dimple Dell Soil or pre-Lake Bonneville fan gravel or colluvium. The upper boundary also can be similarly distinguished from the Draper Formation and other post-Little Cottonwood deposits, especially where the Graniteville Soil is preserved as a separating marker.

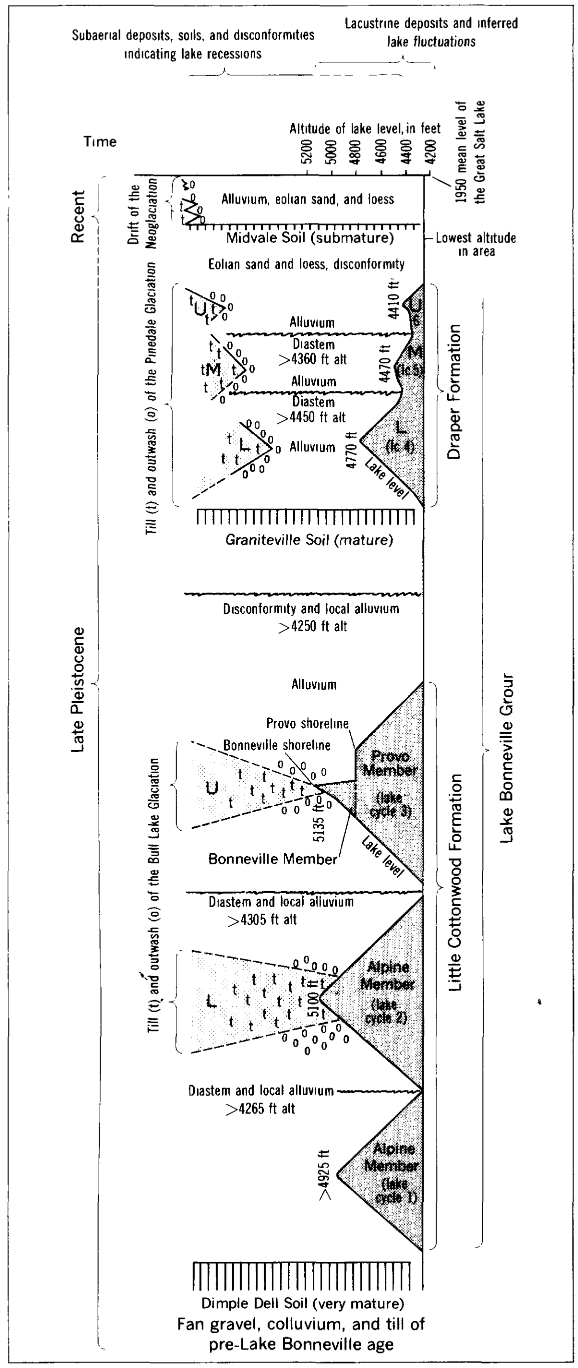

FIGURE 4.—Stratigraphic record of fluctuations of Lake Bonneville in Jordan Valley and of late Quaternary glaciations in Little Cottonwood and Bells Canyons. U, upper part (or tongue), M, middle part (or tongue), L, lower part (or tongue) of a glacial unit or of the Draper Formation; lc, lake cycle; >, disconformity or diastem recording subaerial exposure observed as low as the altitude given; t, till; o, outwash. Time scale (vertical) is not regular in terms of absolute time and is progressively extended toward the present.

ALPINE MEMBER

The lower part of the Little Cottonwood Formation is herein designated as the Alpine Member, a redefinition of the Alpine Formation of Hunt. Hunt (1953b, p. 17) originally defined the Alpine Formation as follows:

Oldest of the Lake Bonneville group is the Alpine formation. Gilbert used the name Intermediate to refer to the lake stage represented by these deposits, the name having been derived from the fact that around the sides of the valley these deposits are exposed at levels intermediate in altitude between the Provo and Bonneville levels (Gilbert, 1890, p. 135–154). The name Intermediate, however, is unsatisfactory because the deposits of that stage underlie the other Lake Bonneville formations. For this reason the name Alpine formation is introduced in this report instead of the old name. The formation is named for the town, around which there are numerous typical exposures.

This definition is ambiguous because, contrary to Hunt's implication, Gilbert did not use the name Intermediate to refer to the deposits of the earliest lake cycles of Lake Bonneville. He used this name solely to refer to shorelines, and to shore morphologic features, lying between the Bonneville and Provo shorelines. Gilbert pointed out (1890, p. 143) that the lake passed over these shorelines four times, on the rise and fall of two deep-lake cycles. Thus, according to Hunt's definition of the Alpine in terms of the Intermediate, it seems that this formation includes deposits of not only the earliest (Alpine) lakes but also those of the later lake cycle that rose to the Bonneville shoreline, the Bonneville-Provo lake cycle (table 3, fig. 4).

The Alpine overlies the pre-Lake Bonneville fan gravel and colluvium and the Dimple Dell Soil, and it is separated from the overlying Bonneville and Provo Members by a locally discernible diastem. In places it intertongues and intergrades with the lower till and outwash of the Bull Lake Glaciation (p. 25–30). The Alpine Member is considered to represent the deposits of the earlier cycles of Lake Bonneville, including those of at least two lake cycles that rose above an altitude of 4,900 feet and that were separated by a major lake recession.[7]

The Alpine, although generally overlain by other units in the Lake Bonneville Group, is extensively exposed below the Bonneville shoreline on the sides of various stream valleys and on many of the fault scarps. It is by far the thickest member, making up about 68 percent of the total volume of the Lake Bonneville Group (table 4). It makes up most of the bulk of the Cottonwood delta above the Provo shoreline—attaining a thickness of 250 feet on the north side of Dry Creek valley 1¼ miles from the mountain front and probably attaining a comparable thickness near Butlerville.

TABLE 4.—*Estimated original depositional volume and area of units composing the Lake Bonneville Group in the Draper quadrangle and in the Midvale quadrangle east of the Jordan River, ignoring subsequent erosion*

	Volume (percent of total Lake Bonneville Group)	*Area (percent of total Lake Bonneville Group)*
Draper Formation	3.5	60
Little Cottonwood Formation:		
Provo Member	22	76
Bonneville Member	6	24
Alpine Member	68	100

Along the mountain front south of the delta, it typically is 50 feet thick and locally is more than 100 feet thick. In the lowlands near the Jordan River, the Alpine typically makes up more than half the total thickness of the silt-clay facies of the Little Cottonwood Formation, which ranges from 50 to more than 100 feet in thickness, as shown by exposures and well logs. Because it is so thick and is at the bottom of the Lake Bonneville Group, its basal contact is exposed at only two localities in the basin interior—in sec. 15, T. 3 S., R. 1 E. (stratigraphic section 18), and in sec. 25, T. 3 S., R. 1 W.

In the high-shore zone the Alpine Member is generally veneered by the Bonneville Member, and both members typically are gravel, although either or both may locally be sand. Only in a few favorable situations can the two members be separated sharply and unambiguously from one another on the basis of differences in lithology or of disconformable relations. Thus, it is possible to determine the maximum altitude reached by the Alpine in only a few places. From the data available, the maximum altitude of the Alpine west of the main Wasatch fault zone seems to be 5,100–5,110 feet, and east of this fault zone, about 5,160 feet. This is a little higher than the maximum generally given for the Alpine along the Wasatch front (Bissell, 1952; Hunt, 1953b, p. 17; Jones and Marsell, 1955, p. 97; Eardley and others, 1957, p. 1165).

The Alpine Member is lithologically similar to the Alpine Formation as described by Hunt (1953b) and by Bissell (1963) in Utah Valley, but the member contains relatively more coarse material. In eastern Jordan Valley the sand facies predominates, both in areal distribution and in thickness, whereas in Utah Valley the silt facies greatly predominates; the silt-clay facies is intermediate in both respects; and the gravel facies is least abundant, as in Utah Valley. The silt-clay

[7] In the Leamington and Old River Bed areas, Varnes and Van Horn (1961) discovered evidence of a major diastem within deposits correlative with the Alpine Member. The evidence from these areas and from Jordan Valley (p. 20) suggests that in early Alpine time Lake Bonneville rose to an altitude of at least 4,925 ft, then receded below an altitude of 4,265 ft, and then rose again to a second high level in late Alpine time.

facies in Jordan Valley is found farther from the Bonneville shoreline than is common in Utah Valley, and nowhere does it reach the highest shoreline of the member, as it does locally in Utah Valley.

GRAVEL FACIES

Gravel of the Alpine Member is exposed in a belt generally 500–1,000 feet wide along the Wasatch front, except on and near the Cottonwood delta where, below the mouths of Big and Little Cottonwood Canyons, it increases in width to more than a mile. Generally this facies as mapped includes a large proportion of sand and pebbly sand interbeds, particularly in the middle part of the member (stratigraphic sections 11, 12, 21). A basal or progressional gravel and an upper or regressional gravel can be distinguished.

The basal gravel is coarsest in the high-shore zone, where it typically contains 10–30 feet of cobble and pebble gravel and, locally, boulder gravel. South of the Cottonwood delta the basal gravel consists almost entirely of material derived locally by wave erosion from the underlying pre-Lake Bonneville colluvium, fan gravel, and bedrock. Very few "displaced" rock types, carried by longshore transport, were seen. Unusually coarse angular basal gravel, containing boulders commonly several feet in diameter, similar to the basal breccia layer described by Bissell (1963, p. 109), is exposed locally along the mountain front. In one exposure 1,000 feet south of the mouth of Cherry Creek Canyon in a fault scarp along the Salt Lake City aqueduct, the outer surfaces of the boulders bear $\frac{1}{16}$–$\frac{1}{2}$ inch coatings of lithoid tufa—the only tufa noted in this member.

Within 100–500 feet of the Bonneville shoreline, the upper 20 feet or more of the upper gravel is mainly cobble and small-boulder gravel. Farther from the shoreline the upper gravel grades to cobble and pebble gravel and generally extends farther basinward than the basal gravel. In thick sections of the Alpine Member, the upper and lower gravels generally are separated by a zone consisting of pebbly sand containing a few interbeds of pebble gravel. Locally this zone is 100 feet or more thick.

Gravel in the upper and middle zones consists mainly of rock types from adjacent Wasatch Mountain drainage reaches, but it contains a few percent of resistant rocks from canyons farther north. From below the mouth of Big Cottonwood Canyon almost to Little Cottonwood Creek, the gravel is composed mainly of resistant rocks exposed in the Big Cottonwood drainage reach (Big Cottonwood Formation, Mineral Fork Tillite, Mutual Formation, Tintic Quartzite, and the Woodside, Thaynes, and Ankareh Formations; table 2). Also present, however, are sparse pebbles of the Nugget Sandstone, which is only exposed much farther north in the drainage areas of Parleys and Mill Creek Canyons. From Little Cottonwood Creek south to Corner Creek and along the northern side of the Traverse Range, the high-shore gravel of the Alpine Member invariably contains a small percentage of the northern lithologies. On the east side of Dry Creek Valley, there are pebbles and cobbles 3–8 and rarely 10 inches in diameter of Mutual Quartzite, Mineral Fork Tillite, Big Cottonwood Formation, Triassic sandstones (mainly Ankareh Formation), and Nugget Sandstone. These rocks persist far southward, but in decreasing abundance and size. Close to Corner Creek they occur as pebbles rather than as cobbles; also present are sparse pebbles of volcanic rocks that probably came from small volcanic remnants exposed in adjoining parts of the Wasatch Mountains (M. D. Crittenden, Jr., written commun., 1960). Along the north side of the Traverse Range, these rocks still are present, in addition to granitic and metamorphic rocks which could only have come from the Wasatch Mountains. The "displaced" pebbles and cobbles invariably are well rounded, whereas the locally derived rocks in the gravel commonly are only subrounded. The notable southward longshore transport manifested by these relations indicates strong waves from the northwest; this southward direction of transport is the reverse of that indicated by the conditions inferred for Alpine time in northern Utah Valley (Hunt, 1953b, p. 18), which was sheltered by the Traverse Range.

Obviously, the beaches must have been continuous across such present-day gaps as the valleys of Little Cottonwood, Dry, Willow, Little Willow, and Corner Creeks. The higher shorelines probably were marked by prominent shore terraces, bars, and spits that are now much eroded, largely concealed by younger deposits, and (or) locally obscured by faulting. Even so, it is difficult to conceive how longshore transport of the magnitude indicated by the proportion of displaced lithologies farther south could have been accomplished in the narrow shore zone of the Alpine Member now exposed between Little Willow and Cherry Canyons. Probably the zone of high-shore gravel here was once broader than at present and has been partly eroded or downfaulted (see p. 51) and covered by younger deposits.

A prominent bar or spit of coarse gravel in the upper part of the Alpine Member is exposed at several places along the mountain front. It was formed a short distance offshore during the Alpine lake maximum; shoreward from this bar only sand and a little fine gravel were deposited. These relations are best revealed by exposures below the mouth of Little Willow Canyon (north of Little Cottonwood Canyon) east of the main part of the Wasatch fault zone; in the NW¼ sec. 23, T. 3 S., R. 1 E.; and in the ridges of Little Cottonwood Formation that lie within 0.3 mile east of the Dimple Dell Road in sec. 14 of this township.

In the basin interior, gravel of the Alpine Member has been positively identified in only one place: three-fourths of a mile east of the Jordan River in the N½ sec. 25, T. 3 S., R. 1 W., at an altitude of about 4,420–4,435 feet. The gravel lies at the base of the member and consists of 1–20 feet of pebble gravel and sand. The facies overlies and is derived from an exposure of pre-Lake Bonneville fan gravel (p. 10) immediately to the north (indicating southward shore transport). It, in turn, is overlain by silt and clay of the Little Cottonwood Formation, which is undifferentiated as to member.

SAND FACIES

The sand facies predominates in the Alpine Member, unlike the typical situation elsewhere in the Lake Bonneville basin. This facies as mapped extends basinward along Big and Little Cottonwood Creeks almost to State Street, and along Dry Creek almost to the Jordan River—about 5 miles from the mountain front. The actual boundaries of the facies are far more complex than the geologic map suggests, owing to intertonguing with the gravel and silt-clay facies—for example, see stratigraphic sections 3, 4, 5, 14, 18, and 19. Interbeds of pebbly sand and pebble gravel occur as much as half a mile west of the mapped limit of the gravel facies in the Cottonwood delta north of Willow Wash. Beds of silt and clay locally extend to within a quarter mile of the Bonneville shoreline—for example, see stratigraphic sections 8, 9, and 10; moreover, even along the Jordan River, the Alpine Member, although mainly silt and clay, has numerous sand interbeds. Where possible, the larger sand interbeds are differentiated on the map; but where the mapping of exposures on steep valley sides had to be generalized, the boundary between the gravel and sand facies was placed where approximately 60 percent of the beds are sand, and the boundary between the sand and the silt-clay facies was placed where about 60 percent of the beds are silt and clay.

The exposures along Dry Creek best illustrate the intertonguing: along upper Dry Creek the Alpine Member consists of upper and lower sandy zones (about 25 and 50 ft thick, respectively, and containing some gravel interbeds locally) separated by a silty zone 5–12 feet thick. (See stratigraphic section 17.) Westward the silt zones become more numerous and generally thicker; for example, 1–1½ miles west of the Bonneville shoreline at least seven alternate silty and sandy zones are indicated by the available exposures.

The sand facies is locally exposed below the gravel facies of the Alpine, Bonneville, and Provo Members in gravel pits, fault scarps, and valley sides near the mouth of Big Cottonwood Canyon. Of special interest is the exposure at the northeastern edge of the floodplain of Big Cottonwood Creek, about three-fourths mile upstream from Knudsens Corner. This exposure was assigned to the Green clay series, of pre-Alpine (pre-Lake Bonneville) age, by Jones and Marsell (1955, p. 92) and Eardley, Gvosdetsky, and Marsell (1957, p. 1165). I, however, correlate it with the Alpine Member because of lack of evidence of greater age. This exposure shows 14 feet of pale-gray silty fine sand and fine sand typical of the Alpine Member in the vicinity, disconformably overlain by colluvium of Draper and post-Lake Bonneville age. The exposure is at the bottom of a bluff that is for the most part mantled by this colluvium and hence cannot be traced laterally for direct correlation with other exposures nearby; moreover, the lower contact of the sand unit is not exposed. Directly above the bluff is a strath terrace that is veneered by alluvial gravel of late Provo age and bears the Graniteville Soil; presumably this alluvial gravel disconformably overlies the sand unit in the exposure.

The sand facies generally is thin parallel bedded, with the bedding essentially horizontal; locally some beds are ripple marked, and in places some zones, 1 to several feet thick, have strongly involute bedding and are sharply bounded at top and bottom by parallel, horizontal beds. Grain sizes in the member range from granule sand, coarse sand, and pebbly sand to very fine sand and silty sand, with all degrees of sorting. The full range, including sizes coarser than medium sand, can commonly be seen on the Cottonwood delta in single thick exposures as far westward as 2 miles from the Bonneville shoreline; south and north of the delta, these thick exposures are only half a mile west of this shoreline. On and south of the delta the sand is pale gray to nearly white and locally pale yellow or pale tan gray. It is arkosic, containing a large proportion of granitic fragments from the Little Cottonwood and other stocks.

Much of the sand seems to have been deposited in fairly shallow water, probably close to shore; this origin is indicated by common oscillation ripple bedding. Commonly the ripple marks are asymmetrical and their axes are normal to the Wasatch Mountain front, indicating that they were formed by longshore currents moving south parallel to the mountain front. J. H. Feth (written commun., 1960) observed similar relations in sand of the Alpine Member in the delta of the

Weber River, near Ogden, Utah. Considerable amounts of sand, including most of the sand interbeds in the silt-clay facies, were probably laid down in deep water by turbidity currents.

SILT-CLAY FACIES

The silt-clay facies of the Alpine Member can be differentiated in only a few places and is described under "Silt-clay facies undivided."

INTRA-ALPINE DIASTEMS

Exposures of the Alpine Member commonly show intramember diastems and in some places show several of them. (See stratigraphic sections 8, 15, 17, 22.) None of the diastems can be traced beyond a given exposure and correlated reliably elsewhere because good exposures of the Alpine generally are widely spaced, because this member lacks distinctive marker units, and because in some areas it is displaced by faults. Most of the diastems were probably caused by sublacustrine slumping, by current-scour—particularly, turbidity currents—or by changes in the profile of equilibrium on the lake bottom. None of the diastems are marked by soils nor do they show other incontrovertible evidence of subaerial exposure except at several outcrops along the Jordan River where alluvial gravel (see p. 31) is intercalated with the Alpine Member. The alluvial gravel probably marks one or more intra-Alpine diastems that record subaerial exposure and lake recession; such a diastem was described by Varnes and Van Horn (1961). The lowest known exposure of alluvial gravel of probable Alpine age is in the SW¼NW¼ sec. 4, T. 2 S., R. 1 W., at an altitude of about 4,265 feet; this gravel obviously indicates a nearly complete lake recession.

ALPINE-BONNEVILLE DIASTEM

The Alpine Member is locally separated from the overlying Bonneville and Provo Members by a diastem that records subaerial erosion and valley cutting induced by a marked recession of Lake Bonneville. This diastem, locally marked by alluvial gravel, is the same as that identified by Gilbert (1890, p. 190–194) between the yellow clay and white marl in the Lower Old River Bed, Upper Old River Bed, and Leamington localities; by Jones and Marsell (1955, p. 101) between Alpine and Provo deposits near the Jordan River just outside the southwestern corner of the map area; by Marsell (in Eardley, Gvosdetsky, and Marsell, 1957, p. 1179 and fig. 18) between the Alpine Formation and Bonneville-level lake sediments a short distance below the mouth of Parleys Canyon; and by Bissell (1963, p. 111) between the Alpine and Bonneville Formations in southern Utah Valley. It also probably is, in part, the unconformity between the Alpine and Provo Formations described by Hunt (1953b, p. 21) in northern Utah Valley. Gilbert presumably identified the diastem at altitudes as low as about 4,450 feet; Bissell and Hunt both found the diastem at altitudes as low as 4,840 feet; Marsell and Jones found the diastem at altitudes as low as 4,390 feet (erroneously given by them as 4,290 ft).

This diastem is especially well displayed in the large excavation (stratigraphic section 8) just northeast of the new Salt Lake City Water Purification Plant in sec. 2, T. 3 S., R. 1 E. In the western part of this exposure, the diastem cuts across at least 10 feet of the horizontally bedded Alpine Member and is overlain by gravel of the Bonneville Member.

Further recording this diastem is evidence that the valleys of Dry Creek and Willow Wash were partly cut, essentially along their present upper courses, after deposition of the Alpine Member but before deposition of the Bonneville and Provo Members. Small spits of gravel of the Bonneville Member occur at several places along the upper edges of the northern sides of both valleys. They formed at the southern ends of gravel bars from gravel that drifted southward along the bar and spilled down the side of the preexisting valley. For example, the big gravel bar at the Bonneville shore level just west of Granite terminates in a prominent spit just northwest of the point where Dimple Dell Road crosses the North Fork of Dry Creek. There is no suggestion that this spit or bar ever extended across Dry Creek Valley. On the opposite side of this valley the Bonneville terrace is cut into the end moraines of the late stade of the Bull Lake Glaciation from Bells Canyon. At its northern end this terrace is narrow and has a scarcely mappable veneer of gravel of the Bonneville Member, apparently derived from local sources. Southward the terrace widens and the Bonneville member thickens. The terrace terminates in a prominent spit, just northwest of the reservoir in the SE¼NE¼ sec. 14, that evidently spilled over into a preexisting valley cut into the Alpine Member. Other indications of this ancient valley are several tongues of the upper outwash gravel of the Bull Lake Glaciation near the NE cor. NW¼ sec. 14, T. 3 S., R. 1 E.; these tongues were deposited in gullies cut into the Alpine Member and into the lower till of the Bull Lake Glaciation. Because the tongues lie at gradients almost as steep as that of the present valley wall (p. 28), they denote that Dry Creek had already cut an appreciable valley into the Alpine fill of the Cottonwood delta. Another "spillover" spit of gravel of the Bonneville Member occurs on the north side of Dry Creek where the valley bends sharply westward (near the NW cor. SW¼ sec. 14).

FIGURE 5.—View eastward across upper valley of Dry Creek showing various significant Quaternary features along the Wasatch Mountain front: (1) terminal moraine of the upper till of the Bull Lake Glaciation below mouth of Bells Canyon, (2) south lateral moraine of the same till below mouth of Little Cottonwood Canyon, (3) remnants of the terminal moraine of the lower till of the Bull Lake Glaciation below Bells Canyon, (4) high-shore zone of the Alpine Member of the Little Cottonwood Formation, (5) the Bonneville shoreline, (6) "spillover" spits of the Bonneville Member at the Bonneville shoreline, (7) fan and strath terrace of the upper outwash of the Bull Lake Glaciation, (8) strath terrace of Dry Creek of Provo stillstand age, (9) faulted alluvial fan of Little Cottonwood age at mouth of South Fork of Dry Creek, (10) upfaulted remnants of fan gravel of pre-Lake Bonneville age. Present flood plain of Dry Creek lies just below bottom of view.

This diastem also probably is marked by several exposures of alluvial gravel (p. 31) in the bluffs along the Jordan River. This alluvium is interbedded with silt-clay of the Little Cottonwood Formation, but here this formation cannot be precisely differentiated as to member; so the correlation is somewhat uncertain. The exposure reported by Jones and Marsell (1955, p. 101) is just outside the southwestern corner of the area mapped and probably marks the diastem in question; the exposure at the SE cor. sec. 35 possibly marks it also. Thus, this diastem has been identified at an altitude at least as low as 4,390 feet in Jordan Valley, and possibly as low as 4,360 feet.

BONNEVILLE MEMBER

The Bonneville Member as herein designated is a redefinition of the Bonneville Formation of Hunt and Bissell. As originally defined (Hunt, 1953b, p. 20), this formation "* * * includes those deposits that accumulated in the lake during its highest stage, the stage that Gilbert (1890, p. 83–125) referred to as the Bonneville stage." Hunt's map of northern Utah Valley shows this formation only as a thin and discontinuous beach gravel along the Bonneville shoreline. Bissell (1963, p. 111–112) redefined this formation to include

> * * * all the lake sediments that overlie the Alpine and are older than the Provo formation; * * * not only lake sediments of the Bonneville shoreline zone, but also local shore and offshore deposits at lower altitudes. The latter includes both sediments laid down while the lake rose from the inter-Alpine and Bonneville minimum to the Bonneville maximum and while it regressed to the Provo shoreline level.

The Bonneville Member comprises the lacustrine sediments, mainly gravel to clay, between the altitudes of the Bonneville and the Provo shorelines. Accordingly, the Bonneville Member represents the lake cycle of Lake Bonneville that rose to the Bonneville shoreline, except for the deposits—transgressive, high-stage, and regressive—laid down at and below the Provo level (at an altitude of about 4,800–4,825 ft) (figs. 1, 18). The Bonneville Member is more inclusive than the Bonneville Formation of Hunt and is similar to this formation as redefined by Bissell, except that it excludes deposits at altitudes below the Provo level.

The reference locality for the Bonneville Member is the large excavation made in 1958 just northeast of the new Salt Lake City Water Purification Plant and approximately at the NE cor. SE¼ sec. 2, T. 3 S., R. 1 E. (site of stratigraphic section 8). This locality illustrates the unconformable relationship of this member to the Alpine Member.

The Bonneville shoreline is clearly marked throughout the area by shore terraces or, locally, by bars and spits. (See figures 5, 6.) It is also carved into the terminal moraines below Little Cottonwood and Bells Canyons, contrary to the observations of Gilbert (1890) and Blackwelder (1931). The shoreline generally lies about 15–35 feet above the highest deposits of the Alpine Member—at altitudes ranging from about 5,120 to about 5,140 feet (average about 5,135) on the western side of the main Wasatch fault zone, and from about 5,150 to about 5,240 feet (average about 5,185 feet) east of the fault zone.

The Bonneville Member extensively overlies the Alpine Member between the Bonneville and Provo shorelines, notably on the intervalley surfaces of the Cottonwood delta where it forms a thin veneer over the much

FIGURE 6.—View from the Provo level a quarter of a mile west of Corner Creek showing Bonneville shoreline, B, along the Wasatch Mountain front in the southern part of the area between Cherry and Corner Creeks. Scarps below this shoreline are partly those of shore terraces but are principally fault scarps in the main Wasatch fault zone. Here thick sections of gravel and sand of the Alpine and Bonneville Members are exposed.

thicker Alpine. The Bonneville ranges in thickness from several feet to about 100 feet in the thickest parts of "spillover" spits on the north side of Dry Creek valley.

Although the Bonneville locally is markedly unconformable on the Alpine, in most places where the contact between them is exposed, it seems conformable. The two members can be distinguished by lithologic differences in at least one-third of the good exposures, although commonly the contact is somewhat gradational (perhaps because of wave reworking of the older deposits) within 5–20 feet. Separation is most difficult where both members are composed of sand or gravel.

The Bonneville Member is all gravel and sand, except for sparse tiny patches of silt. Stratigraphic sections 8, 9, 10, 12, 17, 18, and 21 are representative of this member. The gravel facies occurs principally in two belts: a wide, continuous one along the higher shores, and a discontinuous one along the terrace scarp that rises above the Provo level. Between these belts the member is nearly all sand, even on the Cottonwood delta, with only local small patches of gravel. The gravel in the high-shore belt veneers both the shore features along the Bonneville shoreline and the somewhat lower ones. This gravel belt ranges in width from 100 feet to locally as much as half a mile (near Graniteville), and in thickness from 1 foot to rarely more than 25 feet. It is thus considerably thinner than the high-shore gravel of the Alpine Member.

The gravel of the Bonneville Member in the high-shore belt typically is finer than that in the Alpine. Except for those against the mountain front, the coarsest fragments are mainly of pebble size and include few or no cobbles and boulders. This gravel contains the same rock types as does the underlying gravel of the Alpine, except that the Bonneville gravel has a higher percentage of the more resistant rocks such as Mineral Fork Tillite and quartzite and hornfels of the Big Cottonwood Formation and Mutual and Ankareh Formations; also, the Bonneville gravel generally has more well-rounded pebbles than does that of the Alpine. The gravel of the Bonneville Member obviously was mainly derived from wave reworking of the local gravel of the Alpine, inasmuch as longshore transport of gravel was minor. The direction of longshore transport during the Bonneville lake maximum and recession was from north to south, opposite to that on the eastern side of northern Utah Valley (Hunt, 1953b, p. 21–23).

The gravel in the western belt (just above the Provo level) and in the local patches between the two belts is lithologically similar to that in the eastern belt except that it contains much admixed or interbedded sand and locally is mostly pebbly sand. The gravel between the two main belts appears mainly to mark transgressive shorelines, which commonly were subsequently covered by sand deposited during the lake recession. The gravel in the lower belt appears to have been laid down mainly during the recession, shortly prior to the stillstand at the Provo level.

Sand of this member is mostly medium grained, locally interbedded with either coarse, fine, or pebbly sand; it typically is moderately well to well sorted, unindurated, and massive to well bedded. It commonly so closely resembles sand in the upper part of the Alpine that the contact between the two cannot be placed with certainty where they are in juxtaposition. This sand is several feet to about 50 feet thick.

The silt-clay facies at the top of the member consists of 1 to about 8 feet of pale-gray to nearly white calcareous silt and sandy silt (marl), overlying the gravel or sand facies. It occurs in small patches between altitudes of 4,850 and 5,000 feet in two areas on the upper surface of the Cottonwood delta. One area is about 1½ miles west of the Latter-Day Saints Church in Granite; the other is 1 mile south of Butlerville. These deposits probably were laid down offshore while the lake stood at and near the Bonneville shoreline.

PROVO MEMBER

The Provo Member here designated is the Provo Formation of Hunt and Bissell redefined. According to Hunt's original definition (1953b, p. 21), the Provo Formation "* * * includes the deposits that were laid down while Lake Bonneville stood at what Gilbert (1890, p. 126–134) called the Provo stage." In his description and on his map of northern Utah Valley, however, he included lake deposits formed at various lower lake levels following the Provo stillstand, as well as fan gravel as much as 200 feet above the Provo shoreline; hence the formation as he mapped it includes deposits not covered in the definition (table 3). Hunt did not differentiate the deposits assigned to the lower tongue of the Draper Formation in my report, and he mapped these as a part of the Provo Formation.

Bissell (1963, p. 113) redefined the Provo Formation as "* * * those sediments of Lake Bonneville that were deposited at and below the Provo shoreline and overlie the Alpine formation." He recognized an upper part of the Provo Formation that probably is equivalent to the lower tongue of the Draper Formation of this report, but he did not differentiate the two parts on his map.

The Provo Member consists of the lacustrine sediments—gravel to clay and tufa. Like the Bonneville Member, it overlies the Alpine Member and the inter-Alpine-Bonneville diastem (fig. 4). The Provo Member was deposited during the entire Bonneville-Provo lake cycle at and below the Provo shoreline level, although most of the exposed deposits record merely the regressive stillstand at the Provo level and the ensuing lake recession below this level. The Provo is differentiated from the Bonneville Member merely because it has become well-established custom to differentiate the deposits related to the Provo shoreline. The differentiation is made arbitrarily on the basis of the altitude of the Provo shoreline, horizontally across the entire member, because there seems to be no feasible stratigraphic means of consistently separating the Provo from the Bonneville.

The Provo Member includes all but the uppermost part of the Provo Formation as mapped by Hunt and Bissell, as well as the lake sediments laid down at and below the Provo shoreline during the transgression and higher than Provo levels of this lake cycle. This member is similar to the Provo 1 deposits of Jones and Marsell (1955) and Eardley, Gvosdetsky, and Marsell (1957).

The Provo shoreline, defined by Gilbert (1890), is generally the most conspicuous shoreline below the Bonneville shoreline. The lake level that existed when the Provo shoreline formed is here called the Provo stillstand, and the altitude of this level is called the Provo level. Used in a time sense, Provo is always qualified in this report so that it will not be confused with the time of deposition of the Provo Member, which would include the time of the whole Bonneville-Provo lake cycle. The time following this stillstand, when various recessional shore deposits of the Provo Member were laid down, is called late Provo time [age].

The Provo terrace is especially well displayed on the Cottonwood delta. A scarp commonly 50–80 feet high generally rises above this terrace in the areas between the strath terraces and valleys of Provo stillstand and younger age. The terrace typically has a broad single tread as much as half a mile wide, but locally above this is a minor, relatively faint and discontinuous subterrace at an altitude of about 4,825 feet. This subterrace is best displayed between Dry Creek and Willow Wash in the SE¼ sec. 16, T. 3 S., R. 1 E. The upper (altitude) contact of the Provo Member is placed at the shoreward edge of the Provo terrace or at the shoreward edge of the subterrace where it is present. The Provo shoreline is indistinct where it merges with alluvial terraces of equivalent age; here the alluvial gravel intertongues and intergrades with the lake gravel through a zone commonly 1,000 feet wide.

The reference locality for the Provo Member is the part of the Cottonwood delta that is graded to the Provo shoreline and to the two lower recessional lake levels (see p. 24) and extends from Alta Airpark to a point about half a mile north of Little Cottonwood Creek near the southern edge of Butlerville.

The Provo Member is differentiated in its gravel and sand facies only where these differ appreciably from the underlying Alpine Member. It is exposed extensively on the Provo terrace but is only locally exposed at lower levels because below the tread of this terrace the Provo is generally overlain by the Draper Formation. Within 150–300 feet below the Provo terrace the Provo typically is gravel to coarse and medium sand, whereas the Alpine is fine sand, silt, and clay. At lower altitudes farther westward both members become silt, fine sand, and clay and cannot be differentiated. The Graniteville Soil is locally preserved on the Provo Member and is a distinctive marker for differentiating the Provo from the overlying Draper Formation.

Exposures of the Provo Member good enough to show details of stratigraphy and stratification are rare. Although stream dissection has formed many scarps, valleys, and gullies across the terraces and deltas, the sides of these cuts generally are badly slumped and are mantled by colluvium or eolian sand. The best exposures are along the bluff on the north side of Little Cottonwood Creek and in gravel pits at the outer edges of the Cottonwood delta (fig. 17); those in gravel pits commonly show good examples of both topset and foreset bedding.

The chief deltas of the Provo Member are those parts of the deltas of Big and Little Cottonwood Creeks that are graded to the Provo terrace. They merge upstream with wide coeval strath terraces of these creeks (p. 31–33). Their overall southward distortion records especially strong wave action and marked southward longshore drift. This drift is also indicated by such features as the wide bar (spit) that extends southwestward from Butlerville, other spits to the south (including Draper spit), the strongly "displaced lithologies" in the gravel, and the coarseness of much of the gravel that is far from the source streams (cobbles as much as 8 inches in diameter occur even at the tip of Draper spit). The Provo terrace clearly was continuous from the northern edge of the area mapped to the southern tip of Draper spit, across the valleys of Big and Little Cottonwood Creeks and Dry Creek.

A smaller, lower delta of Little Cottonwood Creek is well exposed at the reference locality for the Provo Member, on the north side of this creek west of 2000 East Street. Part of this delta also is exposed south of the creek near the junction of 1300 East and 7800 South Streets. It is composite, having several successively younger treads, each graded to a recessional shoreline below the Provo shoreline and also probably to a given strath terrace of Little Cottonwood Creek. (See p. 31; fig. 13). The age relations of the strath terraces to the parts of the delta must mainly be inferred from projected gradients, because the zones of intergradation of the lake and alluvial deposits are mostly eroded or concealed. The higher of the two main terraces evidently merged with the sublacustrine part of the delta at an altitude of about 4,700 feet, and the lower main terrace at about 100 feet lower. The relatively undistorted form of the various levels of this delta and the comparative fineness of the gravel on it and on the associated post-Provo shorelines attest to much weaker waves and less pronounced longshore drift than during the Provo stillstand.

Gravel facies.—Gravel of the Provo is exposed over the whole tread and on parts of the frontal slope of the Provo terrace from the northern edge of the area mapped as far south as 9400 South Street in a belt ½–1½ miles wide. Farther south it tongues out between areas of the sand facies, but a prominent spit of gravel extends to the Carters Sky Ranch airfield at the tip of Draper spit. Gravel also occurs locally on the Provo terrace southeast and south of Draper. Here this terrace is unusually subdued because the shore was sheltered from waves by the Draper spit.

Gravel of the Provo Member is mostly well rounded and well sorted and, like that of the Alpine Member, contains a fairly high percentage of rocks that could have been derived only from canyons several miles to the north of this area (Jones and Marsell, 1955, p. 90, 101), indicating marked southward longshore transport. On the Cottonwood delta the gravel generally is coarser, somewhat less well rounded, and less well sorted, and has more granitic roundstones than the gravel of the Bonneville Member. Commonly, several percent of the granitic roundstones are more or less rotten. The gravel of the Provo Member is coarsest, least well rounded, and least well sorted where it intergrades with alluvium, particularly with the coeval strath terraces of Little Cottonwood and Dry Creeks. Away from source streams, the degree of sorting and roundness increases and the proportion of rotten stones decreases; hence, most of the gravel pits are on the frontal slope of the delta. Here, however, much sand is interbedded with the gravel; in several pits only the top few feet are pebble gravel, and the underlying material is sand and pebbly sand with minor lenses of pebble gravel. On the Cottonwood delta the gravel generally is devoid of both lacustrine tufa and soil-lime coatings except locally along the Pedalfer-Pedocal facies boundary of the Graniteville Soil (pl. 2) at the northern fringes of the delta—for example, the lower parts of pebbles bear soil-lime coatings in the top several feet of gravel of the Provo Member at its reference locality, as exposed in the bluff north of Little Cottonwood Creek west of the Reynolds gravel pit. Lithoid tufa commonly coats the upper surfaces of the top pebbles and cobbles in the gravel at the lakeward edge of the Provo terrace southwest of Corner Canyon.

Sand facies.—The sand facies of the Provo Member is widely exposed on the southern part of the Cottonwood delta, especially on Draper spit. It commonly underlies the gravel facies along the delta front—the sand is the offshore deposit coeval with the Provo stillstand, and the overlying gravel is a regressive shore deposit. This sand resembles that of the Bonneville Member; it is typically medium to coarse, commonly has partings and interbeds of pebbly sand, and is highly granitic (on and south of the Cottonwood delta), generally loose and uncemented, and moderately to well sorted.

Fossils.—Two mollusk collections were obtained from the Provo Member; both were recovered from the fine sand in the upper few feet of this member in the reentrant east of the Draper spit in the vicinity of Draper. The Graniteville Soil (Calcic Brown soil facies) is developed on the Provo at both localities. D. W. Taylor, U.S. Geological Survey, identified the forms in both collections.

One collection was taken from the west bank of Willow Creek Wash at an abandoned farmhouse 1 mile north of Pioneer Avenue (12300 South St.), Draper, at an altitude of 4,700 feet in the SE¼ sec. 21, T. 3 S., R. 1 E. (USGS Cenozoic loc. 23275). It yielded the following:

Fresh-water clam:
Pisidium compressum Prime
Fresh-water snails:
Valvata humeralis Say
Lithoglyphus coloradoensis (Morrison)
cf. *Amnicola longinqua* Gould
Lymnaea bonnevillensis Call
Fossaria obrussa (Say)

The other collection was taken from a borrow pit on the east side of a north-south road along the east line of sec. 28, T. 3 S., R. 1 E., a quarter of a mile north of Pioneer Avenue (12300 South St.), Draper, at an altitude of 4,690 feet (USGS Cenozoic loc. 23276). It yielded the following fresh-water snails:

cf. *Amnicola longinqua* Gould
Lymnaea (fragment, unidentifiable)

SILT-CLAY FACIES UNDIVIDED

The silt-clay facies of the Little Cottonwoood Formation, undivided as to member, is well exposed in the bluffs along the Jordan River in sections commonly 50–75 feet thick. This unit also is fairly well exposed along lower Dry Creek and near the mouths of Willow Wash and Corner Creek. It is poorly exposed at many places on the lowlands south of Dry Creek and below Draper spit because of low relief and thin cover by the Draper Formation and by colluvium. The Draper was less than 18 inches in original thickness, and hence unmappable, or has been eroded. Surface and subsurface data indicate that the silt-clay facies underlies most of the Jordan Valley below an altitude of 4,500 feet.

The exposures along the Jordan River show that this unit, though rather monotonous in general aspect, is quite varied in lithologic detail. Stratigraphic sections 15, 22, and 23 are typical. The unit consists, in approximate order of decreasing abundance, of interbedded silt, clayey silt, very fine sand, silty clay, fine-to-medium sand, and clay. The silt is generally light gray; the clayey silt, silty clay, and clay are gray to olive gray; and the sand is light gray and pale yellow to nearly white. Bedding is laminated to massive and is horizontal except for local highly convolute beds that are bounded above and below by horizontal strata. Graded bedding is common, as are also the rhythmic alternations of strata or laminae of silt and clay, or silty clay and sand, which do not have obvious graded bedding; commonly the sand strata or laminae are well sorted. Individual beds are lenticular or discontinuous; they rarely extend more than 100 feet, and some beds extend only a few feet. Persistent marker beds are totally lacking.

The thicker sections are roughly divisible into three zones: (1) an upper zone, about 15 feet thick, of interbedded fine and very fine somewhat silty sand and silt; (2) a middle zone, 15–25 feet thick, of clayey silt and silty clay with much interbedded fine-medium to very fine sand; and (3) a lower zone that is similar to the middle zone but has more silt and clay. Both the middle and lower zones commonly have strongly convolute beds several feet thick. Induration and jointing increase downward, particularly in the more clayey beds. The beds of clayey silt and clay in the lower zone are mostly relatively tough and are conspicuously jointed and, locally, are offset by small faults. Most of the joints and faults die out upward in the section, and the upper zone generally is not conspicuously jointed. The lower zone may correspond approximately to the Alpine Member, and the middle and (or) upper zones to the Provo Member of the Little Cottonwood; but as the boundaries of the zones are gradational and do not show evident unconformity, exact correlations cannot be made.

These deposits, including the numerous sand interbeds, probably were deposited offshore in deep water by density currents from Big and Little Cottonwood Creeks and other streams. The beds probably were contorted, soon after their deposition, by subaqueous slumping.

TILL AND OUTWASH OF THE BULL LAKE GLACIATION

Till and outwash of the Bull Lake Glaciation are exposed below Little Cottonwood and Bells Canyons. These are the only glacial deposits of this age in the

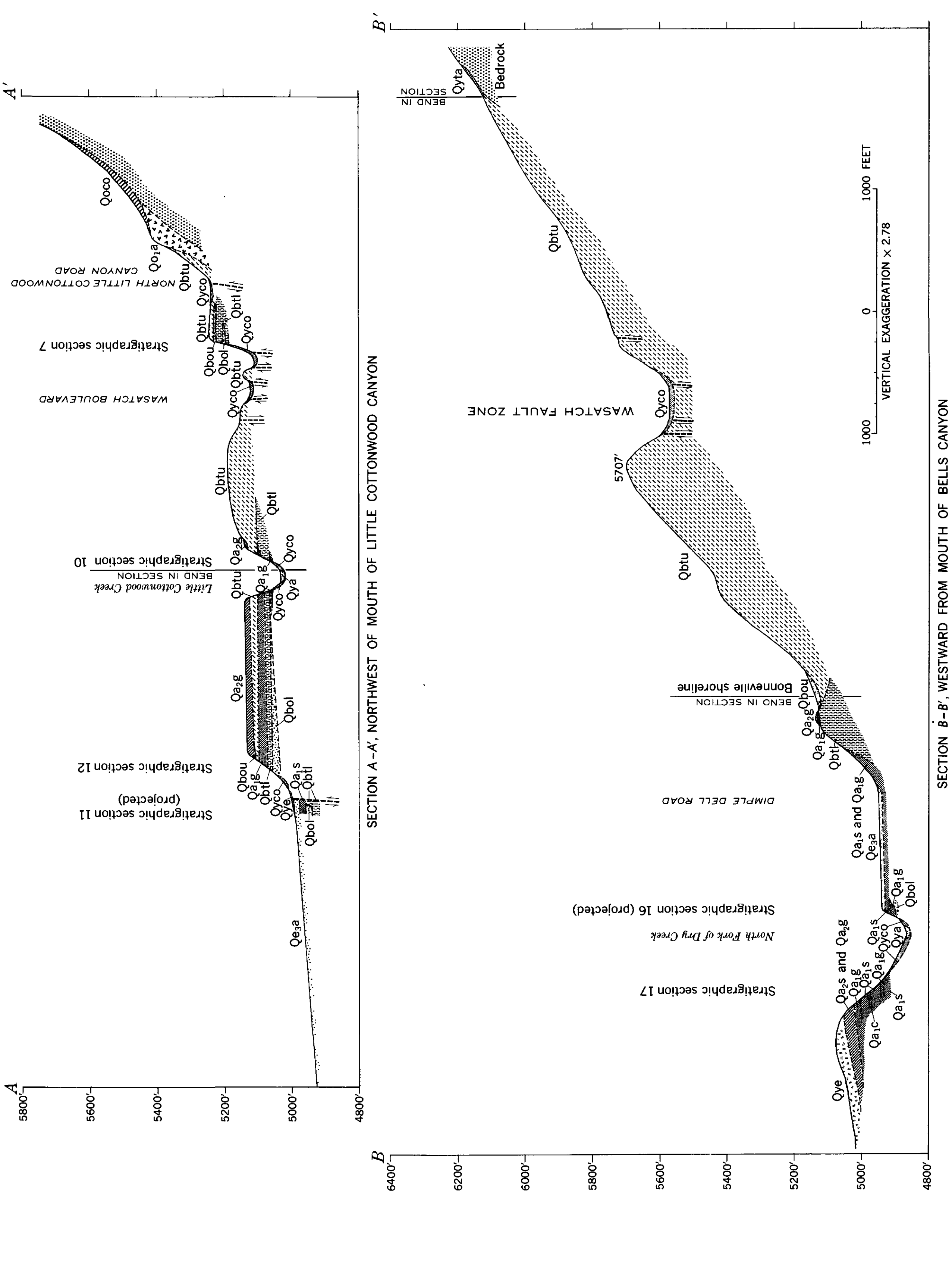

FIGURE 7.—Interrelations of the Alpine and Bonneville Members of the Little Cottonwood Formation and the lower and upper tills and outwash of the Bull Lake Glaciation west from mouths of Little Cottonwood and Bells Canyons. See plate 1 for explanation of symbols; location of sections shown on plate 2.

area mapped.[8] The glacial deposits below Little Cottonwood and Bells Canyons intertongue and intergrade with high-shore sediments of the Alpine and Bonneville Members of the Little Cottonwood Formation and hence can be directly correlated with these members.

TILL BELOW LITTLE COTTONWOOD AND BELLS CANYONS

Within a mile below the mouths of Little Cottonwood and Bells Canyons are sets of arcuate terminal moraines that have been correlated by Blackwelder (1931) and Richmond (1961, 1964), with the Bull Lake Glaciation in the Wind River Mountains of Wyoming. The set of moraines in each canyon comprises an outer and an inner moraine representing the maximum advances of the early and late stades of this glaciation, respectively. The outer moraines are preserved only as local subdued remnants, having lost most of their

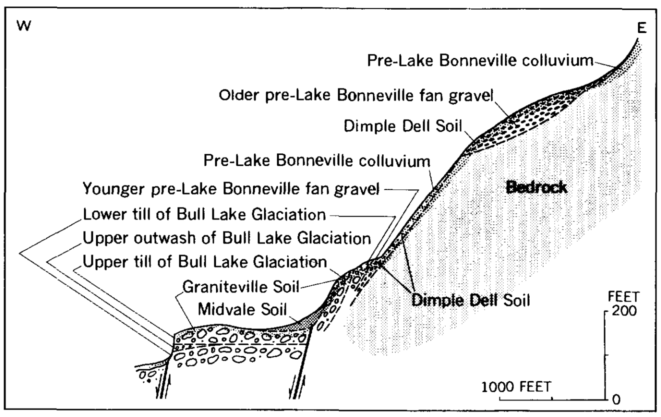

FIGURE 8.—Intertonguing relations of the Alpine and Bonneville Members of the Little Cottonwood Formation with the lower and upper tills and outwash of the Bull Lake Glaciation in vicinity of Little Cottonwood Creek west of the main Wasatch fault zone.

original form because of subsequent erosion and deposition, mainly by transgression of till and outwash of the late stade, concomitantly with inundation by Lake Bonneville. The till, called the lower till of the Bull Lake Glaciation (Richmond, 1964), extends basinward as a thick tongue beneath the younger deposits (figs. 7, 8) to altitudes as low as 4,920 feet, below Bells Canyon, and 5,040 feet, below Little Cottonwood Canyon. This till overlies pre-Lake Bonneville colluvium and fan gravel, which bear the Dimple Dell Soil, at the remnants of both the south lateral moraine below Bells Canyon and the north lateral moraine below Little Cottonwood Canyon (pl. 1, figs. 9, 10). At its outer limits

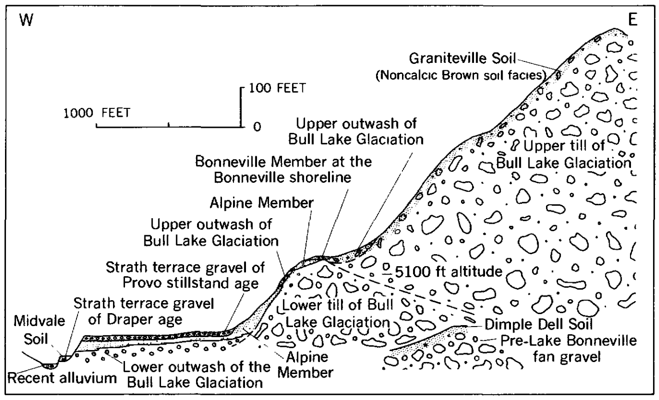

FIGURE 9.—Relations of the upper and lower tills of the Bull Lake Glaciation, older and younger pre-Lake Bonneville fan gravels, and the Dimple Dell, Graniteville, and Midvale Soils from the ridge north of the mouth of Little Cottonwood Canyon to the main Wasatch fault zone.

the lower till intertongues and intergrades with both the lower outwash of the Bull Lake Glaciation and the high-shore sediments of the Alpine Member. The lower till rests on silt, sand, and gravel of the Alpine Member at an altitude of about 5,050 feet in an exposure along little Cottonwood Creek (stratigraphic section 10), and it is overlapped by this member to altitudes as high as 5,080 feet along the outer edge of the early Bull Lake terminal moraine below Bells Canyon, west of the main Wasatch fault zone.

The inner moraines below Bells Canyon are large and strikingly well preserved in an almost unbroken loop (figs. 5, 24). The till of which they are composed, called the upper till of the Bull Lake Glaciation (Richmond, 1964), extends to altitudes as low as 5,060 feet. Below Little Cottonwood Canyon the inner moraine is underlain by outwash of the same age and is breached by a wide strath terrace that is graded to the Bonneville shoreline. The till extends to altitudes as low as 5,080 feet. At the periphery of the inner moraines from both

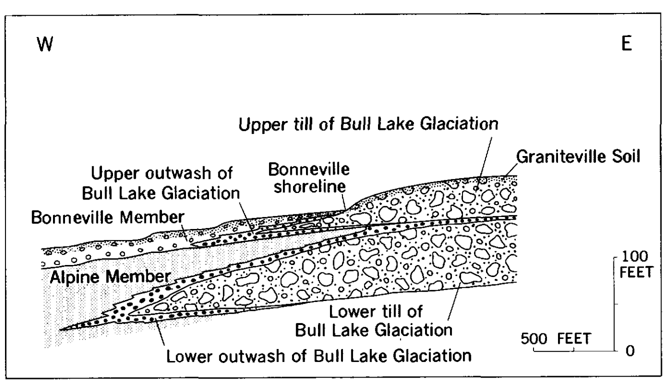

FIGURE 10.—Relations of the upper and lower tills and outwash of the Bull Lake Glaciation, the Bonneville and Alpine Members, strath terrace gravels of Provo stillstand and Draper ages, pre-Lake Bonneville fan gravel, and the Graniteville and Dimple Dell Soils through the upper valley of Dry Creek below the mouth of Bells Canyon.

[8] Below the mouths of Little Willow Canyon and the canyons of South Fork of Dry Creek, Big Willow Creek, and Little Willow Creek are gravel deposits of this age that have been identified as till (moraines) by Atwood (1909, pl. 10 and p. 79, 80, 85), Crittenden, Sharp, and Calkins (1952, pl. 1 and p. 37), and Marsell and Threet (1960). I, however, consider these to be fan gravel. (See p. 30.)

canyons, this till intertongues with and is overlain by the Bonneville Member, and the moraines themselves are distinctly notched by the Bonneville shoreline, as noted by Jones and Marsell (1955).

Both the lower and upper tills in Bells Canyon are pale gray, compact, sandy, and bouldery and are composed entirely of quartz monzonite from the Little Cottonwood stock. The till includes many subangular to subrounded boulders, commonly several feet in diameter and rarely as much as 15 feet in diameter in an abundant matrix of poorly sorted arkosic pebbly sand and silt. Some of the boulders are rotten, particularly in the lower till, although most are fresh. The rotten boulders obviously are derived from quartz monzonite that was deeply weathered prior to the Bull Lake Glaciation. Locally interbedded with the till are stringers of somewhat better rounded and better sorted cobbly to bouldery outwash gravel.

The lower and upper tills below Little Cottonwood Canyon are similar, except that they contain a small percentage of small boulders to pebbles of the more resistant rocks from this drainage area, such as quartzite and hornfels from the Big Cottonwood Formation, Mineral Fork Tillite, and the like. All the larger boulders and nearly all the smaller ones, however, are quartz monzonite.

The end moraines are more eroded than those of the Pinedale Glaciation and are typically strewn with large boulders of quartz monzonite that, after the fines are washed away, appear to be lag; therefore the till appears coarser than it actually is. Many of these lag boulders have irregularly weathered surfaces; their harder parts, such as quartzose veins or dikes and some basic inclusions, typically project a fraction of an inch to locally more than an inch outward from the rest of the surface of the boulder.

Richmond (1964) gave additional details on the character of these moraines and on the two tills composing them, as well as evidence for correlating them with the Bull Lake Glaciation.

OUTWASH BELOW LITTLE COTTONWOOD AND BELLS CANYONS

Outwash from the glaciers of the early stade of the Bull Lake Glaciation, called the lower outwash, is locally exposed near the edges of the tongues of the lower till. The best exposures are in the canyon of Little Cottonwood Creek near the Murray City Power Plant (fig. 8) along the prominent bluff south of the creek and west-southwest from this plant (stratigraphic sections 9, 10, 11, 12), and locally along the bluff on the eastern side of the graben of the Wasatch fault zone within half a mile north of the creek (stratigraphic sections 6, 7). Poorer exposures of this outwash can be seen on both the eastern and northern sides of upper Dry Creek valley (here the outwash comonly is not differentiated from the lower till on the geologic map; see stratigraphic section 13). Traced laterally basinward by means of these exposures, the lower outwash can be seen to intergrade and intertongue with or to overlie the lower till; it likewise intertongues and intergrades with gravel and sand of the Alpine Member within 1,000 feet of the outer edge of the lower till. These relations clearly indicate the contemporaneity of these till, outwash, and lacustrine deposits.

On the south side of the terminal moraines from Bells Canyon is a strath terrace underlain by the lower outwash. This terrace is cut into the lower till and the Alpine Member, showing that it is somewhat younger than the early Bull Lake-Alpine maximum.

The upper outwash of the Bull Lake Glaciation is somewhat more extensively exposed. The best exposures of the part of this outwash derived from the Little Cottonwood glacier are in the sides of the canyon of Little Cottonwood Creek west of the Wasatch fault zone (stratigraphic section 10, fig. 7); good exposures also occur along the high bluff that extends west-southwest from the mouth of this canyon. These exposures show that eastward this outwash is interbedded between the lower and upper tills and intertongues with the upper till; westward it intertongues and intergrades with the Bonneville Member; thus, all three units are essentially contemporaneous.

Along Little Cottonwood Creek the upper outwash underlies a wide strath terrace that is cut through the terminal moraine of late Bull Lake age and graded to the Bonneville shoreline. This terrace can be traced for about three-fourths mile upstream from the inner edge of this moraine; hence it and the Bonneville shoreline are somewhat younger than the late Bull Lake glacial maximum. The terrace cannot, however, be correlated with a specific recessional phase of this glaciation. This terrace crosses the main Wasatch fault zone and is faulted up about 50 feet on the east side.

East of Granite, several tongues of this outwash underlie channels that drained the frontal slope of the late Bull Lake terminal moraine of the Little Cottonwood glacier; these tongues are graded to the floor of a former lagoon on the shoreward side of a big gravel bar just west of Granite, at the Bonneville shoreline. These outwash deposits obviously date from the late Bull Lake glacial maximum, but their relations to the Bonneville shoreline maximum are less clear; they probably are somewhat older than this maximum but could be contemporaneous with it.

FIGURE 11.—Upper outwash gravel of the Bull Lake Glaciation filling channel cut into sand of the Alpine Member and bearing the Graniteville Soil (Noncalcic Brown soil facies). The B horizon of this soil extends about 4 feet below the top of the cut. Roadcut on east side of upper Dry Creek valley, 0.1 mile southeast of point where Dimple Dell Road crosses the North Fork of Dry Creek. Graduations on shovel handle are 1 foot apart.

In upper Dry Creek valley, a conspicuous fan (noted by Marsell, 1953, p. 21) of the upper outwash from the Bells Canyon glacier lies at the mouth of the gulch cut through the late Bull Lake terminal moraine by the North Fork of Dry Creek. This fan slopes as much as 10° and, at its lower edge, tongues out into several outwash-filled channels that pass between remnants of the early Bull Lake terminal moraine. The fan clearly was formed after the late Bull Lake maximum of the glacier. The southern part of the fan is notched by the Bonneville shoreline and locally is overlain by gravel of the Bonneville Member along this shoreline; hence this part is somewhat older than the shoreline. Several of the outwash-filled channels, however, cut through the shoreline deposits and are younger than the Bonneville lake maximum. The channel fillings also indicate that Dry Creek had cut a deep valley into the Alpine Member prior to their deposition, probably before the Bonneville maximum. The channels are nearly accordant with the present steep valley side, extend as much as 60 feet vertically below the top of the Alpine, and in places have cut deeply into this member (fig. 11). The channel fillings, however, terminate well above the broad terrace west of Dimple Dell Road that is veneered with alluvial gravel of Provo stillstand age (p. 32), and they are separated from this terrace by a pronounced steepening of slope; hence they predate the alluvial gravel.

On the south side of the late Bull Lake terminal moraine from Bells Canyon is a strath terrace mantled by the upper outwash and cut below a similar terrace of early Bull Lake age.

Both units of outwash, lower and upper, are lithologically similar: both are made up of boulder to cobble gravel, locally with boulders several feet to 8 feet or more in diameter; this material is typically poorly sorted and poorly rounded near the till margin and becomes better sorted, better rounded, and less coarse downstream. The outwash from Bells Canyon is entirely granitic, and that from Little Cottonwood Canyon is likewise granitic except for a few pebbles and some cobbles of other rocks from this drainage area.

Younger alluvial deposits—those of Provo stillstand age—that may include glacial outwash are here mapped and discussed as alluvium.

STRATIGRAPHIC RELATIONS BETWEEN TILL AND OUTWASH OF THE BULL LAKE GLACIATION AND THE ALPINE AND BONNEVILLE MEMBERS, BELOW LITTLE COTTONWOOD AND BELLS CANYONS

The lower till of the Bull Lake Glaciation, representing the maximum advance of the early stade of this glaciation, is at an altitude of 5,040 feet about a mile west of the mouth of Little Cottonwood Canyon and at an altitude of 4,920 feet about 1¼ miles west of the mouth of Bells Canyon. This till intertongues with both the lower outwash gravel and, along the till's outer edge, the Alpine Member. The lower outwash also lenses out westward into lacustrine beds of the Alpine Member, as shown in figures 7 and 8 and, somewhat generalized, on plate 1. The Alpine Member underlies the lower till at an altitude of about 5,050 feet and overlies it at altitudes as high as 5,080 feet (west of the main Wasatch fault zone); these heights show that the Alpine lake was at or near its maximum prior to, after, and probably during the early Bull Lake glacial maximum.

Similarly, a wedge of the upper till representing the maximum advance of the late stade of the Bull Lake Glaciation extends not quite as far west as the lower till and to minimum altitudes of 5,080 and 5,060 feet, respectively, below Little Cottonwood and Bells Canyons. The upper till similarly intertongues (commonly through an intervening selvage of outwash) with the Bonneville Member. A strath terrace of the upper outwash below Little Cottonwood Canyon cuts through the late Bull Lake terminal moraine and is graded to the Bonneville shoreline; moreover, a fan of the upper outwash is somewhat younger than the late Bull Lake terminal moraine below Bells Canyon and is notched by the Bonneville shoreline. These relations show that the Bonneville lake maximum occurred somewhat later than the late Bull Lake glacial maximum.

The Little Cottonwood Formation and its members can be generally correlated with the till and outwash of the Bull Lake Glaciation on the basis of the similar relations to the Dimple Dell and Graniteville Soils and of the lake and glacial cycles that they record. The Little Cottonwood Formation, by definition, is intermediate in age between these two soils. The lower till of the Bull Lake Glaciation locally rests on the Dimple Dell Soil (figs. 9, 10), and the upper till extensively bears the Graniteville Soil. Inasmuch as the Alpine Member and the Bonneville and Provo Members of the Little Cottonwood Formation record two lake cycles and the lower and upper tills record two stades (cycles) of the Bull Lake Glaciation, and because the lake and glacial oscillations reflect climatic fluctuations of the same type, both cycles are inferred to have been synchronous, and the deposits recording them are inferred to be correlative. The Alpine Member, then, is correlated with the lower till and outwash of the Bull Lake Glaciation, and the Bonneville and Provo Members are correlated with the upper till and outwash of this glaciation.

ALLUVIUM OF LITTLE COTTONWOOD AGE

Alluvium that is equivalent in age to the Little Cottonwood Formation can be identified either by intertonguing relations with this formation and (or) by its position overlying pre-Lake Bonneville alluvium or colluvium or overlying the Dimple Dell Soil and underlying the Graniteville Soil. In places this alluvium correlates with given members of the Little Cottonwood Formation or marks diastems within it. Two main types of alluvium are distinguished in the discussion below (but are not differentiated on the geologic map, plate 1): fan gravel on alluvial fans at the foot of the mountains, and alluvial gravel underlying strath terraces cut by the larger streams.

FAN GRAVEL

At the mouths of many of the canyons along the Wasatch front are alluvial fans of boulder gravel that bear the Graniteville Soil and are younger that the pre-Lake Bonneville fan gravel and colluvium, and are therefore considered to be of Little Cottonwood age. Only rarely, however, can the fan gravel be differentiated into correlatives of specific members of the Little Cottonwood Formation. This alluvium consists of poorly sorted subangular to angular boulders and blocks, commonly several feet across and are locally as much as 20 feet across, admixed with finer gravel, sand, and some silt; it is composed of the more resistant rocks from a given drainage area.

Some of the fan gravel is so coarse and poorly sorted that it appears virtually identical with the till of the Bull Lake glaciation from Bells and Little Cottonwood Canyons (fig. 12). The deceptive lithology of the gravel in the large fans at the mouths of Little Willow Canyon (north of Little Cottonwood Canyon) and in

FIGURE 12.—Large alluvial fan of Little Cottonwood age at mouth of Big Willow Creek, showing scarps of several faults in the main Wasatch fault zone. This fan gravel, called till by Atwood (1909), is so coarse and poorly sorted that it resembles till of the Bull Lake Glaciation in the terminal moraines below Little Cottonwood and Bells Canyons. The lower part of the canyon of Big Willow Creek is similar to the other nonglaciated canyons along the mountain front and is devoid of evidence of glaciation (note its deep V-shaped valley).

the canyons of South Fork of Dry Creek and Big Willow Creek doubtless led Atwood (1909, pl. 10, p. 79–80, 85) to regard these fans as moraines.[9] The complete lack of evidence of glaciation in the lower parts of these canyons is proof that these fans are not moraines. The lower parts of the canyons are narrow and V-shaped and obviously are very youthful stream-cut gorges (fig. 12); they lack U-shaped cross sections, and they contain none of the evidences of glaciation such as glacial smoothing, grooves, or striae, which would surely have been preserved if the canyons had been glaciated to their mouths as recently as Bull Lake time. Furthermore, these fans show a typical alluvial-fan (although faulted) morphology that is devoid of moraines or other glacial landforms. The morainic ridges shown on Atwood's sketch maps of the mouths of these canyons (1909, figs. 12, 13, 19) are nonexistent. The upper parts of these canyons were indeed glaciated in Bull Lake time, but the terminal moraines of this age are far above the canyon mouths, at altitudes of about 7,500, 6,500, and 7,400 feet, respectively, for the three canyons (M. D. Crittenden, Jr., written commun., 1960). The exceptional coarseness and poor sorting of the fan gravel suggest that it was deposited by heavily laden floods (perhaps even mudflows) at the time of the Bull Lake Glaciation.

The gravel in the big fan below the mouth of the canyon of Big Willow Creek is partly of early and partly of late Little Cottonwood age. A small exposure just beyond the western contact of the main part shows that the lower part of the fan gravel is intercalated

[9] Atwood incorrectly designated the Big Willow Creek deposit as below the mouth of Bear Canyon in the text of his report, although he located it correctly on his map (pl. 10).

with the Alpine Member. Furthermore, a wide Bonneville shore terrace, carved into the fan, shows that most of this deposit predates the Bonneville lake maximum. Some of the fan gravel evidently dates from the inter-Alpine-Bonneville lake recession. For example, at the northwestern edge of the main part of the fan, a tongue of gravel—spilled down the side of an ancient valley of Willow Wash—fills a steep gully cut into the Alpine Member. This gravel tongue also is overlain by gravel of the Bonneville Member; so it is younger than the Alpine lake maximum and older than the Bonneville lake maximum. Half a mile below the fan, on both sides of the valley of Willow Wash, two small patches of fan gravel underlie stream terraces cut into the Alpine Member. They bear the Graniteville Soil and appear to be remnants of a tongue of the main fan on the flood plain of the ancient valley.

LOW-LYING OCCURRENCES OF ALLUVIAL GRAVEL INTERBEDDED WITH THE LITTLE COTTONWOOD FORMATION

Alluvial gravel interbedded with silt, sand, and clay of the Little Cottonwood Formation has been recognized in four small exposures, all along the Jordan River. Such gravel marks diastems within the Little Cottonwood Formation that record major lake recessions during Little Cottonwood time. One of these diastems is between the Alpine Member and the Bonneville and Provo Members, and one or more others are within the Alpine Member. (See p. 20.) In some places, however, the exact position of the diastem cannot be established because the Little Cottonwood Formation cannot be precisely differentiated as to member in the exposures.

The northernmost and lowest exposure is in a small hill of the Alpine Member in the flood plain of the Jordan River 0.2 mile east of the NW cor. SW¼ sec. 14, T. 2 S., R. 1 W., at an altitude of about 4,265 feet. It consists of a lens of pebble and cobble gravel as much as several feet thick that is overlain and underlain by tough silty clay that, from its degree of induration, is probably Alpine Member. In other words, this alluvial gravel probably marks an intra-Alpine diastem; moreover, it is at the lowest altitude at which such a diastem has yet been recognized in the area of Lake Bonneville.

In the second exposure, south of and lower than the first exposure, the alluvial gravel also is interbedded with the Alpine Member (stratigraphic section 15). It is one-third mile southwest of the mouth of Dry Creek in sec. 11, T. 3 S., R. 1 W. The alluvium is cobble and pebble gravel as much as 9 feet thick, and its base is at an altitude of 4,310 feet.

Another possible occurrence is in a small hill adjoining the eastern edge of the Jordan River flood plain at the SE cor. sec. 35, T. 3 S., R 1 W. This deposit is poorly exposed pebble gravel, locally with inclined bedding, and may be alluvial and (or) lacustrine; it is overlain by fine sand and silt of the Little Cottonwood Formation on the western side of the hill. The base of the gravel is not exposed but is below an altitude of 4,360 feet.

The southernmost exposure is just outside the area mapped. It is the site of a 1947 canal washout on the western bluff of the Jordan River in the NW¼ sec. 2, T. 4 S., R. 1 W., and was mentioned by Jones and Marsell (1955, p. 101). Here the alluvium is cobble and pebble gravel consisting entirely of rocks from the mountains on the western side of lower Jordan Valley. It is about 14 feet thick, and its base is at an altitude of about 4,390 feet. (The altitude, 4,290 ft, given by Jones and Marsell is erroneous.) This deposit probably marks the diastem between the Alpine and Provo Members.

STRATH-TERRACE GRAVEL OF PROVO STILLSTAND AND LATE PROVO AGE

The most extensive alluvial deposits of Little Cottonwood age are those veneering strath terraces along Little and Big Cottonwood Creeks, Dry Creek, and Willow Wash. The terraces are cut into the Alpine and Bonneville Members of the Little Cottonwood Formation. They are graded to the Provo or lower shorelines, and their alluvium intertongues with the Provo Member and bears the Graniteville Soil; hence, they obviously are of Provo stillstand and late Provo age.

These terraces are especially well formed along Little Cottonwood Creek (figs. 13, 14). They fan out widely below the lower canyon mouth at the old Murray City Power Plant and are graded to seven principal levels separated by scarps 5–80 feet or more high. The inferred age relations of these terraces and of the lacustrine age units with which they intergrade are shown on plate 3. The highest strath terrace of this sequence—strath terrace 8 of Provo stillstand and Provo age on plate 3—which is locally preserved on both sides of the creek is the oldest and is graded to the Provo shoreline.

Later, as Lake Bonneville receded below this shoreline, Little Cottonwood Creek trenched the Provo fan delta, leaving mesalike remnants between valleys. These valleys, all nearly the same age, were formed as Little Cottonwood Creek shifted its course before the lake had receded more than 200 feet below the Provo level. They are represented by terraces 3–7. The southernmost valley is just south of the mesa on which Alta Airpark is located. The middle valley is between the airpark and Flatiron Mesa. The northern valley, along the present valley of Little Cottonwood Creek, graded to a delta whose highest shoreline was at an altitude of about 4,700 feet; this valley now is mostly

FIGURE 13.—Strath terraces of Provo stillstand and later age on south side of Little Cottonwood Creek. View from top of bluff on north side of this creek. Eolian sand of post-Draper age in foreground.

eroded but is represented by strath terrace 7 north of the creek. Dissection of these valleys probably began at the front of the Provo delta; but until the downcutting had progressed to the head of the fan, the creek still was able to swing widely on the upper part of its fan and to occupy first one, then another, valley. The middle valley probably was first to be abandoned, for its flood plain, represented by terrace 4, is graded to a recessional shoreline at an altitude of about 4,680 feet. The flood plain of the southern valley, represented by terrace 3, is graded to a shore terrace at an altitude of about 4,640 feet. Probably the northernmost valley was last to be cut, for the creek, thenceforth, became entrenched along this valley. Terrace levels 2 and 1 were cut late during the lake recession—level 1 probably when the lake level had dropped below an altitude of 4,550 feet.

A prominent terrace of alluvial gravel of probable Provo stillstand age borders the south side of Little Cottonwood Creek for three-fourths mile east of the main Wasatch fault zone. This is the farthest upstream that alluvium of this age can be traced; hence, it cannot be directly tied to a particular recessional phase of the late stade of the Bull Lake Glaciation.

All the terraces of Little Cottonwood Creek have similar alluvial gravel—moderately well sorted subrounded to well-rounded pebble, cobble, and boulder gravel. (See stratigraphic sections 3, 5.) Boulders 1½–2 feet in diameter are common just below the Murray City Power Plant, and boulders 1 foot in diameter are common as much as 2 miles downstream from the plant. Most of the small stones and nearly all the larger ones are quartz monzonite of the Little Cottonwood stock. Typically several percent to locally as much as 10 percent of the stones are appreciably decomposed, not only in the B horizon of the Graniteville Soil, but throughout this alluvial unit.

The strath terraces of Big Cottonwood Creek that are of Provo stillstand and late Provo age are somewhat less conspicuously formed than the similar terraces of Little Cottonwood Creek, and they also are displaced by numerous faults associated with the Wasatch fault zone. The main terrace, which is best preserved on the south side of the creek, is graded to the Provo shoreline and can be traced upstream to at least a mile above the canyon mouth. It is mantled with coarse alluvial-outwash gravel that bears the Graniteville Soil and probably dates from the recession of the late stade of the Bull Lake Glaciation. It is offset vertically more than 100 feet, down on the west, where it crosses the main Wasatch fault zone. For two-thirds of a mile westward from the main fault zone, the southern edge of this terrace appears to be defined by a scarp that is partly due to erosion by Big Cottonwood Creek but probably is mainly caused by faults (concealed by colluvium and eolian sand) that are transverse to the main fault zone. The faults displace the Alpine and Bonneville Members and lose all surface expression at the Provo shoreline; so their movement evidently was during the recession of Lake Bonneville from the Bonneville shoreline maximum and before the end of the Provo stillstand, possibly even during this stillstand.

Farther downstream this fault zone seems to fan out and to be at least partly responsible for defining three successive terraces of Provo stillstand age. (These terraces are graded to the Provo shoreline.) The southernmost, and probably the oldest, terrace slopes downstream about 200 feet per mile; the middle terrace, about 125 feet per mile; and the northern main terrace, about 110 feet per mile. Scarps 10–25 feet high separate the three terraces; and another scarp, probably mainly a fault scarp, bounds the terraces on the southeast and is similar to the southwest-trending fault that

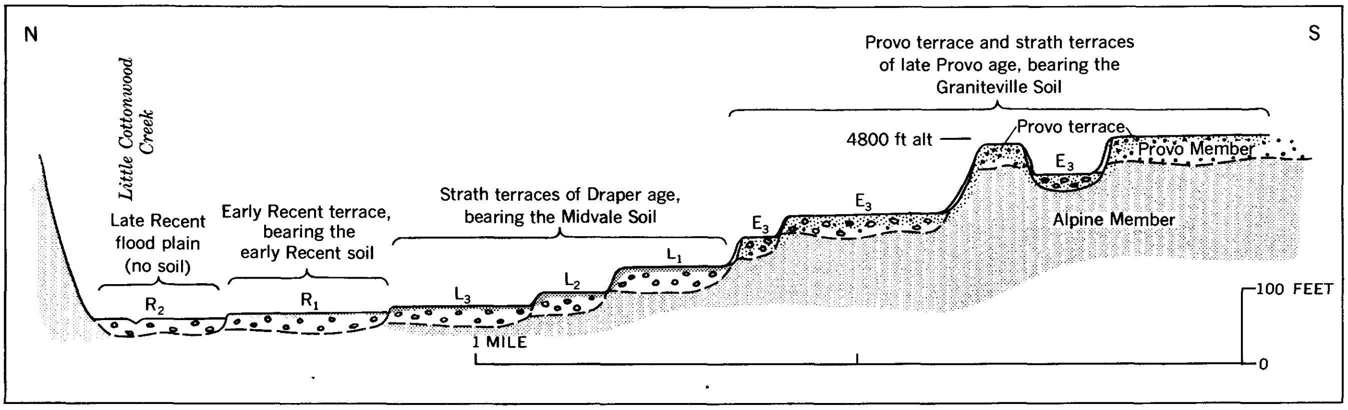

FIGURE 14.—The strath-terrace sequence of Little Cottonwood Creek (through the east end of Flatiron Mesa). Shown is how the Graniteville and Midvale Soils and early Recent soil are used as one of the criteria to differentiate and correlate the terraces of late Provo, Draper, and Recent age. E_3, strath terraces of late Provo age (after the Provo stillstand); L_1, strath terrace of early Draper age; L_2, strath terrace of middle Draper age; L_3, strath terrace of late Draper age; R_1 strath terrace of early Recent age; R_2 flood plain of late Recent age.

bounds the terrace complex of Little Cottonwood Creek below the Murray City Power Plant.

A faulted remnant of an alluvium-mantled strath terrace that probably was graded to the Provo shoreline is preserved on the north side of Big Cottonwood Creek near the SE cor. sec. 23 T. 2 S., R. 1 E. About half a mile downstream is another faulted terrace remnant, probably graded to this or a lower recessional lake level.

The alluvial gravel on all the strath terraces of Big Cottonwood Creek consists mainly of quartzite and hornfels of the Big Cottonwood Formation. It also contains smaller percentages of other resistant rocks (such as Mineral Fork Tillite) from this drainage area but almost no granitic rocks.

Along the eastern and southern sides of the upper part of the valley of Dry Creek is another prominent strath terrace graded to the Provo shoreline; hence it is of Provo stillstand age. The alluvium of this terrace bears the Graniteville Soil and commonly consists of 6–12 feet of pebble and cobble gravel locally with some small boulders, almost entirely of quartz monzonite, overlying sand and gravel of the Bonneville and Alpine Members (stratigraphic section 16). The upstream part of this terrace lies slightly below the outer ends of the remnants of the upper outwash gravel of the Bull Lake Glaciation and is inferred to be younger than the maximum of the late stade of Bull Lake Glaciation of Bells Canyon. Along the north side of the middle part of the Dry Creek valley, small remnants of this alluvium are preserved in several places; they are accordant in level with the terrace on the south side of the creek.

A narrow strath terrace borders Willow Creek Wash for more than a mile above the Provo shoreline. It is mantled by alluvial gravel, graded to this shoreline, that is generally finer and has a smaller proportion of granitic rocks than the alluvium on the similar terraces of Little Cottonwood and Dry Creeks.

DISCONFORMITY BETWEEN THE LITTLE COTTONWOOD AND DRAPER FORMATIONS

The best marked disconformity within the Lake Bonneville Group is between the Little Cottonwood and Draper Formations. It records subaerial erosion and has been identified in this area at altitudes as low as 4,250 feet (only 50 ft above the modern mean level of Great Salt Lake), showing that Lake Bonneville for an appreciable length of time fell below this level, probably at least as low as the level of the present lakes in the Lake Bonneville basin. This interval is called the middle-Lake Bonneville desiccation interval.

This disconformity is best seen either where it bears the Graniteville Soil (figs. 2, 18, 21) and (or) alluvium of middle-Lake Bonneville age, or where it is an erosion surface that cuts at least a few feet into sediments different from those of the overlying Draper Formation. It commonly is not discernible where the Draper and Little Cottonwood Formations are lithologically similar and where the soil and alluvium are lacking, as, for example, many exposures of gravel and sand along the front of the Cottonwood delta below the Provo terrace, where the Graniteville Soil has been completely eroded by waves of the first Draper lake. The disconformity is especially conspicuous where it bears the Calcic Brown soil facies of the Graniteville Soil, for the C_{ca} horizon of this facies is distinctive and also has tended to resist erosion. This disconformity commonly is seen in cellar, sewer, and other excavations on the lowlands below the front of the Cottonwood delta where the overlying Draper Formation is generally only a few feet thick (fig. 16), and it is widely exposed on the lowlands south of Dry Creek and west and southwest of Draper spit where the Draper Formation is only a foot or two thick or is entirely absent. From the W½ sec. 18, T. 3 S., R. 1 E., to the SE¼ sec. 24, T. 3 S., R. 1 W., this disconformity forms the present ground surface and is manifested as a series of small gullies and ridges, commonly with 20 feet or more of local relief, cut in clay of the Little Cottonwood Formation in the scarp between altitudes of 4,400 and 4,475 feet. The Graniteville Soil extensively mantles these features (covering their topography), a fact that attests to their middle-Lake Bonneville age.

The disconformity is most strikingly displayed in the valley of Dry Creek. From about the west line of sec. 16 to the east line of sec. 15, T. 3 S., R. 1 E., at an altitude of about 4,780 feet, the valley is partly filled with sand and gravel of the lower tongue of the Draper Formation (p. 37, figs. 19, 20). These deposits disconformably overlie the Little Cottonwood Formation; they were laid down in an older valley of Dry Creek that was cut below the strath terrace of Provo stillstand age to within a few feet of the present creek bed. The ancient valley surface commonly bears the Graniteville Soil and, locally, along the valley axis, alluvium of middle-Lake Bonneville age. (See next text section and stratigraphic sections 14, 20.) These relations clearly indicate that this episode of valley erosion took place after the end of deposition of the Little Cottonwood Formation and before the development of the Graniteville Soil.

The lowest point at which this disconformity has been identified is in the bluffs on the east side of the Jordan River at the northwestern corner of the map area. Here it is marked by alluvium of middle-Lake Bonneville age (stratigraphic section 1) at an altitude of 4,250 feet.

ALLUVIUM OF MIDDLE-LAKE BONNEVILLE (INTER-LITTLE COTTONWOOD-DRAPER) AGE

A few small patches of alluvial gravel and sand that lie disconformably on the Little Cottonwood Formation and are overlain by the Draper Formation are locally exposed. Many of them are too small in outcrop area to be mappable, but they are especially significant because they mark the disconformity between these two formations and record significant subaerial erosion during a long interval of lake desiccation. They generally bear the Graniteville Soil, where this soil has not been eroded later.

Several remnants of this alluvium are exposed in the middle part of the valley of Dry Creek. They crop out locally in the high banks bordering the north side of the inner valley of this creek in the S½NE¼ sec. 16, T. 35, R. 1 E., at an altitude of about 4,680 feet about 100 feet below the strath terrace of Provo stillstand age in this valley (fig. 21). The best exposures are generally where these banks project farthest toward the axis of the valley. The alluvium consists of sand and gravel as much as 10 feet thick. It rests disconformably on the Alpine Member, bears the Graniteville Soil, and is overlain by sand and gravel of the lower tongue of the Draper Formation (stratigraphic section 20). The lower contact of the alluvium generally slopes several degrees toward the valley axis, and the alluvium itself generally thickens and becomes more gravelly in this direction. These facts show that the alluvium is an ancient valley-bottom deposit of Dry Creek that was laid down during the middle-Lake Bonneville lake desiccation shortly before development of the Graniteville Soil. Evidently Dry Creek had here cut its valley to within 15 or 20 feet of its present depth, so that its gradient and local base level (the ancestral Jordan River) probably were almost as low as they are now.

Another exposure of this alluvium, deposited in a former channel of Neffs Creek, can be seen in a fault scarp a mile northwest of the center of Holladay.

The lowest exposures are in the eastern bluff of the Jordan River at the northwestern corner of the map area, in the S½ sec. 35, T. 1 S., R. 1 W. These extend as low as an altitude of 4,250 feet—the lowest altitude at which the disconformity between the Little Cottonwood and Draper Formations has been observed (stratigraphic section 1.) The thickest deposit, which is as much as 10 feet thick, caps the tip of a small spur that projects southwestward from the bluff in the SW¼SE¼ of this section. Here about half the alluvium is sand and fine pebbly sand, and the other half is very fine pebble gravel which is commonly quite sandy. The pebbles are all well rounded and mainly less than 1 inch in diameter, but occasionally they are as much as 2 inches in diameter. Some of the sand at the base and in the upper part of the unit is fine-medium and is possibly of eolian derivation.

GRANITEVILLE SOIL

The Graniteville Soil, here named after the town of Graniteville (Granite, plate 1), is a distinctive, stratigraphically discrete, zonal soil. It is developed on the Little Cottonwood Formation, on alluvium and colluvium of Little Cottonwood age, on till and outwash of the Bull Lake Glaciation, and also on alluvium of middle-Lake Bonneville age (figs. 2, 8, 9, 10, 14, 18, 21). The type section of the soil is exposed in the SE¼SE¼ sec. 2, T. 3 S., R. 1 E. (See stratigraphic section 10.) The Graniteville Soil also is formed on older deposits, where these were exposed at the land surface while it was forming. This soil is never present on the Draper Formation nor on coeval and younger deposits. Its stratigraphic relations indicate that the Graniteville Soil formed during a time of accelerated weathering in the later part of the middle-Lake Bonneville dessication interval, following deposition of the alluvium of middle-lake Bonneville age and before depostion of the lower tongue of the Draper Formation. Subsequent changes by soil-forming processes other than erosion have been too minor to mask the distinctive characteristics of this soil, even in relict occurrences.

The Graniteville Soil was previously called the middle-Lake Bonneville soil (Morrison, 1961a, b) and the post-Bull Lake soil (Richmond, 1964).[10]

The Graniteville Soil has a strongly developed, mature (zonal) soil profile. It is intermediate in degree of development between the Dimple Dell and Midvale Soils—roughly a third or a quarter as well developed as the Dimple Dell Soil and nearly twice as well developed as the Midvale Soil. It occurs in two principal facies, described below. This soil is widely exposed as a relict soil above the high shore of the first lake of Draper time and is locally exposed as a buried soil below this level. It commonly is partly eroded in both relict and buried occurrences, though less so than the Dimple Dell Soil.

The Graniteville Soil is a Brown Podzolic soil in the higher mountains, mostly east of the area mapped, but it changes facies with changes in altitude and other environmental factors to a Noncalcic Brown soil facies on the lower frontal mountain slopes and upper part of the Cottonwood delta and then through a local Brown Forest soil facies to a Calcic Brown soil facies at the edge of the basin. The Pedalfer-Pedocal boundary southeast of Draper lies close to the base of the mountain front well above the Provo shoreline, but thence it swings sharply westward around the Draper spit and along the western front of the Cottonwood delta between altitudes of 4,760 and 4,560 feet (pl. 2). North of Big Cottonwood Creek it again lies close to the mountain front. The reasons for the rather large change in altitude and the westward shift of this boundary around the delta are not understood. Perhaps precipitation was locally greater (because of proximity to the high peaks of the Little Cottonwood massif), or perhaps the parent material on the delta was generally lower in calcium than elsewhere so that a Pedalfer rather than Pedocal soil was formed.

[10] The post-Bull Lake soil is defined informally by Richmond as "* * * that distinctive and strongly developed zonal soil occurring above the upper limits of the Bonneville Formation on deposits of the late stade of Bull Lake Glaciation, and on deposits of the early stade not covered by those of the late stade." In this report, however, only the one name, Graniteville Soil, is used throughout the area mapped because it seems inadvisable to use a separate name for the same soil where it is formed on glacial deposits. This soil is given a formal name in terms of the lacustrine stratigraphy because its stratigraphic age can be established most precisely in terms of this stratigraphy, and the deposits of Lake Bonneville are far more widespread in this region than are those of the Bull Lake Glaciation.

The Noncalcic Brown soil facies (fig. 15, soil-profile sections S–6, S–11, S–12, S–13) generally is developed on lake or alluvial gravel and sand or on till; consequently its texture typically ranges from stony or gravelly sandy loam to coarse sand and gravel. An A horizon is seen only on relict profiles, not on buried ones. Normally the A horizon is 4–10 inches thick, but locally it is as much as 2 feet thick where burrowing animals have reworked humic material into the upper part of the B horizon. The A horizon is a dark-gray to dark-gray-brown (about 10*YR* 4/1 to 10*YR* 4/2), massive, nonsticky, nonplastic, loose to soft, stony sandy loam. Its lower boundary generally is abrupt to clear but commonly shows evident disconformity upon the B horizon. In such occurrences, and probably generally, the A horizon represents reworking by soil-forming agencies subsequent to the formation of the Graniteville Soil; hence this horizon is not considered part of the profile of the ancient soil.

The B horizon is about 40–50 inches thick in the least eroded occurrences, and it grades from brown (about 7.5*YR* 4/2 to 7.5*YR* 4/4, and locally 10*YR* 5/2 to 10*YR* 4/3) in its upper part to a somewhat lighter and yellowish brown in its lower part (10*YR* 6/3, 10*YR* 6/4, 10*YR* 5/3, 10*YR* 5/4, to 10*YR* 4/3). Typically it is a stony sandy loam with a slight concentration of fines, mainly silt, in the upper part of the horizon. On the Cottonwood delta most of the pebbles are quartz monzonite, and many of them are somewhat rotten, particularly in the upper part of the B horizon. The B horizon is structureless, grading from massive in the uppermost part to single grained below. Consistence grades downward from slightly hard (rarely, hard) in the upper 1½–2 feet to soft below (and locally almost loose, at the bottom of the horizon).

Although the Noncalcic Brown soil facies lacks a true C_{ca} horizon, several deep cuts into the upper till of the Bull Lake Glaciation in the terminal moraines below Bells Canyon show a zone of calcium carbonate concentration 10–15 feet below the top of the Graniteville Soil and separated from the base of the B horizon by 6–8 feet of noncalcareous till. In the carbonate zone the carbonate accumulation is fairly strong in the upper 3 feet and gradually decreases downward. This zone is too far below the B horizon to be a true C_{ca} horizon, although it probably formed by downward leaching and reconcentration of carbonate in the till within the zone of aeration (above the water table).

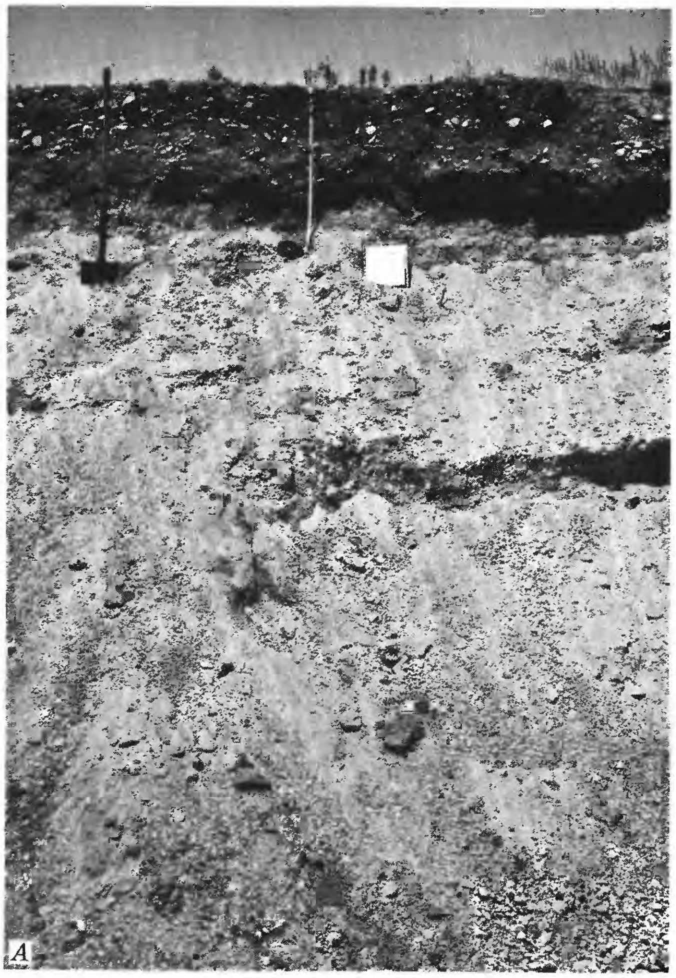

FIGURE 15.—Graniteville Soil. Noncalcic Brown soil facies, developed on gravel of the Bonneville Member. *A*, shows minimum thickness of this facies of this soil at gravel pit 0.25 mile south of Dry Creek and immediately above Provo terrace, SW¼ sec. 19, T. 3 S., R. 1 E. *B*, Close-up. Note that the B horizon is more strongly developed than that of the Midvale Soil (compare with fig. 22), although here this horizon has about the same thickness as the typical thickness of the B horizon in the Midvale Soil.

Relict occurrences of the Graniteville Soil commonly have a veneer of loessic material, several inches to several feet thick, of post-Lake Bonneville (mainly Altithermal) age. This loessic mantle commonly bears the Midvale Soil (of post-Draper age), which may extend downward to meet or even penetrate the Graniteville Soil, so that the mantle and Midvale Soil may be mistaken for part of the older soil. This fine-grained mantle is introduced material and should not be mistaken for material derived from the weathering that formed the B horizon of the Graniteville Soil.

In the Calcic Brown soil facies the B horizon is generally similar but somewhat thinner (generally 1–2½ ft thick) than that in the Noncalcic Brown soil facies, and it is more commonly in the 10*YR* rather than the 7.5*YR* hue range. It grades in its lower several inches through increasingly calcareous material into the underlying C_{ca} horizon. The C_{ca} horizon is 1½–3½ feet thick and has its greatest lime concentration in the upper foot or two (fig. 16, stratigraphic section 5). The B horizon is white to pale gray, massive, and hard, and it grades downward to slightly hard and soft.

Compared with the Dimple Dell Soil, the B horizon (in both the Noncalcic Brown and Calcic Brown soil facies) of the Graniteville Soil is appreciably less clayey, thinner, and somewhat less red and lacks structure; the C_{ca} horizon (in the Calcic Brown soil facies) is thinner and considerably less strongly developed. Compared with that of the Midvale Soil, the B horizon of the Graniteville Soil is somewhat thicker and browner (commonly in the 7.5*YR* hue range, rather than the 10*YR*), and the C_{ca} horizon (in the Calcic Brown soil facies) is considerably stronger.

DRAPER FORMATION

The name Draper Formation is here given to the sediments of Lake Bonneville that are younger than the Graniteville Soil and older than the Midvale Soil.

FIGURE 16.—Cca horizon (white band) of buried, partly eroded Graniteville Soil (Calcic Brown soil facies), developed on sand of the Little Cottonwood Formation and overlain by the lower tongue of the Draper Formation (which bears the Midvale Soil). Note how the Graniteville Soil covers the irregular surface of the disconformity between the Little Cottonwood and Draper Formations. Cellar excavation 0.5 mile west of the base of the frontal scarp of the Cottonwood delta below the Provo terrace and 0.3 mile south of the Alta-Sandy Road (9400 South Street).

These sediments, therefore, commonly overlie the older soil and bear the younger one. They are named after the town of Draper, in and near which they are well exposed. The type area for the formation is a strip extending 0.25 mile to each side of Dry Creek from its mouth to the center of sec. 15, T. 3 S., R. 1 E. In this area can be seen the stratigraphic and geomorphic relations of the formation as a whole and of each of its tongues.

The Draper Formation includes three tongues whose maximum altitudes are, from oldest to youngest, about 4,770, 4,470, and 4,410 feet. Each tongue—the lower, middle, and upper—is inferred to record a given lake cycle. The tongues are locally separated by disconformities and very rarely by subaerial deposits such as alluvium and colluvium, but intercalated soils were not found. Three lithofacies units—gravel, sand, and silt-clay—are differentiated. The tongues are generally differentiated on the geologic map in the gravel and sand facies, never in the silt-clay facies.

This formation can be differentiated from the Little Cottonwood Formation by soil stratigraphy, unconformity, distinctive lithology, and geomorphic relation. The Draper Formation makes up about 3.5 percent of the total volume of the Lake Bonneville Group and underlies about 60 percent of the area underlain by the whole group in the Draper quadrangle and in the eastern part of the Midvale quadrangle (table 4). Moreover, it records a major and fairly neglected part of the history of Lake Bonneville—a major lake rise and two smaller oscillations.

LOWER TONGUE

The lower tongue of the Draper Formation consists mainly of lake gravel and sand. It lies on the disconformity between the Little Cottonwood and Draper Formations and on the Graniteville Soil and is overlain, below an altitude of about 4,470 feet, by the middle tongue, from which it is separated by a local diastem. The lower tongue extends as high as an altitude of about 4,770 feet in this area (to or almost to the outer edge of the tread of the Provo terrace) and is inferred to record the first lake cycle and highest lake maximum of Draper time. East of 700 East Street in the type area for the Draper Formation, the lower tongue is well preserved by shore terraces, spits, and deltas, and also by a distinctive filling in Dry Creek valley. This tongue typically overlaps the Provo Member of the Little Cottonwood Formation and is equivalent to the younger (Provo 2) part of the Provo Formation as redefined by Bissell (1963).

Jones and Marsell (1955, p. 101, 103–104) and Eardley, Gvosdetsky, and Marsell (1957, p. 1166–1168) inferred that after the Provo stillstand a separate lake cycle rose to within a few feet of the Provo shoreline. They called the maximum of this lake cycle the Provo 2 stage. They cited Bissell's evidence for this maximum and also evidence from eastern Jordan Valley, but I am unable to confirm the evidence they gave from the latter area. The dual shorelines on Draper spit do not necessarily prove that significant lake recession separated the Provo 2 maximum from the Provo stillstand; the younger shoreline could record merely a stillstand in the recession from the Provo stillstand. Furthermore, I find no evidence of lake deposits younger than the Provo Member at the Reynolds gravel pit; the sand unit that Jones and Marsell inferred to be lake sand of Provo 2 age I consider to be eolian sand. (See stratigraphic section 2 and fig. 17.)

The lower tongue of the Draper Formation typically is a few inches to a few feet thick, although locally on the deltas and in Dry Creek Valley it is 20 feet or more thick. It commonly varies considerably in thickness within short distances and locally is too thin to be mappable.

Several lines of evidence show that wave action and longshore transport of sediment were only moderate during the higher levels of the first Draper lake. The Graniteville Soil is locally preserved beneath the lower tongue of the Draper even on shores that were most exposed to waves, such as the western front of the Cottonwood delta (fig. 18). Moreover, the lower tongue typically is considerably finer-grained than the Provo Member at a given locality in the high-shore zone. The pattern of spits and bars of gravel of the

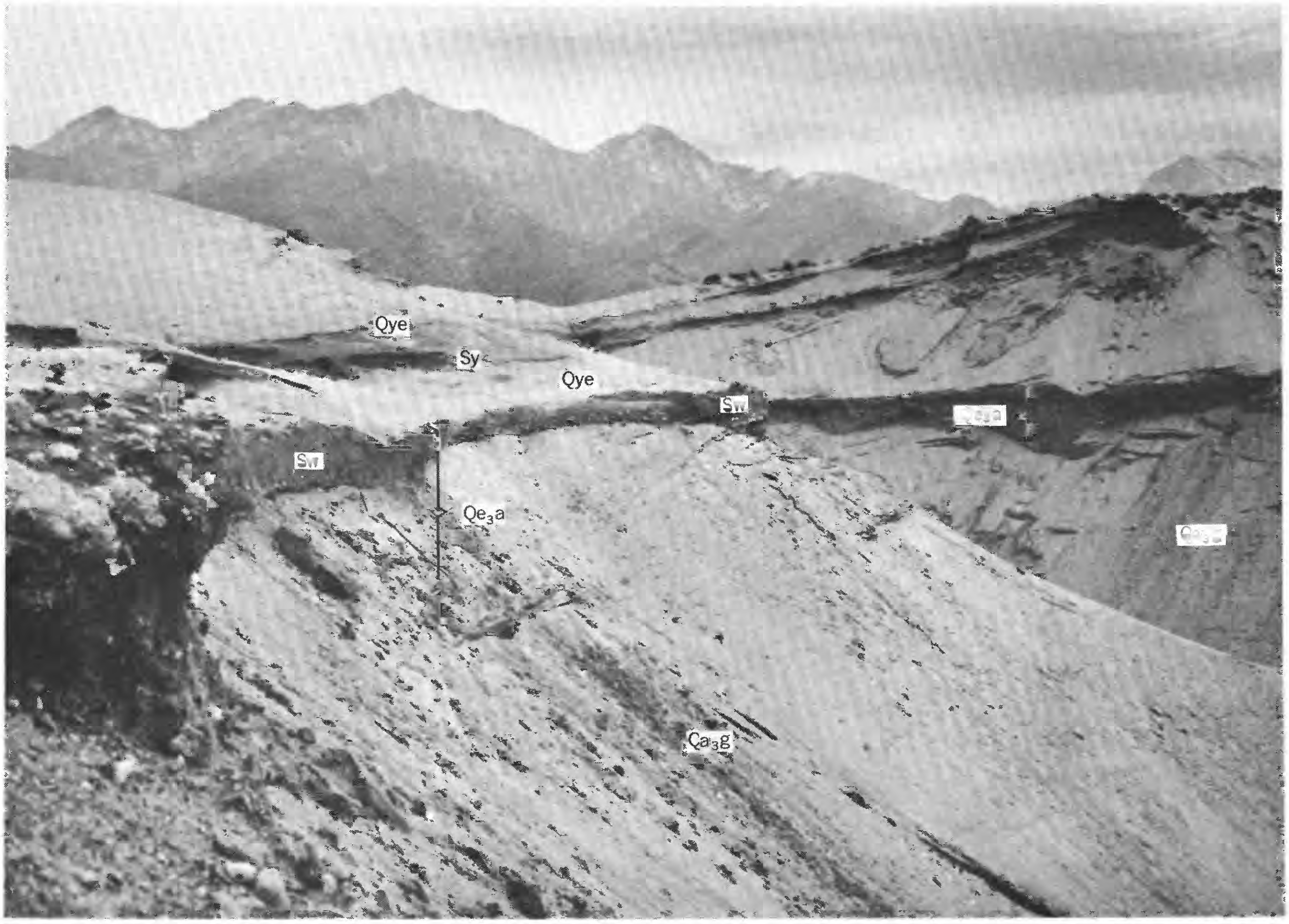

FIGURE 17.—Eolian sand of post-Draper age (Qye) and intercalated Midvale Soil (Sy) overlying the Graniteville Soil (Sw) formed on strath terrace gravel of the late Provo age (Qe_3a). Strath terrace gravel of late Provo age rests on sand and gravel of the Provo Member (Qa_3g). (The eolian sand under the Midvale Soil was regarded as Provo 2 lake sand by Jones and Marsell (1955, p. 101–103). Reynolds gravel pit, 0.2 mile north of Little Cottonwood Creek and just east of 2000 East Street.

lower tongue along the delta front and on Draper spit indicates moderate southward transport of sediment, but the comparative thinness of this tongue on the north side of the valley of Dry Creek, below the high shore of the first Draper lake, shows that the transport was much less than in Provo stillstand time. There is no suggestion, for instance, that the valleys of Little Cottonwood and Dry Creeks (which were deepened during the middle-Lake Bonneville desiccation) were entirely dammed by spits or bars built during the higher levels of the first Draper lake.

Gravel of this tongue is confined to the front of the Cottonwood delta except near Little Cottonwood and Dry Creeks, where deltaic gravels occur at lower altitudes (stratigraphic section 14). This gravel resembles the gravel of the Provo Member in its vicinity but is finer. It is mostly pebble gravel (rarely cobble gravel), is generally very sandy and commonly is only 1 to several feet thick; it overlies a greater thickness of sand containing minor pebble gravel and pebbly sand. Along the front of the Cottonwood delta, various gravel pits expose 20–50 feet of such material.

Sand of this tongue forms an almost continuous north-south band through the area, commonly a mile or more wide. Along the front of the Cottonwood delta it generally either underlies the gravel facies or is exposed at the surface between the gravel spits, bars, and beach terraces. Here this sand is several feet to locally more than 20 feet thick; typically it is medium sand, locally containing admixed or interbedded coarse, fine, and pebbly sand; it is arkosic, nearly white, generally loose, and, in places, crossbedded. Westward from the foot of the delta front it thins rather rapidly to generally less than 5 feet and commonly to only 1–3 feet in thickness, and grades to fine sand and silty sand. North and south of the Cottonwood delta this facies generally is mostly fine sand and, locally, medium sand. On the lower piedmont slopes northeast of Big Cottonwood

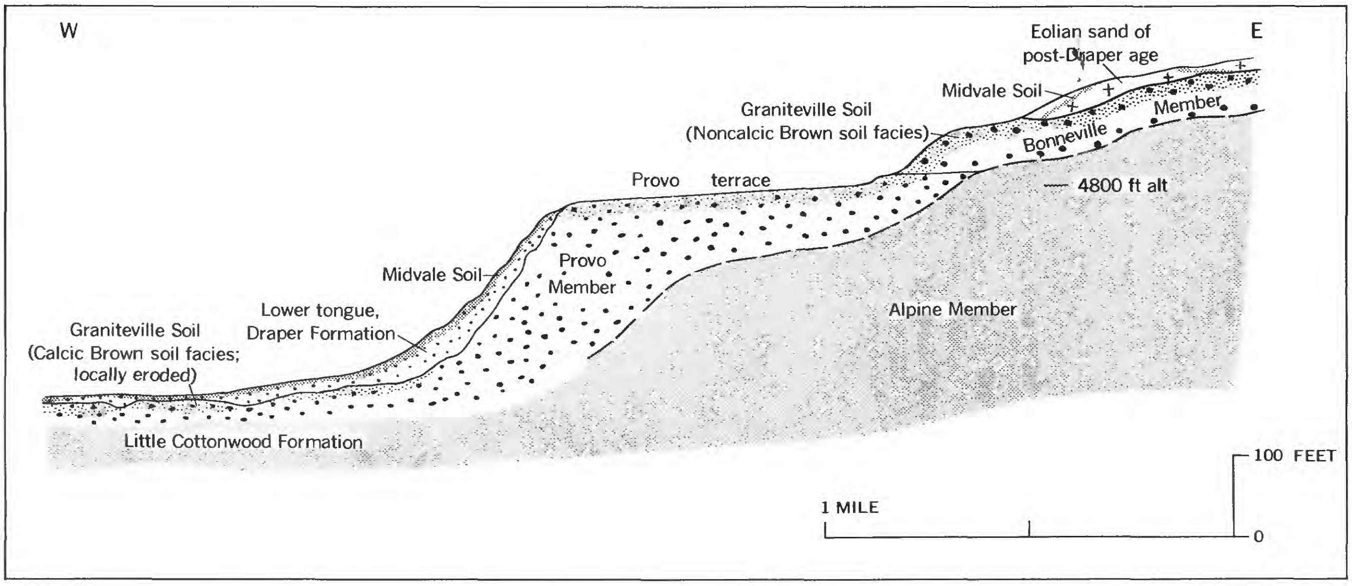

FIGURE 18.—Typical relations of the lower tongue of the Draper Formation, the Provo, Bonneville, and Alpine Members of the Little Cottonwood Formation, and the Midvale and Graniteville Soils along the front of the Cottonwood delta between Little Cottonwood Creek and Draper. Note that along the scarp below the Provo terrace the Graniteville Soil commonly is absent because of wave erosion of the first Draper lake.

Creek it forms a disconformable mantle a few inches to several feet thick over the partly eroded Graniteville Soil (Pedocal facies), which is developed on sand and silt of the Little Cottonwood Formation.

The previously mentioned fill of this tongue that was washed into the valley of Dry Creek is unlike any other lake deposit of the area. It occurs as a partial veneer a few feet thick on the north side of the valley in the N½ sec. 16, T. 3 S., R. 1 E., and it underlies a prominent low terrace on the north side of the creek upstream to the east line of sec. 15 where it commonly is exposed to depths of 10–20 feet—in places to the creekbed (figs. 19, 20, 21). This fill is mainly pale-gray poorly sorted pebbly sand (stratigraphic section 20). It is mainly medium sand but contains varied amounts of fine sand, silt, coarse sand, grit, and a few small pebbles. It also contains some lenticular stringers of poorly to well-sorted sandy pebble gravel. It is coherent, probably because of its contained silt. Although variable in detail, this fill is remarkably uniform in general, from top to bottom and laterally throughout its exposure in the valley. It is poorly bedded, and the bedding dips toward the valley axis.

FIGURE 19.—Sand and gravel of the lower tongue of the Draper Formation ($Qd_{1}s$) disconformably overlying silt, sand, and clay of the Alpine Member of the Little Cottonwood Formation ($Qa_{1}c$) on the north side of the valley of Dry Creek. The upper unit here partly fills an early valley of Dry Creek that was cut into the Little Cottonwood Formation during the middle-Lake Bonneville desiccation. Skyline surface at left and center of view is the top of a gravel spit of the Provo Member at the Provo level.

A small remnant of a similar fill of sand and gravel of this tongue is exposed in the valley of Willow Wash in the SE¼ sec. 21, T. 3 S., R. 1 E.

MIDDLE TONGUE

The middle tongue of the Draper Formation reaches a maximum altitude of about 4,470 feet. It is inferred to record the second lake cycle of Draper age—the second Draper lake. This tongue is differentiated on the map only in the gravel and sand facies and as mapped constitutes a high shore selvage. It overlaps the lower tongue from Dry Creek northward and locally is unconformable on the lower tongue. The middle tongue is partly overlapped by, and is locally unconformable beneath, the upper tongue near the mouth of Dry Creek and between Midvale and the valley of Big Cottonwood Creek.

The maximum altitude of the middle tongue (the maximum of the second Draper lake) is the average

FIGURE 20.—Relations of Little Cottonwood Formation and lower tongue of Draper Formation on north side of the valley of Dry Creek, near the site of stratigraphic section 19. The higher zone of whitish exposures is sand and silt of the Alpine Member, thinly veneered by gravel and sand of the Bonneville Member of the Little Cottonwood Formation (see stratigraphic section 19). The lower zone of exposures, just above the creekbed, is sand and gravel of the lower tongue of the Draper Formation, deposited as a partial filling of an earlier valley of Dry Creek cut into the Little Cottonwood Formation during the middle-Lake Bonneville desiccation. Remnants of a strath terrace graded to the Provo shoreline are locally preserved near the middle of the slope between the two zones of exposures.

maximum altitude of the controversial Stansbury shoreline of Lake Bonneville, as inferred by Eardley, Gvosdetsky, and Marsell (1957, p. 1161–1164, 1168–1169, figs. 7, 9, 10, 12). In the Little Cottonwood-Draper area this shoreline is generally obscure and highly discontinuous; rarely is it recognizable by morphologic features such as shore terraces, spits, and bars. This is scarcely surprising, for the arm of Lake Bonneville in Jordan Valley at this level was only 3–9 miles wide. The high shoreline of the second Draper lake is best marked by the small deltas of Big Cottonwood, Little Cottonwood, and Dry Creeks, but even at these places its exact altitude can be determined only approximately. A slight difference in soil development is the best guide: relict occurrences of the Midvale Soil are slightly weaker below the shoreline. The best evidence available in the area shows that this lake maximum reached altitudes at least as high as 4,470 feet.

The Stansbury shoreline is less definite and continuous in this area than a recent map (Eardley and others, 1957, fig. 7) suggests. The "distinct beach" shown south of the Dry Creek delta is nonexistent. The "Crescent Spit" is not a spit at all, but an erosional remnant whose shape probably is controlled by pre-Draper faulting (p. 51); it is underlain by the Little Cottonwood Formation and, at its tip, by pre-Lake Bonneville fan gravel. The Jordan spit appears to be of similar origin, although it is overlain by a discontinuous thin bed of sand of the middle tongue of the Draper Formation.

Gravel of this tongue is confined to small deltaic areas bordering Big Cottonwood, Little Cottonwood, and Dry Creeks and is mostly pebbly gravel; locally the gravel is cobble gravel that grades rapidly into sandy pebble gravel and pebbly sand at its distal edges. Sand of this tongue underlies most of the Stansbury terrace and Jordan spit (of Eardley, Gvosdetsky, and Marsell, 1957, fig. 7) northward from the Dry Creek delta in a belt $\frac{1}{4}$–1 mile wide; to the south, however, it is limited to a single thin patch on the west side of the Crescent spit.

UPPER TONGUE

The upper tongue of the Draper Formation is found at altitudes as high as about 4,410 feet. It is inferred to record the third lake cycle of Draper time, the third Draper lake. This tongue occurs mainly as sand and gravel deposited on low-gradient deltas of the Jordan River and Dry, Little Cottonwood, and Big Cottonwood Creeks. These deltas formed at the lower ends of alluvial terraces that are of late Draper age. Representative exposures of the upper tongue can be seen near Dry Creek west of the Denver and Rio Grande Western Railroad (stratigraphic section 15).

The highest shoreline of the third Draper lake is marked by distinctive shore morphologic features in only a few places. Evidently wave action was very weak, for at this lake maximum this arm of the lake had gently sloping shores, had its head a mile or less from the southern edge of the area mapped, and was only about 8 miles wide at the northern edge of the area. The most conspicuous shore features are the above-mentioned deltas, but even on the deltas the transition between subaerial and sublacustrine deposits is so gradational and indefinite that the lake maximum can be placed only as probably between altitudes of 4,400 and 4,420 feet. The lake maximum can be placed most exactly on the part of the delta of Little Cottonwood Creek in the SE$\frac{1}{4}$ sec. 19, T. 2 S., R. 1 E.; there the shoreline overlaps an underlying layer of alluvial gravel that shortly predates this lake maximum.

The two main deltas composing this tongue are those of Little Cottonwood Creek and the Jordan River. In most places the delta of Big Cottonwood Creek appears to have been downfaulted and buried by younger alluvium or has been eroded. The small delta of Dry Creek merges with that of the Jordan River.

The delta of the Jordan River appears—from the lithology, facies distribution, and stratification of the upper tongue—to have formed prior to most of the cutting of the present inner valley of this river. Two small patches of pebble gravel of this tongue are along the top edge of the Jordan River bluff and appear to be remnants of a central "core" facies of the delta that

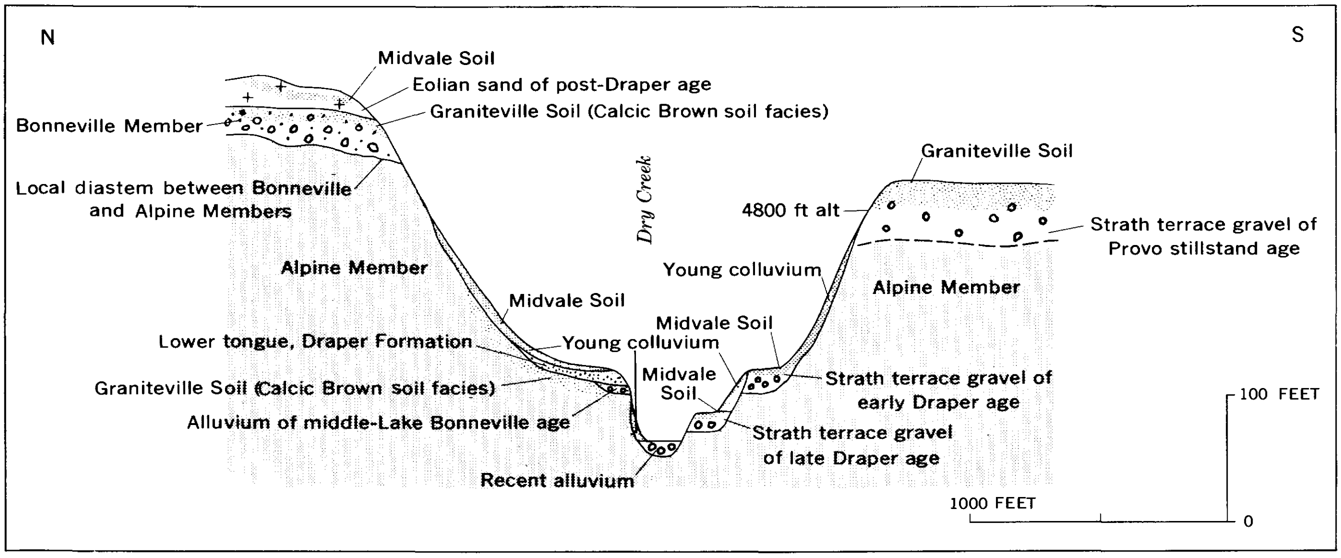

FIGURE 21.—Diagrammatic section across valley of Dry Creek (about 200 yards west of the line between secs. 15 and 16 and 200 yards east of the Provo shoreline on the Cotonwood delta above the valley). Recorded at this locality is the following depositional and erosional history:

1. Alpine rise(s) of Lake Bonneville and deposition of the Alpine Member on the ancestral Cottonwood delta.
2. Inter-Alpine–Bonneville–Provo lake recession and erosion of an early valley of Dry Creek.
3. Bonneville–Provo rise (cycle) of Lake Bonneville and deposition of the Bonneville Member.
4. Lake recession, with long stillstand at the Provo level; renewed valley erosion and deposition of strath terrace gravel graded to the Provo shoreline.
5. Further lake recession, valley entrenchment to about 140 feet below the Provo shoreline, and deposition of alluvium of middle-lake Bonneville age along the axis of the valley.
6. Development of the Graniteville Soil.
7. Rise of the first Draper lake and deposition of the lower tongue of the Draper Formation as a partial fill washed into the valley as a result of southward longshore drift during the higher levels of this lake.
8. Recession of the first Draper lake; renewed valley erosion (continuing uninterrupted to the present); deposition of strath terrace gravels of early Draper age and then of late Draper age.
9. Deposition of the post-Draper eolian sand, with an intervening interval when the Midvale Soil formed.

lay mostly within the area now occupied by the inner valley of the river. A patch at the NW cor. sec. 36, T. 3 S., R. 1 W., at an altitude of 4,410 feet, is the highest occurrence and contains the coarsest gravel—mostly fine pebble gravel with some larger pebbles and cobbles rarely as much as 6 inches in diameter. The main part of this delta is a belt of lake sand that forms a natural-leveelike deposit extending ¼–½ mile eastward from the top of the Jordan River bluff. This deposit ranges in altitude from about 4,410 feet at the southern edge of the area mapped to 4,350 feet where it pinches out west of Sandy; it ranges in thickness from 1 foot to about 5 feet. It is thickest and coarsest (mainly fine sand with some medium sand, locally with a few small pebbles), close to the Jordan River (stratigraphic sections 15, 22, 23) and thins and grades to finer sand away from the river. It is generally evenly parallel bedded, and its lithology changes little from top to bottom.

The delta of the upper tongue built by Little Cottonwood Creek is relatively coarser and larger, with a gravel facies extending as much as a mile below the high shoreline. This delta overlies a deposit of alluvial gravel that appears to have been deposited mainly during the rise of the third Draper lake. Sand of the upper tongue locally overlies the alluvial gravel along and near the high shoreline and extends westward as a thin sheet over the middle and lower tongues of the Draper Formation (which at this locality cannot be differentiated on the geologic map) and over the Little Cottonwood Formation to the bluffs along the Jordan River; there it merges with sand of the delta of Big Cottonwood Creek.

DIASTEMS BETWEEN THE LOWER, MIDDLE, AND UPPER TONGUES

Two diastems locally separate the three tongues of the Draper Formation from each other. These diastems show that deposition of the tongues was interrupted by subaerial exposure and erosion owing to lake recession; they also show that the tongues are not merely deposits of successive recessional stillstands of a single lake cycle. The diastem between the lower and middle tongues is here called the lower diastem, and that between the middle and upper tongues, the upper diastem. These unconformities are exceptionally difficult to trace in this area because they are only locally identifiable owing to the thinness and poor exposure of the Draper

Formation below an altitude of 4,500 feet. Each was identified over a small range of altitude, but further studies in more favorable areas may show that they extend considerably lower than the lower limits given here.

The lower diastem was seen in a few cellar and sewer excavations in the high shore zone of the middle tongue from altitudes of 4,470 to 4,450 feet, but not at lower altitudes. At these places the diastem is manifested as a surface recording subaerial exposure, probably for a brief interval, and, in places, as a few inches of erosion. It commonly is overlain by an inch to several inches of disturbed material, probably colluvium.

The upper diastem is similarly shown locally in cellar and sewer excavations, particularly along the eastern margin of its outcrop belt. The extent of the hiatus between the middle and upper tongues is further indicated by small terraces of sand of the upper tongue resting disconformably upon the Little Cottonwood Formation in several small post-middle-tongue gullies in the Jordan River bluff in sec. 36, T. 3 S., R. 1 W. These sand terraces, which were graded to the incised river valley, show that the inner valley of the river was partly cut prior to deposition of the upper tongue, probably after deposition of the middle tongue, indicating a lake recession below an altitude of 4,375 feet between the second and third Draper lake maxima. In exposures of the upper tongue along the Jordan River bluffs, the middle and lower tongues of the Draper commonly have been eroded, and the upper tongue rests directly on the Graniteville Soil (where it also has not been eroded) and on the Little Cottonwood Formation.

The upper diastem is particularly well recorded by the overlap of sand and gravel of the upper tongue of the Draper Formation upon alluvial gravel of late Draper age in Little Cottonwood Creek southeast of Murray in the S½ sec. 18 and sec. 19, T. 2 S., R. 1 E. The alluvium can be traced under the upper tongue at least as low as an altitude of 4,360 feet, the lowest altitude at which this diastem has been definitely observed in the area mapped.

Possible further evidence of this diastem and of subaerial erosion between deposition of the middle and upper members consists of two gullies that head south of Murray in sec. 19, T. 2 S., R. 1 E., about a quarter of a mile below the high shore of the third Draper lake and downstream from a wide strath terrace of late Draper age. Additional evidence may be another gully southwest of Murray that joins the Jordan River flood plain just west of the Bonnyview School. Sand of the upper tongue locally drapes over the walls of these gullies, suggesting that they were cut by Little Cottonwood Creek prior to the rise of the third Draper lake. The alluvium in the lower parts and mouths of these gullies that is mapped as being of Recent age may actually be mostly of later Draper age.

Relict occurrences of the Midvale Soil on the several tongues of the Draper Formation are progressively somewhat weaker in profile development for each younger tongue. (They are most mature on the lower tongue and least mature on the upper tongue; see p. 44.) This suggests that appreciable time intervals, during which very weak soil-profile development occurred, separated the deposition of successive tongues.

SILT-CLAY FACIES UNDIVIDED

The silt-clay facies of the Draper Formation is not divided as to a tongue on the geologic map because it is commonly only 1 or 2 feet thick—rarely more than 3 feet thick—and because lithologic differences or diastems permitting separation into tongues are rarely seen.

Although thin, this unit underlies most of the lowlands not underlain by the sand or gravel facies of the middle and upper tongues. It consists of various shades of gray, dark-gray, and grayish-brown fine sandy silt, silt, clayey silt, and silty clay that is well to poorly sorted and is generally evenly bedded. The silt-clay facies generally is darker and somewhat less consolidated than the underlying silt and sand of the Little Cottonwood Formation; also, the Graniteville Soil (Pedocal facies) is a distinctive marker between the two units where it is preserved (fig. 2). Commonly the upper foot or so of this facies of the Draper has been disturbed by plowing or other reworking by man.

ALLUVIAL GRAVEL OF DRAPER AGE

Alluvium of Draper age is of two kinds: fan gravel, and alluvial gravel on strath terraces. Like the Draper Formation, it bears only the Midvale Soil, never the Graniteville Soil.

The fan gravel occurs at the mouths of many of the smaller canyons along the Wasatch front. These fans generally are smaller than those of Little Cottonwood age, which originated in the same canyon, and the gravel in them is finer. The fan gravel rarely contains boulders larger than 4 feet in diameter, even at the apices of the fans, and generally the boulders are less than 2 feet in diameter.

Wide strath terraces veneered with alluvial gravel of this age border Little Cottonwood Creek on the south (fig. 13), and similar but narrower terraces occur along Big Cottonwood and Dry Creeks and along Willow Wash. These gravels are distinguished in age according to three principal levels of the strath terraces of each stream. These levels appear to be graded to the three lake maxima of Draper time and hence the gravels can be correlated with specific tongues of the Draper Formation. Like the fan gravel, the strath-terrace alluvium is somewhat less coarse than the nearby strath-terrace gravel of Little Cottonwood age, which was deposited from the same stream, but otherwise it is similar.

DEPOSITS OF THE PINEDALE GLACIATION

Till correlated by Richmond (1964) with the Pinedale Glaciation in the Rocky Mountain region is exposed in Bells Canyon within the area mapped and east of the map area in Little Cottonwood Canyon. Till that probably is correlative with this glaciation also has been recognized in upper Big Cottonwood Canyon and in some of its main tributaries, such as the canyon of Mill B South Fork (M. D. Crittenden, Jr., oral commun., 1960). In both Bells and Little Cottonwood Canyons, this till forms sets of three end moraines—lower, middle, and upper—that are considered to represent three stades (early, middle, and late) of the Pinedale Glaciation (Richmond, 1964). The moraines still preserve most of their original morphology except where they are breached by streams or outwash plains, and their till is similar in internal characteristics; moreover, a similar soil profile is developed on all three moraines in each set—an immature interzonal Noncalcic Brown or Brown Podzolic Soil that is distinctly less well developed than the soil profile on the end moraines of the Bull Lake Glaciation. This soil is similar to the Midvale Soil in its degree of development relative to the older soils. The distribution and character of these moraines and their till are described in detail by Richmond (1964).

CORRELATION OF THE DRAPER FORMATION AND ALLUVIUM OF DRAPER AGE WITH DEPOSITS OF THE PINEDALE GLACIATION

The Draper Formation (and coeval alluvium) is correlated with till and outwash of the Pinedale Glaciation in Little Cottonwood, Big Cottonwood, and Bells Canyons by soils stratigraphy and by matching depositional cycles of similar relative age and climatic genesis. These lake deposits and the terminal moraines of the Pinedale Glaciation are many miles apart, and they are not connected by stream terraces and outwash gravels. They are correlated, however, by their age relations to two soils in each sequence: the mature Graniteville Soil, underlying the Draper Formation and overlying the Little Cottonwood Formation, is correlated with the mature post-Bull Lake soil (Richmond, 1964), which predates the deposits of the Pinedale Glaciation. Likewise, the submature Midvale Soil is correlated with the submature post-Pinedale soil, which is developed on the deposits of this glaciation. The three tongues of the Draper Formation record three successive lake cycles, each lower than the preceding one, that are comparable in relative magnitude to the three progressively diminishing stades of Pinedale Glaciation, and these tongues are correlated with the respective glacial stades on the basis of similarity of depositional cycles (fig. 4).

Significant lake recessions are recorded between each of the three Draper lake maxima, indicating three separate lake cycles, whereas there is no evidence to indicate whether the glaciers receded appreciably between the three stades of the Pinedale Glaciation (Richmond, 1964)— these stades could be interpreted as temporary halts during the recession of a single glacial cycle.

YOUNGER COLLUVIUM AND TALUS

A veneer of young colluvium, 1 to several feet thick, commonly mantles the steeper slopes, such as the scarps of stream terraces, valley and gully sides, and fault scarps. This colluvium is mostly creep and solifluction mantle and slope wash except locally on and below the steeper mountain slopes where it is largely blocky talus. (The talus is differentiated from other colluvium on the geologic map, plate 1.) Below the Provo level the younger colluvium is entirely of post-Draper age; between the Provo and Bonneville shoreline levels it is mostly of this age but locally includes some colluvium of Draper age. Above the Bonneville shoreline, however, the younger colluvium and talus also includes some colluvium or talus of Little Cottonwood age, and locally even some of pre-Lake Bonneville age.

EOLIAN SAND AND LOESS OF POST-DRAPER AGE

Eolian sand of post-Draper age occurs locally throughout the area and is widespread on the Cottonwood delta. On parts of the delta it forms extensive drift sand sheets and, in places, longitudinal dune complexes commonly 10 to more than 50 feet in thickness. Only deposits more than 5 feet thick are mapped. The sand is mainly fine-medium and medium grained in varying proportions and commonly displays eolian crossbedding or inclined bedding. It commonly bears or is intercalated with the Midvale ("Altithermal") Soil and (or) the early Recent soil; many exposures show one or both of the soils buried by younger eolian sand (for example, see stratigraphic section 2; fig. 22). Thus, three ages of eolian sand can be distinguished: Post-Draper pre-early Recent (early Altithermal), early Recent, and late Recent.

Loess of post-Draper age is ubiquitous but thin. It mantles nearly every pre-Recent surface in Jordan Valley and in the lower mountain valleys to depths ranging from 1 inch to rarely 3 feet. It consists of silt and fine sand in varying proportions. It commonly bears the Midvale Soil and hence is presumed to be mostly of Altithermal age, though minor increments may be younger. The A and B horizons of this soil are abnormally thick where developed on loess, as is typical of all soils formed on loess.

MIDVALE SOIL

The alluvium, colluvium, and lacustrine sediments deposited during Draper time all bear a moderately strongly developed (submature) soil that does not occur on younger deposits. This soil is here named the Midvale Soil, after the town in the vicinity of which it is widely exposed. It is equivalent to the post-Lake Bonneville soil of Morrison (1961a,b) and to the post Pinedale soil of Richmond (1964). The Midvale Soil is believed to have formed during the warm postpluvial interval that Antevs (1948, p. 176, 178–179; 1952; 1955) called the Altithermal age. Most occurrences are relict and, compared with the older soils, are generally little eroded.

This soil has two facies in this area: a Noncalcic Brown soil (Pedalfer) facies in the eastern part of the area, and a Calcic Brown soil (Pedocal) facies in the western part. Plate 2 shows the approximate boundary between these two facies. A Brown Podzolic facies (characterized by a bleached A_2 subhorizon) was not recognized within the area mapped.

The type locality for the Midvale Soil is the crest of the narrow ridge between the lowermost part of Dry Creek and the Jordan River; it extends half a mile southeast from the tip of the ridge, within the NE¼ sec. 11, T. 3 S., R. 1 W. There this soil is developed in its Pedocal facies, and its stratigraphic relations are well displayed (stratigraphic section 15). The Midvale Soil is developed partly on eolian sand of early post-Draper age and partly on the upper tongue of the Draper Formation, which disconformably overlies the Graniteville Soil (locally eroded) and the Little Cottonwood Formation. Locally the Midvale Soil also is buried beneath eolian sand of late post-Draper age.

Good exposures of the Pedalfer facies of this soil can be seen in the gravel pits in the front of the Cottonwood delta below the Provo terrace and east of Sandy (figs. 22, 23).

The following general horizon descriptions refer to locations that are fairly flat and well drained, where the soil is uneroded, and where it developed on sand or gravel. Soil-profile sections S–1, S–2, S–4, S–7, S–8, S–9, and S–10 are representative of its development under such conditions.

The A horizon typically is 6 inches to a foot thick, gray to dark gray (10*YR* 4/1, 4/2, 5/1, to 5/2), soft to slightly hard, structureless (massive) to weak subangular blocky, weak granular. The B horizon typically is 12–18 inches thick in the Pedocal facies and 18–30 inches (mean about 22 inches) thick in the Pedalfer facies. Its upper 6–12 inches generally is brown (10*YR* 5/3 to 4/3, locally 7.5*YR* 5/2 to 5/4) but commonly is gray brown (10*YR* 5/2) on the upper tongue of the Draper Formation and on the eolian sand. The upper part is soft to hard and structureless to moderate subangular blocky. Downward the color gradually lightens, consistence softens, and structure weakens: the lower 6–12 inches generally is gray brown (10*YR* 5/2), light brownish gray (10*YR* 6/2), or pale brown (10*YR* 6/3); is very soft (almost loose) and in single grains; and has a clear to gradual, even wavy, lower boundary.

The C_{ca} horizon in the Calcic Brown soil facies generally is weakly developed. It generally increases somewhat in development westward from the Pedalfer-Pedocal boundary, although the development of the soil as a whole decreases slightly in that direction because it is developed as a relict soil on somewhat younger parent material (generally the upper tongue of the Draper Formation). The C_{ca} horizon commonly intergrades with the B horizon and ranges in thickness from 12 to locally as much as 20 inches on sand. It generally is light gray (10*YR* 7/2) or very pale brown (10*YR* 7/3), is soft to loose and massive to single grains, and

FIGURE 22.—Midvale Soil (Noncalcic Brown soil facies, minimum development), formed on post-Draper eolian sand and buried by younger (post-Altithermal) eolian sand. Site of soil-profile section S–2; sand pit just east of 2000 East Street, 0.25 mile north of Reynolds gravel pit (crest of north bluff along Little Cottonwood Creek).

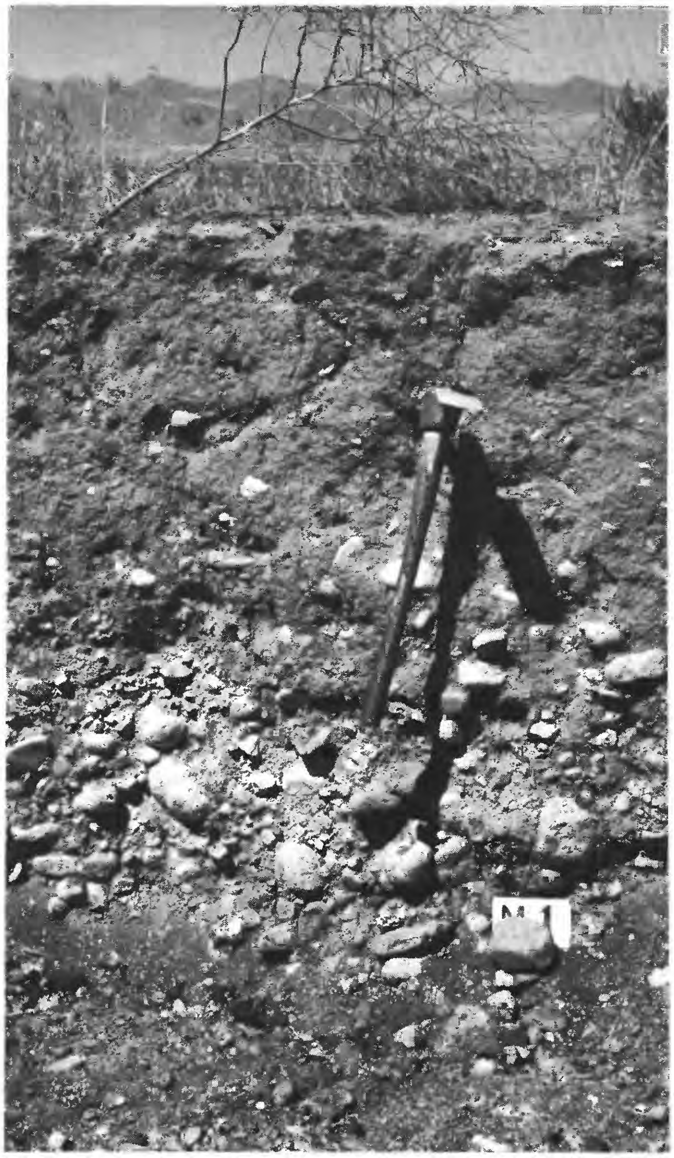

FIGURE 23.—Midvale Soil (Noncalcic Brown soil facies, maximum development), developed on gravel of the lower tongue of the Draper Formation. Soil development is somewhat greater for relict occurrences on this tongue than on younger deposits. Whole soil profile is 24–26 inches thick, but soil-horizon boundaries are gradational. Pick point marks approximate base of A horizon, and pick handle extends slightly below base of B horizon. At gravel pit on outer scarp of Provo terrace, 0.1 mile north of SE cor. SW¼ sec. 5, T. 3 S., R. 1 E.

has a very weak to moderate calcium carbonate concentration. Its lower boundary is gradual to diffuse and commonly is wavy to irregular.

Compared with the Graniteville Soil, the B horizon generally is thinner, paler, grayer, and softer; the C_{ca} horizon also is thinner and distinctly weaker. The profile of the Midvale Soil also varies more with parent material and other local environmental factors than do the profiles of the older soils, not only in total thickness but also in details of the B and C_{ca} horizons.

Based on stratigraphic relations, the Midvale Soil is younger than the upper tongue of the Draper Formation and the eolian sand and loess of early post-Draper age, and it is older than the eolian sand of late post-Draper age and the Recent alluvium. It evidently developed its chief characteristics as a profile of weathering during the later part of the Altithermal age of Antevs (1948, 1952, 1955), probably within the interval from about 5,000 to 4,000 years ago. This soil, however, shows slight but discernible differences in development depending on the length of time it has been exposed at the land surface; and, consequently, it has been subjected to weak weathering processes before and after the main soil-forming interval. It is slightly more strongly developed in relict occurrences on the lower tongue than on the middle tongue of the Draper Formation, and likewise is slightly more strongly developed on the middle tongue than on the upper tongue of this formation. These differences are proportionately greater than those of the older soils, because the post-Lake Bonneville soil is the least strongly developed of the soils.

In this report the boundary between the Pleistocene and Recent Epochs is interpreted to be at the top of the Midvale Soil, and this soil is believed to be correlative with a soil of the Carson Desert area, Nevada, which was used as a marker for this boundary for the Great Basin region (Morrison, 1961d).

RECENT ALLUVIUM

Alluvium of Recent age underlies the present flood plains and locally mantles the lowermost terraces of the streams; it also forms fans at the mouths of various mountain canyons and gulches. Generally this unit is not subdivided, but locally along Little and Big Cottonwood Creeks and the Jordan River, two age units are differentiated. The older alluvium mantles the lowermost terraces of these main streams, bears the early Recent soil, and is considered to be of early Recent age. These terraces are typically 5–10 feet above the present flood plains. The younger alluvium underlies the flood plains of these streams, shows no discernible soil development, and is considered to be of late Recent age. The alluvium of both ages is similar in lithology.

The Recent alluvium of Big and Little Cottonwood Creeks is coarse. It is mainly boulder and cobble gravel as far as 3 and 4 miles downstream, from the respective canyon mouths, then grades from mainly cobble and pebble gravel to mainly pebble gravel with some cobble gravel and pebbly sand near the Jordan River. The alluvium along Dry Cottonwood Creek is cobble gravel with some small boulders in the upper part of the creek, grading downstream to pebble gravel and pebbly sand

746-815 O-65—4

in the middle sector of the creek and to sand, silt, and local gravel lenses near the mouth of this creek. The alluvium of Willow Creek Wash, Corner Creek, and adjacent streams on the lowlands near Draper is mainly sand and silt with local lenses of gravelly sand and gravel.

The Recent alluvium along the Jordan River is mostly silt and sand in the uppermost foot to several feet, but at greater depth it is mostly fine pebble gravel, locally 5 feet or more thick. For example, an excavation for the western abutment for a bridge across the Jordan River at the Murray-Taylorsville Road (4800 South St.) showed more than 6 feet of well-sorted pebble gravel with few pebbles larger than 1 inch. The bed of the Jordan River throughout the area is mostly such gravel.

EARLY RECENT SOIL

A weak soil profile is developed on the Recent alluvium of the lowermost terraces of Big and Little Cottonwood Creeks and the Jordan River and locally on Recent alluvium and on eolian sand of post-Draper age elsewhere. This soil is of early Recent age. It is similar in degree of development and stratigraphic position to the post-Temple Lake soil in the mountains east of the area (Richmond, 1964), and is correlated with that soil. The early Recent soil can not be distinguished on deposits that bear the Midvale Soil as a relict soil because the weakly developed weathering profile of the younger soil is masked by the stronger development of the older soil.

The profile of the early Recent soil (soil-profile section S-3) on alluvial gravel consists of an A horizon typically 10–14 inches thick and does not have a B horizon. The upper several inches generally are darkest and most humic—gray to dark gray (about 10*YR* 5/1 to 10*YR* 4/1). Downward the soil grades successively through gray to gray brown and, in the upper part of the C horizon, to light brown gray and light gray. The profile is loose and structureless throughout. On eolian sand the soil is generally similar but is somewhat more varied in thickness and commonly is in somewhat lighter shades of gray. A pedocal facies of this soil has not been recognized in the area mapped.

FAULTS ACTIVE IN QUATERNARY TIME

GENERAL STRUCTURAL FEATURES OF JORDAN VALLEY; THE WASATCH FAULT ZONE

Jordan Valley is one of the larger grabens along the "Wasatch structural trough" of Cook and Berg (1961). This trough is bounded on the east by the Wasatch fault zone and on the west by a complex, less regularly alined zone of faults. The Wasatch zone is one of the major fault zones that was active in late Cenozoic time in the Western United States. It defines the western edge of the Wasatch Range for 115 miles and marks an abrupt boundary between the Rocky Mountain physiographic and structural division and the Great Basin section of the Basin and Range province. It is essentially a dip-slip normal fault dipping 50°–75° W., and having a vertical displacement ranging from 1,000 to at least 6,000 feet (Eardley, 1939, 1944, 1951). In detail, however, the Wasatch fault zone is complex—more complex, wider, and of greater extent westward than until recently had been thought. Recent gravity studies have given new information on this fault zone and on the Wasatch structural trough, and Cook and Berg (1961, p. 87) summarized this information as follows:

> * * * The gravity data indicate that the principal vertical displacement of the blocks has occurred along a northerly trend just west of the Wasatch fault zone. Here, for at least 100 miles along the zone just west of the Wasatch front, there exists an intermont trough—here designated as the Wasatch structural trough—which comprises a belt of grabens and smaller fault blocks whose dislocations are varied and more complex than previously realized. The floor of the trough, which lies between the Wasatch block and the Oquirrh-Boulter-Tintic block, is highly irregular, and is formed by the tops of the blocks, in some places buried beneath thick alluvium and rocks of Tertiary age, and in other places rising exceptionally high to form the tops of the exposed fault-block spurs. All these blocks were displaced downward relative to the Wasatch Mountains block; some dropped deeper as if slipping into a great crevasse. Some fragments were wedged in between other blocks and remained lodged at intermediate height * * *.

Gilbert (1928) and Gilluly (1928, p. 1122) cited evidence suggesting that the Jordan Valley graben has been tilted eastward.

The present study affirms and supplements these finding, insofar as is possible from faults exposed at the surface in Jordan Valley. Many previously unrecognized faults are mapped that, although of small displacement at the surface, may have progressively greater displacement at depth. The gross pattern of these surface faults probably outlines many of the main faults in the deeper subsurface more precisely than is possible with the gravity study. Furthermore, the detailed stratigraphic mapping done for the present study enabled dating of the latest movement of the surface faults (pl. 4).

Most of the Quaternary uplift of the Wasatch Range with respect to Jordan Valley, amounting to several thousand feet since early Quaternary time, took place long prior to the first rise of Lake Bonneville. During the intervals of strong faulting, uplift of the range considerably exceeded deposition in Jordan Valley, with effects that still are strikingly evident—the steep range front with its faceted spurs and exceptionally steep and youthful canyons that generally are rock floored to their mouths. Since the rise of Lake Bonneville, however, deposition in Jordan Valley has more nearly kept pace with the uplift of the mountain block. This is shown by the comparatively small displacement of the Bonneville shoreline and of the end moraines of the Bull Lake Glaciation below Little Cottonwood and Bells Canyons, by the small amount of post-Bull Lake canyon cutting in the lower parts of the canyons of Little Cottonwood and Big Cottonwood Creeks, and by the fact that these creeks increase little in gradient where they cross the fault zone at and near the mountain front. The oldest clearly recognizable fault scarps, along the base of the mountain front east of the main part of the Wasatch fault zone, are partly concealed by younger pre-Lake Bonneville fan gravel and colluvium and partly displace these deposits but not the deposits of Lake Bonneville age. The principal pre-Lake Bonneville displacement, however, doubtless was effected by faults somewhat farther west (probably generally along the main Wasatch fault zone) and now deeply buried beneath younger Quaternary sediments.

Crittenden (1961; written commun., 1961) observed that the post-Bonneville shoreline displacements on the Wasatch fault are opposite in direction from those that would be expected due to isostatic unloading of Lake Bonneville. This suggests that the Basin and Range faulting operates within the crust, and that isostatic compensation acts independently below the crust. Perhaps the comparatively small post-Bonneville shoreline displacement by the Wasatch fault is because the long-term trend of Basin and Range displacement has been temporarily partly neutralized by isostatic compensation.

No compelling evidence was found either for or against Marsell's conclusion (1946a) that displacement occurred by uplift of the Wasatch Mountain block while the Jordan Valley block remained stable.

DESCRIPTION OF FAULTS

Within the map area the exposed part of the Wasatch fault zone ranges from about a quarter of a mile to more than 5 miles in width and consists of many branching, intersecting, and en echelon faults, as well as faults transverse to the general trend. Nearly all the surface faults are in Quaternary sediments west of the mountain front; comparatively few are in bedrock along the mountain front. The eastern boundary of the fault zone is fairly well defined at the base of the Wasatch Range front, but the western boundary is indefinite because faults that apparently are related to this fault zone occur at least as far west as the inner valley of the Jordan River, and only the younger displacements are evident at the surface.

The actual fault surfaces can be seen only where they are exposed by excavations, for elsewhere they are concealed by material slumped and washed from their scarps. The faults are evinced chiefly by their scarps, many of which are striking landscape features at least 100 feet high; they generally are transverse to the drainage and clearly displaced deposits and surfaces of erosion or deposition. The location of most faults can be estimated, from their scarps, within 10–100 feet, although a few of the oldest scarps are so eroded as to make the placement of their faults less accurate.

MAIN PART OF THE WASATCH FAULT ZONE

Close to the eastern edge of the Wasatch fault zone is a zone where the surface faults are more closely spaced and more regularly alined and where they generally show greater surface displacement than they do in the rest of the Wasatch fault zone. This zone is entirely within the outcrop area of the later Quaternary fill, but a few small exposures of sheared bedrock can be seen. This zone obviously has undergone the most intense displacement in late Quaternary time and is here called the main part of the Wasatch fault zone or the main Wasatch fault zone. This part of the Wasatch fault zone is only ⅛–⅓ mile wide from the southern edge of the area mapped to just south of Big Cottonwood Creek; it generally lies within a quarter of a mile of the base of the range front, closely paralleling this front in broadly sinuous fashion. Farther northward the main fault zone gradually fans out: at the northern edge of the area mapped, the fault zone is more than 2 miles wide and its western edge is about 3 miles from the range front.

The narrow sector of the main Wasatch fault zone south of Big Cottonwood Creek is primarily a series of normal, dip-slip step faults, somewhat braided and en echelon, that have moved down on the west. Most of the individual faults parallel the main fault zone and persist 1–3 miles or more. Some faults, however, curve at acute angles across the zone, forming cross faults. This sector also is characterized by a continuous but somewhat en echelon series of small grabens 20–150 feet deep and 100–700 feet wide. In most places there is only a single graben, but in a few places there are two or three parallel grabens separated by small horsts. The grabens are particularly conspicuous in the area extending from Big Cottonwood Creek to Little Willow Creek (south of Big Willow Creek), as typified by the famous faulted moraines below Little Cottonwood and Bells Canyons (fig. 24) and the graben along Wasatch Boulevard. The grabens are minor features, however, and the net displacement across the main fault zone invariably is down on the west.

FIGURE 24.—Area below the mouths of Little Cottonwood and Bells Canyons, showing displacement of the end moraines of the Bull Lake Glaciation by the main Wasatch fault zone (A). Note the conspicuous graben that characterizes this sector of the main fault zone. Oblique aerial view by A. E. Granger.

Just south of Big Cottonwood Creek the main fault zone swings sharply northwestward and abruptly changes character; there it is intersected from the west and northwest by a complex zone of large faults. Northwestward from this creek the main fault zone steadily widens. The sector between Big Cottonwood Creek and the western tip of the Mount Olympus salient is especially complex: it is essentially a great zone of breccia. The zone consists mainly of branching and intersecting longitudinal faults that are generally more curving and less persistent than those in the southern sector, but also it includes many faults that trend generally transverse to the main zone. There are also many small grabens and horsts that trend both parallel to and across the main fault zone.

Northwestward from the tip of the Mount Olympus salient to the northern edge of the area mapped, the main fault zone fans out rapidly and consists of approximately a dozen main longitudinal faults, as well as smaller unmapped ones. The displacements are down on the west, except for two grabens, one north and the other west of the center of Holladay. Northward the several easternmost faults in this sector rapidly diminish in throw and appear to die out close to the northern boundary of the area mapped. The zone of greatest surface displacement runs approximately along the northeastern edge of the flood plain of Big Cottonwood Creek and thence north-northwestward, parallel to Highland Drive; it is a southern continuation of the East Bench fault in the Salt Lake City area (Marsell, 1946a; Marine, 1961). This part of the main Wasatch fault zone evidently also has the maximum subsurface displacement, for it acts as a boundary between two ground water districts having quite different groundwater conditions (Marine, 1961).

All the faults in the main Wasatch fault zone have been active since the time of the Bonneville shoreline maximum, and most of them have been active since the Graniteville Soil formed. A measure of the magnitude of faulting since the time of the Bonneville lake maximum and the correlative late Bull Lake glacial maximum is the displacement of both the Bonneville shoreline and the end moraines of the late stade of the Bull Lake Glaciation where the main fault zone crosses them. This displacement amounts to about 50–60 feet net, down on the west, at places such as south of the mouth of Big Cottonwood Canyon, below the mouth of Little Cottonwood and Bells Canyons, below the mouth of Little Willow Creek, and at the mouth of Corner Canyon. Southward from the tip of the Mount Olympus salient, many of the faults in the main fault zone have been active in Recent time, for they displace alluvium of Draper age, Midvale Soil, and also, locally, Recent alluvium. Indeed, dozens of these faults appear to have moved 20 feet or more within the last few hundred years, judging from the freshness and steepness of their scarps in unconsolidated deposits. This faulting was prior to the coming of white men to the Great Salt Lake region, however, for there are no records of earthquakes causing surface breakage in this sector.

In the widened sector of the main fault zone northwest of the tip of the Mount Olympus salient, the age of the youngest displacements is commonly difficult to determine. Faulting in the eastern part of this sector appears to have occurred mainly after the Provo stillstand and perhaps locally during Draper time. The most recent displacements are in the western part of the sector, and all appear to be younger than the Graniteville Soil. (For example, this soil, developed on alluvium of middle-Lake Bonneville age, is faulted up on the western side of a graben a mile northwest of Holladay.) These western faults also appear generally to displace the lower tongue of the Draper Formation, but their scarps are somewhat more eroded than are the youngest ones farther south; hence the youngest displacements in this sector presumably are somewhat older, perhaps of later Draper to possibly early Recent age.

Dip of the main Wasatch fault.—Gilbert (1928) believed that the dip of the Wasatch fault is the same as the slope of the lower (least eroded) parts of the triangular facets of the mountain spurs that are truncated by the fault. As corroborative evidence he cited several measurements of dip of brecciated zones in bedrock on the footwall side of the fault that average 33.4°. He concluded (1928, p. 52) that the average dip in the Cottonwood area is about 34°. He interpreted the steeper dips commonly shown by piedmont fault scarps in the Quaternary sediments as generally superficial and not reflecting the dip of the main fault—in other words, he considered them to be the result of subsidiary faulting or slumping in the hanging-wall block above the more gently dipping main fault.

Other geologists (Schneider, 1925; Pack, 1926; Gilluly, 1928, p. 1113–1116; Eardley, 1939, 1944, 1951), however, considered the dip of the main Wasatch fault to be considerably steeper. I concur with this view and also interpret the main zone of piedmont fault scarps—the main Wasatch fault zone of this report—to be essentially a direct upward continuation and surface expression of the main zone of late Quaternary displacement in the subsurface bedrock. The slight deflection of the fault scarps in this zone where they cross high ridges suggests that the main faults generally dip 55°–75°. For example, the dip of the easternmost fault that crosses the high morainal ridges below Little Cottonwood and Bells Canyons is at least 60°. Furthermore, the fact that the graben of the main fault zone in this area maintains almost the same width over a vertical relief of as much as 600 feet indicates that the opposing faults on both sides of the graben dip nearly vertical, probably at least as steep as 70°. These steep dips do not appear to be restricted to the Quaternary sediments, for similar dips can be seen on shear planes in local exposures of bedrock along the main fault zone. If detailed data on the dip of the faults were available, however, many faults would probably be found to vary in dip, just as they do in strike.

FAULTS WEST OF THE MAIN WASATCH FAULT ZONE

In the northern two-fifths of the area mapped and west of the main Wasatch fault zone, there appears to be a major zone of faults that intersects the main Wasatch fault zone near the mouth of Big Cottonwood Canyon. This western zone is rather poorly defined by exposed faults, because many of its probable faults are concealed beneath Recent alluvium and streamcut scarps commonly tend to be alined along the fault scarps. The zone consists of various rather discontinuous and randomly oriented faults, both parallel to and transverse to the main Wasatch fault zone. This western fault zone appears to extend at least to the northwestern corner of the area mapped, but northwest of Murray the throw of the faults decreases. The southern edge of the eastern end of this fault zone is just south of Big Cottonwood Creek and is well marked by the series of west-northwest- to southwest-trending faults that displace strath terraces of Provo stillstand age; these faults probably also date from the Provo stillstand, as described on page 32.

The main feature of the western fault zone is a large graben, occupied by the widened flood plain of Big Cottonwood Creek, that extends at least 2 miles downstream from Knudsens Corner. This area is considerably below a normal gradient projected from the upstream sector of this creek and has extensive marshy and poorly drained areas, all suggestive of recent local downfaulting. The northeastern side of this part of the flood plain is bounded by scarps of somewhat en echelon faults of the southwestern part of the main Wasatch fault zone. The southwestern side of the flood plain appears also to be at least partly delimited by faults, although these faults generally are concealed by alluvium or colluvium and cannot be precisely located. Also, the flood plain itself is crossed by various low scarps—presumably fault scarps—that commonly are about 5 feet high, transverse to the drainage, and down on the west. Only the more prominent of these are shown on the geologic map. They obviously are mostly of late Recent age, inasmuch as they displace alluvium of early Recent and (or) late Recent age.

Farther west, near Murray, a few west-northwest- and northwest-trending faults of probable post-Draper age have been recognized. They are partly parallel and partly transverse to the valleys of Big and Little Cottonwood Creeks that are cut into the Little Cottonwood Formation. The orientation of these valleys suggests that the valleys may be partly controlled by these and other concealed faults. (The faults that cross the ridges between the valleys can be identified much more readily than those along the valleys.)

A major spur fault branches southwestward from the main Wasatch fault zone near the mouth of Little Willow Canyon. It passes just west of the Murray City Power Plant and is chiefly responsible for the high scarp that runs northeast past the power plant. This scarp marks the southeastern boundary of the strath-terrace complex of Provo stillstand and late Provo age of Little Cottonwood Creek. It appears to have partly controlled the pattern of these terraces. A sequence of the Alpine Member underlain by the lower till and outwash of the Bull Lake Glaciation (stratigraphic section 11) is exposed in the south bluff of Little Cottonwood Creek opposite the power plant, and the contact between these lake and glacial units appears to be dropped down at least 110 feet below its position as projected from exposures in the scarp. The alinement of this scarp and the various topographic discontinuities it produces also suggest faulting, although the scarp probably was somewhat modified by lateral cutting by Little Cottonwood Creek in Provo stillstand time. The fault scarp displaces the Bonneville Member and appears to date from the recession of the Bonneville-Provo lake cycle, after the Bonneville shoreline maximum, and probably shortly before or perhaps even during the Provo stillstand.

OTHER POSSIBLE FAULTS WEST OF THE MAIN WASATCH FAULT ZONE

The main outlines of several of the larger topographic features in the interior of Jordan Valley, such as the inner trench of the Jordan River and the western front of the Cottonwood delta and Draper spit, possibly were determined by relatively old faults, mainly of late Alpine to early Bonneville-Provo age. No exposures of these faults were found, and their scarps are considerably modified by subsequent erosion and deposition. All the following possible faults and fault zones are buried beneath younger sediments such as Draper Formation, young colluvium, and eolian sand of post-Draper age.

The following considerations suggest that the steep western front—a scarp 80–160 feet high—of the Cottonwood delta and Draper spit is not primarily the result of deltaic and spit deposition but of faulting probably of post-Alpine, pre-Provo stillstand age along a zone just west of 1300 East Street:

1. The steepness and nearly straight alinement of this front.
2. The frontal scarp, as well as areas to the west and east, only thinly veneered by the Provo Member and younger deposits and underlain at shallow depth by the Alpine Member. Available exposures of the Alpine Member at and near the scarp show no suggestion of deltaic foreset structure adequate to explain so high and steep a scarp.
3. Change of facies in exposures of the Alpine Member, from mainly silt east of the scarp to mainly sand west of it, suggesting that the western exposures are in the sandier upper part of this member, and have been downfaulted relative to those to the east.
4. Shore gravel of the Provo Member resting disconformably on the Alpine along the scarp, indicating

that the scarp formed between Alpine time and the Provo stillstand.

The western part of the Cottonwood delta between Little and Big Cottonwood Creeks has probably been further modified by somewhat younger faulting. Operations in the Reynolds gravel pit (in the SW¼ sec. 27, T. 2 S., R. 1 E.) exposed a northwest-trending fault displaced about 20 feet down on the west (Mr. Reynolds, oral commun., September 1960). The abrupt eastward swing of the front of the delta, along the line between secs. 21 and 28, just south of 7000 South Street, also is likely due to faulting. This faulting probably dates from shortly after the Provo stillstand, inasmuch as these faults displace post-Provo stillstand parts of the Cottonwood delta, but their scarps appear to have been somewhat wave eroded in later Provo time.

Relations similar to those at the western front of the Cottonwood delta and Draper spit suggest that a fault of post-Bonneville maximum and pre-Provo stillstand age possibly is partly responsible for the prominent scarp that rises above the Provo shore terrace south of the Alta-Sandy Road (9400 South St.) and northeast of Draper. This fault joins the main Wasatch fault zone below the mouth of the canyon of Little Willow Creek.

The noselike ridges that extend southwestward from Sandy and Crescent also seem to be defined mainly by faults rather than by erosion or deposition. Eardley, Gvosdetsky, and Marsell (1957, fig. 7) termed these ridges the Sandy and Crescent spits, respectively. The following considerations suggest that they are essentially horsts (or upwarps) dating from pre-Alpine, and probably also from post-Alpine, time:

1. They are oriented pointing upstream on the Jordan River, whereas if they were formed by normal stream dissection they should point downstream.
2. They are mainly silt and clay of the Alpine Member, with only a thin discontinuous veneer of Draper Formation. The Draper Formation forms a small spit at the end of the Sandy spit, but is absent at the end of the Crescent spit. At the tip of the Cresent spit is an exposure of pre-Lake Bonneville fan gravel underlying the Alpine Member. The fan gravel appears to be well above the projected gradient of the pre-Lake Bonneville piedmont west of the Jordan River, and probably is also above it east of the river. At the base of the Alpine Member at the tip of the Cresent spit is a tiny spit of sand and gravel derived from the underlying fan gravel. It shows that the fan gravel was exposed as a ridge or hill in early Alpine time, although it may also have undergone some later uplift.

Other possible faults appear to partly define the inner valley of the Jordan River and the lowermost courses of Dry and Willow Creeks. They appear to be of both intra-Alpine and post-Alpine age. Near the Jordan River the lower part of the Little Cottonwood Formation commonly is closely jointed and in places shows small faults. The peculiar alinement of the valleys of the lowermost courses of Dry and Willow Creeks, at the ends of and at right angles to the Sandy and Crescent spits, and also the alinement of the narrow ridges between these creeks and the Jordan River, suggest that the creek courses and ridges are alined along faults at the southwestern ends of and transverse to the two spits. An east-west fault, up on the north, possibly is partly responsible for the abrupt narrowing of the inner valley of the Jordan River just south of 6400 South Street, as well as being responsible for the marshy area adjoining the valley to the south.

DEPTH TO BEDROCK BENEATH THE QUATERNARY FILL

Gravity studies (Cook and Berg, 1961) and well data (Marine, 1961) indicate that west of the main Wasatch fault zone the pre-Quaternary bedrock floor lies generally more than 1,000 feet below the present surface of Jordan Valley. In the area mapped south of Draper, however, bedrock lies within a few hundred feet of the surface. Cook and Berg (1961, p. 80) cited a well a mile southeast of Draper and half a mile west of the main Wasatch fault zone that penetrated andesite at a depth of 390 feet, and another well at the east edge of the Prison Farm grounds and just south of the area mapped that penetrated quartzite at 300 feet. Quartzite of the Oquirrh Formation is exposed locally in sec. 6, T. 4 S., R. 1 E., south of 13800 South Street.

Bedrock also lies within several hundred feet of the surface northeast of Holladay, which is east of the most active part of the main fault zone. This area appears to be a buried pediment that is cut by many rather small faults, generally successively down on the west but with local grabens, that generally parallel the trend of the main fault zone. A buried ridge appears to adjoin this area on the west at a somewhat greater depth than the pediment because of downfaulting by the main Wasatch fault zone. The ridge shows as a low-gravity ridge extending west-southwestward past Murray (Cook and Berg, 1961), and it also is recognized (Marine, 1961) as a district where wells penetrate bedrock at depths of generally less than 500 feet.

Big Cottonwood Canyon is either rock floored or has only a few feet of alluvial fill as far as its mouth. Little Cottonwood Canyon has a deeper fill, which probably is partly till of the Bull Lake Glaciation and partly outwash and alluvium deposited behind the end moraines of this glaciation. Bedrock is exposed along the channel of Little Cottonwood Creek where it is near the northern edge of the canyon mouth, in the NW¼ sec. 12., T. 3 S., R. 1 E. Along the former axis of the canyon, however, the fill is considerably thicker. A section (Richmond, 1964) based on several exploratory boreholes indicates a maximum thickness of at least 170 feet of fill at a point about one-eighth of a mile south of the eastern end of the creekbed rock exposure. A well in Glacio Park south of the creek penetrated bedrock at a depth of 170 feet (R. E. Marsell, oral commun., 1959).

EARTHQUAKE HAZARDS

From the foregoing discussion it is evident that the Wasatch fault zone is not only one of the major zones of crustal displacement in the region but also that it can be considered to be still active: displacements causing earthquakes can be expected to occur intermittently along this fault zone far into the future. Unfortunately, all that a geologic study such as this one can do is to point out the potential hazard; it cannot predict when the future earthquakes may occur nor their severity. Probably most of the future displacements will occur along the main part of the Wasatch fault zone, inasmuch as the most numerous faults, the most recently active ones, and the greatest total displacement are all along this part of the fault zone. Thus, this part of the fault zone probably will determine a line of epicenters of future earthquakes. Earthquake intensities generally decrease rapidly away from an epicenter; consequently, it might seem that the part of Jordan Valley where earthquakes would be most intense is a narrow zone along the surface trace of the main Wasatch fault zone. This is not necessarily true, however, because of two other factors.

First, the effect of the westward dip of the main Wasatch fault zone is the displacement of the epicenter westward from the surface trace of an earthquake-producing fault. Earthquakes in the Basin and Range region have shallow-seated epicenters, ranging from essentially at the surface to 25 kilometers maximum depth and probably averaging around 10–15 kilometers (6.2–9.3 miles). This means that virtually any part of the area mapped can be expected to lie within or close to the maximum intensity area for various types of shocks.

Second, various earth materials differ in their reaction to seismic shock. Thick fills of unconsolidated sediments, such as underlie all the area mapped west of the main Wasatch fault zone, are notoriously erratic in behavior and commonly amplify the shock intensity. The coarser facies of the basin fill near the mountains probably generally provides relatively stable foundation conditions except along steep erosional or fault scarps, which may landslide during severe shocks. Water-saturated unindurated clay, silt, and sand lying close to the surface provide relatively unfavorable foundation conditions. Such conditions are found locally on the lowlands in the western part of the area. Thick artificial fills generally are especially poor, but these are rare within the area mapped. The bedrock areas generally provide the best foundation conditions, although sites on or below the steeper slopes along the mountain front or in canyons may be subject to landslides or rockfall-avalanches triggered by severe earthquake shocks.

Very few of the existing residential, commercial, or other structures in the area are designed for resistance to severe earthquake shocks. In view of the obvious potential earthquake hazard throughout the area, wider adoption of recognized earthquake-resistant practices in construction of buildings and other structures would seem well advised. Up-to-date references on this subject are listed in Duke (1958b, p. 39–41; 1958a).

QUATERNARY HISTORY

PRE-LAKE BONNEVILLE TIME

The record of pre-Lake Bonneville Quaternary time is exceedingly incomplete for the exposed deposits. The fan gravels and colluvium of pre-Lake Bonneville age attest to several intervals of active alluviation and mass wasting; and the high remnants of fan gravel along the Wasatch Mountain front attest to intermittent uplift of the range with respect to Jordan Valley, totaling probably more than 2,000 feet and dating far back into the Quaternary. The large differential uplift exceeded deposition in Jordan Valley, resulting in an exceptionally steep mountain front and causing the canyons that head close to the range front to remain steep and youthful. Most of the uplift, as well as the erosional shaping of all but the smaller landforms along the mountain front, was accomplished prior to the first rise of Lake Bonneville.

The remnants of ancient till and possible till on the ridges adjoining the mouth of Little Cottonwood Canyon record at least one pre-Bull Lake glaciation, probably of middle Pleistocene age, that was nearly, and perhaps fully, as extensive as the Bull Lake Glaciation. At this time, Big and Little Cottonwood Canyons were broader and shallower than they are now, and their floors were about 1,000 feet above the present floors at the canyon mouths.

A possible pre-Alpine deep-lake cycle is suggested by a single exposure of questionable lacustrine gravel along upper Dry Creek.

Shortly prior to the first rise of Lake Bonneville, there was an interval of accelerated chemical weathering and reduced erosion during which the Dimple Dell Soil formed. The very mature development of this soil suggests that this soil-forming interval, compared with subsequent ones, was long. The strongly developed reddish-brown clayey B horizon of the soil would seem to indicate a warm temperate climate, appreciably warmer and probably also considerably wetter than that of today. Local presence of a C_{ca} horizon shows that the climate was semiarid, not subhumid. At this time the mountain slopes probably were more generally mantled by colluvium and soil, making them less cliffy and more rounded than now, particularly in the higher mountains.

EARLY LAKE BONNEVILLE (LITTLE COTTONWOOD) AND MIDDLE-LAKE BONNEVILLE TIME

The early part of Lake Bonneville history is recorded by the Alpine Member. This part of the lake's history is evidently longer but less clear than subsequent parts. The first rise of Lake Bonneville took place soon after the Dimple Dell Soil was formed. Evidence from JordanValley and from the Leamington-Old River Bed areas (Varnes and Van Horn, 1961) suggests that in early Alpine time a deep lake rose to an altitude of at least 4,925 feet, then receded below an altitude of 4,265 feet, and was followed by another lake cycle during which the highest and last deep lake of Alpine time was evidently formed.

During these lake cycles, Big and Little Cottonwood and Dry Creeks contributed large amounts of gravel, sand, and silt (more sediment than at any subsequent time) derived mainly from outwash from large contemporaneous glaciers in their canyons. These sediments were deposited on deltas that coalesced to form the ancestral Cottonwood delta. The two high lake stands, at least, were characterized by strong longshore currents moving from north to south, as evidenced in the shore gravel by the marked southward displacement (commonly several to 20 miles or more) of rock types from their source areas. Such currents imply strong waves and strong northwesterly winds. Prominent shore terraces, spits, and bars were built, but only local traces of these remain because they were mostly buried or eroded during the succeeding Bonneville-Provo lake cycle. Probably approximately contemporaneous with the last lake maximum in Alpine time was the maximum of the early stade of the Bull Lake Glaciation in Little Cottonwood and Bells Canyons. The glaciers extended about a mile beyond the canyon mouths and built bulky terminal moraines that reached altitudes as low as 4,930 and 5,050 feet, respectively, overlapping the Alpine Member, after the lake had risen to an altitude of at least 5,050 feet. Subsequently in Alpine time the lake rose to its maximum, at an altitude of 5,100–5,110 feet (west of the main Wasatch fault zone), depositing silt, sand, and gravel overlapping the toes of the moraines.

A major lake recession, probably to below an altitude of 4,310 feet, intervened between this lake cycle and the next, the Bonneville-Provo. Presumably the glaciers also receded. The valleys of Dry Creek and Willow Wash (and presumably other valleys as well) were cut into the thick Alpine Member to about two-thirds of their present depth and along essentially their present courses.

As Lake Bonneville rose during its next lake cycle, recorded by the Bonneville and Provo Members of the Little Cottonwood Formation, considerable sand and gravel was added to the Cottonwood delta, although it constituted merely a top dressing compared with deposits of Alpine time. Much of this sediment was outwash from the contemporaneous glacial advance of the late stade of Bull Lake Glaciation in the Wasatch Mountains. At their farthest extent these glaciers from Little Cottonwood and Bells Canyons reached just upstream from their earlier maximums, again building bulky moraines beyond the canyon mouths. Shortly following this glacial maximum, Lake Bonneville attained its all-time maximum and formed the Bonneville shoreline against the toes of the terminal moraines and elsewhere. After the glacier from Little Cottonwood Canyon had receded at least a mile from its maximum, Little Cottonwood Creek cut a strath outwash terrace through the terminal moraine and became graded to this shoreline.

Moderate longshore drift from north to south occurred during the intermediate and higher levels of the Bonneville-Provo lake cycle, as evidenced by small "spillover" spits on the north side of the valleys of Dry Creek and Willow Wash. The transport of sand and gravel was far insufficient, however, to fill these larger valleys that had been cut during the previous lake recession, which indicates that waves and longshore currents were weaker than during Alpine time, and windstorms were less frequent and milder.

Evidently this lake cycle receded very rapidly from the Bonneville shoreline to the Provo level, for regressive shorelines and shore deposits between these levels are trivial.

There followed a long stillstand at the Provo shoreline level—at an altitude of 4,825–4,800 feet—during which the strongest of the shore terraces of Lake Bonneville, the Provo terrace, was formed. Presumably this stillstand was caused by near-cessation of downcutting of the overflow channel at Red Rock Pass, Idaho (Gilbert, 1890; Williams, 1952; Eardley, Gvosdetsky, and Marsell, 1957, p. 1196). The glaciers probably had retreated only a short distance, for Big Cottonwood, Little Cottonwood, and Dry Creeks cut wide strath terraces that were graded to this level and added considerably to the Cottonwood delta, showing that they still carried much glacial melt water and outwash. The deltaic deposits were reworked southward by strong longshore currents, forming prominent gravel bars and spits, including the main part of the Draper spit. The bars and spits extended completely across the valleys of Big Cottonwood, Little Cottonwood, and Dry Creeks, which had been cut during the post-Alpine lake recession. Obviously these currents were caused by strong waves, produced by strong northwesterly winds.

Finally the lake receded below the Provo level, but with temporary stillstands, forming several fairly prominent lower shorelines. During the lake recession, Little Cottonwood Creek cut a series of strath terraces graded to the shorelines, below its earlier ones. It also augmented its part of the Cottonwod delta complex by the addition of a small compound delta graded to two recessional stillstand levels at altitudes of about 4,750 and 4,650 feet, respectively.

The lake recession continued until Lake Bonneville fell below an altitude of 4,250 feet and probably became nearly or entirely dry. Evidently this desiccation interval was long, for the valleys of Little Cottonwood Creek, Dry Creek, Willow Wash, the Jordon River, and other streams, including small gullies below the Cottonwood delta, were cut nearly to their present depth and alluvial sand and gravel was locally deposited on their bottoms. During the last part of this interval, downcutting and alluviation slackened, and the Graniteville Soil formed, mantling all the exposed deposits with its distinctive profile. This mature soil, with its widespread Pedocal facies, suggests a climate appreciably warmer than it is now, yet semiarid—in other words, a true interglacial-interpluvial climate.

LATE LAKE BONNEVILLE (DRAPER) AND POST-LAKE BONNEVILLE TIME

The later lake cycles of Lake Bonneville are recorded by the Draper Formation. The first of these lake maxima reached an altitude of about 4,770 feet, which is within a few feet of the Provo level. This maximum seems to have been brief and accompanied by comparatively slight longshore drift—much less than during the Bonneville maximum—indicating that strong waves were absent, for its highest shoreline is poorly marked by shore terraces or other geomorphic features, and its deposits are relatively scanty. Small "spillover" spits were built on the north side of the valleys of Little Cottonwood and Dry Creeks, but they were far too small to dam these valleys. A distinctive deposit of deltaic sand and gravel was laid down along Dry Creek, disconformably within the valley that had been cut in the interval between Little Cottonwood and Draper time. Lake-bottom sedimentation was trivial, typically only a few inches of silt and clay, much less than during the Alpine and the Bonneville-Provo lake cycles.

A major glacial advance, the early stade of the Pinedale Glaciation, seems, by indirect correlation, to have been contemporaneous with this lake cycle in early Draper time. The glacier in Little Cottonwood Canyon advanced to just below the mouth of Hogum Canyon, at an altitude of 6,500 feet, and in Bells Canyon to its mouth, at an altitude of 5,600 feet (Richmond, 1964). This stade attained the maximum for the Pinedale Glaciation, just as the maximum of the first Draper lake was the highest of Draper time. Concurrently with this and the later stades of the Pinedale Glaciation, accelerated mass-wasting took place in the areas not covered by ice.

During recession from the lake maxima in early Draper time, Little Cottonwood Creek cut a prominent strath terrace, and Big Cottonwood and Dry Creeks cut lesser ones. Little Cottonwood, Big Cottonwood, and Dry Creeks also built small recessional deltas just below the main front of the Cottonwood delta, all evincing minor southward longshore drift. The lake then receded at least as low as an altitude of 4,450 feet, and probably receded considerably lower than this.

The second lake cycle in Draper time rose to an altitude of about 4,470 feet—to the Stansbury shoreline of Gilbert (1890) and of Eardley, Gvosdetsky, and Marsell (1957). Little Cottonwood, Big Cottonwood, and Dry Creeks formed prominent strath terraces and deltas graded to this shoreline, but otherwise the shoreline is poorly marked by shore features and deposits. This lake maximum seems to have been even briefer and to have had fewer longshore currents than its immediate predecessor. The maximum of the middle stade of the Pinedale Glaciation probably was concurrent with this lake maximum in Little Cottonwood and Bells Canyons. Subsequently, Lake Bonneville fell briefly at least as low as 4,360 feet, and then rose to a third maximum at about 4,410 feet. During this third maximum in Draper time the Jordan River built a sandy delta whose deposits top the bluffs and along the river in the southern two-thirds of the area; also Big and Little Cottonwood Creeks formed strath terraces and deltas. Probably coeval with this lake maximum was the maximum of the late stade of the Pinedale Glaciation. Recession from the third lake maximum in Draper time terminated the history of Lake Bonneville in this part of Jordan Valley.

This recession marked a trend to increasing aridity, which culminated in an extremely arid interval that is correlated with the early part of the Altithermal age of Antevs (1948, 1952, 1955). This interval started between 7,500 and 6,500 years ago and was characterized by a climate that was both warmer and more arid than that of today and, accordingly, had a reduced vegetative cover. As it also was very windy during this interval, the interval was marked by wind erosion and by extensive deposition of loess and eolian sand. The Great Salt Lake area undoubtedly was completely desiccated during much of this interval, and the Wasatch Range was completely deglaciated.

During later Altithermal time, eolian erosion and deposition virtually ceased, and a submature soil, the Midvale Soil, formed. The soil-forming interval probably did not last more than 1,000 years and obviously was a time of accelerated chemical weathering. In fact, this short interval had the most active chemical weathering of all Draper and later time which was at least 25 times longer. For such soil development, the climate must have continued to remain appreciably warmer than it is now, and precipitation also must have increased moderately, or else the continued aridity would have inhibited soil development. The local Pedocal facies of the soil in Jordan Valley further indicates a semiarid climate. Probably the evaporation rate remained high enough so that the Great Salt Lake area remained essentially a playa. Having a lowered base level, the Jordan River and its tributaries gradually incised their valleys nearly to their present depth.

The time since the Midvale Soil formed, about 4,000 years, is interpreted as representing the Recent Epoch. The early part of this epoch was marked by the formation of strath terraces along Little Cottonwood and Big Cottonwood Creeks and along the lower Jordan River, and also by a minor stade of glaciation, when small glaciers re-formed in the higher cirque basins. Subsequently erosion and alluviation decreased, the weak early Recent soil formed, and the glaciers probably melted completely. In late Recent time the main streams trenched a few feet deeper to form their present flood plains; and another stade of glaciation, smaller that the preceding one, temporarily reactivated glaciers in a few of the higher cirques.

COMPARISON WITH INTERPRETATIONS OF OTHER WORKERS

The present study generally supports Eardley, Gvosdetsky, and Marsell's conclusions (1957) on the history of the lake oscillations (but not all of their correlations with the glacial sequence). It also is in accord with the opinion of nearly all workers that each lake cycle was essentially synchronous with a glacial cycle of similar relative magnitude.[11] It differs, however, in various details from the interpretations on lake history and (or) on lacustrine-glacial correlations of Gilbert (1890), Atwood (1909), Blackwelder (1931), Marsell (1946b), Antevs (1945, 1948, 1952, 1955), Ives (1948, 1950, 1951), Hunt (1953b), Gvosdetsky and Hawkes (1953, 1954, 1956), Jones and Marsell (1955), Bissell (1952, 1962), Broecker and Orr (1958), and Broecker and Walton (1959).

[11] Jones and Marsell (1955), however, did not correlate the separate lake cycles represented by the Bonneville shoreline, the Alpine Formation, and the green clay series with matching glacial cycles, although they did correlate the Provo Formation (and the separate lake cycle they inferred it to represent) with the last glacial advance that reached beyond the mouths of Little Cottonwood and Bells Canyons.

Evidence of at least two deep-lake cycles in early Lake Bonneville time, recorded by the Alpine Member and its correlatives (for example, the yellow clay of Gilbert), supports the conclusions of Varnes and Van Horn (1961), and supplements the interpretations of Gilbert (1890), Jones and Marsell (1952, 1955), Antevs (1945, 1948, 1952), Ives (1948, 1950, 1951), Hunt (1953b), Gvosdetsky and Hawkes (1953), Bissell (1952, 1962), Eardley and others (1957), and Morrison (1961b and 1964). These early lake cycles are here correlated with the Bull Lake Glaciation (which is correlative with the Tahoe Glaciation). On the other hand, the equivalent lake cycle was correlated with the Durango or Illinoian Glaciation by Antevs (1945, 1952) and Ives (1950, 1951),[12] with the Kansan Glaciation by Eardley and others (1957), and with the Nebraskan Glaciation by Gvosdetsky and Hawkes (1953).

This study also affirms the conclusion made by Gilbert (1890), Antevs (1945, 1948, 1952), Ives (1951), Jones and Marsell (1952, 1955), Hunt (1953b), Bissell (1952, 1962), and Eardley and others (1957) that Lake Bonneville receded markedly between the Alpine and the Bonneville-Provo lake cycles. The lowest known exposure of the unconformity that records this recession is in Jordan Valley. According to the present study, however, this recession was not as long relative to subsequent lake history as the other workers have supposed, and the coeval deglaciation was of interstadial, rather than of interglacial, magnitude.

The age and correlation of the Bonneville shoreline seem to be the most controversial topic in Lake Bonneville history. The present study supports the conclusions of Gilbert (1890), Antevs (1945, 1948), Hunt (1953b), Bissell (1962), and Eardley, Gvosdetsky, and Marsell (1957) on the age of this shoreline with respect to the earlier lake cycle(s) that are recorded by the Alpine Member and its correlatives—(for example, the yellow clay of Gilbert). This shoreline seems to record the maximum of only one lake cycle instead of two, as Ives (1950, 1951) and Antevs (1952) concluded. The Bonneville shoreline was formed shortly after the maximum of its coeval glacial cycle, as Antevs (1945, 1948) concluded, and not before this glacial maximum, as Gilbert, Atwood, Hunt, and Eardley and others postulated. It did not form in pre-Lake Bonneville time, prior to deposition of the Alpine Formation, as Jones and Marsell (1955) suggested. The lake cycle that culminated at this shoreline (and presumably overflowed at Red Rock Pass) is here correlated with the Bull Lake, Tahoe, and Iowan Glaciations, as Antevs (1945, 1948), Ives (1950, 1951), and Eardley and others (1957)[13] inferred. This contrasts with conclusions that this lake cycle is of Kansan age (Gvosdetsky and Hawkes, 1953) or of Tioga age (Blackwelder, 1931; Antevs, 1952, 1955).

The present study also affirms the interpretation that the Provo stillstand and principal occupation of the Provo shoreline level took place during recession of the same lake cycle that rose to the Bonneville shoreline (and overflowed), as Gilbert (1890), Ives (1951), Hunt (1953b), Bissell (1962), Antevs (1952), and Eardley and others (1957) maintained, and, conversely, does not support the interpretation that the main Provo occupation was during a separate later lake cycle, as Antevs (1945, 1948), Bissell (1952), Gvosdetsky and Hawkes (1953), and Jones and Marsell (1955) inferred. The Provo stillstand was in late Bull Lake-Tahoe time, contrary to the correlations of Antevs (1945, 1948, 1952, 1955), Ives (1950), Richmond, Morrison, and Bissell (1952), Gvosdetsky and Hawkes (1953 and 1956), and Hunt and Morrison (1957).

Jones and Marsell (1955), Bissell (1952, 1962), Antevs (1952, 1955), and Eardley and others (1957) recognized a Provo 2 stage that they inferred was the maximum of a separate lake cycle of post-Provo stillstand age, which is equivalent to the maximum of the early Draper lake, recorded by the lower tongue of the Draper Formation of the present study. C. B. Hunt (letter quoted on p. 1168 in Eardley and others, 1957), however, attacked the validity of the Provo 2 stage as the maximum of a significant and separate lake cycle. The present study establishes that a long interval of probably complete dessication, probably the longest and most complete dessication of Lake Bonneville time, did indeed intervene between the Provo stillstand and the Provo 2 (early Draper) lake maximum. This is the Bull Lake-Pinedale (Tahoe-Tioga) interglacial and was a time of complete deglaciation in the mountains (Richmond, 1964), contrary to Antevs' inference (1945, 1948, 1952).

The later lake oscillations that are recorded by the Draper Formation have been recognized previously only by Eardley and others (1957) as a series of three

[12] Ives (1950) correlated these lake deposits with the "Graniteville erratics," which he believed to be older than the other glacial deposits below the mouths of Little Cottonwood and Bells Canyons. The deposits designated as "Graniteville erratics" on Ives' map are, however, mostly till of Bull Lake age and, locally along Dry Creek, torrent levee debris of post-Pinedale age.

[13] Eardley and others correlated this lake cycle with Iowan and Tazewell, evidently implying Early Wisconsin in the usage of several years ago.

separate lake cycles distinctly later than the deep-lake cycles recorded by the earlier lake deposits. (These authors, however, did not give evidence for postulating significant recessions between the lake maxima.)

The maximum of the middle Draper lake is marked by the Stansbury shoreline of Gilbert (1890), who inferred that this shoreline was formed during a temporary halt of the fall of Lake Bonneville below the Provo shoreline. Antevs (1945, 1948) likewise interpreted this (the Stansbury II) shoreline as marking a stillstand on the recession of a lake cycle ("Lake Provo") that rose to the Provo shoreline. He later (1952, 1955), following Ives (1951), inferred that this shoreline marks the maximum of a minor lake oscillation superposed on the recession from the Provo stillstand. The present study is in agreement with Eardley and others (1957) that the Stansbury shoreline marks the maximum of a lake cycle that is separated from the Provo 2 (early Draper) lake cycle by marked lake recession. They correlate this lake cycle with the Mankato substage (and erroneously with the Temple Lake "stage" of the Rocky Mountain region). Gvosdetsky and Hawkes earlier (1953, 1954, 1956) inferred two post-Provo lake cycles that rose to the Stansbury shoreline and were separated by an interval of soil formation that they correlated with the Brady Soil.

A lake cycle corresponding to that recorded by the upper tongue of the Draper Formation, whose maximum was at an altitude of about 4,410 feet, is recognized for the first time in this report. The Gilbert stage of Eardley and others (1957), which they inferred to be pre-Altithermal, is recorded 170 feet lower but is probably younger.

Complete lake dessication during the Altithermal interval is postulated by Antevs (1945, 1948, 1952, 1955), Ives (1951), and Eardley and others (1957). Eardley and others (1957) did not postulate any post-Altithermal lake cycles. Ives (1951), however, inferred several minor lake cycles with maxima successively at altitudes of 4,330 feet ("Dugway stage") and 4,245 feet ("Timpie stage"), and he correlated these with a minor glaciation (Albion Basin moraines) in the Little Cottonwood Canyon area. Antevs (1952, 1955), however, considered that lake level did not rise above an altitude of 4,262 feet ("Dugway stage") in post-Altithermal time. The area covered in the present study does not extend to altitudes low enough to give evidence on these young lake cycles, which are the only ones I consider to be of Recent age (contrary to Hunt's opinion (1953b, p. 14) that all the post-Provo-stillstand deposits should be considered Recent).

STRATIGRAPHIC SECTIONS

(Location of sections shown on pl. 2)

1. *Alluvium of middle-Lake Bonneville (inter-Little Cottonwood–Draper) age (lowest occurrence in area mapped) bearing the Graniteville Soil and developed on Little Cottonwood Formation*

[Exposed in east bluff of the Jordan River Valley, about 100 ft from the river, 2 miles northwest of Murray in the NE¼SW¼ sec. 35, T. 1 S., R. 1 W.; altitude, top of section, about 4,274 ft]

	Thickness (ft)	*Depth (ft)*
Eolian sand of post-Draper age:		
Upper 2–8± ft is pale-brownish-gray fine-medium sand; loose; crossbedded; has no discernible soil development; probably of Recent age.		
Lower 2.5± ft is gray to light-brownish-gray fine-medium sand; slightly indurated; weak to moderate calcareous cementation; locally has weak coarse prismatic structure; crossbedded to massive. Fragments of underlying C_{ca} horizon of Graniteville Soil at base. Eolian sand of early post-Draper (early Altithermal) age bearing the partly eroded Midvale Soil (B horizon of soil is absent)	10.5±	10.5±
Disconformity; sharp, somewhat undulating boundary; records subaerial erosion.		
Alluvium of middle-Lake Bonneville (inter-Little Cottonwood–Draper) age, bearing Graniteville Soil:		
Upper 2.5–3 ft is interbedded sand; fine pebbly sand, and granule, fine, and medium sand, generally rather poorly sorted. Bears strong white soil-lime carbonate concentration (caliche)—the somewhat eroded C_{ca} horizon of the Graniteville Soil (B horizon is missing)—which decreases somewhat irregularly downward, to diffuse lower boundary approximately at base of this sandy zone.		
Lower 3–5 ft is sandy very fine pebble gravel interbedded with some very fine pebbly sand; pebbles generally less than 1 in., rarely as much as 2 in., in diameter; clean and loose, except locally uppermost several inches are somewhat cemented by downward extensions of the calcareous horizon of Graniteville Soil	6.0–8.0	17.5±
Disconformity.		
Little Cottonwood Formation (lacustrine):		
Silt and fine sand, interbedded; mostly silty very fine sand, silty fine sand, and fine sandy silt; some thin beds and laminae of clayey silt, and a few beds of clean fine sand; thin to thick bedded (some beds 1 ft or more thick); mostly parallel bedded, but in upper several feet bedding locally is contorted	12.0	29.5±
Base concealed (base of exposure is about 10 ft above water level of Jordan River).		

2. Eolian sand of post-Draper age, strath-terrace gravel of late Provo age, and Provo Member of Little Cottonwood Formation

[Exposed in and near Reynolds gravel pit, in bluff 0.2 mile north of Little Cottonwood Creek, on east side of 2000 East St., SW¼SW¼ sec. 27, T. 2 S., R. 1 E. Top of section is crest of highest sand dune east of gravel pit; altitude about 4,775 ft]

	Thickness (ft)	*Depth (ft)*
Eolian sand of post-Draper age:		
Sand, fine-medium and medium, white to pale-gray, generally loose, crossbedded; forms prominent dunes; ranges in thickness from 10 to 80 ft. Two distinct parts, separated by the Midvale Soil, which is 2–4 ft thick. (See soil-profile section S–2 and fig. 17.) Upper part is 0–40 ft thick, shows no discernible soil-profile development. Lower part is 5–50 ft thick and somewhat more indurated than upper part. (Jones and Marsell (1955) interpreted this part as lacustrine sand of Provo 2 age)	80±	80±
Disconformity, erosion surface.		
Loess of middle-Lake Bonneville age and strath-terrace gravel of late Provo age, bearing the Graniteville Soil:		
Top 1–4 ft is poorly sorted fine and medium sand and silt; not bedded; probably loess. Lower several feet are pebble gravel, probably alluvium with some cobbles as much as 8 in. in diameter. The B horizon (somewhat eroded) of Graniteville Soil is preserved in upper 2–2.5 ft of these deposits. It is brown (about 7.5*YR* 5/4); structureless; slightly hard, grading downward to soft; and noncalcareous. The next 1.5–3 ft is the C_{ca} horizon of this soil (Pedocal-Pedalfer facies boundary passes just east of this locality), which is gray, slightly to moderately calcareous, structureless, friable; undersides of pebbles generally have thin lime coatings	6±	86±
Diastem.		
Little Cottonwood Formation, Provo Member (lacustrine):		
Sand, pebbly sand, and sandy pebble gravel, interbedded, unconsolidated; locally with conspicuous deltaic foreset bedding dipping westward 5°–30°	50±	136±
Base concealed.		

NOTE.—The Alpine Member is locally exposed, unconformably beneath Provo Member, in a gravel pit and adjoining bluff about 0.1 mile southeast, below an altitude of about 4,650 ft. The Alpine consists of light-gray silt and fine sand that is thinly interbedded and somewhat indurated.

3. Strath-terrace gravel of late Provo age, underlain by sand of Little Cottonwood Formation

[Exposed in roadcuts on north side of Danish Road where this road climbs bluff on north side of Little Cottonwood Creek, to crest of a remnant of the strath terrace, northwest of road. SW¼NW¼ sec. 35, T. 2 S., R. 1 E.,; altitude, top of section, 4,770± ft]

	Thickness (ft)
Strath-terrace gravel of late Provo age, bearing Graniteville Soil:	
Gravel, cobble and pebble; sandy in lower part; typical Little Cottonwood Creek assemblage; many of the granitic and gneissic roundstones are rotten; probably alluvial. Poorly exposed. Bears the Graniteville Soil, Noncalcic Brown soil facies; B horizon exposed in roadcut is only 2 ft thick but strongly developed and reddish brown; probably somewhat eroded	12. 0
Concealed	4. 0
Little Cottonwood Formation, Alpine Member (lacustrine):	
Sand, fairly well sorted, loose. In upper 3 ft, equal parts interbedded medium sand and fine sand; fine sand is thinly ripple bedded. Lower 4 ft is very pale gray medium sand with some interbeds of medium sand containing varying amounts of coarse sand, granules, and very small pebbles	7. 0
Sand, fine and very fine, interbedded, pale-gray to white, thinly ripple bedded; lower one-third is cemented	. 7
Sand, interbedded medium, coarse, and some fine; well sorted; loose; pale gray to nearly white; strongly ripple bedded and crossbedded	8. 0
Sand, fine, white, very well sorted, loose	5. 0
Silt, and clayey silt; thinly interbedded; pale gray; hard	. 5
Silt, pale-gray, well-sorted, indistinctly bedded, fairly soft; has some hard (cemented) partings	. 7
Sand, fine, pale-gray, clean, unindurated, thinly ripple bedded	1. 2
Sand, silty, fine, light tan-gray, unindurated	. 4
Sand, fine, white, clean and loose, ripple-bedded; some interbeds of silty fine sand and, near base, thin partings of silt	4. 3
Silt, very fine sand, and some clayey silt; thinly interbedded; pale gray	. 7
Sand, very fine, pale-gray, well-sorted	3. 0
Base not exposed.	
Total thickness	47. 5±

4. Little Cottonwood Formation, Alpine Member, exposed at tip of spur in bluff on north side of Little Cottonwood Creek

[SW¼NW¼ sec. 35, T. 2 S., R. 1 E.; altitude, top of section (crest of spur), about 4,780 ft]

	Thickness (ft)
Eolian sand of Recent (post-Altithermal) age:	
Sand, eolian, with weak or no soil-profile development; discontinuous, highly irregular veneer	0–20. 0
Disconformity.	
Eolian sand of post-Draper Altithermal age:	
Sand, eolian; bears Midvale Soil	3. 0+

4. Little Cottonwood Formation, Alpine Member, exposed at tip of spur in bluff on north side of Little Cottonwood Creek—Continued

	Thickness (ft)
Disconformity.	
Little Cottonwood Formation, Alpine Member (lacustrine):	
Silt, pale-gray, hard, cemented, thinly bedded	0.3
Sand, fine, pale-gray, clean, loose; 2-in. silt layer at base	2.5
Sand, medium, white, clean, loose	.5
Silt, thinly laminated; semi-indurated	.5
Sand, pale-gray; most beds are medium sand and medium and coarse sand with some grit and a few very small pebbles (rarely more than 1 in. in diameter); loose	18.0
Sand, fine, white, ripple-bedded and crossbedded	2.5
Sand, very fine, white, ripple-bedded and crossbedded, unindurated	1.0
Silt, pale yellowish-gray, thick-bedded, slightly indurated	1.5
Sand, very fine, pale-gray, soft, ripple-bedded	2.0
Sand, mostly interbedded medium sand and medium and coarse sand with a little grit and very small pebbles; loose	35.0
Sand, very fine, pale-gray, clean, thinly ripple bedded	.8
Sand, medium, with some interbedded medium and coarse sand and a little grit; clean and loose	2.5
Sand, fine, and very fine, interbedded, nearly white, soft (unindurated), massive to thinly ripple bedded	8.0
Silt, well-sorted, moderately thin bedded; has several thin interbeds of clay and silty clay in middle part (one 4-in. clay bed at base of this middle zone)	2.5
Sand, very fine, nearly white, clean and loose	1.0
Base concealed.	
Total Alpine Member of Little Cottonwood Formation	78.6

5. Strath-terrace alluvium of late Provo age disconformably overlying Alpine Member of Little Cottonwood Formation

[North bluff of Little Cottonwood Creek, about 0.5 mile west of Danish (Creek) road bridge, NW¼NE¼ sec. 34, T. 2 S., R. 1 E.; altitude, top of section, about 4,760 ft; base of section about 20 ft above flood plain of Little Cottonwood Creek]

	Thickness (ft)
Post-Draper eolian sand:	
Sand, mainly fine-medium and medium, but locally near scarp front has a little white granitic grit (blown upslope from exposures of the underlying sand in bluff of Little Cottonwood Creek). Upper part shows little or no soil development; lower part locally bears (where not eroded) the Midvale Soil. Thickens westward to 25–30 ft	10.0±

5. Strath-terrace alluvium of late Provo age disconformably overlying Alpine Member of Little Cottonwood Formation—Continued

	Thickness (ft)
Disconformity, recording subaerial erosion.	
Strath-terrace alluvium of late Provo age bearing Graniteville Soil:	
Sand, light-yellow; upper 1.5 ft is fine to medium sand; in next 2 ft sand gradually becomes coarser, with some coarse sand and grit; lower 3 ft is medium sand and some coarse sand with a few small pebbles. Bears somewhat eroded Graniteville Soil; pedocal facies; upper 0.3 ft is B_{ca} horizon, brown, with local moderate lime concentration. Next 2 ft is white, with strong lime concentration (main part of C_{ca} horizon); next 1–1.5 ft has moderate to weak (irregular) lime concentration (lower part of C_{ca} horizon)	6.5
Gravel, pebble and cobble; some cobbles as much as 9 in. in diameter; typical Little Cottonwood Creek assemblage. Few rotten stones. Thickens fairly rapidly westward	5.0
Disconformity, surface of subaerial erosion.	
Little Cottonwood Formation, Alpine Member (lacustrine):	
Silt, well-bedded, thick-bedded, homogeneous; no sand partings; pale gray, nearly white; top 10 ft is massive, forms cliffs	20.0±
Silt, silty clay, fine sandy silt, in alternating thin beds, with some partings of fine sand or medium sand. Middle and lower parts poorly exposed; seem to be mainly fine-sandy silt with some fine sand partings that commonly are silty and pebbly	30.0±
Silt, commonly with some fine sand intermixed; well-bedded	4.0±
Silt, clayey silt, and silty clay, interbedded, poorly exposed. Contact with underlying unit sharp	8.0±
Gravel and gravelly sand, light-gray; upper 3 ft is poorly sorted sandy and silty pebble gravel, with some pebbles as much as 4 in. in diameter (coarsest in upper 1 ft); grades finer downward; lower 2 ft is silty fine-pebble sand	5.0
Base concealed.	
Total thickness	77.5

6. Upper and lower tills of Bull Lake Glaciation intercalated with and overlying Little Cottonwood Formation, just below Bonneville shoreline

[Exposed in steep gully caused by old pipeline break on bluff on east side of graben of main Wasatch fault zone, 0.5 mile north of Little Cottonwood Creek; SW¼ sec. 1, T. 3 S., R. 1 E.; altitude, top of section, about 5,240 ft]

	Thickness (ft)
Loess of post-Draper age, bearing Midvale Soil:	
Silt, fine sand, some fine-medium sand with a few pebbles (colluvial); massive	2.0
Disconformity, erosion surface.	
Little Cottonwood Formation, Bonneville Member (lacustrine):	
Silt and intercalated fine sand, fairly well-, thin-, and parallel-bedded, light-gray	1.5

6. Upper and lower tills of Bull Lake Glaciation intercalated with and overlying Little Cottonwood Formation, just below Bonneville shoreline—Continued

	Thickness (ft)
Upper till of Bull Lake Glaciation:	
Till, bouldery, very poorly sorted—clay to boulders about 5 ft in maximum diameter. Larger boulders all porphyritic quartz monzonite from Little Cottonwood stock; smaller ones also include quartzite, some limestone and dolomite. Unit thickens to 20 ft a few hundred feet southward	2. 5
Diastem.	
Little Cottonwood Formation (lacustrine), Alpine Member (thins rapidly southward and the sand and gravel units become less well sorted and less obviously lacustrine—they apparently intergrade with glacial outwash):	
Silt, light-greenish-gray; contains some pebbles and sparse blocks and boulders as much as 1 ft in diameter. Irregular upper and lower contacts; average thickness given	. 7
Sand, coarse, grit sand, and lenses of very fine pebble gravel (mostly ⅛–½ in. in diameter); all very well sorted; slight silt and lime cement; somewhat rust-stained, light gray-brown. Probably lacustrine	2. 2
Gravel, fine-pebble, rust-stained, medium-red-brown. Very well sorted in upper two-thirds—small pebbles, mostly less than 2 in. in diameter and rarely more than 4 in. in diameter in matrix of clean medium sand, some grit (2 size-grade maximums). Few pebbles are quartz monzonite; most are quartzite but some are hornfels or sandstone from Big Cottonwood, Mutual, and Ankareh Formations that indicate derivation mainly by longshore transport from north. Probably lacustrine	4. 2
Gravel, pale-gray, pebble and cobble, rather poorly sorted—evenly graded from silt to cobbles as much as half a foot in diameter. Few pebbles and cobbles are granitic. Probably lacustrine	2. 5
Lower till of the Bull Lake Glaciation:	
Till, bouldery, very poorly sorted—clay to boulders more than 6 ft in diameter. Most boulders, including all larger ones, are porphyritic quartz monzonite from Little Cottonwood stock	10. 0
Poorly exposed, base concealed.	
Total exposed thickness	24. 6

7. Upper and lower tills of Bull Lake Glaciation exposed in bluff on east (upthrown) side of fault graben of Wasatch fault zone, in steep gully caused by old pipeline break

[SW¼SW¼ sec. 1, T. 3 S., R. 1 E. Top of section, at an altitude of 5,250± ft, is a few feet above Bonneville shoreline]

	Thickness (ft)
Upper till of Bull Lake Glaciation, bearing Graniteville Soil:	
Till, bouldery, clayey; brown (7.5*YR* 5/4 to 10*YR* 5/3) in upper 4 ft, light gray below. Very poorly sorted—clay to boulders 5 ft and more in diameter. Coarse fraction typical of tills near mouth of Little Cottonwood Creek—mainly quartz monzonite of Little Cottonwood stock and quartzite, with some limestone and dolomite; larger boulders are all quartz monzonite and some are fairly rotten, especially in their outer rinds	16. 5

7. Upper and lower tills of Bull Lake Glaciation, exposed in bluff on east (upthrown) side of fault graben of Wasatch fault zone, in steep gully caused by old pipeline break—Con.

	Thickness (ft)
Alluvium or colluvium of Little Cottonwood-Bull Lake age, possibly coeval with inter-Alpine-Bonneville lake recession:	
Boulder gravel, sandy, fairly well sorted; probably alluvium, outwash, or colluvium (slope-wash mantle?)	1. 5
Silt, sandy, with some pebbles, mostly less than 2.5 in. in diameter; discontinuous; loessic slope-wash mantle(?)	2. 0
Lower till of Bull Lake Glaciation:	
Till, bouldery; like till above but somewhat more reddish brown and sandier, except near base. Upper one-third has fewer and smaller boulders than the upper till; lower one-third is coarsest, with a few boulders more than 5 ft in diameter	20. 0
Diastem.	
Little Cottonwood Formation, Alpine Member, and (or) lower outwash gravel of Bull Lake Glaciation:	
Sand, gravelly, light-yellowish-gray; coarse to fine-medium sand, somewhat silty, with a few pebbles (mostly less than 2 in. in diameter) and sparse cobbles and small boulders. Alluvial or lacustrine	2. 0
Gravel, fairly well sorted; mostly pebble gravel with some cobbles and lenses of pebbly grit. Alluvial or lacustrine	10. 0
Diastem.	
Lower till of Bull Lake Glaciation:	
Till, bouldery. Poorly exposed	5. 0
Base concealed.	
Total thickness exposed	57. 0

8. Little Cottonwood Formation, Alpine and Bonneville Members: reference section for Bonneville Member

[South face of large cut made in 1958 during construction of new Salt Lake City Water Purification Plant, about 0.1 mile northeast of this plant and 0.5 mile north of Little Cottonwood Creek, 250 ft west of NE cor. SE¼ sec. 2, T. 3 S., R. 1 E.; top of section, at an altitude of about 5,130 ft, is crest of a bay bar of gravel of Bonneville Member, approximately at Bonneville shoreline]

	Thickness (ft)
Little Cottonwood Formation (lacustrine):	
Bonneville Member, bearing Graniteville Soil:	
Pebble gravel; in upper 8 ft, pebbles rarely more than 3 in. in diameter; in lower part, pebbles rarely more than 5 in. in diameter; maximum, 9 in. Upper 4 ft is brown, becoming lighter (7.5*YR* hue) downward (B horizon of middle-Lake Bonneville soil, Noncalcic Brown soil facies)	26. 0
Diastem; erosion surface sloping gently westward, truncates about 10 ft of underlying beds.	
Alpine Member:	
Sand, medium, white to very pale gray, granitic, very clean, loose; rare partings of fine-pebbly sand and grit sand; small-scale crossbedding locally, and locally ripple marked near top	16. 5
Small diastem.	
Silt, clayey, massive	1. 5

8. Little Cottonwood Formation, Alpine and Bonneville Members: reference section for Bonneville Member—Continued

	Thickness (ft)
Little Cottonwood Formation (lacustrine)—Continued	
Alpine member—Continued	
Sand, fine; some interbedded medium sand and silt. In upper several feet, fine sand, clean and unconsolidated, with 0.5–4-in. partings of silt and clayey silt at 2–6-in. intervals; mostly fine sand, with medium sand below	9.0
Sand, medium, coarse, and fine-pebbly coarse, white to light-buff, locally crossbedded and ripple marked; 4 in. of silty fine sand and fine sand 2 ft below top	6.0
Sand, fine and medium, interbedded; clean (well sorted), strongly ripple marked	3.0
Sand; beds of fine sand about 10 in. thick and massive and parallel-bedded, alternating with beds of white strongly ripple marked medium sand 4 in. to 1 ft thick	7.0
Sand, medium, and some grit containing occasional very small pebbles; some fine sand interbeds about two-thirds of thickness from top; well bedded and mostly parallel bedded, but locally small scale crossbedded	4.5
Sand, mostly fine. At top, 1 ft of fine sand and very fine sand, strongly ripple marked; then half a foot of clean medium sand, strongly ripple marked; then 2 ft of fine-medium sand, partly parallel-bedded, partly faintly ripple marked; at bottom, 1 ft of fine sand, parallel-bedded	4.5
Diastem, undulating contact with about 1 ft of relief in 50 ft.	
Silt, silty clay, and clay (grades finer downward), medium-gray; thin bedded becoming thinly parallel laminated and varvelike in lower half	2.0
Sand, medium, clean, unconsolidated; strongly ripple marked near top	2.0
Sand; medium, fine, and very fine sand alternating in thin parallel beds; poorly exposed	3.0
Base not reached.	
Total thickness Alpine Member	59.0
Total thickness Little Cottonwood Formation	85.0

9. Outwash and till of Bull Lake Glaciation interbedded with Bonneville and Alpine Members of Little Cottonwood Formation

[Gully exposure in bluff (probably an eroded fault scarp) about 300 ft east of Salt Lake City Water Purification Plant and 0.25 mile north of Little Cottonwood Creek. NE¼SE¼ sec. 2, T. 3 S., R. 1 E. Altitude top of section, 5,125 ft]

	Thickness (ft)
Loess of post-Draper age, bearing Midvale Soil:	
Loess; silt and fine sand, nonbedded. Upper 1± ft dark gray, rich in humic matter (A horizon); remainder yellowish brown (B horizon), grading lighter downward	4.0±
Disconformity, irregular erosion surface.	

9. Outwash and till of Bull Lake Glaciation interbedded with Bonneville and Alpine Members of Little Cottonwood Formation—Continued

	Thickness (ft)
Little Cottonwood Formation:	
Bonneville Member (lacustrine); in lower part perhaps intergrades with upper outwash of Bull Lake Glaciation:	
Silt, light-gray, distinctly to indistinctly thin bedded, 1–2 in. above base has 1–2-in. layer of silty grit-sand with some very small pebbles. Thickens eastward	1.0±
Pebble gravel with silt matrix, almost no sand; pebbles mostly less than 1 in. in diameter, but some as much as 5 in. in diameter. Thins abruptly eastward	1.5
Pebble gravel with some cobbles and sparse small boulders, as much as 1.5 ft in diameter; loose sandy matrix. This layer and the overlying pebble gravel lens out rapidly eastward (suggesting that they are part of a bar or spit) and are represented by the thickened silt unit at top of the Bonneville Member	2.0
Bonneville and (or) Alpine Members; probably mostly lacustrine, although partly alluvial (glacial outwash):	
Sand, medium, loose and clean, well-sorted; upper part contains sparse granules and very small pebbles	1.3
Gravel, cobble, in loose medium-sand matrix	.6
Sand, medium and coarse; some granules; loose	.5
Sand, medium, clean, loose	1.0
Sand, medium, pale-gray, with some admixed coarse sand and granules and a few interbeds of fine-pebble gravel	2.2
Sand, pebbly, medium-gravel; pebbles in upper part are mostly less than 1 in. in diameter, rarely more than 2 in. in diameter; lower three-fourths of thickness is less well sorted, with some larger pebbles and cobbles, rarely as much as 10–12 in. in diameter, and some silt, which acts as weak cement and gives light-gray color	11.0
Sand, very fine, very pale gray, nearly white, clean	.3
Sand; in upper part, clean and loose medium sand with some small pebbles; grades downward to loose coarse sand with some admixed granules and, in some beds, small pebbles	7.1
Gravel, sandy pebble; pebbles mostly smaller than 1.5 in. in diameter, rarely larger than 3 in. in diameter, some beds of fairly clean fine-pebble gravel in lower part	12.5
Diastem(?).	
Silt, pale-gray, coherent, thinly and evenly bedded	1.0

746-815 O-65—5

9. Outwash and till of Bull Lake Glaciation interbedded with Bonneville and Alpine Members of Little Cottonwood Formation —Continued

	Thickness (ft)
Disconformity.	
Lower till of Bull Lake Glaciation, or outwash alluvium or colluvium coeval with inter-Alpine–Bonneville-Provo lake recession:	
Boulder gravel, very poorly sorted—clay, sand, gravel, and boulders as much as 4 ft in diameter; boulders generally quite angular	3.0
Disconformity(?).	
Little Cottonwood Formation:	
Alpine Member (lacustrine):	
Silt and very fine sand, pale-gray	.7
Sand, medium, clean, loose; some beds have some coarse sand, granules, and a few very small pebbles	11.0
Base not exposed.	
Total exposed thickness	60.7±

NOTE.—About 400 ft south and 20 ft vertically below bottom of this section, a huge boulder (about 20 ft in diameter), which may represent an underlying unit of the lower till of the Bull Lake Glaciation, crops out in the bluff.

10. Upper and lower tills of Bull Lake Glaciation, interbedded with Bonneville and Alpine Members of Little Cottonwood Formation

[Exposed on bluff on north side of gorge of Little Cottonwood Creek about 1,100 ft dne south of Murray City Power Plant. SE¼SE¼ sec. 2, T. 3 S., R. 1 E.; altitude, top of section, about 5,140 ft]

	Thickness (ft)
Post-Lake Bonneville loess and colluvium:	
Sand, some silt and small pebbles, dark- to medium-brownish-gray; loessic slope wash, top eroded	1.0±
Disconformity.	
Little Cottonwood Formation:	
Bonneville Member (lacustrine):	
Pebble gravel, with much medium and coarse sand and grit in matrix; some cobbles, rarely as much as 6 in. in diameter; stones well rounded; thickens markedly to west and north. Bears Graniteville Soil (eroded), with a 3.5- 4-ft B horizon (irregular lower boundary) extending into next two underlying beds; upper part of B horizon, in this bed, is brown (about 7.5*YR* 5/4), slightly clayey, and structureless	2.0
Sand, pebbly; poorly sorted medium and coarse sand, grit, and small pebbles, rarely more than 1 in. in diameter, loose. Part of B horizon of Graniteville Soil in this bed is medium brown and has slight orange cast and is structureless	1.5
Sand, fine, light-yellow, clean and loose; some thin lenses of granule sand and fine pebbly sand in lower half	3.0
Sand, gravelly, poorly sorted, with pebbles, cobbles, and small boulders; increasingly coarser and more poorly sorted downward; gradational into underlying till	1.5
Upper till of Bull Lake Glaciation:	
Till, light-gray, compact, bouldery, very poorly sorted—clay to boulders, some more than 2 ft in diameter; assemblage typical of tills at mouth of Little Cottonwood Canyon; boulders mostly quartz monzonite. Lower contact poorly exposed	32.0±

10. Upper and lower tills of Bull Lake Glaciation, interbedded with Bonneville and Alpine Members of Little Cottonwood Formation—Continued

	Thickness (ft)
Diastem(?)	
Little Cottonwood Formation:	
Alpine Member (lacustrine):	
Gravel. Upper one-third is pebble gravel; pebbles generally less than 1 in. in diameter, but a few cobbles are as much as 8 in. in diameter; stones well rounded; fairly clean, loose (unindurated). Lower two-thirds is interbedded coarser pebble gravel and cobble gravel with some boulders as much as 1 ft in diameter; stones generally fairly well rounded; sorting decreases downward, and lower several feet rather poorly sorted. Bedding in whole unit dips 15°–20° WSW, similar to the slope of the lower contact on the underlying till; hence, this unit thickens markedly westward, and pinches out entirely within 100 ft eastward	15.0
Lower till of Bull Lake Glaciation:	
Till, bouldery, light-gray, compact; similar to the upper till but thicker. Thickens eastward; a few hundred feet to east this till is overlain by upper till, and the two tills are locally separated by several feet of slightly (lake or colluvial?) reworked material	38.0
Little Cottonwood Formation:	
Alpine Member (lacustrine), possibly with some coeval outwash:	
Boulder gravel, grading downward to cobble gravel; poorly sorted; stones subrounded to well rounded	3.0±
Sand, silty, and sandy silt; very poorly sorted; contains some granules and small pebbles; coherent	3.0
Base concealed.	
Total exposed thickness	100±

NOTE.—Bed of Little Cottonwood Creek is about 30 ft vertically below base of exposed section.

11. Little Cottonwood Formation overlying lower till and lower outwash of Bull Lake Glaciation, exposed on southwest side of valley of Little Cottonwood Creek opposite Murray City Power Plant

[Top of section, at an altitude of about 4,975 ft, is top of a narrow strath terrace of late Provo age; base of section is at ditch about 35 ft above bed of Little Cottonwood Creek. This section appears to be downfaulted with respect to the sequence exposed a short distance to the southeast. (See stratigraphic sections 10 and 12 and the geologic map.) NW¼ SE¼ sec. 2, T. 3 S., R. 1 E.]

	Thickness (ft)
Strath terrace of late Provo age:	
Gravel, coarse, bouldery (assemblage typical of Little Cottonwood Creek); bears Graniteville Soil (partly eroded)	1.5±
Diastem.	
Little Cottonwood Formation:	
Alpine Member (lacustrine):	
Silt, well-sorted, pale-gray	2.0
Sand, very fine, well-sorted, unindurated	3.0
Sand, medium, well-sorted, loose	5.0
Silt and fine to medium sand, thinly interbedded, light-gray to light-greenish-gray, evenly parallel bedded; local 0.5–1 ft lens of sandy pebble gravel in middle	4.0±
Pebble gravel, fairly well sorted	1.0–2.0

11. Little Cottonwood Formation overlying lower till and lower outwash of Bull Lake Glaciation, exposed on southwest side of valley of Little Cottonwood Creek opposite Murray City Power Plant—Continued

	Thickness (ft.)
Lower till and lower outwash of Bull Lake Glaciation:	
Gravel, coarse. In 200 ft of lateral exposure, grades from very poorly sorted clayey boulder gravel at upstream end—much clay and large proportion of angular to subrounded blocks, cobbles and boulders—to somewhat less poorly sorted (less clayey) cobble and small boulder gravel (maximum diameter, 18 in.) at downstream end with a large proportion of subrounded to well-rounded stones. Probably distal edge of moraine of early Bull Lake age, grading to outwash of similar age	18. 0±
Total thickness	35±

NOTE.—The steep valley wall below this section shows many boulders as much as 5 ft in diameter, apparently almost in place, which suggests that at least 20 ft of the lower till and outwash of the Bull Lake Glaciation underlies this section.

12. Bonneville and Alpine Members of Little Cottonwood Formation interbedded with upper and lower tills and outwash of Bull Lake Glaciation

[Exposed in bluff (eroded fault scarp) 0.12 mile south of Little Cottonwood Creek and 0.75 mile north of Granite Church, in SE¼SW¼ sec. 2, T. 3 S., R. 1 E.; top of section, altitude about 5,130 ft, about 5 ft below Bonneville shoreline (which here is indistinct owing to intergradation just east of this locality with outwash of a strath terrace that slopes to this shoreline)]

	Thickness (ft)	Depth (ft)
Little Cottonwood Formation:		
Bonneville Member (lacustrine):		
Gravel, pebble and cobble, well-rounded, well-bedded; sandy matrix; mostly quartz monzonite; some quartzite, hornfels, Mineral Fork Tillite, dolomite, limestone, and red Nugget(?) Sandstone	20	20
Gradational contact.		
Upper outwash of Bull Lake Glaciation:		
Gravel; pebble to small boulder, subrounded to subangular, poorly sorted; sandy matrix. Entirely quartz monzonite (with some rotten cobbles and pebbles), except for sparse pebbles of limestone, quartzite, and tillite. Thickness varies	3±	23±
Gradational contact.		
Upper till of Bull Lake Glaciation:		
Till, bouldery, very poorly sorted, nonbedded; angular to subangular blocks and boulders as much as 7 ft in diameter in a fairly abundant matrix of silt, arkosic sand, and gravel; wholly quartz monzonite; some rotten cobbles and pebbles. Poorly exposed	12	35±

12. Bonneville and Alpine Members of Little Cottonwood Formation interbedded with upper and lower tills and outwash of Bull Lake Glaciation—Continued

	Thickness (ft)	Depth (ft)
Diastem, poorly exposed.		
Little Cottonwood Formation:		
Alpine Member (lacustrine):		
Sand, gravelly sand, and gravel, interbedded. Upper one-third is mainly fine to medium sand with a few thin silt interbeds in uppermost part; well bedded; well sorted; loose; pale yellowish gray. Lower two-thirds is medium to coarse sand interbedded with pebbly sand and pebble gravel, grading downward to generally coarse (with local lenses of cobble gravel), more angular, more poorly sorted, and less well bedded sand. Mostly quartz monzonite; some rotten cobbles; a few pebbles of quartzite, tillite, and hornfels	20±	55±
Gradational contact, poorly exposed.		
Lower outwash of Bull Lake Glaciation:		
Gravel, cobble and boulder, generally rather poorly sorted, irregularly bedded; some boulders more than 1 ft in diameter; arkosic pebbly sand matrix; mostly quartz monzonite; some rotten cobbles; thickness varied	5±	60±
Contact poorly exposed.		
Lower till of Bull Lake Glaciation:		
Till, pale-gray, bouldery; unsorted boulders and blocks as much as 15 ft diameter in matrix of angular gravel, arkosic sand, and silt; nonbedded. Entirely quartz monzonite; some partially rotten cobbles. Poorly exposed	15±	75±
Gradational contact, poorly exposed.		
Lower outwash of Bull Lake Glaciation:		
Gravel, cobble, and small boulder, poorly sorted; arkosic pebbly sand matrix; irregularly bedded; nearly all quartz monzonite, some partially rotten cobbles. Poorly exposed	20±	95±
Base concealed.		

13. Alpine and Bonneville Members of Little Cottonwood Formation overlying lower outwash and lower till of Bull Lake Glaciation

[Gulch just west of a spit at Bonneville shoreline that spilled down north side of upper Dry Creek valley; 0.1 mile west of Dimple Dell Road, SE¼SW¼ sec. 11 T. 3 S., R. 1 E. Altitude, top of section, 5,100 ft]

	Thickness (ft)
Little Cottonwood Formation:	
Bonneville Member (lacustrine):	
Gravel, poorly exposed. Top 5± ft is pebble gravel; next 10± ft is pebble and cobble gravel with much sand; some cobbles as much as 10 in. in diameter. Thickens to 25 ft in spit just to east. Bears the Graniteville Soil, Noncalcic Brown soil facies	15±
Sand, pebbly, interbedded with coarse sand; white; loose; highly arkosic; grades finer downward	22

13. Alpine and Bonneville Members of Little Cottonwood Formation overlying lower outwash and lower till of Bull Lake Glaciation—Continued

	Thickness (ft)
Little Cottonwood Formation—Continued	
Bonneville Member (lacustrine)—Continued	
Sand, medium, loose, white	5
Diastem, sharp contact, probable erosion surface.	
Alpine Member (lacustrine):	
Sand, very fine, clean, pale-gray, thinly interbedded with silt, compact and hard; some calcium carbonate (soil lime?) concentration	2
Pebble gravel, poorly sorted, with much silt and sand; pebbles as much as 5 in. in diameter, many very rotten; interbedded with some poorly sorted coarse pebbly sand	3
Concealed	45
Silt; top several feet is laminated, almost varved, pale-gray to gray, hard silt with a few partings of very fine sand; grades downward to thick-bedded sandy (poorly sorted) silt	7
Lower outwash of Bull Lake Glaciation:	
Sand and gravel, poorly exposed except for several feet at top and bottom. At top, silty fine-medium compact pale-gray sand with rare small pebbles; grades coarser downward to sandy pebble gravel and fine-pebble gravel and some cobble gravel in lower part. Devoid of "displaced lithologies" (such as Mineral Fork Tillite) that might indicate derivation from Little Cottonwood Creek	11±
Lower till of Bull Lake Glaciation:	
Boulder gravel, coarse, very poorly sorted; boulders all quartz monzonite (of Little Cottonwood stock), as much as 6 ft in diameter; all sizes of finer material; poorly exposed to creek bed	40±
Total	150±

14. Lower tongue of Draper Formation disconformably overlying Little Cottonwood Formation

[North bluff of Dry Creek, 0.15 mile west of 700 East St., E½SE¼ sec. 7, T. 3 S., R. 1 E.; top of section, at an altitude of 4,520 ft, is top surface of a recessional delta of early Draper age. Composite section of several exposures—natural, in roadcuts, and in dug trenches. Base of section is about 10 ft above creekbed]

	Thickness (ft)
Draper Formation, lower tongue (lacustrine, deltaic):	
Sandy pebble gravel and pebbly sand, with some cobbles rarely as much as 6 in. in diameter; typical Dry Creek assemblage; poorly exposed. Pinches out a few hundred feet to west	8±
Coarse and medium sand, medium sand, and fine-pebbly coarse and medium sand, interbedded; white, loose (unconsolidated)	10±
Disconformity, surface recording subaerial erosion; slopes 3°–10° S.; apparently the former north side of the valley of Dry Creek of inter-Little Cottonwood-Draper age, which was somewhat shallower than the present valley.	

14. Lower tongue of Draper Formation disconformably overlying Little Cottonwood Formation—Continued

	Thickness (ft)
Little Cottonwood Formation (lacustrine) undifferentiated as to member:	
Sand, fine, white, micaceous, well-sorted and loose, with some thin (½–5-in. thick) interbeds of very fine, well-sorted, white to pale-gray sand and silt; parallel horizontal beds; variable in thickness owing to sloping surface of overlying disconformity. Bears eroded Graniteville Soil (Calcic Brown soil facies); in places nearly 4 ft of B horizon is preserved, underlain by 1½–2 ft of strong calcareous concentration (C_{ca} horizon)	5 (max)
Silt and some fine sand, thinly interbedded, pale-gray. Upper 1–2 ft is mostly silt, parallel-bedded. Next is a zone as much as 5 ft thick, mainly silt, with some partings of fine sand; two beds, each about 1½ ft thick, have strongly contorted bedding. Remaining strata have parallel horizontal bedding	7±
Silt, pale-gray, nearly white, with some to many fine sand partings; parallel horizontal bedded	4±
Sand, pale-gray, with some silt interbeds and partings; parallel horizontal bedded; poorly exposed	4±
Base concealed.	
Total exposed thickness	38±

15. Upper tongue of Draper Formation overlying Little Cottonwood Formation and alluvium of intra-Alpine age

[East bluff of inner valley of Jordan River, 0.3 mile southwest of mouth of Dry Creek; NW¼NE¼ sec. 11, T. 3 S., R. 1 W.; top of section, at an altitude of 4,370 ft, is crest of highest sand dunes on ridge between Jordan River and Dry Creek; base of section is about 6 ft above Jordan River]

	Thickness (ft)
Eolian sand of post-Draper age:	
Sand, fine, poorly consolidated to unconsolidated, very pale-brown to pale-gray. Two main generations, separated by the weak early Recent soil. Fairly abundant stone artifacts—many projectile-point flakes, manos, and cooking(?) stones	10.0±
Disconformity; irregular surface recording subaerial erosion.	
Draper Formation (lacustrine), upper tongue:	
Sand, fine, very pale brown to pale-gray; in lower 0.5–1 ft locally contains admixed grit and fine-pebbly coarse sand. Locally, bears weak to moderate soil-lime concentration in top 1–1.5 ft, which is the eroded C_{ca} horizon of the Midvale Soil	2.0–3.0
Diastem; surface recording subaerial erosion.	
Little Cottonwood Formation:	
Provo Member (lacustrine):	
Silt, pale-gray and pale-olive-gray, thin, parallel-bedded; essentially homogeneous top to bottom except for a few interbeds of clean very fine sand in top several feet	8.0

15. Upper tongue of Draper Formation overlying Little Cottonwood Formation and alluvium of intra-Alpine age—Continued

Thickness (ft)

Little Cottonwood Formation:

Provo and (or) Alpine Member (lacustrine):

Sand, fine, pale-yellow to pale-yellowish-gray; alternates with thin- to well-bedded, generally horizontal- and parallel-bedded gray silt and silty clay; some clay partings within the thicker sand beds are discontinuous, apparently broken. In detail, upper 2.0 ft is thinly interbedded fine sand, silt, and silty clay; next 0.6 ft is silty clay; then successively are 0.8 ft clean fine sand with broken 0.75-in. clay bed in middle part, 0.8 ft silty clay with some fine sand and silt partings, 0.15 ft clean fine sand, 0.15 ft interbedded silt and silty clay, 0.6 ft clean fine sand with broken silty clay interbed, 0.9 ft silty clay and some thin fine sand and silt interbeds, 0.8 ft clean fine sand, 0.8 ft thinly interbedded silt, fine sand, and silty clay, 0.5 ft clean fine sand, 0.8 ft interbedded silty clay and silt, and, at base, 0.6 ft clean fine sand 9.5

Diastem (possibly recording sublacustrine erosion).

Little Cottonwood Formation:

Probably Alpine Member:

Silty clay with some interbedded fine sand, well- to thin-bedded; bedding highly contorted throughout. This involute zone can be traced laterally for more than 0.1 mile and thins to 5–6 ft thick 500 ft to the southwest. It and all lower beds are strongly jointed (vertical joints in two principal directions). A few to sparse pebbles, commonly 1 to rarely 1.5 in. in diameter, are kneaded into the contorted strata. At base of zone is 1–1.5 ft of less contorted fine sand with some medium and coarse sand and grit 8.0

Diastem; undulating surface, with several feet of relief in 500 ft, that truncates underlying beds.

Clay, silty, thin- and horizontal-bedded 1.5

Sand, fine; grades downward to clean very fine sand; horizontal bedded 2.2

Silt, thin- and horizontal-bedded 2.2

Sand, fine, clean, with some interbedded silt and very fine sand in lower 1 ft 2.1

Silt, somewhat clayey in upper 1.5 ft, and somewhat sandy, with some very fine sand interbeds, in lower 2 ft 5.0

Sharp contact, possible diastem.

15. Upper tongue of Draper Formation overlying Little Cottonwood Formation and alluvium of intra-Alpine age—Continued

Thickness (ft)

Alluvial gravel of intra-Alpine age:

Gravel, cobble and pebble, subangular to well-rounded; largest cobble seen was 1.0 by 0.4 by 0.35 ft; stones are mainly grayish to white quartzite; some dark-gray to black chert, volcanics (andesitic(?) porphyries) and sericitized granitic rocks—typical of rocks exposed in mountains on both the western and eastern sides of lower Jordan Valley; all have rusty-brown limonitic coatings from ground-water deposition. Exposed for 400 ft laterally in bulldozer excavations made in 1959 .... 9.0

Little Cottonwood Formation:

Alpine Member:

Clay, medium-olive-gray, tough; thin parallel and horizontal beds 1.1

Base not exposed.

Total exposed maximum thickness 61.6

16. Strath-terrace gravel of Provo stillstand age overlying Bonneville and Alpine Members of Little Cottonwood Formation

[Exposed in small gully at west edge of broad strath terrace on eastern side of upper Dry Creek valley, N½NW¼ sec. 14, T. 3 S., R. 1 E. Top of section, at an altitude of 4,925+ ft, is at top of the strath terrace; base of section is the bed of an abandoned irrigation canal]

Thickness (ft)

Post-Little Cottonwood loess and colluvium:

Silty sand, somewhat pebbly; upper 0.9 ft is dark brownish gray (A horizon, partly eroded), grading browner and less gray downward; remainder is brown (7.5*YR* 5/4; B horizon of Graniteville Soil) .... 1.8±

Strath-terrace gravel of Provo stillstand age:

Gravel, cobble and boulder, well-rounded; sorting and sizes fairly uniform top to bottom; many cobbles 4–5 in. in diameter, some 8–10 in. in diameter, rarely 1 ft in diameter; matrix is pebbles of all sizes, grit, and sand (coarse to fine sand). Practically all quartz monzonite, a few percent of which are very rotten, especially in upper 2 ft. Bears lower part of B horizon of Graniteville Soil, as follows: Uppermost 0.4 ft is brown (7.4*YR* 5/4), structureless, and soft, with many rotten pebbles and cobbles; clear boundary; next 2.5 ft is light grayish brown, about 10*YR* 6/3; remainder is light gray 7.5

Diastem, somewhat irregular erosion surface.

Little Cottonwood Formation:

Bonneville(?) Member:

Sand; medium sand interbedded with coarse and medium sand and some granule sand; loose; unconsolidated. Beds generally parallel and horizontal, but lenticular in detail and locally crossbedded; ¼–½ in. thick. Silt parting 0.5 ft above base; lowermost 0.1 ft is somwhat lime cemented 3.5

Sand, fine, grading downward to very fine sand; pale gray; well sorted; thinly laminated 1.4

16. Strath-terrace gravel of Provo stillstand age overlying Bonneville and Alpine Members of Little Cottonwood Formation—Continued

	Thickness (ft)
Little Cottonwood Formation—Continued	
Bonneville (?) Member—Continued	
Sand, intermixed coarse, medium, and fine; some granules; well to poorly sorted; loose; parallel bedded	0. 7
Sand, very fine, and silt, interlaminated; pale-gray	. 1
Sand, interbedded coarse and medium, pale-gray	1. 6
Sand, interbedded coarse, medium, fine, and very fine sand	. 5
Sand, interbedded medium, coarse, and small pebbly coarse sand	. 8
Gravel, sandy pebble; pebbles fairly angular; rather poorly sorted; some pebbles more than 1 in. in diameter, rarely as much as 2 in. in diameter; all are granitic	2. 4
Sand, medium and coarse, with a few granules and a few very small pebbles, thinly interbedded	1. 0
Gravel, sandy, very fine pebble; pebbles mostly less than 0.5 in. in diameter, rarely 1 in. in diameter; much medium and coarse sand and granules; some interbeds of medium and coarse sand; mostly rather poorly bedded	2. 0
Sand, very fine, well-sorted, thinly laminated, pale-gray	. 2
Sand, pebbly; medium and coarse sand and granules with some pebbles as large as 0.5 in. in diameter	. 15
Sand, very fine, laminated, pale-gray	. 4
Sand, interbedded very fine, fine, medium, and coarse (some coarse sand beds have a few granules)	. 6
Alpine Member (probably intergrades with the lower outwash of the Bull Lake Glaciation):	
Gravel. Nearly all quartz monzonite; a few pebbles of schist, gneiss, and quartzite. Upper 3.5 ft is small-pebble gravel to pebbly-granule sand alternating with fine to coarse sand; next 2 ft is pebble gravel with a few cobbles as much as nearly 4 in. in diameter and a little sand in matrix; next 2 ft is interbedded medium to coarse sand and sandy fine-pebble gravel; next 4 ft is fine-pebble gravel with a few cobbles as much as 4 in. (rarely 5 in.) in diameter, and a few lens-shaped sand partings; next 2.5 ft is cobble gravel, poorly sorted, from fine sand to pebbles and cobbles of all sizes, rarely 10 in. in diameter. Bottom 4.5 ft is pebble gravel, poorly parallel and horizontal bedded; pebbles commonly more than 1 in. in diameter but rarely more than 3 in.; lower parts lime coated in some beds	18. 5
Base concealed.	
Total exposed thickness	43. 15±

17. Alpine and Bonneville Members of Little Cottonwood Formation

[Type section for this formation and reference section for Alpine Member. Western bluff of upper Dry Creek, exposed partly in cuts along an old road, and partly by dug pits and trenches; NW¼NW¼ sec. 14, T. 3 S., R. 1 E.; altitude, top of section, 5,075 ft]

	Thickness (ft)
Eolian sand of post-Draper age	25. 0 (max)
Disconformity; surface of subaerial erosion; poorly exposed.	
Little Cottonwood Formation:	
Bonneville Member (lacustrine):	
Sand, pebbly, unconsolidated, poorly exposed. (Graniteville Soil is here eroded, although preserved nearby)	3. 0±
Gravel, pebble and cobble; cobbles as much as 6 in. and rarely 7 in. in diameter; much quartz monzonite from the Little Cottonwood stock, a few pebbles of Mineral Fork Tillite and hornfels and quartzite typical of the Big Cottonwood Formation, Ankareh and Mutual Formations, rarely some Nugget Sandstone. Unconsolidated, fairly well exposed	8. 0±
Bonneville and (or) Alpine Member (lacustrine):	
Sand and pebbly sand, unconsolidated, poorly exposed	20. 0±
Gravel, cobble and pebble, similar to above, unconsolidated, moderately well to poorly exposed	16. 0±
Alpine Member (lacustrine):	
Sand, unconsolidated; upper 7 ft poorly exposed, apparently is somewhat pebbly sand; lower part, exposed by trenching, consists of 5 ft of well-sorted loose pale-gray medium sand underlain by 3 ft of pebbly sand (pebbles rarely as much as 3 in. in diameter), interbedded with medium sand, coarse and medium sand, and granule sand containing some small pebbles	15. 0±
Diastem (probably minor).	
Sand, very fine grained, pale-gray to white, well-sorted, homogeneous; loose except for 1.5–2-ft slightly cemented layer 1 ft above base; massive except lower 2–3 ft, which is well- to thin-bedded extremely fine sand	6. 7
Diastem, locally very irregular; joints and a few very minor faults in underlying beds terminate against this surface.	
Silt, some very fine sand, and a little silty clay, thinly interbedded, pale-gray to white; strata dip 10°–40° E and SE; many joints and some small faults (maximum displacement about 1 ft), downthrown on southwest	1. 5±
Minor diastem.	
Silt, very fine, sandy, massive, pale-gray. Thins to 0.5 ft thick 200 ft to north	2. 0±
Silty clay, silt, and a little very fine sand; thinly interbedded to interlaminated (locally almost varved); 200 ft to north, bedding is highly contorted (penecontemporaneous deformation). Jointed; some very small faults like above	1. 2

17. Alpine and Bonneville Members of Little Cottonwood Formation—Continued

	Thickness (ft)
Little Cottonwood Formation—Continued	
Alpine Member (lacustrine)—Continued	
Sand, very fine, white, well-sorted; 200 ft to north has lens-shaped partings of granule sand; coarse to medium sand at top and bottom	0.4
Silty clay, silt, and very fine sand, thinly interbedded	.3
Sand, medium, white, loose	.2
Sand, fine, poorly sorted, generally very silty, with some coarse sand, granules, and small pebbles; 0.75-in. parting of laminated silt and silty clay at base	1.5
Sand, nearly white; top 0.8 ft is fine and medium sand, clean and loose; next 4.2 ft is well-sorted loose medium sand; lower 3.5 ft is well-sorted loose fine sand	8.5±
Silt and very fine sand, thinly interbedded; locally cemented by calcium carbonate at top	.7
Sand, rather poorly sorted; mainly fine-medium sand, intermixed with some coarse sand, granules, and very small pebbles (one pebble 2 in. in diameter at base); slightly cemented	1.5
Sand, rather poorly sorted fine to coarse, with some pebbles; loose	2.0±
Gravel, cobble and pebble, poorly sorted, very silty, with some cobbles as much as 0.5 ft. in diameter; compact; pebbles are representative of the Little Cottonwood stock (quartz monzonite), Big Cottonwood Formation, Mineral Fork Tillite, Ankareh Formation, and rarely of Nugget Sandstone	10.0±
Sand, pebbly, grading finer and less pebbly downward; lower 5 ft is mainly medium sand with some coarse sand and granules	12.0±
Sand, very fine	1.0±
Silt, pale-gray, sandy; poorly sorted silt with all sizes of sand, some granules, and a few pebbles; hard; compact; massive	3.2
Sand, upper 3 ft is coarse and medium sand with some granules and a few very small pebbles; remainder is poorly exposed, seems to be somewhat more pebbly sand	10.0±
Base concealed.	
Total exposed thickness of Little Cottonwood Formation	124.7±

18. South bank of Dry Creek and side of Dry Creek valley, NW¼SE¼ sec. 15, T. 3 S., R. 1 E.

[Top of section is tread of strath terrace of Provo stillstand age, at an altitude of about 4,850 ft; base of section is bed of Dry Creek, at an altitude of about 4,765 ft. Composite of two exposures: an upper one in cut of an old road, and a lower one in south bank of Dry Creek. Lower exposure is the type locality of the Dimple Dell Soil; a 37-ft concealed zone separates the exposures]

	Thickness (ft)	Depth (ft)
Strath-terrace gravel of Provo stillstand age:		
Cobble gravel, mainly granitic cobbles and pebbles, well-rounded; bears Graniteville Soil, Noncalcic Brown soil facies. Poorly exposed except for lower 2 ft	8.0±	8.0±

18. South bank of Dry Creek and side of Dry Creek valley, NW¼SE¼ sec. 15, T. 3 S., R. 1 E.—Continued

	Thickness (ft)	Depth (ft)
Disconformity, erosion surface.		
Little Cottonwood Formation:		
Alpine Member (lacustrine):		
Silt and fine sand, interbedded; silt is laminated, varvelike	0.7	8.7±
Silt, laminated (much is varvelike), grading downward to interlaminated silty clay and clay; at base, 1 ft of silt and silty clay thinly interbedded with clean fine and very fine sand	8.0	16.7±
Sand, fine, grading downward to medium and fine sand with some coarse sand and grit	3.0	19.7±
Concealed; appears to be mainly sand	37.0±	56.7±
Sand; rather poorly sorted irregularly bedded fine, medium, coarse, and granule sand, some with small pebbles mostly less than 0.5 in. in diameter; a few thin gravelly sand lenses with some pebbles as much as 1 in. in diameter; many thin partings of clean fine-medium sand; highly granitic; loose	10.0±	66.7±
Silt and fine sand, interbedded, thin-bedded to laminated. Upper 1 ft is off-white clean loose fine sand; next 0.1–0.2 ft is clean very fine sand; then 0.7 ft of interbedded clean fine and very fine sand; next 0.7–1.2 ft of laminated silty clay, clayey silt, and silt with irregular lower contact; then 1.5–2.5 ft of clean white medium sand with contorted bedding and some curving partings of silty clay, silt, and very fine sand. Approximately horizontal bottom contact	3.3	70.0±
Sand, loose. Upper 1.7± ft is coarse and medium sand, locally with some granules; dips 5°–20° E.; lower 1.3± ft is pale-gray clean fine-medium horizontally bedded sand	3.0	73.0±
Silt and very fine sand, thinly interbedded, parallel-bedded, clean, pale-gray, soft	.6	73.6±
Sand, rusty-orange, medium and coarse, with some granules and sparse small pebbles; loose	.1±	73.7±
Sand, silty, and sandy silt, very poorly sorted, with some granules and sparse small pebbles; yellow (about 10*YR* 7/6) to very pale brown (about 10*YR* 7/3); coherent (hard); calcium carbonate cementation; strong horizontal platy structure; probably lacustrine (reworked from underlying soil), but possibly colluvium	.5±.2	74.2±

18. South bank of Dry Creek and side of Dry Creek valley, NW¼SE¼ sec. 15, T. 3 S., R 1 E.—Continued

	Thickness (ft)	Depth (ft)
Disconformity, undulating contact with 5 in. of local relief in 20 ft of exposure.		
Dimple Dell Soil (Calcic Brown soil facies), developed on pre-Lake Bonneville colluvium or alluvium:		
B horizon (B_3 subhorizon): very poorly sorted sandy silt (sandy loam) with a few small pebbles (rarely more than 1 in. in diameter); brown (about 10*YR* 5/3, pale brown (10*YR* 6/3), light brown gray (10*YR* 6/2), to light gray (10*YR* 7/2), grading lighter downward. Noncalcareous except in lowermost 0.1 ft. Structure in main part of horizon is strong medium prismatic and coarse angular blocky; structure dies out rapidly in upper 0.15 ft and in lower 0.1 ft	0. 7±. 15	74. 9±
Clear to gradual boundary.		
C_{ca} horizon: Upper 2.0±0.3 ft is white, extremely hard, very strong caliche impregnating very poorly sorted slightly pebbly sandy silt and silty sand. Massive in uppermost 0.3± ft; remainder of upper part has weak to strong platy structure. Lower 2.2± ft has irregular calcareous carbonate (caliche) concentration, with rectilinear white zones of greatest concentration along vertical partings and horizontal bedding planes, irregularly interspersed with pale-brown to light-gray interstitial masses having only moderate to weak lime concentration. Parent material is poorly sorted pebbly silty sand, changing gradually in lower 1.5 ft to better sorted pebbly sand. Lower boundary of C_{ca} horizon is diffuse, highly irregular, and locally broken	4. 2±. 4	79. 1±
Pre-Lake Bonneville fan gravel (and (or) lacustrine gravel):		
Pebble gravel, well-sorted to moderately sorted, with little to abundant medium-, coarse-, and granule-sand matrix; pebbles mostly less than 4 in. in diameter; rare cobbles as much as 8 in. in diameter. Some interbedded lenses of clean medium sand, coarse sand, fine-pebbly sand, and granule sand; also one bed of very fine pebble gravel, very well sorted. Loose; all pebbles are well rounded; most pebbles of quartz monzonite of the Little Cottonwood stock, but about 10 percent are quartzite, hornfels, quartz- and quartz-mica schist and gneiss, and tillite, from the Precambrian sedimentary units	5. 5	84. 6±

19. *Bonneville and Alpine Members of Little Cottonwood Formation*

[North bluff of Dry Creek valley, SE¼NW¼ sec. 15, T. 3 S., R. 1 E.; top of section, at an altitude of 4,940 ft, is at crest of sand dune veneering top surface of Cottonwood delta. Base of section is about 25 ft above top of a small hill (at an altitude of about 4,845 ft and about halfway between base of section and Dry Creek) that is an erosional remnant of a strath terrace of late Graniteville age bearing a local veneer, several feet thick, of lake sand and gravel of lower tongue of Draper Formation]

	Thickness (ft)
Eolian sand of post-Draper age:	
Sand, medium and fine-medium, very pale brown, generally unconsolidated; upper part devoid of soil development, but about 3 ft above base is eroded Midvale Soil, 0.5–1 ft thick	15 (max)
Disconformity; irregular surface recording subaerial erosion.	
Little Cottonwood Formation:	
Bonneville Member (lacustrine):	
Gravel, pebble, and pebbly sand; upper several feet is pebble gravel with variable amounts of sand and some cobbles as much as 8 in. in diameter; well graded; lithologies include Mineral Fork Tillite, Ankareh, and Mutual Formations, Big Cottonwood Formation, and Nugget Sandstone. Upper 1.5± ft shows moderate to strong lime concentration on lower halves of pebbles—probably the (eroded) C_{ca} horizon of Graniteville Soil. Grades downward to unconsolidated pebbly sand and has 1–2 ft of clean pebbly granule sand at base	8
Sand and some silt, thinly interbedded, parallel-bedded, well-sorted. At top 0.6 ft of clean pale-yellow very fine sand; next, 0.3 ft of silt, grading downward to silty clay; then 0.6 ft of fine sand, grading downward to small-pebbly fine-medium sand; then 0.2 ft of pale-gray clean very fine sand; then 0.4 ft of pale-yellowish-gray fine sand; then 0.8 ft of light-gray clean very fine sand, grading downward to silt; then 1.8 ft of light-yellow micaceous clean and loose fine sand; then 0.6 ft of pale-gray clean very fine sand, grading downward to silt; then 0.1 ft of clean and loose light-yellow fine sand; next, 0.2 ft of very fine sand, grading downward to silt and to silty sandy clay; then, at base, 0.25–0.5-in. parting of hard lacustrine limestone	7. 6
Bonneville and (or) Alpine Member (lacustrine):	
Sand; top 0.4 ft is slightly silty and clayey medium sand with some small pebbles; next 1 ft is mostly medium sand with some coarse sand, granules, and small pebbles as much as 1 in. in diameter; grades more pebbly downward; lowermost 1 ft is pebbly coarse sand and pebbly grit	2. 5
Gravel, sandy pebble, loose, pale-yellow; pebbles rarely more than 3 in. in diameter; much medium sand and some coarse sand in matrix	2. 5
Alpine Member:	
Sand, fine-pebbly coarse and medium, clean, loose, light-yellow	2. 3
Sand, fine, clean, loose, light-yellowish-gray	2. 5
Silt, light-gray, thin-bedded; grades to mainly silty clay in lower one-third	4. 0

19. Bonneville and Alpine Members of Little Cottonwood Formation—Continued

	Thickness (ft)
Little Cottonwood Formation—Continued	
Alpine Member—Continued	
Sand, light-gray, very fine, with a few interbeds of silty very fine sand and of silt	4.8
Silt, light-gray, grades downward to silty very fine sand; very saline	1.5
Sand, light-gray, medium, silty and slightly clayey (very poorly sorted)	1.0
Slight diastem (due to wave reworking?).	
Sand, coarse, loose, clean; upper part has much grit and a few very small pebbles, rarely more than 0.75 in. in diameter; middle part is somewhat more pebbly; lower 1 ft is mostly medium sand with some coarse sand and granules	3.3
Sand, fine, very fine sand, silty very fine sand, silt, and some silty clay, all thinly interbedded	4.5
Sand, medium, with some coarse sand and granules and a few small pebbles; loose	2.5
Sand, fine; interbedded with very fine sand and two partings of silt	6.0
Sand, fine, with some interbedded medium and coarse sand (intermixed)	3.0
Silt, grading downward to silt and silty clay; thinly interbedded	1.5
Base concealed.	
Total exposed thickness Little Cottonwood Formation	57.5
Total exposed thickness	72.5

20. Lower tongue of Draper Formation, alluvium of middle-Lake Bonneville age, and Alpine Member of Little Cottonwood Formation

[North bank of Dry Creek near tip of spur projecting southward into the Recent inner trench of this creek in the NE¼ sec. 16, T. 3 S., R. 1 E. Top of section, at an altitude of about 4,660 ft, is the end depositional surface on the lower tongue of the Draper Formation, which here slopes (toward axis of valley) about 3° S. Base of section is about 5 ft above creekbed]

	Thickness (ft)	Depth (ft)
Draper Formation, lower tongue:		
Sand, silty and somewhat pebbly (pebbles nearly all less than 1 in. in diameter). Bears the Midvale Soil, whose profile is as follows: upper 0.4 ft, A horizon, is dark gray to medium gray, is loose to soft, and has abrupt boundary; next 0.6 ft, B horizon, is gray-brown to brown (10*YR* 5/2 to 10*YR* 5/3), is soft, and has gradual boundary; next 0.9 ft ±1 ft, C_{ca} horizon (lower 0.3± ft is in next underlying bed), is light gray, slightly calcareous, and loose to soft	1.6	1.6
Gravel, pebble; pebbles as much as 4 in. in diameter; some silty sand matrix	.4	2.0
Sand, pale-yellowish-gray, fine-medium, somewhat silty	.7	2.7
Disconformity, erosion surface sloping 4°–5° S. (toward valley axis).		

20. Lower tongue of Draper Formation, alluvium of middle-Lake Bonneville age, and Alpine Member of Little Cottonwood Formation—Continued

	Thickness (ft)	Depth (ft)
Alluvium of middle-Lake Bonneville (inter-Draper-Little Cottonwood) age, bearing eroded Graniteville Soil:		
Sand, white fine, silty and somewhat pebbly, with a little coarse sand and grit; pebbles as much as about 1 in. in diameter; hard to slightly hard; massive; strongly calcareous; C_{ca} horizon of the Graniteville Soil (which here is partly eroded); clear lower boundary	3.0	5.7
Sand, pale-yellow; fine, medium, and coarse sand, with variable amounts of grit, interbedded with local lenses of pebble gravel; grades to wholly pebble gravel and thins to 2.5 ft at tip of spur, 50 ft to south	4.0	9.7
Gravel, cobble and pebble; cobbles as much as 8 in. in diameter; some lens-shaped partings of sand and pebbly sand; varicolored, partly light gray, partly bright orange-yellow (ground-water limonitic staining). Thins to about 2.5 ft at tip of spur, 50 ft to south	3.5	13.2
Disconformity, erosion surface sloping southward several degrees.		
Little Cottonwood Formation:		
Alpine Member:		
Silt, pale-gray to light-olive-gray, thinly parallel bedded, with some interbedded silty clay, fine sand, and very fine sand	9.0	22.2
Sand, fine, light-yellowish-gray, clean	2.5	24.7
Sand, fine, with some silt partings 0.5–1.5 in. thick	1.0	25.7
Base concealed.		

21. *Alpine and Bonneville Members of Little Cottonwood Formation, just below highest shireline of Alpine age*

[West bank of gully, in NE¼NW¼ sec. 23, T. 3 S., R. 1 E., 0.1 mile northwest of Draper Irrigation Co. ditch; altitude, top of section, about 5,110 ft. Exposure is just east of (on shoreward side of) a big high-level gravel bar of the Alpine Member, which is overlain by a few feet of Bonneville Member]

	Thickness (ft)
Little Cottonwood Formation (lacustrine):	
Bonneville Member:	
Sand, pebbly fine-medium to coarse, with some pebbles, mostly less than 1 in. in diameter, rarely as much as 2 in. in diameter. Bears Graniteville Soil	6.0
Bonneville and (or) Alpine Member:	
Gravel, sandy; upper 2± ft is pebble gravel and pebbly sand, with few pebbles larger than 1.5 in. in diameter; maximum, 4 in. in diameter. Next 3.5± is somewhat coarser gravel, with sparse cobbles as much as 8 in. in diameter. Bottom 2± ft is pebbly sand and sandy gravel like top part	7.0
Alpine Member:	
Sand, medium, very clean (well-sorted), loose, white; homogeneous throughout; essentially nonbedded	23.0

21. Alpine and Bonneville Members of Little Cottonwood Formation, just below highest shoreline of Alpine age—Continued

	Thickness (ft)
Alpine Member—Continued	
Possible small diastem, sloping about 2° N. Silt, medium-gray; thinly interbedded with white fine sand	0.6
Granule sand, poorly sorted, silty and pebbly (pebbles rarely as much as 2 in. in diameter)	.2
Granule sand, very well sorted; most particles between 2 and 10 mm in diameter; almost no fine or medium sand nor pebbles; some coarse sand. Upper 1.5 ft has a little silt and is somewhat coherent, but lower 2.5 ft lacks silt and is loose	4.0
Gravel, fine-pebble; pebbles mostly less than 1 in. in diameter, rarely as much as 2 in. in diameter; fine sand matrix at base	1.5
Granule sand, fine-pebbly; mostly granules; some small pebbles, mostly less than 1 in. in diameter; some stringers of sandy fine pebble gravel; well sorted; loose; little fine sand or silt	5.0
Base concealed.	
Total exposed thickness	47.3

NOTE—Throughout the section the pebbles, although mostly quartz monzonite (of Little Cottonwood stock), include many rock types "displaced" from drainage areas a few miles to north, such as those typical of the Mineral Fork Tillite, Big Cottonwood Formation, Ankareh and Mutual Formations, and, rarely, Nugget Sandstone.

22. Upper tongue of Draper Formation overlying Little Cottonwood Formation

[East bluff of inner valley of Jordan River, about 0.5 mile southwest of mouth of Willow Creek, SE¼NE¼ sec. 23, T. 3 S., R. 1 W. Composite section. Eastern (higher) part is trenched natural exposure on bluff above (east of) the Galena (irrigation) Canal; top is within a few feet of highest part of ridge between Willow Creek and Jordan River, at an altitude of about 4,395 ft, and base is 1 ft below water level in this canal. Western part is about 300 ft southwest of the eastern part, at tip of a narrow spur that juts west of the canal; its top is 8 ft above water level in canal, and its base is 2.5 ft above water level in Jordan River. All strata are parallel and horizontally bedded unless otherwise noted]

Eastern part

	Thickness (ft)
Draper Formation, upper tongue:	
Sand, pale-yellow to light-yellowish-gray, fine, clean to somewhat silty, with sparse small pebbles, rarely as much as 1 in. in diameter; indistinctly bedded	6.0±
Disconformity; probable erosion surface.	
Little Cottonwood Formation:	
Alpine and Provo Members, undivided:	
Silt, alternating with fine sand and very fine sand; thin-bedded	1.5
Sand, pale-yellow, fine, clean, thin parallel-bedded	4.5
Silt, light-gray to light-brownish-gray, clayey, and silty clay; thinly laminated	.5
Sand, light-yellow, fine, clean, thin parallel-bedded	1.2
Sand, light-gray, silty, fine	.2
Clay, silty, alternating with clean silt and some clean very fine sand; thin-bedded	.5
Sand, very fine, clean; bottom sharply truncates the contorted zone below	.3

22. Upper tongue of Draper Formation overlying Little Cottonwood Formation—Continued

	Thickness (ft)
Little Cottonwood Formation—Continued	
Alpine and Provo Members, undivided—Continued	
Diastem.	
Silt, clayey, with 0.6-in. lens of clean very fine sand 0.4 ft below top; lower part has contorted bedding and some entrapped curving clean medium sand partings; sparse pebbles as much as 0.75 in. in diameter disseminated mainly in the silt	1.4
Sand, light-yellow, fine-medium, clean	1.0
Diastem.	
Sand, fine-medium, clean; thinly interbedded with clayey silt and silty clay; broken curving strata (contorted bedding), with irregular top and bottom boundaries	.6
Sand, fine-medium, clean	.45
Clay, silty; in 0.5–2.5-in. strata, with partings of clean very fine sand	.55
Sand, fine, clean	.3
Clay, light-gray, silty	.2
Sand, light-grayish-yellow, very fine, clean	.3
Diastem.	
Sand; fine light-yellow sand in top 0.3–1.0 ft; remainder is white to pale-yellow clean fine sand interbedded with about equal proportion of clayey silt and silty clay beds, generally several inches thick, highly contorted	3.2
Silt, light-brownish-gray, thin parallel-bedded	1.6
Sand, light-yellow, fine, clean; locally has inclined bedding	.2
Silt and fine sandy silt; some thin interbeds of clean fine sand	1.5
Clay, silty	.05

Western part

	Thickness (ft)
Sand, light-yellow, very fine, clean; grades downward to clean fine sand	1.05
Clay, silty	.1
Sand, pale-yellow, fine-medium, clean; local lime-cemented parting at base	.1
Clay, silty	.6
Clay, silty, interbedded with silt and very fine sand	.4
Clay, silty, and clayey silt; thick to thin parallel-bedded; homogeneous. Base of exposure is 1 ft below water level in canal	7.0
Total exposed thickness of Little Cottonwood Formation	29.3
Total exposed thickness	35.3±

NOTE.—The fine sand beds seen in the lower 9 ft of the eastern part of the section (the amount of overlap between the eastern and western parts) are absent in the western part.

	Thickness (ft)
Little Cottonwood Formation:	
Alpine and Provo Members, undivided:	
Clay and silty clay, medium-gray (5*Y* 5/1), and a little interbedded, thin-bedded tough silt; local rusty-brown stains along bedding planes	4.0

22. Upper tongue of Draper Formation overlying Little Cottonwood Formation—Continued

	Thickness (ft)
Little Cottonwood Formation—Continued	
Alpine and Provo Members, undivided—Continued	
Silt, pale-yellow (2.5*Y* 7/4), thin-bedded	2.7
Silt, light-gray (about 5*Y* 7/2), laminated; variegated with rusty-brown streaks	2.4
Clay and silty clay, somewhat variegated gray (5*Y* 6/2 to 5*Y* 4/1), thin-bedded, homogeneous, tough	1.75
Sand, fine, clean, light-gray (2.5*Y* 7/2), homogeneous	2.1
Silt, light-brown-gray (2.5*Y* 6/2), thin-bedded	.7
Silt, clayey, silty clay, and some silt; thinly interbedded; light gray (2.5*Y* 7/2) to light brown gray (10*YR* 6/2)	1.45
Sand, very fine, silty; some interbedded very fine sand, fine sandy silt, and silt; thin-bedded; pale olive (5*Y* 6/3) to pale-yellow (5*Y* 8/3)	15.3
Clay and silty clay, thinly interbedded, olive-gray (5*Y* 4/2) to dark-gray (5*Y* 4/1), tough. Base of exposure is 2.5 ft above water level in Jordan River	1.0
Total exposed thickness of Little Cottonwood Formation in western part of section	31.4
Total exposed thickness of Little Cottonwood Formation, in both eastern and western parts	51.7

23. Upper tongue of Draper Formation, disconformably overlying Little Cottonwood Formation

[East bluff of inner valley of the Jordan River, NW¼SE¼ sec. 2, T. 4 S., R. 1 W (just south of area shown on pl. 2). Altitude, top of section, 4,420 ft; base is about 15 ft above Jordan River]

	Thickness (ft)
Draper Formation, upper tongue (lacustrine, deltaic):	
Sand, fine, well-sorted; bears the Midvale Soil as follows: upper 0.5 ft, humic (A) horizon, is gray (about 10*YR* 5/1 to 10*YR* 6/1) loose to soft single-grained sand; next 0.3 ft is transitional light-brownish-gray (about 10*YR* 6/2) loose and single-grained sand; next 1.3–1.6 ft is calcareous (C_{ca}) horizon, showing moderate calcium carbonate concentration, and is slightly hard to soft, massive, and white to light gray (10*YR* 8/1 to 10*YR* 7/1). Remainder of this bed is "parent material" below the soil: clean light-gray (10*YR* 7/1) fairly loose fine sand	4.2
Disconformity; somewhat irregular erosion surface.	
Little Cottonwood Formation:	
Alpine and Provo Members, undivided (lacustrine):	
Silt, well- to thin-bedded, with some silty clay and clayey silt partings and interbeds in lower part; gray; poorly consolidated	9±
Clay, silty, and clayey silt; thinly interbedded with fine-medium to very fine sand. Proportion of clay beds gradually increases downward; lower 10 ft is mainly clay. Lower 20 ft is poorly exposed	32±
Base concealed.	
Total exposed thickness	45.2

SOIL-PROFILE SECTIONS

(See p. 6 for discussion of descriptive nomenclature. Location of sections shown on pl. 2)

S–1. Midvale Soil, Calcic Brown soil facies, on lower tongue of the Draper Formation

[Cellar excavation (open Oct. 18, 1959) about 0.15 mile west of 2000 East St. and 200 feet south of 7200 South St., NE¼NE¼ sec. 28, T. 2 S., R. 1 E.; altitude, 4,520 ft]

Soil horizon	Depth (ft)	Thickness (ft)	
A	0–0.45	0.45	Loam, sandy; mainly medium sand to silt with a little coarse sand and grit; dark gray (10*YR* 4/1.5); soft to slightly hard; weak medium crumb to single grained.
B_1	0.45–1.05	.6	Loam, sandy; like above but grayish brown (10*YR* 5/2); upper 0.1 ft slightly hard and moderate medium crumb; lower 0.5 ft hard, very fine to medium subangular blocky. (Transitional between A and B horizons.)
B	1.05–2.0	.95	Loam, sandy; like above but pale brown (10*YR* 6/3); hard to slightly hard; fine to coarse subangular blocky; lime free.
B_3	2.0–2.8	.8	Sand, loamy; mainly medium and fine sand; some coarse sand, grit, and silt; a few pebbles as much as about 0.5 in. in diameter; pale brown (about 10*YR* 6/3); slightly calcareous (very slight effervescence with HCl); slightly hard; fine to coarse subangular blocky.
B_3	2.8–3.0	.2	Sand; mainly coarse and medium sand and grit; some fine sand and pebbles as much as 0.5 in. in diameter; pale brown; slightly calcareous; soft to slightly hard; fine to coarse subangular blocky.
C_{ca}	3.0–3.4	.4	Sand, pebbly; like above but with a few pebbles, max. 1.5 in. in diameter; light gray (10*YR* 7/2) to pale brown (10*YR* 6/3); loose; single grained; somewhat calcareous: some effervescence with HCl and lower parts of pebbles have very thin white lime coatings.
C	3.4–4.0	.6	Sand, pebbly; like above, light-gray (about 10*YR* 7/2); loose; single grained; noncalcareous.

S–2. *Midvale Soil, Noncalcic Brown soil facies, on post-Draper eolian sand*

[Sand pit just east of 2000 East St. and 0.25 mile north of Reynolds gravel pit, NW¼SW¼ sec. 27, T. 2 S., R. 1 E; altitude, about 4,680 ft. Illustrates minimum development of this soil]

Soil horizon	Depth (ft)	Thickness (ft)	
A	0–1. 3	1. 3	Sand, mainly medium and fine, with a little coarse sand and silt (slightly loamy); dark grayish brown (about 10*YR* 4/2); very soft; single grained. Top of horizon appears slightly eroded.
A_3	1. 3–1. 7	. 4	Sand, mainly medium to very fine, with a little coarse sand; dark grayish brown (about 10*YR* 4.5/2); loose; single grained. Transitional into B horizon.
B	1. 7–2. 5	. 8	Sand, like above, grayish brown (10*YR* 5/2 to 5/2.5), loose, single grained.
B_3	2. 5–2. 7	. 2	Sand, like above, pale-brown (10*YR* 6/3), loose, single grained.
C	2. 7–4. 3	1. 6	Sand, like above, light-gray (about 10*YR* 7/2), slightly hard to almost loose (slightly indurated), noncalcareous (no effervescence with dilute HCl); very weak granular to single grained.
C	4. 3–4. 8	. 5	Sand, like above, light-gray (about 10*YR* 7/2), loose, single grained.

S–3. *Early Recent soil on strath terrace gravel of early Recent age*

[Roadcut at terrace scarp at south edge of flood plain of Little Cottonwood Creek, at intersection of Creek and Danish Roads; near NE cor. SE¼ sec. 34, T. 2 S., R. 1 E; altitude 4,680 ft. A–C type profile (lacks B horizon)]

Soil horizon	Depth (ft)	Thickness (ft)	
A	0–	0. 3	Sand, loamy pebbly, very dark gray to dark-gray (10*YR* 4/1 and slightly darker), loose, single grained.
A	0. 3–0. 7	. 4	Sand, loamy; mainly fine to coarse sand with some silt, grit, and small pebbles, mostly less than 1.5 in. in diameter; dark grayish brown (about 10*YR* 3.5/2); loose; single grained.
A	0. 7–1. 0	. 3	Sand, loamy; like above but dark-gray (about 10*YR* 4/1); loose; single grained.
A_3	1. 0–1. 15	. 15	Gravel, sandy; mainly fine to coarse sand and grit and pebbles of all sizes, some cobbles and small boulders. Gray (about 10*YR* 5/1.5); loose; single grained; noncalcareous.
C	1. 15–1. 9	. 75	Gravel, sandy; like above but light brownish gray to light-gray (10*YR* 6/2 to 10*YR* 7/2); loose; single grained; noncalcareous.

S–4. *Midvale Soil, Noncalcic Brown soil facies, on strath terrace gravel of Little Cottonwood Creek coeval with middle tongue of Draper Formation*

[Cellar excavation near entrance of Willow Creek Country Club NE¼SE¼ sec. 34, T. 2 S., R. 1 E; altitude, about 4,690 ft]

Soil horizon	Depth (ft)	Thickness (ft)	
A	0–0. 7	0. 7	Gravel, loamy; sand and gravel, all sizes, to boulders as much as 1 ft in diameter; somewhat silty; dark grayish brown (10*YR* 4/2), soft and single grained in upper part; slightly hard, very weak granular to single grained in lower 0.2 ft.
B	. 7–1. 2	. 5	Gravel, loamy; like above but somewhat more silty and more brown (10*YR* 4.5/3); hard; moderate medium to coarse subangular blocky. Many pebbles and cobbles (quartz monzonite) are very rotten.
B	1. 2–2. 2	1. 0	Gravel, like above but with only a little silt and very fine sand; dark-brown (about 10*YR* 3.5/3); soft to loose; single grained. Many rotten roundstones; noncalcareous.
C	2. 2–3. 0	. 8	Gravel, pebbly, to small boulders, with little interstitial sand, almost no silt; brown (about 10*YR* 5/3); loose single grained; noncalcareous.

S–5. *Dimple Dell Soil, Noncalcic Brown soil facies, developed on pre-Lake Bonneville colluvium* (*slope wash*)

[Exposed by dug pit on gently sloping ridge crest 600 ft east of North Little Cottonwood Canyon road, SE¼SW¼ sec. 1, T. 3 S., R. 1 E.; altitude about 5,450 ft]

Soil horizon	Depth (ft)	Thickness (ft)	
A	0–0. 4	0. 4	Loam, clayey and somewhat stony, dark-reddish-gray to reddish-gray (about 5*YR* 4/2 to 5*YR* 5/2). Slightly hard to hard, weak to moderate granular. (Younger than the Dimple Dell Soil and not properly part of its profile.)
B_2	. 4–4. 4	4. 0	Loam, upper 2 ft is clay, stony, reddish brown (5*YR* 5/4, 5*YR* 4/3, 5*YR* 4/4), very hard, strong coarse angular blocky to strong medium and coarse granular. Stones are angular fragments of quartzite and hornfels of Big Cottonwood Formation (derived from directly upslope). Lower 2 ft is loam and clay, very stony. Color like above at top, grading downward to somewhat lighter and less red; brown (about 7.5*YR* 5/4) in lower 1.5 ft. Also grades downward to somewhat less clayey and less hard; structure strong medium angular blocky to strong medium and coarse granular. Noncalcareous.
B_3	4. 4–6. 5	2. 6	Loam, very stony. Brown to light brown, grading lighter downward, and also less clayey, more stony, and weaker in structure. Noncalcareous. Indefinite lower boundary.

NOTE.—Cuts of a fire-prevention road, made in 1961 up this ridge, expose as much as 5 ft of B_2 subhorizon of this soil over as much as 5 feet of B_3 subhorizon, developed on pre-Lake Bonneville colluvium similar to that in the above soil pit.

S–6. Graniteville Soil, Noncalcic Brown soil facies, on upper till of Bull Lake Glaciation

[Exposed in pit 100 ft south of Little Cottonwood road, at east edge of Granite (village), about 400 ft west of intersection with Wasatch Blvd. NE¼ sec. 11, T. 3 S., R. 1 E.; altitude, 5,180 ft]

Soil horizon	*Depth (ft)*	*Thickness (ft)*	
A	0–0. 7	0. 7	Loam, sandy, somewhat stony; like below, brownish-gray grading downward to dark grayish-brown (about 10*YR*4/2). Top of horizon probably eroded. Colluvially reworked till, probably with loessic increment.
			Gradual boundary.
B	. 7–2. 5+	1. 8+	Loam, sandy, somewhat stony. Some small pebbles and rock fragments, mostly less than 2 in. in diameter; some boulders ranging to more than 1 ft in diameter; mostly fresh quartz monzonite, sparse smaller fragments of weathered quartz monzonite. Brown (about 10*YR* 4/3). Massive; structureless; single grained; slightly hard to hard. Uniform color and texture top to bottom. Base of B horizon not reached—hole bottomed on large boulder.

NOTE.—Roadcut exposures in vicinity indicate that total thickness of the B horizon is 3½–4 ft, and that horizon grades to lighter brown in lower part.

S–7. Midvale Soil, Noncalcic Brown, soil facies on deltaic alluvial gravel of early Draper age

[Cellar excavation 0.1 mile north of Dry Creek and 0.6 mile east of 700 East St., SW¼SE¼ sec. 8, T. 3 S., R. 1 E.; altitude, 4,590 ft]

Soil horizon	*Depth (ft)*	*Thickness (ft)*	
A	0–0. 5	0. 5	Sand, fine-pebbly, poorly sorted, gray-brown (about 10*YR* 5/2), slightly hard to soft, single-grained. Probably post-Draper Spit colluvium.
B	0. 5–2. 5±0. 2	2. 0±0. 2	Gravel, sandy pebble, and fine pebbly sand, interbedded; brown (7.5*YR* 5/4 in upper part, grading to 10*YR* 5/3 in lower 0.5 ft); slightly hard to soft; structureless, single grained.
			Clear boundary.
C	2. 5–8. 5	6	Gravel, sandy pebble, and fine pebbly sand, with some cobbles as much as 6 in. in diameter, rarely as much as 8 in. in diameter; much quartz monzonite and quartzite metamorphics and a few pebbles of Mineral Fork Tillite. Light gray (about 10*YR* 7/2); fairly well to poorly horizontally bedded. Noncalcareous. Parent material.

S–8. Midvale Soil, Calcic Brown soil facies, on alluvial gravel of middle Draper age

[Dug pit 0.1 mile north of Dry Creek and 0.05 mile west of Union Pacific Railroad, SE¼SW¼ sec. 7, T. 3 S., R. 1 E.; altitude, 4,450 ft]

Soil horizon	*Depth (ft)*	*Thickness (ft)*	
A	0–0. 6	0. 6	Loam, stony, sandy; somewhat silty fine-medium sand with some pebbles and a few cobbles. Dark gray brown (10*YR* 4/2) at top, grading to gray brown (10*YR* 5/2) in lower part. Soft; weak subangular blocky (top) to single grained in lower part.
			Abrupt boundary.
B	0. 6–1. 9	1. 3	Loam, stony, sandy, grading downward to stony (pebbly) sand. Upper 0.5 ft is compact claypan with considerable silt and clay; hard; medium to coarse subangular blocky; dark brown (10*YR* 4/3); grades downward to (lower half a foot) brown (10*YR* 5/3) soft single-grained pebbly sand with almost no silt and clay.
			Clear boundary.
C_{ca}	1. 9–2. 9	1. 0	Pebble- and cobble-gravel, sandy, light-gray to very pale brown (10*YR* 7/2 to 10*YR* 7/3), loose, single-grained. Fine sand to coarse sand, grit, and pebbles of all sizes; some cobbles 6 in. and rarely as much as 8 in. in diameter; well rounded. Lower parts of some pebbles have thin lime coatings, but the interstitial sand is noncalcareous with HCl test.
C	2. 9–12. 0	9. 1	Sand, medium, clean, with some coarse sand and grit and local lenses of pebbly sand (most pebbles less than 1 in. in diameter); loose; single grained; light gray to very pale brown (about 10*YR* 7/2 to 10*YR* 7/3).

S–9. Midvale Soil, Noncalcic Brown soil facies, on sand of middle tongue of Draper Formation

[Trenched side of old sand pit 1,200 ft south of 9400 South St. and 1,500 ft west of State St., center NE¼ sec. 12, T. 3 S., R. 1 W.; altitude, 4,465 ft]

Soil horizon	*Depth (ft)*	*Thickness (ft)*	
A	0–1. 25	1. 25	Sand, loamy; medium and some coarse sand and a little silt and fine sand, with considerable grit and a few pebbles as much as 1 in. in diameter, mostly less than 0.5 in. in diameter. Upper 0.9 ft is dark gray (10*YR* 4/1); remainder is dark brownish gray (10*YR* 4/2) and has slightly less silt. Soft, very weak subangular blocky; slightly more coherent than material below.
			Abrupt boundary.
B	1. 25–1. 9	0. 65	Sand; mostly medium and coarse sand with a little fine sand and silt, some grit, and a few pebbles, mostly less than 0.5 in. in diameter, rarely as much as 1 in. in diameter. Brown (about 10*YR* 4/3); soft and very weak fine subangular blocky in upper part, grading to single-grained below; noncalcareous.

S-9. Midvale Soil, Noncalcic Brown soil facies, on sand of middle tongue of Draper Formation—Continued

Soil horizon	*Depth (ft)*	*Thickness (ft)*	
B	1. 9–2. 2	0. 3	Sand, like above but slightly paler brown (about 10*YR* 5/3) and slightly less coherent.
B	2. 2–2. 7	0. 5	Sand, somewhat coarser and more pebbly than above (about 30 percent grit and 10–15 percent small pebbles, mostly less than 0.75 in. in diameter; some as large as 1.5 in. in diameter). Very soft, almost loose; grayish brown (10*YR* 5/2); noncalcareous. Sharp boundary.
C	2. 7–7. 5	4. 8	Pebbly coarse sand like above, with some lenses of grit-sand and pebbly grit-sand; pebbles mostly less than 1.25 in. in diameter, rarely as large as 2 in. in diameter; loose (single grained); pale gray (10*YR* 7/2); noncalcareous.
C	7. 5–9. 0	1. 5	Sand, coarse-medium, and some grit, interbedded with medium sand; clean and loose; lowermost 5 in. is medium sand. Basal contact is disconformity, erosion surface.
		1	Clay, silty, pale-olive (about 5*Y* 6/3), tough, strongly calcareous (C_{ca} horizon of the Graniteville Soil, developed on Little Cottonwood Formation). Base not exposed.

S-10. *Midvale Soil, Noncalcic Brown soil facies, on middle tongue of Draper Formation*

[Dug pit at tip of the Sandy spit, 0.5 mile west of State St., SW¼NE¼ sec. 12, T. 3 S., R. 1 W.; altitude, 4,410 ft]

Soil horizon	*Depth (ft)*	*Thickness (ft)*	
A	0–0. 9	0. 9	Loam, sandy; silty medium and fine sand; dark brownish gray (10*YR* 4/2); soft; single grained. Clear boundary.
B	. 9–2. 5	1. 6	Sand, somewhat loamy (silty); mainly fine-medium and medium sand, with a little coarse sand and grit and a very few very small pebbles; top 0.5 ft is dark brown (10*YR* 4/3), soft, weak medium granular; lower foot is very soft to single grained and brown (10*YR* 5/3); limefree.
B	2. 5–3. 6	1. 1	Sand like above but with almost no silt; micaceous; pale brown (10*YR* 6/3); single grained and loose; noncalcareous. Grades very slightly paler near base. Clear boundary.
C	3. 6–4. 5	. 9	Sand, like above, pale-yellow (2.5*Y* 7/3); single grained and loose, noncalcareous. Parent material.

Note—Zonation is indistinct, with gradual transitions in color, throughout this profile.

S-11. *Graniteville Soil, Noncalcic Brown soil facies, on upper till of Bull Lake Glaciation.*

[Exposed in pit at crest of highest terminal moraine remnant, just west of graben fault zone, below mouth of Bells Canyon and 400 ft southwest of Lower Bells Canyon Reservoir; NE¼NE¼ sec. 14, T. 3 S., R. 1 E.; altitude, 5,707 ft]

Soil horizon	*Depth (ft)*	*Thickness (ft)*	
A	0–1. 2	1. 2	Loam, stony, dark-gray (10*YR* 4/1). Silt and fine to medium sand, some grit; many small pebbles, rarely more than 2 in. in diameter; sparse cobbles and boulders. Pebbles mostly angular and subangular, some moderately rounded. Numerous crotovinas (rodent burrows filled with soil material—some of it from B horizon). Structureless; single grained; soft to slightly hard. Highly irregular boundary due to crotovinas.
B	1. 2–4. 9	3. 7	Loam, sandy, stony; brown to yellowish-brown (10*YR* 5/3 to 5/4) in upper 15 in., grading to pale brown (10*YR* 6/3) in next 15 in., and to light brownish gray (2.5*Y* 6/3) in remaining 13 in. Very poorly sorted bouldery till; silt, sand, gravel, and some boulders as large as 4 ft in diameter; practically all quartz monzonite. Upper 15 in. is in places completely reworked by animal borings (crotovinas), and even where best preserved, not more than one-third of original B horizon remains undisturbed—remainder is crotovinas filled with dark-gray material from the A horizon. Top of the B horizon is indefinite and probably reworked. Crotovinas decrease downward and are absent in lower part of B horizon. Weak medium to very coarse granular in upper part, grading to structureless and single grained in lower part. Hard to slightly hard. Diffuse boundary.
C	4. 9–6. 1+	1. 2+	Till, bouldery, compact; like above but light gray (2.5*Y* 7/2). Parent material.

Note.—Reworking by burrowing animals apparently has partly destroyed the upper part of the B horizon, making this horizon seem less strongly developed and thinner than normal.

S–12. Graniteville Soil, Noncalcic Brown soil facies, on sand of Provo Member of Little Cottonwood Formation

[Dug pit on east side of the Draper spit, a few feet below the Provo level; 0.1 mile northeast of north end of the north-south runway at Carter Sky Ranch and 0.3 mile west of 1700 East St., in SW¼ sec. 21, T. 3 S., R. 1 E.; altitude, 4,770 ft]

Soil horizon	*Depth (ft)*	*Thickness (ft)*	
A	0–0.5	0.5	Loam, sandy, with some small pebbles; gray brown to dark gray brown (10*YR* 5/2 to 10*YR* 4/2); soft; single grained. Young colluvium.
B	.5–1.9	1.4	Loam, pebbly-sandy, medium sand, some coarse sand and a little grit, some silt, some pebbles as large as 2 in. in diameter. At top, dark brown (7.5*YR* 4/3), slightly hard, weak medium to coarse angular blocky; silt decreases downward, and color lightens to brown (7.5*YR* 5/4), and soil is single grained (structureless).
B	1.9–3.6	1.7	Sand, pebbly, with larger pebbles and a few cobbles as much as 6–7 in. in diameter; no silt. Brown (7.5*YR* 5/4); structureless (single grained) and loose.
B_3	3.6–3.8	.2	Sand, pebbly, like above, but lighter and less red (about 10*YR* 5/3 to 10*YR* 6/3); gradational base of B horizon. Clear boundary.
C	3.8	.7	Gravel, sandy pebble, with some small cobbles. Parent material. Pale gray (10*YR* 7/2) to light brown (10*YR* 6/3), loose, and structureless; noncalcareous, yet is only 0.5 mile from numerous occurrences of the Calcic Brown soil facies along Willow Wash that have strong C_{ca} horizons.

S–13. Graniteville Soil, Noncalcic Brown soil facies, on Provo Member of Little Cottonwood Formation at crest of south end of Draper spit

[Dug pit at south end of the north-south runway at Carter Sky Ranch, SW¼NW¼ sec. 28, T. 3 S., R. 1 E.: altitude, 4,760 ft]

Soil horizon	*Depth (ft)*	*Thickness (ft)*	
A	0–0.6	0.6	Sand, loamy, gray-brown (10*YR* 5/2); silty medium sand with coarse sand and some grit and a few very small pebbles, rarely as much as three-fourths inch in diameter; loose; soft; single grained. Abrupt boundary (possible small disconformity).
B	.6–3.2	2.6	Sand, gravelly, slightly loamy. Top of horizon probably slightly eroded. Upper 1.5± ft is brown (7.5*YR* 4/3), slightly hard, weak medium subangular blocky; lower part is brown (about 10*YR* 5/3), soft and single grained. Clear, wavy to irregular boundary.
C	3.2–4.2	1.0	Sand with some small pebbles, very pale brown to pale-brown (10*YR* 7/3 to 10*YR* 6/3), loose, single-grained; noncalcareous. Parent material.

REFERENCES CITED

American Commission on Stratigraphic Nomenclature, 1956, Nature, usage, and nomenclature of rock-stratigraphic units—Rept. 4: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 8, p. 2003–2014.

———1961, Code of Stratigraphic Nomenclature: Am. Assoc. Petroleum Geologists Bull., v. 45, no. 5, p. 645–665.

Antevs, E. V., 1925. On the Pleistocene history of the Great Basin, *in* Quaternary climates: Carnegie Inst. Washington Pub. 352, p. 51–114.

———1945, Correlation of Wisconsin glacial maxima, *in* Problems in geology and geophysics (Daly volume): Am. Jour. Sci., v. 243–A, p. 1–39.

———1948, Climatic changes and pre-white man, *in* The Great Basin, with emphasis on glacial and postglacial times: Utah Univ. Bull., v. 36, no. 20, p. 168–191; Biol. ser., v. 10, no. 7.

———1952, Cenozoic climates of the Great Basin [abs.]: Geol. Rundschau, v. 40, no. 1, p. 94–108. [in English]

———1955, Geologic-climatic dating in the west [U.S.]: Am. Antiquity, v. 20, no. 4, pt. 1, p. 317–335.

Atwood, W. W., 1909, Glaciation of the Uinta and Wasatch Mountains: U.S. Geol. Survey Prof. Paper 61, 96 p.

Baldwin, Mark, Kellogg, C. E., and Thorp, James, 1938, Soil classification, *in* Soils and Men: U.S. Dept. Agriculture Yearbook, 1938, p. 979–1001.

Bissell, H. J., 1952, Stratigraphy of Lake Bonneville and associated Quaternary deposits in Utah Valley, Utah [abs.]: Geol. Soc. America Bull., v. 63, no. 12, pt. 2, p. 1358.

———1963, Lake Bonneville: Geology of southern Utah Valley, Utah: U.S. Geol. Survey Prof. Paper 257–B, p. 101–130.

Blackwelder, Eliot, 1910, New light on the geology of the Wasatch Mountains, Utah: Geol. Soc. America Bull., v. 21, p. 517–542.

———1928, The recognition of fault scarps: Jour. Geology, v. 36, no. 4, p. 289–311.

———1931, Pleistocene glaciation in the Sierra Nevada and Basin Ranges: Geol. Soc. America Bull., v. 42, no. 4, p. 865–922.

———1948, The geological background, *in* The Great Basin, with emphasis on glacial and postglacial times: Utah Univ. Bull., v. 36, no. 20, p. 3–16; Biol. ser., v. 10, no. 7.

Broecker, W. S., and Orr, P. C., 1958, Radiocarbon chronology of Lake Lahontan and Lake Bonneville: Geol. Soc. America Bull., v. 69, no. 8, p. 1009–1032.

Broecker, W. S., and Walton, A. F., 1959, Re-evaluation of the salt chronology of several Great Basin lakes: Geol. Soc. America Bull., v. 70, no. 5, p. 601–618.

Calkins, F. C., and Butler, B. S., 1943, Geology and ore deposits of the Cottonwood-American Fork area, Utah: U.S. Geol. Survey Prof. Paper 201, 152 p.

Cook, K. L., and Berg, J. W., Jr., 1961, Regional gravity survey along the central and southern Wasatch Front, Utah: U.S. Geol. Survey Prof. Paper 316–E, 89 p.

Crittenden, M. D., Jr., 1961, Isostatic deformation of Bonneville shorelines: Summary, prepared for Friends of the Pleistocene, Rocky Mountain Section, 7th Ann. Field Trip, August 1961; 7 p. mimeographed preprint.

Crittenden, M. D., Jr., Sharp, B. J., and Calkins, F. C., 1952, Geology of the Wasatch Mountains east of Salt Lake City; Parleys Canyon to the Traverse Range, *in* Utah Geol. Soc. Guidebook 8, Geology of the central Wasatch Mountains, Utah: p. 1–37.

Davis, W. M., 1901, The ranges of the Great Basin—Physiographic evidence of faulting: Science, v. 14, no. 351, p. 457–459 [repub. 1909].

———1903, The mountain ranges of the Great Basin: Harvard Coll. Comp. Zoology Mus. Bull., v. 42, p. 129–177 [repub. 1954].

———1925, The Basin Range problem: Natl. Acad. Sci. Proc., v. 11, no. 7, p. 387–392.

Duke, C. M., 1958a, Effects of ground on destructiveness of large earthquakes: Am. Soc. Civil Engineers Proc., Paper 1730, v. 84, no. SM3, 23 p.

———1958b, Bibliography of effects of soil conditions on earthquake damage: San Francisco, Calif., Earthquake Eng. Research Inst., 47 p.

Eardley, A. J., 1939, Structure of the Wasatch-Great Basin region: Geol. Soc. America Bull., v. 50, no. 8, p. 1277–1310.

———1944, Geology of the north-central Wasatch Mountains, Utah: Geol. Soc. America Bull., v. 55, no. 7, p. 819–894.

———1951, Structural geology of North America: New York, Harper & Bros., 624 p.

———1952, Wasatch hinterland, *in* Utah Geol. Soc. Guidebook 8, Geology of the central Wasatch Mountains, Utah: p. 52–60.

Eardley, A. J., 1955, Tertiary history of north-central Utah, *in* Utah Geol. Soc. Guidebook 10, Tertiary and Quaternary geology of the eastern Bonneville basin: p. 37–44.

Eardley, A. J., Gvosdetsky, Vasyl, and Marsell, R. E., 1957, Hydrology of Lake Bonneville and sediments and soils of its basin [Utah]: Geol. Soc. America Bull., v. 68, no. 9, p. 1141–1201.

Gilbert, G. K., 1874, Preliminary geological report, expedition of 1872, *in* Wheeler, G. M., Prog. Rept. upon U.S. Geographical and Geological Explorations and Surveys West of the 100th Meridian, in 1872: p. 48–52.

———1875, Report on the geology of portions of Nevada, Utah, California, and Arizona, pt. 1, *in* Wheeler, G. M., U.S. Geographical and Geological Explorations and Surveys West of the 100th Meridian: v. 3, p. 17–187.

———1890, Lake Bonneville: U.S. Geol. Survey Mon. 1, 438 p.

———1928, Studies of Basin Range structure: U.S. Geol. Survey Prof. Paper 153, 92 p.

Gilluly, James, 1928, Basin-Range faulting along the Oquirrh Range, Utah: Geol. Soc. America Bull., v. 39, no. 4, p. 1103–1130.

Gvosdetsky, Vasyl, and Hawkes, H. B., 1953, Reappraisal of the history of Lake Bonneville [Utah]: Utah [Univ.] Eng. Expt. Sta. Bull. 60, v. 43, no. 5, 70 p.

———1954, Fossil soils as a key to the past climates of the Bonneville Basin [Utah] [abs.]: Geol. Soc. America Bull., v. 65, no. 12, pt. 2, p. 1394.

———1956, Middle stream terrace of the Bonneville Basin—a key to the history of Lake Stansbury: Utah [Univ.] Eng. Expt. Sta. Bull. 81, v. 47, no. 16, 46 p.

Hague, Arnold, and Emmons, S. F., 1877, Descriptive geology, v. 2 *of* U.S. geological exploration of the 40th parallel: U.S. Army Eng. Dept. Prof. Paper 18, 890 p.

Hunt, C. B., 1953a, Pleistocene-Recent boundary in the Rocky Mountain region: U.S. Geol. Survey Bull. 996–A, p. 1–25.

Hunt, C. B., 1953b, General geology, *in* Hunt, C. B., Varnes, H. D., and Thomas, H. E., Lake Bonneville—geology of northern Utah Valley, Utah: U.S. Geol. Survey Prof. Paper 257–A, p. 11–45.

Hunt, C. B., and Morrison, R. B., 1957, Geology of Danger and Juke Box Caves, near Wendover, Utah, App. A *of* Jennings, J. D., Danger Cave: Utah Univ. Anthropol. Papers, no. 27, p. 298–301.

Hunt, C. B., and Sokoloff, V. P., 1950, Pre-Wisconsin soil in the Rocky Mountain region, a progress report: U.S. Geol. Survey Prof. Paper 221–G, p. 109–123.

Hunt, C. B., Varnes, H. D., and Thomas, H. E., 1953, Lake Bonneville—geology of northern Utah Valley, Utah: U.S. Geol. Survey Prof. Paper 257–A, 99 p.

Ives, R. L., 1948, The outlet of Lake Bonneville: Sci. Monthly, v. 67, no. 6, p. 415–426.

———1950, Glaciations in Little Cottonwood Canyon, Utah: Sci. Monthly, v. 71, no. 2, p. 105–117.

———1951, Pleistocene valley sediments of the Dugway area, Utah: Geol. Soc. America Bull., v. 62, no. 7, p. 781–797.

Jennings, D. S., Fletcher, J. E., Wallace, M. H., Wilson, Lemoyne, Zobell, I. D., Youngs, F. O., and Bartholomew, O. F., 1946, Soil survey, the Salt Lake area, Utah: U.S. Dept. Agriculture Soil Survey ser. 1936, no. 22, 83 p., 2 maps.

Joffe, J. S., 1949, Pedology: 2d ed., New Brunswick, N.J., Pedology Pubs., 662 p.

Jones, D. J., and Marsell, R. E., 1952, Pleistocene lake sediments in the vicinity of Salt Lake City, Utah [abs.]: Geol. Soc. America Bull., v. 63, no. 12, pt. 2, p. 1364.

———1955, Pleistocene sediments of lower Jordan Valley, Utah, *in* Utah Geol. Soc. Guidebook 10, Tertiary and Quaternary geology of the eastern Bonneville basin: p. 85–112.

King, Clarence, 1878, Systematic geology, v. 1 *of* U.S. geological exploration of the 40th parallel: U.S. Army Eng. Dept. Prof. Paper 18, 803 p.

Lambert, Hubert, 1952, Road logs, Utah Geological Society, Two-day field conference, *in* Utah Geol. Soc. Guidebook 8, Geology of the central Wasatch Mountains, Utah: p. 61–71.

Marbut, C. F., 1935, Soils of the United States: U.S. Dept. Agriculture, Atlas of Am. Agriculture, pt. 3, advance sheets, no. 8, 95 p.

Marine, I. W., 1961, Subdividing the Jordan Valley ground-water basin, Utah, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, p. D132–D134.

Marsell, R. E., 1946a, Basin Range faulting near Salt Lake City [Utah] [abs.]: Utah Acad. Sci. Proc., v. 23, p. 15–16 [1947].

———1946b, The relations of the Little Cottonwood and Bell Canyon glaciers to Lake Bonneville [Utah] [abs.]: Utah Acad. Sci. Proc., v. 23, p. 18 [1947].

———1953, Wasatch front [Utah]: Compass, v. 31, no. 1, p. 2–22.

Marsell, R. E., and Jones, D. J., 1955, Pleistocene history of lower Jordan Valley, Utah, *in* Utah Geol. Soc. Guidebook 10, Tertiary and Quaternary geology of the eastern Bonneville Basin: p. 113–120.

Marsell, R. E., and Threet, R. L., 1960, Geologic map of Salt Lake County, Utah: Utah Geol. and Mineralog. Survey map RS 83 (suppl. to Bull. 69).

Morrison, R. B., 1961a, New evidence on the history of Lake Bonneville from an area south of Salt Lake City, Utah, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, p. D125–D127.

——— 1961b, Correlation of the deposits of Lakes Lahontan and Bonneville and the glacial sequences of the Sierra Nevada and Wasatch Mountains, California, Nevada, and Utah, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, p. D122–D124.

——— 1961c, Lake Lahontan stratigraphy and history in the Carson Desert (Fallon) area, Nevada, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, p. D111–D114.

——— 1961d, A suggested Pleistocene-Recent (Holocene) boundary for the Great Basin region, Nevada-Utah, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, p. D115–D116.

——— 1964, Lake Lahontan: Geology of southern Carson Desert, Nevada: U.S. Geol. Survey Prof. Paper 401, 156 p.

Morrison, R. B., Gilluly, James, Richmond, G. M., and Hunt, C. B., 1957, In behalf of the Recent: Am. Jour. Sci., v. 255, no. 6, p. 385–393.

Munsell Color Company, Inc., 1949, Munsell soil color charts, hues 7.5*R* thru 5*Y*—special form for use of soil scientists, geologists, archaeologists: Baltimore, Munsell Color Co., Inc., unpaged.

Pack, F. J., 1926, New discoveries relating to the Wasatch fault: Am. Jour. Sci. 5th ser., v. 11, p. 399–410.

Richmond, G. M., 1961, New evidence of the age of Lake Bonneville from the moraines in Little Cottonwood Canyon, Utah, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–D, p. D127–D128.

——— 1964, Glaciation of Little Cottonwood and Bells Canyons, Wasatch Mountains, Utah: U.S. Geol. Survey Prof. Paper 454–D, 41 p.

Richmond, G. M., and Frye, J. C., 1957, Status of soils in stratigraphic nomenclature, Note 19 *of* American Commission on Stratigraphic Nomenclature: Am. Assoc. Petroleum Geologists Bull., v. 41, no. 4, p. 758–763.

Richmond, G. M., Morrison, R. B., and Bissell, H. J., 1952, Correlation of the late Quaternary deposits of the La Sal Mountains, Utah, and of Lakes Bonneville and Lahontan by means of interstadial soils [abs.]: Geol. Soc. America Bull., v. 63, no. 12, pt. 2, p. 1369.

Schneider, Hyrum, 1925, A discussion of certain geologic features of the Wasatch Mountains: Jour. Geology, v. 33, no. 1, p. 28–48.

Spurr, J. E., 1901, Origin and structure of the Basin ranges: Geol. Soc. America Bull., v. 12, p. 217–270.

U.S. Department of Agriculture, 1938, Soils and men, 1938 yearbook, 1232 p.

U.S. Department of Agriculture, Soil Survey staff, 1951, Soil Survey Manual: U.S. Dept. Agriculture Handbook 18, revised ed., 503 p.

University of Utah Bureau of Economic and Business Research, 1953, Water resources of the Bonneville basin, pt. 1, The water crop and its disposition: Utah Econ. and Business Rev., v. 13, no. 1–A, 56 p.

Varnes, D. J., and Van Horn, Richard, 1951, Surficial geology of the Oak City area, Millard County, Utah: U.S. Geol. Survey open-file report.

——— 1961, A reinterpretation of two of G. K. Gilbert's Lake Bonneville sections, Utah, *in* Short papers in the geologic and hydrologic sciences: U.S. Geol. Survey Prof. Paper 424–C, p. C98–C99.

Williams, J. Stewart, 1952, Red Rock Pass [Idaho], outlet of Lake Bonneville [abs.]: Geol. Soc. America Bull., v. 63, no. 12, pt. 2, p. 1375.

——— 1962, Lake Bonneville: Geology of southern Cache Valley, Utah: U.S. Geol. Survey Prof. Paper 257–C, p. 131–152.

INDEX

[Italic page numbers indicate major references]

U.S. GOVERNMENT PRINTING OFFICE : 1965 O—746-815