Lake Bonneville: Geology of Southern Cache Valley, Utah

GEOLOGICAL SURVEY PROFESSIONAL PAPER 257-C

Lake Bonneville: Geology of Southern Cache Valley, Utah

By J. STEWART WILLIAMS

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Cenozoic geology of a part of the area inundated by a late Pleistocene lake

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LAKE BONNEVILLE: GEOLOGY OF SOUTHERN CACHE VALLEY, UTAH

By J. Stewart Williams

ABSTRACT

This report, covering about 450 square miles in southern Cache Vally, Utah, is one of a series dealing with the geology of Pleistocene Lake Bonneville. The report summarizes in tabular form the Paleozoic formations that are exposed in the mountains adjacent to Cache Valley and describes briefly the Tertiary formations—the Wasatch and Salt Lake formations—which are exposed in the valley. Most of the report deals with the Quaternary deposits.

Fan gravel and landslides of pre-Lake Bonneville Quaternary age are exposed in a few places at the edges of the basin, and well logs indicate a deep fill of this age in the subsurface of the basin interior. The sediments of Lake Bonneville comprise the Lake Bonneville group. The oldest of the unconsolidated deposits are the Alpine and Bonneville formations, which were mostly mapped together in southern Cache Valley. These formations are composed mostly of silt, but they include some gravel in embankments and small deltas. Their thickness ranges from about 50 to 100 feet.

Overlying the Alpine and Bonneville formations is the Provo formation 50 to 75 feet thick. In Cache Valley, as elsewhere in the Lake Bonneville basin, the Provo includes extensive gravel deposits in bars, spits, and deltas. It is the surface formation in much of Cache Valley. Deposits younger than the Provo, mostly of Recent age, include alluvial fans, flood-plain alluvium, natural levee deposits along the Bear River, slope wash, eolian sand, and cones of spring tufa. Several faults, active in Tertiary time, are mapped.

Well logs indicate that the pre-Lake Bonneville deposits of Quaternary age are surprisingly thin in Cache Valley, suggesting that the valley had exterior drainage during mostof Pleistocene time. The logs show two main aquifers of gravel and sand—the upper one between the Provo formation and the Alpine and Bonneville formations and the other directly beneath the Alpine and Bonneville deposits. These aquifers probably are alluvium deposited during interlake intervals.

The shore embankments and deltas of the Lake Bonneville group are abundant sources of gravel and sand for construction. Much of the gravel is suitable for concrete aggregate.

INTRODUCTION

Cache Valley is a narrow elongate basin lying at the northeast corner of the Great Basin (fig. 38). The northern half of the valley is in Idaho, the southern half in Cache County, Utah. This report covers the Utah part of the valley, which extends over approximately two-thirds of two 15-minute quadrangles constituting the west half of the 30-minute Logan quadrangle.

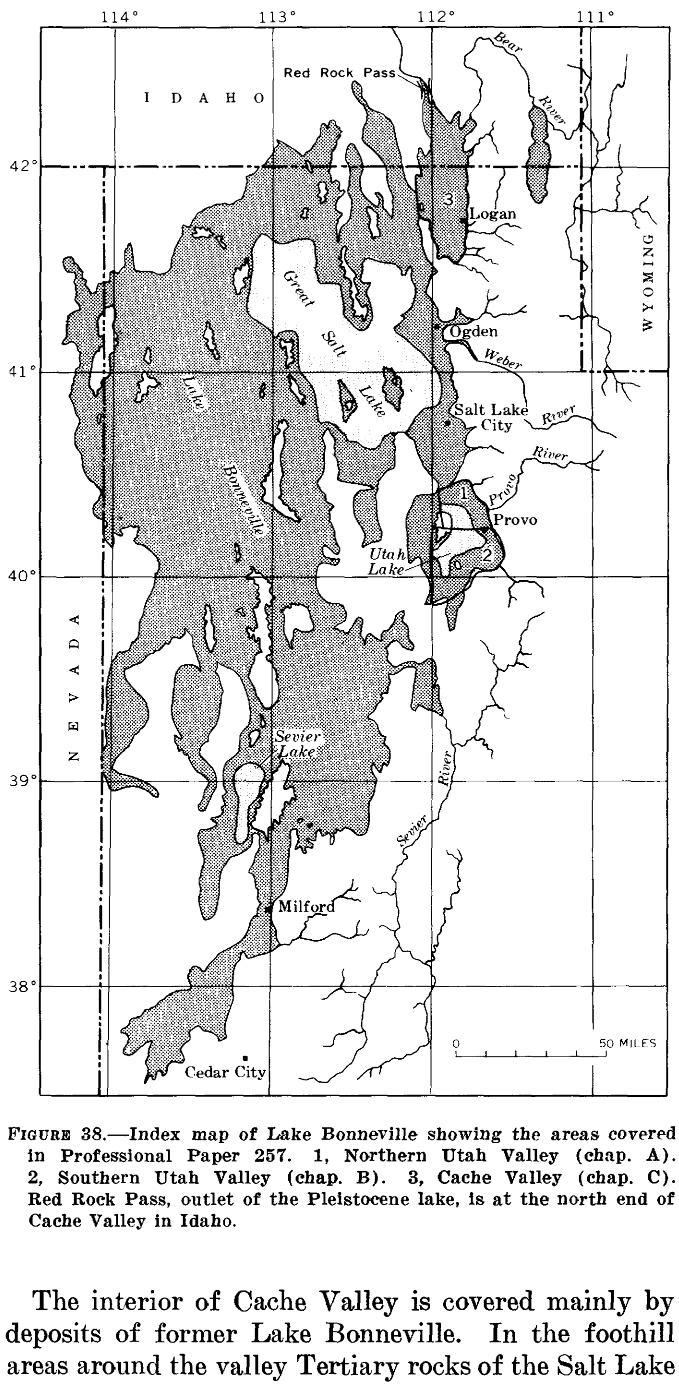

Figure 38.—Index map of Lake Bonneville showing the areas covered in Professional Paper 257. 1, Northern Utah Valley (chap. A). 2, Southern Utah Valley (chap. B). 3, Cache Valley (chap. C). Red Rock Pass, outlet of the Pleistocene lake, is at the north end of Cache Valley in Idaho.

The interior of Cache Valley is covered mainly by deposits of former Lake Bonneville. In the foothill areas around the valley Tertiary rocks of the Salt Lake formation, aggregating several thousand feet thick, are fairly well exposed. The higher mountains bordering the valley are composed of Paleozoic rocks.

Mapping was begun in September 1946 and was continued intermittently until June 1948. About 200 days of fieldwork resulted in mapping about 450 square miles. The base map is a planimetric compilation from aerial photographs. Geologic boundaries were drawn in the field on acetate overlays covering the photographs and subsequently transferred to the base (pl. 6).

STRATIGRAPHY

PRE-TERTIARY ROCKS

Paleozoic rocks aggregating more than 30,000 feet thick are well represented in the mountains adjacent to southern Cache Valley. They were the source of most of the detrital material that makes up the Tertiary and Quaternary deposits in the valley. The most abundant rock type is sandstone, followed, in turn, by limestone and dolomite. The Paleozoic formations are summarized in table 1.

TABLE 1.—*Paleozoic formations in the mountains adjacent to southern Cache Valley*
[After Williams, 1948]

System	Formation	Lithology	Thickness (feet)
Pennsylvanian	Wells formation	Brown-weathering calcareous sandstone and gray limestone	1,000–6,140+
	—Unconformity—		
Mississippian	Brazer limestone	Gray limestone and silty limestone, and black shale and black phosphatic shale.	1,500–3,700
	—Disconformity—		
	Madison limestone	Thin-bedded fossiliferous gray limestone; some black shale near base.	845
	—Unconformity—		
Devonian	Jefferson formation	Thin-bedded buff sandstone and siltstone, and dark-gray dolomite and limestone.	0–2,120
	—Disconformity—		
	Water Canyon formation	Thin-bedded buff, sandy and silty dolomite, sandy shale and sandstone.	150–540
	—Disconformity—		
Silurian	Laketown dolomite	Light- and dark-gray dolomite, generally massive	1,510
	—Disconformity—		
Ordovician	Fish Haven dolomite	Dark-gray massive dolomite	140
	—Unconformity—		
	Swan Peak formation	Gray and brown fucoidal quartzite, and black shale	340
	Garden City limestone	Dark-gray thin-bedded limestone and shaly limestone, weathering olive buff.	1,400
	—Disconformity—		
Cambrian	St. Charles formation	Massive gray dolomite and thin-bedded limestone; drab quartzite member at base.	1,015–1,130
	—Disconformity—		
	Nounan dolomite	Gray dolomite; some gray limestone in upper part	825–1,125
	Bloomington formation	Gray limestone and tawny-olive shale	1,050–1,500
	—Disconformity—		
	Blacksmith dolomite	Neutral-gray dolomite and dolomitic limestone, generally massive	325–800
	Ute formation	Citrine-drab shale interbedded with brown-weathering sandy and silty limestone, gray oolitic limestone, algal limestone, and intraformational limestone breccia.	665
	Langston formation	Gray dolomite, tan-weathering; black, green, and gray shale; some limestone.	310–485
	Brigham quartzite	Gray and light-brown quartzite	1,800–4,800+

Probably a considerable thickness of Triassic rocks and also some Jurassic sediments were deposited over the Cache Valley area, but these were removed when, near the close of Jurassic time, northwestern Utah was raised in a broad geanticline. This uplift held the Cretaceous shoreline east of the future site of Cache Valley. The rise of this ancient landmass may be considered the onset of the Laramide orogeny which completed destruction of the Cordilleran geosyncline by folding its sediments into a great mountain system. As a result of the Laramide orogeny the rocks in this region were folded and broken by thrust faults. Broad anticlines and synclines were formed in the mountains east of Cache Valley.

TERTIARY SYSTEM

WASATCH FORMATION

A few tiny exposures of conglomerate and sandstone on the western side of Cache Valley are assigned to the Wasatch formation. Two small areas on Wellsville

Mountain are pebble and cobble conglomerate, with a matrix of coarse red sand. Here the Wasatch deposits are unconformable upon the Paleozoic strata and are overlain by the younger Tertiary rocks of the Salt Lake formation. The pebbles and cobbles are mostly sandstone, calcareous sandstone, and limestone from the Carboniferous formations. Another tiny area on Newton Hill is conglomerate composed of subangular fragments of pebble and cobble size (90 percent of the rock), derived from the Madison, Water Canyon, and Wells formations, in a red matrix (10 percent) of sand and calcium carbonate. In the extreme southern end of the mapped area are several unmapped exposures of soft reddish sandstone, beneath limestone of the Salt Lake formation, that are tentatively assigned to the Wasatch formation because of their color. These exposures occur west of Paradise in Tps. 9 and 10 N., R. 1 E., in the short north tributary to McMurdie Hollow, NW¼ sec. 30, T. 10 N., R. 1 E.; in Big Spring Hollow, NE¼ sec. 6, T. 9 N., R. 1 E.; and in the West Fork of Big Spring Hollow, NE¼ sec. 7, T. 9 N., R. 1 E.

SALT LAKE FORMATION

The light-colored poorly consolidated rocks that crop out in Salt Lake and Morgan Valleys, 50 to 100 miles south of Cache Valley, were named the Salt Lake group by Hayden (1869, p. 92). He thought them to be of late Tertiary age. Similar rocks were discovered shortly thereafter by Peale (1879, p. 588) in Cache Valley, Bear Lake Valley, and other valleys in southeastern Idaho. Mansfield (1929, 1927) designated and mapped similar rocks in southeastern Idaho as the Salt Lake formation of Pliocene (?) age. Later workers in northern Utah and southern Idaho have continued to use the name Salt Lake formation (or group) for these diverse volcanic-derived rocks. They have variously considered them to be partly Oligocene (Eardley, 1944), mostly or entirely Miocene and Pliocene (Adamson and others, 1955; Slentz, 1955), and probably Pliocene (Hunt, 1953; Bissell, 1962).

Rocks of the Salt Lake formation are widely exposed in the pediments and foothills around the margins of Cache Valley in an almost continuous belt that commonly is 1 mile or more wide and in places 2,000 feet above the valley floor. A comprehensive discussion of these rocks over the whole of Cache Valley has recently been published (Adamson and others, 1955). They are here divided into three units, from oldest to youngest—the lower conglomerate unit, the tuff unit, and the upper conglomerate and sandstone unit. Table 2 shows the correlation of these units with those previously named by other geologists who have published on this area.

TABLE 2.—*Past usage in stratigraphic nomenclature in the Salt Lake formation in Cache Valley, Utah and Idaho*

<table>
<tr><th colspan="2">Williams (*in* Smith, 1953)</th><th colspan="2">A. S. Keller (1952)[1]</th><th colspan="2">Adamson and others (1955)</th><th colspan="2">Present report</th></tr>
<tr><td colspan="2"></td><td rowspan="3">Mink Creek formation</td><td>Conglomerate member</td><td rowspan="4">Salt Lake group</td><td>Mink Creek conglomerate</td><td colspan="2">?—?—?</td></tr>
<tr><td rowspan="3">Salt Lake group</td><td>Cache Valley formation</td><td rowspan="2">Tuff member</td><td rowspan="2">Cache Valley formation</td><td rowspan="3">Salt Lake formation</td><td>Upper conglomerate and sandstone unit</td></tr>
<tr><td>West Spring formation</td><td>Tuff unit</td></tr>
<tr><td>Collinston conglomerate</td><td colspan="2"></td><td>Collinston conglomerate</td><td>Lower conglomerate unit</td></tr>
</table>

[1] Geology of the Mink Creek region, Idaho: Unpublished master of science thesis, Utah Univ.

LOWER CONGLOMERATE UNIT

The lowermost unit of the Salt Lake formation in the Utah part of Cache Valley is here designated the lower conglomerate unit. It consists of boulder and cobble conglomerate having a white matrix, distinctive from conglomerate of the Wasatch formation, which has a reddish matrix. This unit crops out in the foothills near Mendon and Wellsville, on the southwestern side of Cache Valley. It apparently is continuous with a conglomerate unit in the lower part of the Salt Lake that crops out in a belt about a mile wide around the northern end of Wellsville Mountain from Mendon to Collinston (outside the mapped area), that was previously designated the Collinston conglomerate (Williams, *in* Smith, 1953; Adamson and others, 1955). West of Mendon and outside the mapped area the conglomerate is thinly mantled by loose round stones and is too poorly exposed to show its exact attitude, but it appears to dip valleyward more steeply than the present ridge crests. Assuming a 30° dip and no repetition by faulting, the unit is about 2,500 feet thick; however, the dip may be less and the unit correspondingly thinner; also it may be faulted. A boulder conglomerate tentatively correlated with this unit is exposed about 3 miles west of the mapped area in the bank of the West Side Canal, near Wheelon, in the SW¼ sec. 27, T. 13 N.,

R. 2 W.; it overlies Paleozoic dolomite and contains large fragments of conglomerate of Wasatch age.

Traced from the north end of Wellsville Mountain into the mapped area, the conglomerate unit is believed to underlie most of the foothill belt between Mendon and Wellsville. It is mantled with loose cobbles and pebbles, but the hummocky undulatory surface suggests weak bedrock rather than Quaternary fan gravel.

Southeast of Wellsville, a boulder conglomerate, presumed to be this unit, underlies both the low ridge in secs. 14 and 23 and the arcuate hill in secs. 1, 2, 11, and 12, T. 10 N., R. 1 W. In the ridge the conglomerate overlies calcareous sandstone of the Wells formation. On the hill there is no clue to the material that underlies the conglomerate. At these localities the conglomerate is composed largely of cobbles and boulders of sandstone, calcareous sandstone, and cherty limestone from the Wells formation, and some large boulders of brown and white quartzite, probably Precambrian.

TUFF UNIT

The tuff unit of the Salt Lake formation was formerly the West Spring formation of Williams (*in* Smith, 1953) and later was placed in the lower part of the Cache Valley formation of Adamson, Hardy, and Williams (1955). In the report area it is restricted to Hyrum Bench and consists mostly of soft earthy-gray tuff that weathers to smooth drab-gray slopes. It also contains a minor amount of pebble conglomerate. It is estimated to be about 1,200 feet thick on the ridge north of West Fork and is overlain unconformably by the upper conglomerate and sandstone unit.

At the base of the tuff unit are two distinctive limestone beds. The lower one is buff, pinkish buff, or white compact commonly siliceous fresh-water limestone, about 10 feet thick and unconformable either on Paleozoic rocks or on the red Wasatch formation (p. 133). The upper is a 1- to 2-foot bed of gray stromatolitic limestone that is separated from the lower limestone by a few feet of tuffaceous sandstone. Small patches of these limestones west of the main body of the tuff unit are scattered over the Paleozoic rocks in Hyrum Bench, particularly in secs. 25 and 36, T. 10 N., R. 1 W.; and suggest that this unit once covered a much larger area.

UPPER CONGLOMERATE AND SANDSTONE UNIT

Overlying the tuff unit on Hyrum Bench is a succession of pebble conglomerate and tuffaceous sandstone beds that probably belong in the upper part of the Salt Lake formation. This succession is broken by the Willow Grove fault so that its total thickness cannot be measured, but it is estimated to be 1,000 to 2,000 feet. This unit is herein referred to as the upper conglomerate and sandstone unit of the Salt Lake formation. It is believed to be equivalent in age to the beds that were first included in the Cache Valley formation (Williams, *in* Smith, 1953), and later limited to the upper part of this formation (Adamson and others, 1955).

It is not possible to trace the upper conglomerate and sandstone unit by continuous exposures from Hyrum Bench either northward or eastward. Even the conglomerate in Paradise Bench is separated by younger deposits for a distance of nearly 2 miles. There is some fossil evidence, however, to support the theory that the rocks on Newton and Bergeson Hills on the west side of the valley, as well as those near Richmond and Paradise on the east side, are correlative with the upper conglomerate and sandstone exposed on Hyrum Bench. Plants collected on the east side of Hyrum Bench near the Little Bear River in SE¼ sec. 20, T. 10 N., R. 1 E., are thought by Roland W. Brown (1949) to be late Pliocene in age. Yen (1947) studied a molluscan fauna containing 3 species of pelecypods and 17 of gastropods, from the Junction Hills directly west of Newton, in sec. 15, T. 13 N., R. 2 W., 3 miles beyond the west boundary of this map, and concluded that it was of Pliocene age, probably late Pliocene. Swain (1947) studied ostracodes (12 species, of which 11 were new) from the same locality, and, although not able to determine the age from the ostracodes, he pointed out the modern character of the fauna and the close resemblance of most of the species to modern forms.

The sedimentary materials in the conglomerate and sandstone unit are clearly of local origin and are confined to the valley and to the low passes that lead to adjacent valleys. These deposits, therefore, are younger than the valley and accumulated within it.

The unit contains a wide variety of rock types, both fluviatile and lacustrine. Four fairly distinct facies are present, which are locally differentiated on the geologic map.

A fanglomerate facies, presumably deposited as alluvial fans, occurs along the east side of the valley from the Idaho line to the mouth of Green Canyon northeast of Logan. It underlies gently sloping ridges that are remnants of a pediment developed on the weak Tertiary rocks and extending as far as 3 miles into the valley from the mountain front. The ridges weather to smooth surfaces mantled with residual fragments from the underlying fanglomerate. The fanglomerate typically consists of angular to subrounded pebbles and cobbles of limestone and dolomite cemented by calcium carbonate. There is little or no interstitial fine clastic material. The size of the fragments increases upslope, and large boulders are common near the mountain front. No fossils were found.

A conglomerate facies, characterized by rounded fragments, is widely exposed in the south end of Cache Valley, on both sides of the Little Bear River, and locally on the south end of Newton Hill and on Bergeson Hill. It generally consists of rounded pebbles and cobbles in a matrix of calcium carbonate and tuffaceous sand. The pebbles and cobbles are chert, sandstone, calcareous sandstone, and limestone, mostly from Carboniferous formations. West of the area mapped, in the Junction Hills, the conglomerate grades into calcareous oolite. In Bergeson Hill it is interbedded with tuff and tuffaceous sandstone. In the hills at the south end of Cache Valley it is interbedded with oolite, tuffaceous sandstone, tuffaceous marl, and a few beds of compact limestone.

On West Fork a conspicuous conglomerate marks the base of the upper conglomerate and sandstone unit. It contains cobbles of purple, brown, and buff Precambrian quartzite, also cobbles from the Carboniferous formations of the area, and cobbles of stromatolitic and compact limestone from the underlying tuff unit of the Salt Lake, indicating lack of conformity between the two units.

On the west side of the valley from the Idaho line to the south tip of Newton Hill the rocks of the upper conglomerate and sandstone unit are largely thin-bedded tuff and tuffaceous sandstone interlayered with a few beds of conglomerate and compact limestone, which are differentiated as the tuff and tuffaceous sandstone facies. On the southeast slopes of Bergeson Hill the tuff has been silicified into a chertlike rock. This facies crops out locally southward; in a quarry west of Newton, thick-bedded tuff is interbedded with calcareous oolite; in the south end of Cache Valley conglomerate predominates, but along the Little Bear River west of Paradise are several outcrops of calcareous tuffaceous sandstone, tuffaceous marl, and compact limestone, bearing ostracodes, imprints of grass roots, and many impressions of a small clam. Remains of fishes, terrestrial plants, and insects have been found in SE¼ sec. 20, T. 10 N., R. 1 E.

The upper conglomerate and sandstone unit also includes massive beds of oolitic limestone differentiated as the oolitic limestone facies at several localities: the north end of Cache Butte; a small isolated hill in sec. 19, T. 12 N., R. 1 W., 2 miles south of the butte; and south and west of Hyrum Reservoir. The oolitic limestone is porous, with no fine interstitial material and little cement. Commonly it contains many small snail and clam shells, which weather out on exposure, leaving molds. In Junction Hills (west of the area mapped) the oolite intergrades with conglomerate; in the south end of Cache Valley, thinner beds of oolite are interlayered with sandstone and conglomerate; in the quarry west of Newton massive beds of oolite are interbedded with thick beds of tuff and tuffaceous sandstone.

QUATERNARY DEPOSITS

In southern Cache Valley the exposed Quaternary deposits are predominantly sediments of Lake Bonneville and younger alluvium. Fan gravel and landslides of pre-Lake Bonneville age are locally exposed at the margins of the basin. Well logs indicate at least several hundred feet of fluviatile and lacustrine sediments in the subsurface of the basin interior, overlying the Salt Lake formation and underlying the Lake Bonneville group, which are mainly or entirely of Quaternary age.

PRE-LAKE BONNEVILLE DEPOSITS

FAN GRAVEL

In the foothills along the east side of the valley between Blacksmith Fork and Green canyons, the gently sloping surface beneath the embankments and deltas of Lake Bonneville is interpreted as a piedmont of coarse alluvium, that is, a series of coalesced alluvial fans deposited at the mouths of the numerous gullies along the mountain front. The only exposure that shows this material to appreciable depth is along the lower road at the mouth of Logan Canyon, in the gravel pit directly across the road from the college hydroelectric plant, in the NW¼ sec. 36, T. 12 N., R. 1 E. Here a few feet of coarse, angular, and poorly sorted alluvium crop out beneath well-sorted nearly horizontal beds of sand and gravel of the Lake Bonneville group. The alluvium contains much silt and clay and was deposited by muddy water. It includes a block of Paleozoic limestone several feet in diameter. Similar material is exposed along a canal bank for several hundred feet to the west. These exposures probably are representative of the pre-Lake Bonneville fan gravel to the north and south in this area. Elsewhere, the fan surfaces are rather steeply sloping (3°–6°) and are characterized by large angular blocks, largely buried and surrounded by finer angular alluvium.

CONCEALED DEPOSITS

Logs of a few wells give limited information on the buried pre-Bonneville deposits of Quaternary age overlying the Salt Lake formation (figs. 39, 43–47). The contact of these sediments with the Lake Bonneville group is irregular and lies from 60 to 160 feet below the present ground surface. Few wells have gone entirely through the pre-Bonneville beds, but several have penetrated 75 to 130 feet of them without reaching the basal contact. One well (B3, fig. 39) which was sunk deep into the Salt Lake formation logged about 250 feet of

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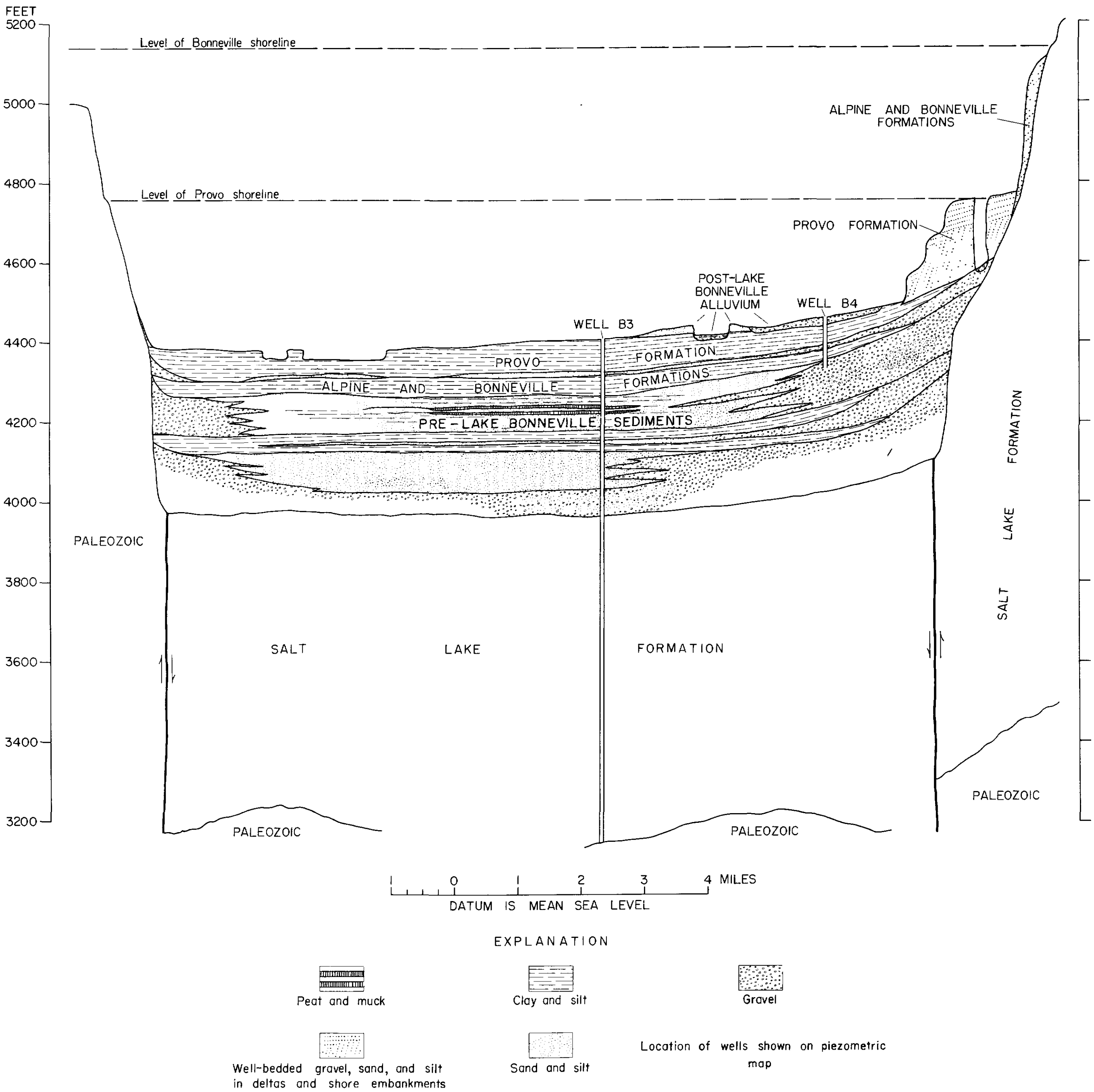

FIGURE 39.—Diagrammatic cross section of Cache Valley from Cache Butte through Amalga to Smithfield.

pre-Bonneville deposits of Quaternary(?) age. Both lacustrine and fluviatile sediments are represented in the logs. Most prominent are comparatively thick clay zones that may have been laid down in earlier deep lakes. Interbedded with these are gravelly and sandy zones that probably are either alluvial or deltaic deposits.

LANDSLIDES

Several landslides older than Lake Bonneville are exposed around the edges of the valley especially along the steep east flank of Wellsville Mountain. Most involve weak rocks of the Salt Lake formation, but one is composed of calcareous sandstone of the Wells formation.

One of the larger slides is situated on the east side of Newton Hill. This slide is about 1 mile long and is composed of tuffaceous sandstone of the Salt Lake formation. Its pre-Lake Bonneville age is shown by the Bonneville and other shorelines carved on its upper part and by the lake-bottom sediments which cover all of its lower part, except a few low hills at its toe.

A similar but smaller slide from the west side of the hill serves as an abutment for the Newton Dam in sec. 5, T. 13 N., R. 1 W. Northwest of Avon, along the east side of Hyrum Bench, is another landslide which is more than a mile wide. The Bonneville shoreline is carved on its lower part, showing that this slide antedates this lake level. Similar but smaller slides occur north of the main slide.

LAKE BONNEVILLE GROUP

ALPINE AND BONNEVILLE FORMATIONS, UNDIFFERENTIATED

Hunt (1953, p. 17) proposed the name Alpine formation for the oldest deposits of Lake Bonneville, exposed below the Bonneville shoreline and mainly above the Provo shoreline, and he proposed the name Bonneville formation (op. cit., p. 20) for somewhat younger deposits laid down while the lake stood at its highest level, marked by the Bonneville shoreline. The Alpine formation consists of lacustrine gravel, sand, silt, and clay; but the Bonneville formation is mostly gravel. The Alpine probably extends to an altitude of about 5,100 feet in southern Cache Valley, and the Bonneville about 35 feet higher, to the Bonneville shoreline, about 5,135 feet. Exposures generally are too poor in southern Cache Valley to show details of stratification and evidence of unconformity between the two formations, such as Hunt (1953) and Bissell (1962) have inferred in Utah Valley. In some areas the highest level deposits thought to be Alpine are silty, whereas the Bonneville formation is mostly gravel. Although the silt could be interpreted as Alpine formation and the gravel as Bonneville, there is uncertainty whether some of the silt is a silty facies of the Bonneville, and some of the gravel a gravel facies of the Alpine. In this report, therefore, I have not separated the two formations, except for a local selvage of gravel of the Bonneville formation along the Bonneville shoreline.

GRAVEL

Lake gravel of the Alpine and Bonneville formations occurs in small local and discontinuous patches along both the eastern and western sides of the basin, mainly as constructional shore-terrace embankments. On the eastern side the gravel embankments overlie embankments of lake silt, but on the western side the silt generally is absent (fig. 40).

The embankments in the southwest corner of the valley consist of coarse gravel, derived from coarse resistant detritus from Tertiary conglomerate exposed on the piedmont west of Wellsville, from the Wells sandstone exposed from Wellsville to Sardine Canyon, and from Pine and Brushy Canyons, whose upper reaches held valley glaciers. Boulders and cobbles of blue-gray limestone from the Brazer limestone and buff-weathering calcareous sandstone from the Wells formation were washed from these canyons onto the piedmont and thence transported by waves southward into the embankments. Part of the debris from the canyons may have been deposited on the piedmont as terminal moraines; but if so, the moraines have been completely removed or reworked by wave action. These embankments of coarse gravel are undissected, in marked contrast to the embankments of fine-grained sediments. A series of embankments at the mouth of Wellsville Canyon includes several that sweep away from the shore and then recurve to meet it, thereby enclosing a depression between embankment and shore. Here, as at Reservoir Butte, in the western part of Lake Bonneville (Gilbert, 1890, p. 110), the embankments appear to have been built as the lake rose.

Eighteen feet of embankment gravel are exposed in a pit on the north side of Newton Hill, SE¼ sec. 33, T. 14 N., R. 1 W. Most of the gravel is in layers averaging a few inches thick and extending completely across the top of the embankment; but a few layers are two to three times the average thickness. Only the thicker layers are crossbedded, which also suggests that the embankments were built while the lake level was steadily rising.

Deltaic gravel was deposited at or near the mouths of the larger canyons on the eastern side of the valley. The mouths of most of these canyons were graded below the higher lake levels, and they were drowned for some distance upstream when the lake stood at these levels, causing deltaic deposition to be largely confined within the canyons. These intracanyon deltas subsequently have been eroded, except for local remnants. Examples of such deltas are those of Smithfield and High Creeks (the Smithfield Creek delta contains an unusually large amount of silt). No deltaic deposits remain in the canyons of the Logan River and Blacksmith Fork, but unusually thick shore-terrace embankments of gravel bordering the mouths of these canyons suggest that their deltas reached the edge of Cache Valley. Deltas were built into Cache Valley where the canyon mouths were graded to the higher shorelines, notably at the mouths of Millville and Providence Canyons. Such deltas are asymmetric, lying mostly south of the canyon mouths, attesting to southward-flowing longshore currents. At Green Canyon (north of Logan) the gravel was entirely

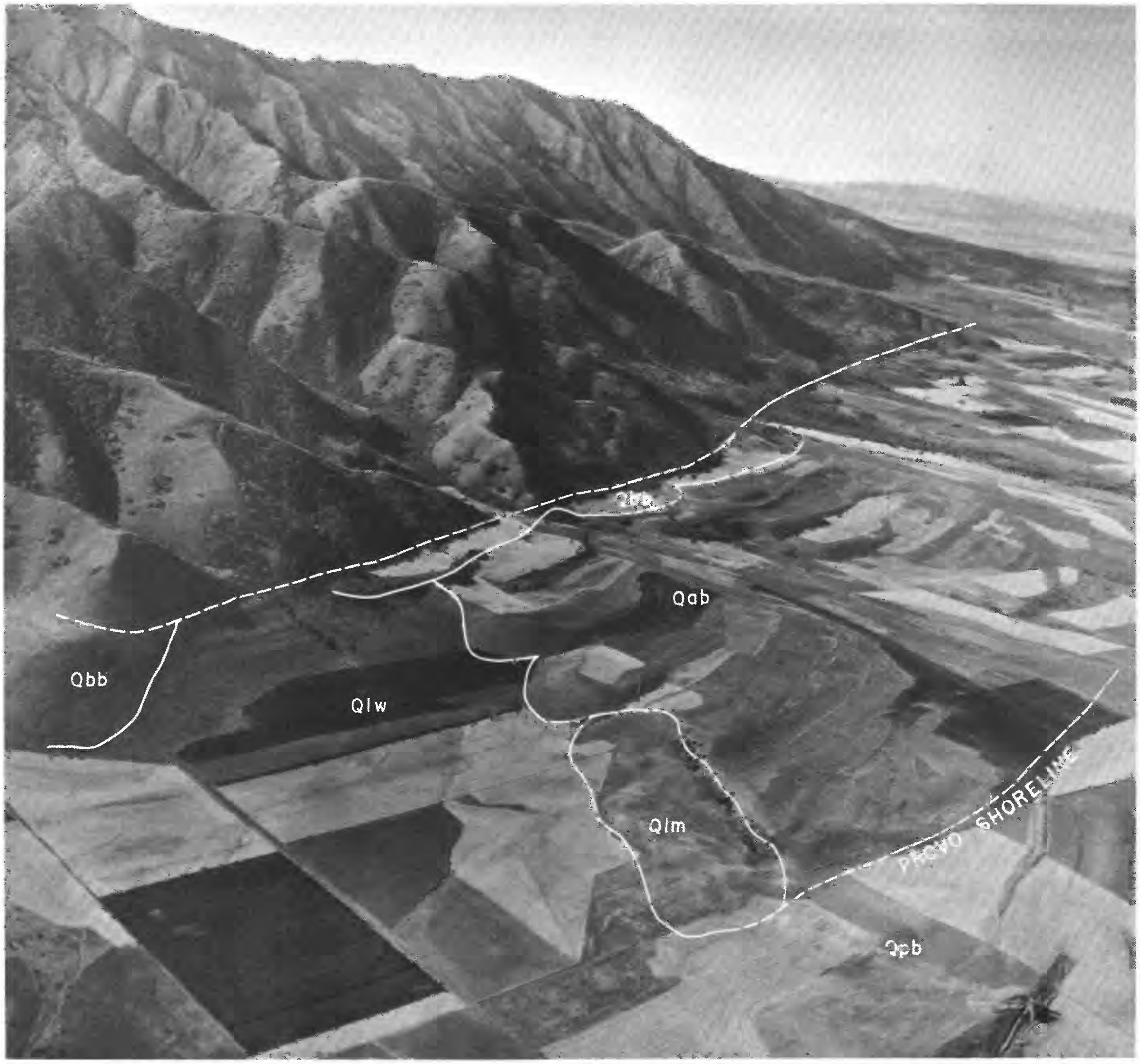

FIGURE 40.—Embankments of gravel of the Alpine and Bonneville formations. Oblique aerial view to northwest from Wellsville; Wellsville Mountain at left. Qab, Alpine and Bonneville formations, undifferentiated; Qbb, Bonneville formation; Qpb, Provo formation; Qlm, landslide; Qlw, post-Lake Bonneville slope wash. Photograph by Bert Allen.

transported into shore embankments and no delta was formed.

The gravel mapped as Bonneville formation along the Bonneville shoreline is thin and discontinuous. The thickest deposits are bars of coarse and rather angular gravel, formed at the ends of wave-cut terraces where the shoreline extends from a ridge or headland across a small canyon or bay. Where the bay was deep, an epaulet-shaped bar was formed on the side of the ravine; where the bay was shallow, a crescentic bar was built completely across the mouth of the bay.

The only delta at the Bonneville level is at the mouth of Providence Canyon, which now has a perennial stream. The large gravel embankments at the Bonneville level on both sides of Pine Canyon, west of Wellsville (fig. 40), reflect the large amount of debris that moved down this canyon, much of it perhaps glacial outwash. Strong shore currents moved the debris laterally into the embankments and no delta was formed.

Gravel referred to the Alpine and Bonneville formations crops out locally in small hills that project above lowland benches mantled by lake-bottom silt and clay of the Provo formation; the gravel appears to stratigraphically underlie the Provo. In a hill north of Mendon, in sec. 5, T. 11 N., R. 1 W., the lake gravel largely mantles a buried hill of conglomerate of the Salt Lake formation and appears to have been derived by wave erosion of the bedrock. On the eastern side of the valley are three occurrences: in North Logan at Greenville (secs. 22 and 23, T. 12 N., R. 1 E.); north of Smithfield, in sec. 21, T. 13 N., R. 1 E.; and south of Providence, on the line between secs. 10 and 15, T. 11 N., R. 1 E. In all these occurrences the gravel is well sorted, crossbedded, and comparable in lithology, fragment size, and degree of sorting to the gravel in nearby deltas of Provo age.

SILT AND FINE SAND

Current-built embankments of buff silt and fine sand are the outstanding feature of Lake Bonneville deposits at levels between the Provo and Bonneville shorelines (fig. 41). The deposits may have been derived from erosion of the pre-Wisconsin soil that presumably thickly mantled the hills and valley before Lake Bonne-

FIGURE 41.—Eroded embankment of silt and fine sand of the Alpine and Bonneville formations. Oblique aerial view southeast from 1 mile southeast of Hyrum showing Provo delta of Blacksmith Fork and Little Bear River in foreground. Photograph by Bert Allen.

ville time (Hunt and Sokoloff, 1950). The embankments extend almost continuously along the east side of the valley and are well developed along the west side from Cornish to Mendon. Here they provide patches of arable land, in the midst of rocky or stony ground that was formed by the older and underlying rocks. These embankments have been severely dissected by closely spaced generally parallel gullies consequent upon the soft and only moderately permeable silts, forming a subdued "badland" topography. At many localities, particularly along the east side of the valley, embankments that once were continuous for miles when first uncovered by the shrinking lake are now represented by scattered low mounds and parallel ridges (transverse to the valley side), as a result of being cut by streams from the mountains.

The wide embankment in sec. 15, T. 10 N., R. 1 E. (fig. 41) appears to preserve its original configuration on the interstream ridges, except at their upper ends where the silt has been removed. This embankment is half a mile wide, 30 feet thick, and lies upon a pediment sloping 10°. Other embankments, such as those between Logan and Providence, thicken valleyward and end in steep slopes, which may approximate the original shape of their lakeward edges.

Stratification in the silt embankments does not parallel the underlying surface, but is for the most part horizontal. Presumably the constituent sediments were moved into place by traction rather than in suspension, a conclusion also indicated by the occurrence of the sediments in distinct embankments or terraces at the shore. Embankments of uniform height around the valley sides presumably indicate deposition during steadily rising water level. In places the silt also appears to lie upon lake gravel of the Alpine and Bonneville formations, a relationship that further suggests overlap by a rising lake. This kind of an overlap is exposed in secs. 27 and 33, T. 11 N., R. 1 E., northwest of Wellsville and northeast of Paradise in secs. 22 and 27, T. 10 N., R. 1 E. Also, on High Creek, in sec. 7, T. 14 N., R. 2 E., silt overlies deltaic gravel.

The preponderance of silt and fine sand in the embankments can be explained in two ways:

1. Where the lake transgressed foothill slopes of soft and deeply weathered rocks of the Salt Lake formation, waves stirred up much silt and fine sand, which was transported by shore currents onto the embankments. This seems to have been the source for the embankments between the major canyons of the east side of the valley north of Green Canyon, on Hyrum Bench south of Hyrum Reservoir, and on Junction Hills (west of the mapped area) and Bergeson Hill.

2. In the principal tributary streams, slack water extended far up the canyons and most of the gravel was deposited there; only fine-grained detritus was transported to the open lake to contribute to the embankments being built by the shore drift. The extensive embankments between Green Canyon and Paradise on the east side of the valley probably were derived in this manner.

PROVO FORMATION

Hunt (1953, p. 21) defined the Provo formation in northern Utah Valley as the deposits that were laid down while Lake Bonneville stood at what Gilbert (1890, p. 126–134) called the Provo stage. This usage is followed in this report.

The Provo is the most extensively exposed formation in the Lake Bonneville group in Cache Valley. It is subdivided into two members, the gravel and sand member and the silt and clay member, which are intertonguing and intergrading lithofacies units of virtually similar age.

GRAVEL AND SAND MEMBER

The gravel and sand member makes up numerous deltas, bars, and spits; the largest of such features are in the valley. The deltas are the most important shore deposits of Lake Bonneville, in bulk as well as in area. They cover nearly 15 square miles in the mapped area and reach a maximum thickness of about 70 feet. Most of their sediment was deposited while the lake stood at the Provo level; minor increments were deposited when the lake receded from this level. Each of the principal streams entering the east side of the valley formed a large delta of the Provo formation, and several of these deltas coalesced with adjacent ones. The delta of Blacksmith Fork coalesced with those of Little Bear River and Millville Canyon, the delta of Logan River merged with the small delta of Green Canyon, and the deltas of High and Cherry Creeks also joined. On several deltas, coeval fan gravel intergrades with the lacustrine gravel and sand and is mapped with the gravel and sand member of the Provo formation. The fan gravel locally extends considerably above the Provo shoreline—clear up to the Bonneville shoreline on the composite delta and fan below Providence Canyon.

The smaller deltas are composed entirely of gravel; but the larger ones of Logan River, Blacksmith Fork, and Little Bear River contain considerable amounts of sand and silt. A road cut of the Logan River delta at Logan, where Sixth East Street descends toward Logan River, exposes 20 feet of laminated silt and fine sand. Eastward from this locality along a canal and westward in other road cuts the same fine-grained sediments are exposed for nearly a mile. Two wide patches of sand on the delta at Logan contain no pebbles. There are similar but less extensive exposures on the south side of the river.

The deltas of Blacksmith Fork, sec. 34, T. 11 N., R. 1 E., and of Little Bear River at Hyrum Reservoir, sec. 8, T. 11 N., R. 1 E., also contain fine-grained sediments. Three large patches of sand on the surface of the Blacksmith Fork delta contain no pebbles.

The largest bar of gravel and sand of the Provo formation crosses the south end of the valley from the dam at Hyrum Reservoir to the Pisgah Hills at the mouth of Wellsville Canyon, a distance of 3½ miles (fig. 42). The bar attains a maximum width of 1 mile near its east end. It is called the Sterling bar, from Sterling Bench, a farming area on its west half, and is composed of sand and fine gravel swept westward from the edge of the Provo delta of Blacksmith Fork. Behind and south of the bar are two shallow depressions floored with Recent slope wash and silt.

A spit of the gravel and sand member extends southward from Cherry Creek in sec. 23, T. 14 N., R. 1 E.,

FIGURE 42.—Sterling bar of gravel and sand of the Provo formation. In upper left are eroded embankments of silt and fine sand of the Alpine and Bonneville formations. Oblique aerial view is to southwest from Hyrum Reservoir. Photograph by Bert Allen.

and another spit of this member, nearly 1 mile long and 100 feet thick, extends southward from the edge of the piedmont west of Wellsville. The gravel appears to have been derived from the Tertiary conglomerate in the piedmont. Several fairly large embankments of similar lithology flank Newton Hill at the Provo and lower levels. The gravel came from conglomerate of the Salt Lake formation.

SILT AND CLAY MEMBER

The silt and clay member of the Provo formation represents sediment that settled from suspension in the lake water onto the lake bottom. This member underlies much of the lowlands of Cache Valley, but it is rarely exposed to depth, owing to its low position and susceptibility to erosion. The best exposures are along the low bluffs bordering the flood plains of the Bear River and its tributaries. About 20 feet of the member is exposed in bluffs along the river northwest of Cache Junction, in NW¼ sec. 30, T. 13 N., R. 1 W. About 10 feet of the member is exposed west of Richmond on the north side of State Highway 170, where it rises through the bluffs west of Cub River, near the west boundary of sec. 28, T. 14 N., R. 1 E. About 15 feet is exposed in a deep gully north of Smithfield, along the lane that follows the north boundary of sec. 16, T. 13 N., R. 1 E.

Table 3 shows mechanical analyses of composite samples of the sediment from these localities, over the intervals indicated. A bottom withdrawal tube was used to make the particle-size separations. The samples are largely silt; 75 to 87 percent of the particles is smaller than sand size and only 8 to 15 percent smaller than silt size.

TABLE 3.—*Particle-size composition of silt and clay member of Provo formation*

Particle size (mm)	North of Cache Junction (Interval, 3–15 ft)	West of Richmond (Interval, 3–9 ft)	North of Smithfield (Interval, 3–6 ft)
0.1250	85.0	100.0	100.0
.0625	75	87	83.8
.0442	69	76	68.5
.0312	41.5	47.5	54.2
.0221	26.5	40.8	41.3
.0156	22.5	39.5	31.5
.011	18.5	26.8	24.2
.0078	14.5	23.5	18
.0055	9.2	16.5	13.2
.0039	7.8	14.8	11.5

NOTE.—Figures in columns 2–4 show the percentage of particles smaller than the particle sizes given in column 1.

LANDSLIDES OF LAKE BONNEVILLE AND POST-LAKE BONNEVILLE AGE

Several post-Bonneville shoreline landslides are mapped along the piedmont between Mendon and Wellsville. The largest is a rockslide, more than a mile long and a quarter of a mile wide, that extends across the piedmont surface from Wellsville Mountain where it originated. It is a tongue-shaped mass too rocky to farm and still covered with native brush. It resulted from undercutting the steep dipslope of the mountain face when the lake stood at the Bonneville level.

Smaller landslides involve the ends of gravel embankments at levels between the Bonneville and Provo shorelines. For example, the large embankments of the mouths of Brushy and Pine Canyons (fig. 40) were built with their distal ends over lake-bottom silt and clay. The foundation sediments were unable to support the thick piles of gravel, causing the ends of the embankments to collapse into slides. These slides may have been active any time after the embankments were built.

POST-LAKE BONNEVILLE DEPOSITS

FAN GRAVEL

Numerous alluvial fans, composed of coarse angular poorly sorted fan gravel, have been deposited over the Lake Bonneville sediments along the mountain fronts. The streams have trenched the deltas and shore embankments of gravel and sand of the Provo formation and have redeposited the sediment in fans at lower elevations, over the silt and clay member of the Provo. High, Cherry, Smithfield, and Providence Creeks have built the largest post-Provo fans, but even these are small compared with the deltas of these creeks of Provo age.

FLOOD-PLAIN ALLUVIUM

The modern flood plains are floored with coarse gravel to slightly beyond the distal edges of the deltas of Provo age; farther downstream gravel becomes increasingly finer and admixed with sand until 4 or 5 miles beyond the deltas even the stream channels are sandy and largely free of pebbles. The flood plains of the Bear River and the lowermost parts of the Cub and Little Bear Rivers are underlain mainly by sand and silt, some interbedded clay, and perhaps a little gravel locally.

ALLUVIAL SAND IN NATURAL LEVEES OF THE BEAR RIVER

No postlake deposit in Cache Valley is as widespread or as important economically as the natural levees of sand along the Bear River. These levees border the channel of the Bear River throughout its course in Cache Valley, comprising about 40 square miles of sandy well-drained ground that includes some of the best agricultural land in the valley. From Trenton southward through Amalga they are ½ to 1 mile wide, near Benson Ward they are somewhat wider, and between Cornish and Lewiston they border multiple channels and have a total maximum width of about 4½ miles.

The sand probably was derived mainly from the Provo delta of Bear River, in northern Cache Valley. When the lake level dropped below the Provo shoreline, Bear River incised its channel through the delta and moved large quantities of the sand onto the lake-bottom clay and silts. The earliest sand deposits were covered by lake-bottom silt and clay as a result of a minor readvance of the lake, and the channel through the delta was partly refilled with sand. After this interruption, the process was repeated. The river spread widely to the south and east, carrying sand as far as the Cub River, and creating the sandy area about Lewiston.

SLOPE WASH

Post-Lake Bonneville slope wash is mapped in two areas: At the south end of the valley it floors two closed basins behind the Sterling bar (p. 141). The eastern basin has received wash from a large area of silt of the Alpine and Bonneville formations; the western one, from surrounding hills of sandstone of the Wells formation. The other area is along the west side of the valley from Newton Hill to the Idaho line. Here the slope wash came from thin embankments of the Provo formation on the steep valley side.

EOLIAN SAND

Small patches of eolian sand are mapped north and east of Cornish. The sand is reworked from nearby sandy post-Lake Bonneville levees of the Bear River and forms small dunes.

SPRING TUFA CONES

West of Trenton, in Tps. 13 and 14 N., R. 1 W., several small low cones of porous limestone have been deposited by warm springs that are alined along the face of Newton Hill and north-northwestward for more than a mile. This alinement, close to and parallel with the face of Newton Hill, suggests the presence of a fault, which is called the Dayton fault zone. The cones are still growing. The outer and older parts of some of the larger cones are tilled, but the newer parts commonly are obstacles to cultivation.

INTERPRETATION OF WELL LOGS

Numerous water wells have been drilled into the Quaternary sediments in southern Cache Valley. Those drilled before 1946 are reported by Peterson (1946) in a review of the ground-water resources of the valley. Records of 16 other wells drilled between 1946 and 1952 were obtained from the office of the Utah State Engineer. Dr. O. W. Israelsen kindly provided logs of three test wells drilled in the Lewiston area as part of a drainage study made by him.

The well logs are shown in five cross sections, figures 43 to 47, whose locations are shown on plate 7. As no collar altitudes are available for the wells, the actual vertical position of the aquifers and lake-bottom members can only be inferred. Also, the spacing between logs is not proportional to the distances between wells; hence, the cross sections are largely diagrammatic.

Almost all these logs show an aquifer of sand or gravel at a depth between 50 and 100 feet, underlying an upper zone of clay and silt. This aquifer is interpreted as an interlake alluvial or deltaic deposit, and probably records recession of Lake Bonneville between the Provo and an earlier high-lake stage. Thus, the clay zone above the aquifer may represent the Provo formation, and the clay zone beneath it may belong to the Alpine and Bonneville formations.

In the wells southwest of Logan (figs. 46, 47) in the area traversed by the Logan River, Blacksmith Fork, and Little Bear River, a second distinct aquifer underlies the lower clay zone. This presumably represents an interlake episode earlier than Lake Bonneville, and perhaps is correlative with the "shallow Pleistocene artesian aquifer" of Thomas (1953, p. 83–84) in northern Utah Valley. This deep aquifer is also apparent in wells A1 and A4 in the Cornish-Lewiston section (fig. 43) and in three of the wells of the Cache Junction-Smithfield section (fig. 44). It is not so readily distinguished in the wells west of Smithfield (fig. 45), where all the sediments are finer and there is less contrast between aquifers and aquicludes.

In several logs of the section from Logan toward Wellsville (fig. 47), a thin gravel unit is shown near the surface, beneath less than 20 feet of silt and clay. These wells are adjacent to the present courses of the rivers of the area, and this high gravel may mark a late interlake event when the stream flood plains had slightly different boundaries which was followed by a brief expansion of the lake.

The well logs indicate that the Quaternary deposits in Cache Valley are very thin, suggesting that the valley had exterior drainage during most of Quaternary time.

OUTLET OF LAKE BONNEVILLE AT RED ROCK PASS

A brief examination was made of Red Rock Pass, at the north end of Cache Valley in Idaho (fig. 38) where Lake Bonneville overflowed to the Snake River. The pass is across a low east-trending ridge connecting the Northern Malad Range (west of the pass) with the Portneuf Range (east of the pass). The ridge consists of resistant Paleozoic dolomite, limestone, and shale, flanked by conglomerate and tuff of the Salt Lake formation. The highest point in the central part of the ridge is at an altitude of 5,560 feet. A pass near the

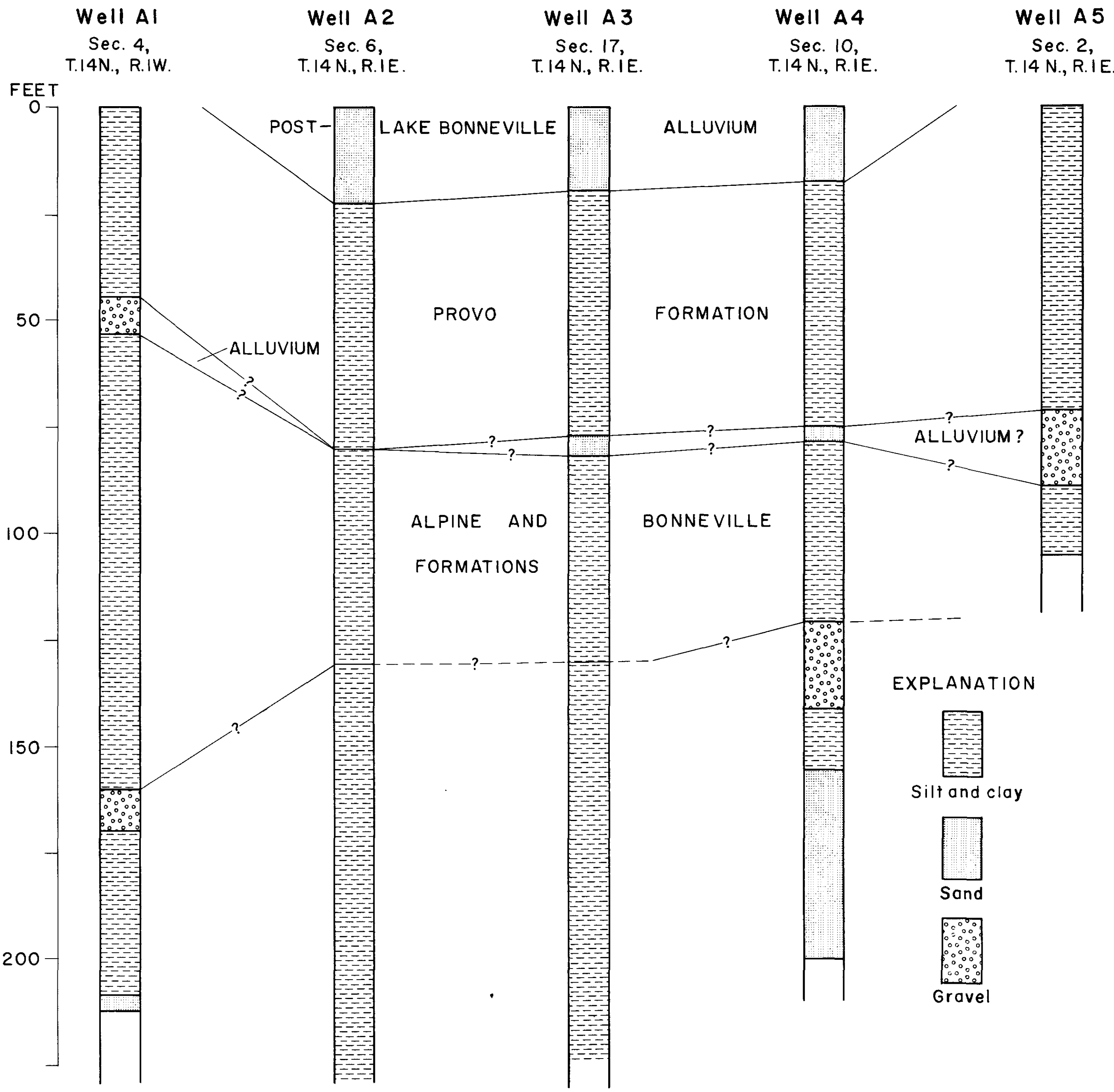

FIGURE 43.—Correlation of lake beds in Cache Valley between Cornish and Lewiston. Wells are located on plates 6 and 7. Altitudes of well collars are not accurately known and not the same, but they differ by no more than 20 feet. Spacing between logs not to scale.

east end of the ridge is 5,180 feet in altitude, but it shows no evidence of having ever served as an overflow channel. The floor of the pass is at 4,770 feet, virtually the Provo level of the lake.

The outlet channel is about 4,300 feet wide at the Bonneville shoreline level where it cuts the Paleozoic core of the ridge, but only half that wide at the bottom of the pass, that is, at the Provo level. The channel is cut in Paleozoic rocks for 2 miles and trends northwest, parallel to the strike of these rocks. These rocks dip steeply, as much as 60°, eastward. On the west wall is olive-drab shale interbedded with thin limestone layers; on the east side is little shale but much gray dolomite (probably the transition zone between the Bloomington formation on the west and the Nounan limestone on the east). A conspicuous conical hill rises from the channel bottom near the west side. It is composed of Tertiary conglomerate, probably the lower

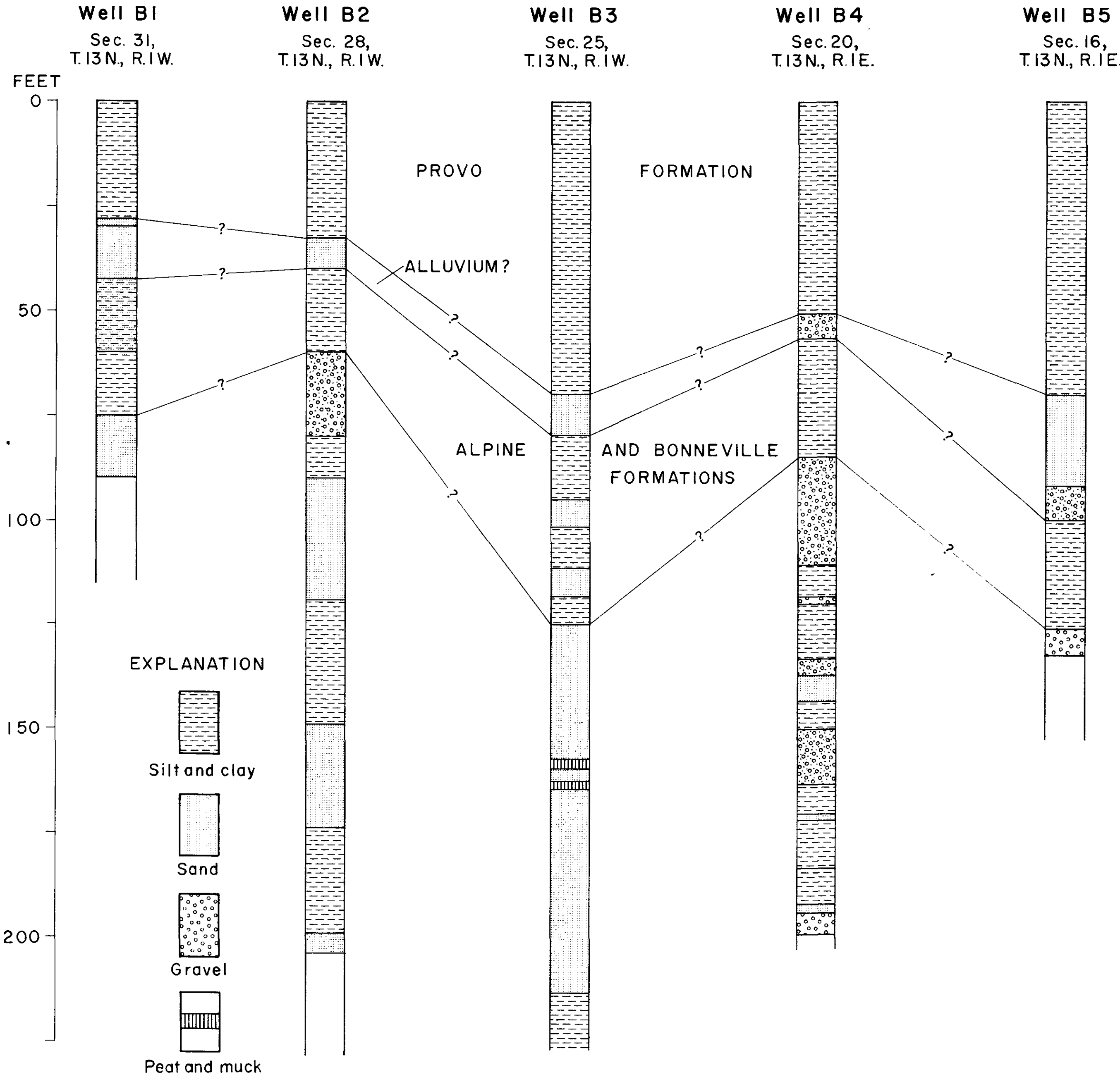

FIGURE 44.—Correlation of lake beds in Cache Valley between Cache Junction and Smithfield. Wells are located on plates 6 and 7. Altitudes of well collars are not accurately known and not the same, but they differ by no more than 50 feet at extremes of section. Spacing between logs not to scale.

conglomerate unit of the Salt Lake formation and may be either an old cayon fill in the pre-Tertiary surface of the ridge, or it may be an infaulted block.

The highest traces of the channel at the pass are approximately at an altitude of 5,135 feet, the same as the nearest marks of the Bonneville shoreline south of the pass, and probably the original elevation of the overflow point was near this figure. East of the channel in the northeast corner of sec. 32, and in the W½NW¼ sec. 29, are several abandoned channels in bedrock that probably represent temporary stands during lowering of the outlet.

A large alluvial fan, built by Marsh Creek, heads about 3 miles north-northeast of the outlet. Projected southward, the gradient of this fan falls well below the Bonneville shoreline, and thus the fan played no part in controlling the lake overflow, contrary to Gilbert's (1890, p. 175–178) interpretation.

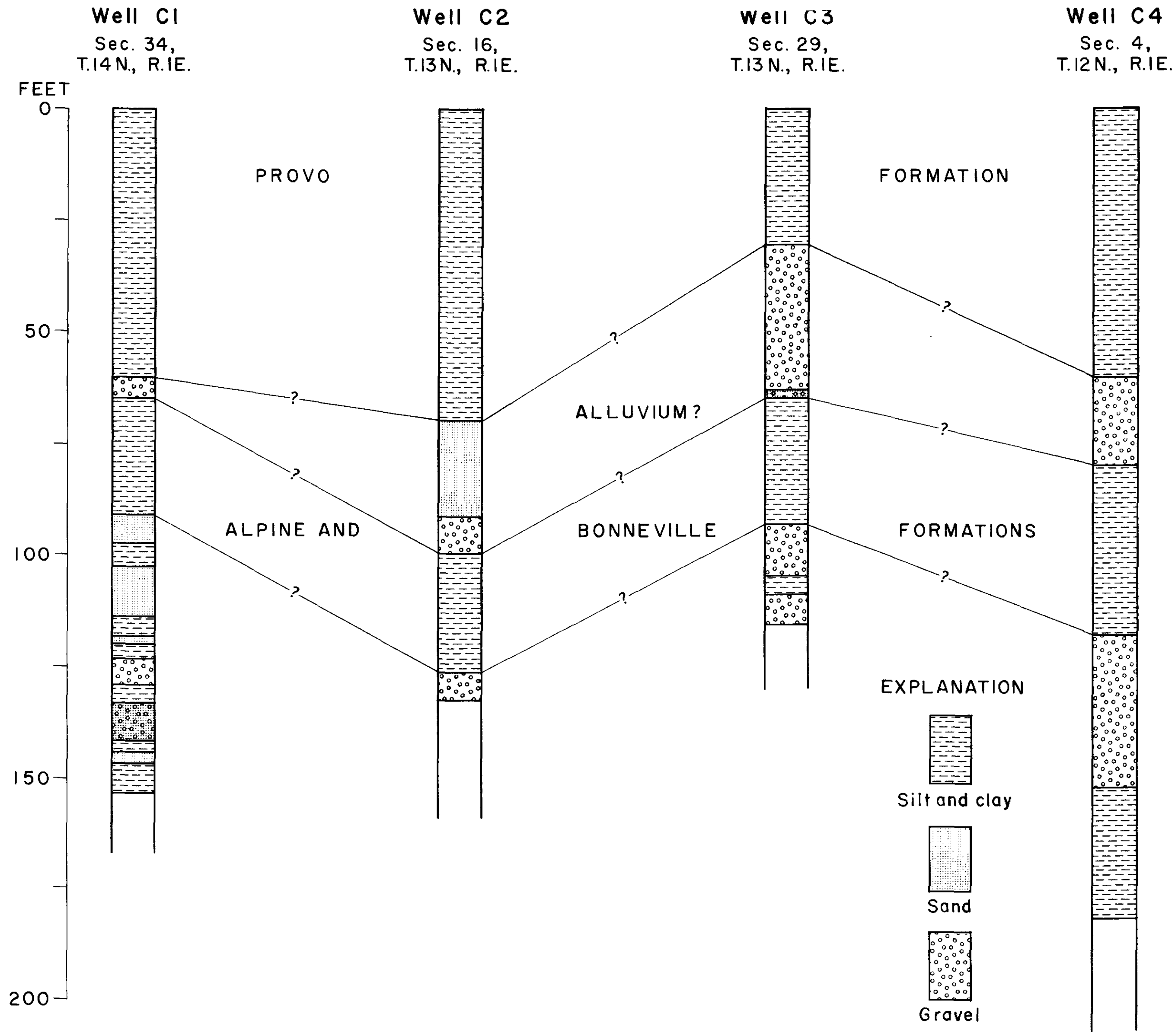

FIGURE 45.—Correlation of lake beds in Cache Valley between Richmond and Smithfield. Wells are located on plates 6 and 7. Altitudes of well collars are not accurately known and not the same, but they differ by no more than 25 feet. Spacing between logs not to scale.

STRUCTURAL GEOLOGY

Southern Cache Valley probably is a graben bounded by high-angle normal faults similar to those that bound other basins of the Basin and Range province. Although earlier folding and faulting in the surrounding mountains is assumed, the evolution of the present features of the valley apparently began in the middle Tertiary and has continued to the present. The major faults displace Wasatch and older units and, locally, beds of the Salt Lake formation. No displacement of the Lake Bonneville group was recognized.

In most of southern Cache Valley the beds of the Salt Lake dip moderately to steeply. In some areas, dips change markedly in direction and magnitude over short distances, presumably because of faulting; elsewhere, strikes and dips are fairly uniform for miles. Some of the faults of post-Salt Lake time lie basinward from the mountain fronts, causing foothill benches of Tertiary rock above the general level of the valley floor. Only the major faults are mapped. Intermittent or fairly continuous faulting and tilting during deposition of the Salt Lake formation is indicated by unconformities between the various units of the group.

On the west side of the valley are the Clarkston and Dayton fault zones and the Wellsville and Willow Grove faults; along the east side of the valley is the

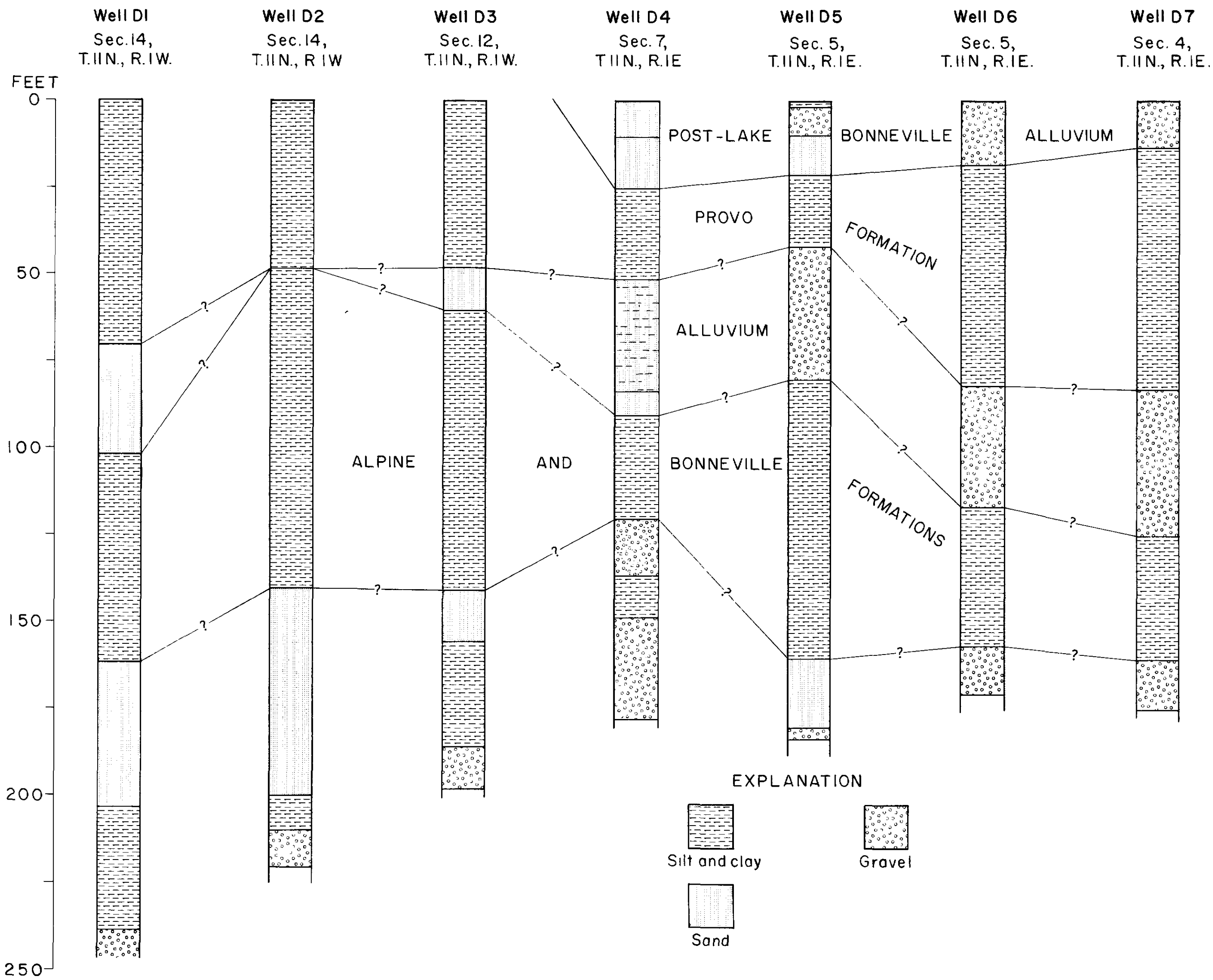

FIGURE 46.—Correlation of lake beds in Cache Valley southwest of Logan. Wells are located on plates 6 and 7. Altitudes of well collars are not accurately known and not the same. Altitude along section increases from 4,435 feet at west to about 4,500 feet at east. Spacing between logs not to scale.

East Cache Valley fault zone. Only the Willow Grove fault is actually exposed in the area mapped; the others are concealed by Salt Lake or Quaternary deposits, but are inferred from physiographic evidence to lie close to the foot of the steep mountain slopes.

The Clarkston fault zone extends from north of Cache Junction southward along the base of Cache Butte. The fault is inferred from the escarpment at Cache Butte, which rises several hundred feet from the valley floor and exposes both Paleozoic rocks and oolitic limestone and tuff of the Salt Lake formation. The Dayton fault zone borders Newton and Bergeson Hills on the east and extends far to the north beyond the boundary of the map to Red Rock Pass, the outlet of former Lake Bonneville. Rocks of the Salt Lake exposed on the east side of Bergeson Hill and on Newton Hill are brecciated because of movement in this fault zone, although massive beds of oolitic limestone in the isolated hill in sec. 19, T. 12 N., R. 1 W., are undeformed. In secs. 28 and 33, T. 14 N., R. 1 W., and sec. 3, T. 13 N., R. 1 W., small warm springs, marked by low tufa cones, are alined at the based of an escarpment along the main fault. Several small faults of similar trend, but small displacement, appear along Bergeson Hill.

The Willow Grove fault extends northward along Hyrum Bench, parallel to the inferred fault at the eastern margin of Paradise Bench. The beds on the east side of the fault appear to have been downdropped and rotated until they lie nearly horizontal against the moderately dipping beds on the west side. The beds west of the fault, in the upper conglomerate and

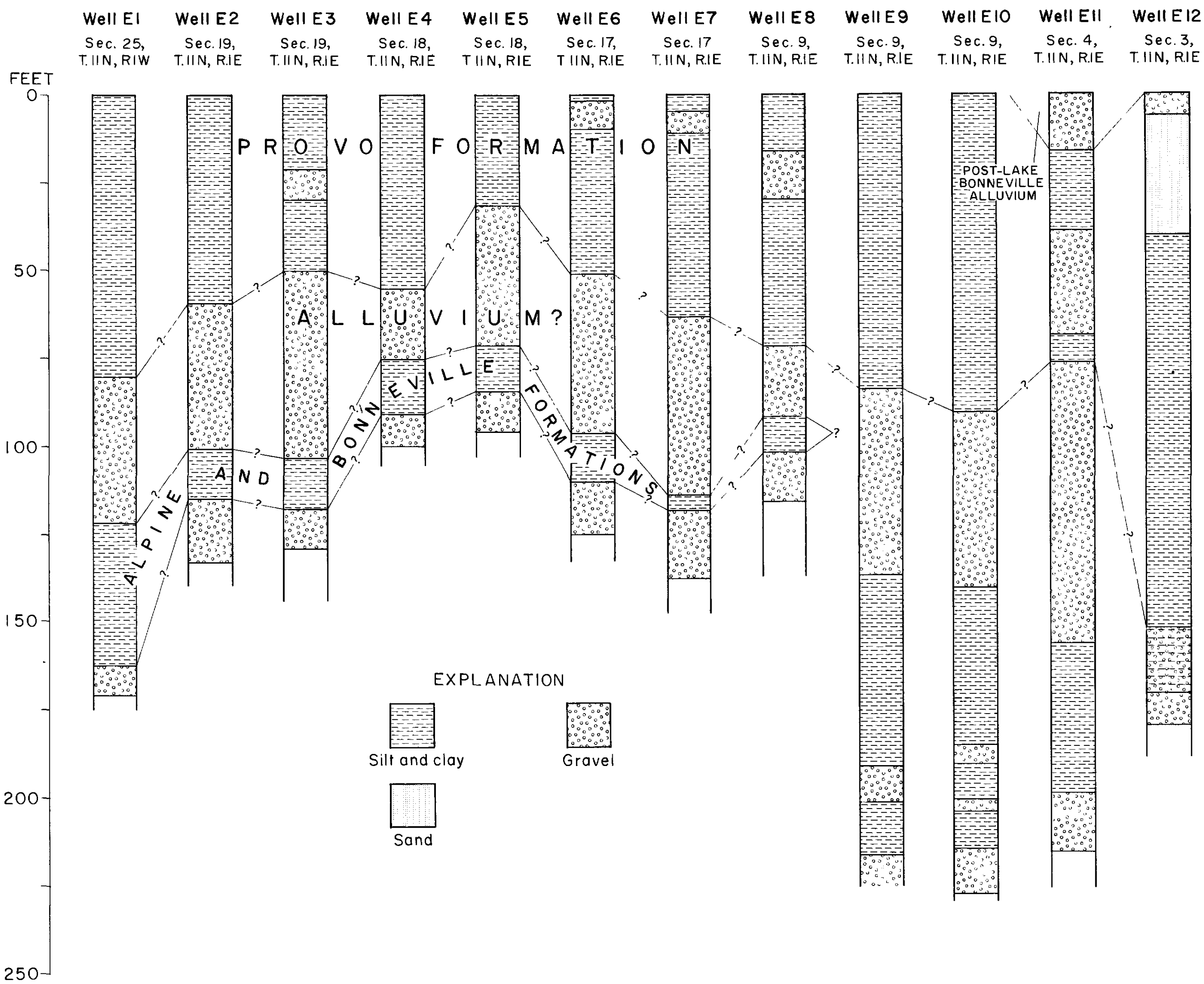

FIGURE 47.—Correlation of lake beds in Cache Valley from Logan toward Wellsville. Wells are located on plates 6 and 7. Altitudes of well collars are not known and not the same, but they differ less than 100 feet from east (highest) to west ends of line. Spacing between logs not to scale.

sandstone unit of the Salt Lake formation are fairly regular in attitude from the Hyrum Reservoir south into Big Spring Hollow, a distance of 5 miles. Their strike averages N. 45° W. and their dip 25° to the northeast.

ENGINEERING GEOLOGY

GROUND WATER

Cache Valley is well watered. At least five major perennial streams cross the valley, and several smaller ones contribute substantially to surface and subsurface water supplies. The Lake Bonneville group and pre-Lake Bonneville sediments of Quaternary age constitute the ground-water reservoir of the valley, and the underlying much better consolidated and less permeable rocks of the Salt Lake form the sides and bottom of the basin. The ground-water supplies have been reported on by Peterson (1946).

Beneath the central lowlands the water table is within a few feet of the surface throughout the year, and in many places is so shallow as to create serious drainage problems. On the deltas and shore embankments of the Lake Bonneville group, however, the depth to water is locally 100 feet or more. The high water table makes shallow wells possible everywhere on the valley floor, but such wells are uncommon because of the ease of obtaining artesian water that is more potable and less likely to be contaminated. Artesian water is obtained from two principal aquifers of gravel and sand (p. 136, and figs. 39, 43–47), which are separated by relatively impermeable clayey zones. The map (pl. 7), showing the artesian piezometric surface, probably represents a composite pressure surface, as many wells tap both aquifers. The isopiestic lines show that recharge to the aquifers is by perennial streams where they emerge from canyons onto the alluvial fans or lake deltas.

East and north of Newton Hill are several warm springs marked by low cones of porous tufa (p. 143).

CONSTRUCTION MATERIALS

The delta, bar, and Recent flood-plain deposits in Cache Valley are sources of sand and gravel for construction materials. The principal and preferred sources for sand and gravel are the deltas of the Provo stage that are adjacent to the larger canyons and larger towns along the east side of the valley, but gravel shore embankments and stream-channel deposits also have been utilized; thus, gravel pits are rather evenly and widely distributed in the valley.

The largest sand and gravel operations are near Logan. Here the sand is screened from the pebbles and cobbles, crushing the latter down to the maximum diameter suitable for concrete aggregate. Both the sand and coarse aggregate are washed. At the smaller pits elsewhere the demand does not justify crushing or washing, and the sand and gravel are merely separated by screening without further processing. In sec. 14, T. 14 N., R. 1 E., at Merrills, and in sec. 21, T. 11 N., R. 1 E., at Nibley, pits have been opened in post-lake stream gravel. Between Richmond and Smithfield and also east of Paradise are small pits in embankments of Alpine and Bonneville sediment. Just west of Wellsville a pit utilizes gravel from the large spit at the Provo level (p. 142), but the large embankments of gravel of the Alpine and Bonneville formations farther from town have not been utilized. Small quantities of gravel have been excavated from a pre-Lake Bonneville deposit north of Mendon and from three gravel embankments on the south side of Newton Hill, at and below the Provo level. On the north end of Newton Hill, pits have been opened in embankments of the Alpine, Bonneville, and Provo formations; but here the gravel is crumbly, for the pebbles and cobbles consist of soft tuff and tuffaceous sandstone of the Salt Lake formation.

Much of the gravel has been utilized for road metal. Every pit has supplied some gravel, and some pits have been operated solely for road-building material. Through the years large quantities of gravel have been distributed along the roads not only to raise the grades and provide better drainage, but also to improve the road surfaces. The first pavements of concrete utilized large quantities of gravel for aggregate, and the most common form of paving today, a bituminous mix, requires finely crushed stone. Both the gravel and the stone have been supplied largely from the gravel deltas and embankments of the Provo formation.

The crumbly gravel from the west side of the valley near Trenton and Cornish, in which the pebbles and cobbles are composed of soft tuff and tuffaceous sandstone, provides a satisfactory surface on secondary roads. It breaks down to a degree just sufficient to make a desirably smooth surface on little-traveled lanes and farm-access roads.

The lake-bottom sediments on the floor of Cache Valley include a large quantity of clay suitable for the manufacture of bricks, but only one brick kiln, in the northwestern part of Smithfield, has been operated in the valley. Here, to 1957, most of one city block has been excavated to a depth of about 15 feet. During the present building boom (1957) much brick used in Cache Valley is being brought from larger plants at Ogden and Salt Lake City. Clay that appears identical with that at Smithfield extends northward for 6 miles in a belt 2 miles wide, and this area represents but a small part of the clay underlying the whole valley floor.

ENGINEERING APPLICATIONS

In Cache Valley at least 35 percent of the farmland lies below irrigation canals, and about 75 percent of the total crop value is produced from irrigated land. Water is obtained from every perennial stream entering the valley; but Bear, Little Bear, Logan, and Blacksmith Fork Rivers furnish most of the supply, particularly late in the growing season. The canals cross all the geologic formations in the valley, and their seepage losses range widely, from negligible to as high as 50 percent of the total flow in a distance of 1,800 feet. Generally speaking, seepage losses are high to moderate on the deltas and lake embankments of gravel and sand, gravel flood plains, and alluvial fans, and sandy natural levees of the Bear River; they are moderate to low on pediments and foothill slopes on the Wasatch and Salt Lake formations; and low to negligible on the embankments of silt and fine sand of the Alpine and Bonneville formations and on silt and clay of the Provo formation in the valley bottom. Improved efficiency in maintenance and improvement of the agricultural lands require the elimination, as far as practicable, of seepage losses by lining the canals where they cross permeable deposits. The best natural material in the valley for lining canals is clay of the Provo formation, and it is available throughout the valley within a mile or two of where it will be required.

Three types of areas require drainage to be productive cropland. Most of the poorly drained areas occur where silt and clay emerge from beneath more permeable deposits of gravel and sand in shore embankments, deltas, or alluvial fans. Water, infiltrating the gravel, travels downward to the water table perched on the clay, then percolates valleyward to seep out at the toe of the gravel deposit and saturate a strip of land below. Irrigation on the gravel deltas, fans, and embankments increases the discharge of the seeps. The largest of these seep areas are on the east side of the valley, below the large deltas and fans. On the west side of the valley, however, from Trenton to the Idaho line, is an almost continuous line of seeps, along the contact of gravelly colluvium and fan gravel overlying silt and clay of the Provo formation. Seep areas of this type can be corrected or ameliorated by reducing canal seepage losses from canals crossing the overlying gravel deposits, by reducing irrigation of these areas, and by constructing drainage canals just downslope from the contact of the gravel and underlying clay.

The sandy natural levees along the Bear River comprise about 40 square miles of excellent cropland in the north end of the valley. Water seeping from Bear River, from irrigation canals, and from irrigated fields, sinks rapidly to the base of the sand where it forms a water table perched on the underlying clay, and then emerges at the outer edge of the sand deposit. Over the thinner outer parts of the levees farming is possible only where open or subsurface drains have been constructed.

An area northwest of Logan, between U.S. Highway 91 and the Logan-Cache airport, is waterlogged by artesian water moving upward from a gravel aquifer about 40 feet below the ground surface (Israelsen and McLaughlin, 1935).

Two small earthfill dams have been constructed by the U.S. Bureau of Reclamation, one near Hyrum in sec. 7, T. 10 N., R. 1 E., the other near Newton in sec. 5, T. 13 N., R. 1 W. The dam near Hyrum is 500 feet long, 90 feet high, and impounds the Little Bear River. The stream's course at this point is along the contact between deltaic gravel of the Provo and Salt Lake formations. Fill for the dam consisted of silt and fine sand, with some small pebbles, from a Provo level bar half a mile west of the damsite. Blocks of massive oolitic limestone, from a bedrock hill half a mile south of the damsite, were used for facing the dam.

The dam near Newton is on the west side of Newton Hill, which is underlain by thin-bedded tuffaceous sandstone of the Salt Lake formation. The abutment of the dam is in a pre-Lake Bonneville landslide composed of this sandstone, and fill for the dam was obtained from the slide mass. The dam is faced with blocks of oolitic limestone from an outcrop of the Salt Lake formation 2 miles west of the town of Newton. Gravel from the large bars of the Alpine and Bonneville formations just north of the dam were unsuitable for concrete aggregate because they contain too much soft tuffaceous sandstone.

REFERENCES CITED

Adamson, R. D., Hardy, C. T., and Williams, J. S., 1955, Tertiary rocks of Cache Valley, Utah and Idaho, *in* Utah Geol. Soc. Guidebook 10, p. 1–22.

Bissell, H. J., 1962, Lake Bonneville—Geology of southern Utah Valley, Utah: U.S. Geol. Survey Prof. Paper 257–B, p. 101–130.

Brown, R. W., 1949, Pliocene plants from Cache Valley, Utah: Washington Acad. Sci. Jour., v. 39, no. 7, p. 224–229.

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

Gilbert, G. K., 1890, Lake Bonneville: U.S. Geol. Survey Mon., v. 1, 438 p.

Hayden, F. V., 1869, Preliminary field report of the United States Geological Survey of Colorado and New Mexico: U.S. Geol. and Geog. Survey of the Terr. (Hayden), 3d Ann. [Prelim.] Field Rept., 155 p., [rep. 1873, p. 103–261].

Hunt, C. B., 1953, *in* 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, p. 11–47.

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.

Israelsen, O. W., and McLaughlin, W. W., 1935, Drainage of land overlying an artesian ground water reservoir: Utah Agr. Expt. Sta. Bull. 259.

Mansfield, G. R., 1920, The Wasatch and Salt Lake formations of southeastern Idaho: Am. Jour. Sci., 4th ser., v. 49, p. 399–406.

——— 1927, Geography, geology, and mineral resources of part of southeastern Idaho: U.S. Geol. Survey Prof. Paper 152, 409 p.

Peale, A. C., 1879, Report on the geology of the Green River district [Wyo.]: U.S. Geol. Geog. Survey Terr. (Hayden) Ann. Rept. 11, p. 509–646.

Peterson, W., 1946, Ground water supply in Cache Valley, Utah, available for domestic use and irrigation: Utah State Agr. College Ext. Service, N.S. 133.

Slentz, L. W., 1955, Salt Lake group in lower Jordan Valley, Utah, *in* Utah Geol. Soc. Guidebook 10, p. 23–36.

Smith, N. J., 1953, Tertiary stratigraphy of northern Utah and southeastern Idaho, *in* Intermountain Assoc. Petroleum Geologists, 4th Ann. Field Conf., p. 73–77.

Swain, F. M., 1947, Tertiary non-marine Ostracoda from the Salt Lake formation, northern Utah: Jour. Paleontology, v. 21, no. 6, p. 518–528.

Thomas, H. E., 1953, Water resources, *in* 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, p. 60–92.

Williams, J. S., 1948, Geology of the Paleozoic rocks, Logan quadrangle, Utah: Geol. Soc. America Bull., v. 59, no. 11, p. 1121–1163.

Yen, Teng-Chien, 1947, Pliocene fresh-water mollusks from northern Utah: Jour. Paleontology, v. 21, no. 3, p. 268–277.

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STEWART L. UDALL, *Secretary*

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