Guide to the Geology of the Wasatch Mountain Front, Between Provo Canyon and Y Mountain, Northeast of Provo, Utah

J. Keith Rigby and Lehi F. Hintze

Studies for Students No. 1

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by

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Studies for Students supplements the regular issue of *Brigham Young University Geology Studies* and is intended as a series of short papers of general interest and a guide which may serve to introduce beginning students and other interested individuals to geology and to the geology of Utah.

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INTRODUCTION

Landscape features of Utah Valley (Text-fig. 1) have been brought to their present form through the interplay between two different geologic processes: faulting, mainly along the Wasatch Fault zone; and depositing of sediments in an Ice-Age lake called Lake Bonneville which intermittently filled the valley.
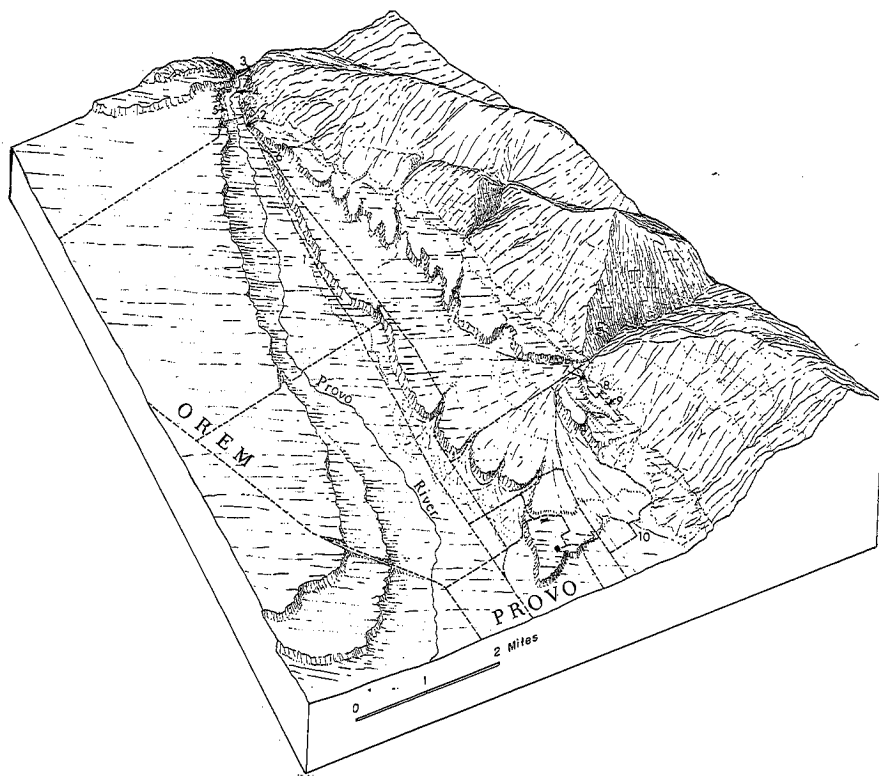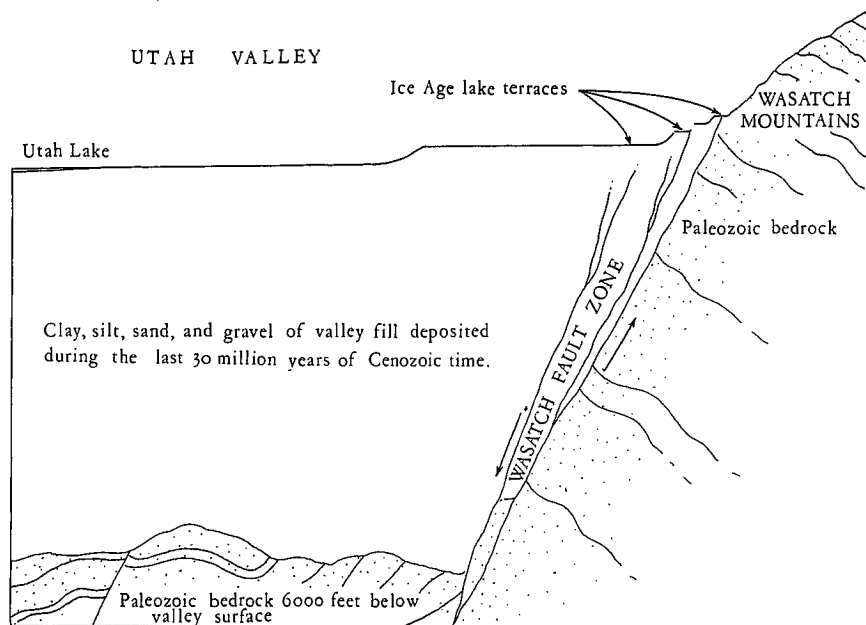

TEXT-FIGURE 1.—Physiographic diagram of the valley of Provo River and the front of the Wasatch Mountains between Provo Canyon and Y Mountain. Heavy dashed lines are main roads and show the route of the fieldtrip. Geologic stops are numbered to correspond with the road log.

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Faulting has produced the grandest effects. In fact Utah Valley would not exist had there not been thousands of feet of vertical displacement along the Wasatch Fault. This fault has been intermittently active throughout the last 30 million years and has raised the Wasatch Range to its present prominence, at the same time allowing the valley area to remain at a low elevation.

While the faulting has been proceeding, another geologic process has been steadily at work. Erosion of the uplifted mountain mass has brought stream gravel, sand, and mud into Utah Valley and built up an accumulation of this stream-transported sediment more than a mile in thickness (Text-fig. 2).

At the very top of this accumulation of valley-filling sediment are recorded some of the latest events in the geologic history of Utah Valley, namely, the events related to an extensive lake called Lake Bonneville, which intermittently filled the lower parts of Utah Valley to various levels during the last million years or so in what geologists call the Pleistocene Ice Age.

UTAH   VALLEY

Ice Age lake terraces

WASATCH
MOUNTAINS

Utah Lake

Paleozoic bedrock

Clay, silt, sand, and gravel of valley fill deposited
during the last 30 million years of Cenozoic time.

WASATCH FAULT ZONE

Paleozoic bedrock 6000 feet below
valley surface

TEXT-FIGURE 2.—Generalized cross-section from Utah Lake and Utah Valley through the Wasatch Fault Zone to the Wasatch Mountains. Utah Valley is filled to its present level by debris washed from the adjacent mountains which has buried Paleozoic bedrock within the valley.

The most striking evidences for Lake Bonneville are its many terraces which remain to our view (Text-figs. 1, 4), features which developed on the valley sides much as rings on a bathtub. More extensive flat areas developed where deltas of major rivers, such as the Provo River, were built into the lake as it stood at various levels.

ROAD LOG
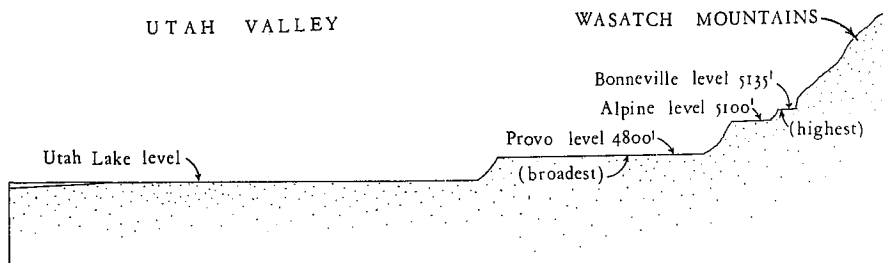
Mileage
Interval   Cumulative

0.0   0.0   PARKING LOT, EAST SIDE OF EYRING SCIENCE
                    CENTER. Proceed from here toward the north entrance of
                    the campus, north of the Smoot Administration Building.
                    The upper campus of Brigham Young University is built on
                    a large flat above the general level of Utah Valley (Text-
                    figs., 1, 3).

                         This flat surface was formed sometime within the
                    latest million years of earth history when a large fresh-water
                    lake, called Lake Bonneville, filled most of the valleys of
                    western Utah (Text-fig. 5). The level of this lake fluctuated,
                    according to rainfall, from the present Utah Lake level at
                    elevation 4490 feet to the highest level, called "Bonneville"
                    level, at elevation 5135 feet. The "Provo" level of the lake
                    is the best marked of all levels, and was formed after the
                    lake waters overflowed their "Bonneville" level at a pass
                    leading to the Snake River in southern Idaho. The rushing
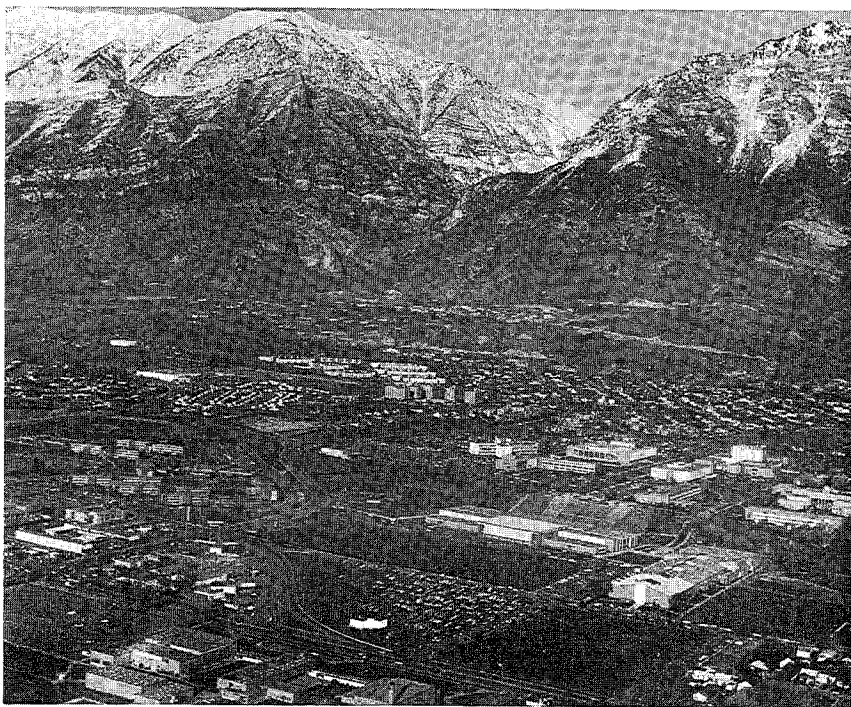
TEXT-FIGURE 3.—Aerial view to the northeast across the campus of Brigham Young
    University showing the Provo delta surface and the higher terraces of Lake Bonne-
    ville on either side of Rock Canyon.

UTAH   VALLEY   WASATCH   MOUNTAINS

Bonneville level 5135'
Alpine level 5100'
Provo level 4800'
Utah Lake level
(broadest)   (highest)

TEXT-FIGURE 4.—Generalized cross-section from Utah Lake to the Wasatch Mountains showing relationships and elevations of the various lake levels evident in Utah Valley. Provo, Alpine, and Bonneville levels are terraces and deltas associated with Lake Bonneville.

water quickly cut a canyon down to a resistant rock stratum there which served to stabilize the lake level at an elevation of about 4800 feet. The lake apparently rose to the level of this outlet several times during its history, and each time this occurred the beaches and deltas at this level were enlarged until as we see them today they form the most conspicuous remnants of geologic activity in this Ice-Age lake. We call this most prominent level the "Provo" level because the Ice-Age Provo River built a tremendous delta into the lake. Parts of this delta are preserved to us as the Orem bench and the Edgemont bench, and the bench on which the BYU upper campus is built (Text-fig. 1).

The area between the Smoot Administration Building and the southern margin of the campus, at the brow of the hill south of the Joseph Smith Memorial Building, is an erosional surface cut by the meandering Provo River when Lake Bonneville stood at approximately the elevation of the campus.

TABLE I

LAKE LEVELS VISIBLE IN UTAH VALLEY

youngest   UTAH LAKE LEVEL - present level 4490 feet elevation; Lake Bonneville shrank to this level several times during the Ice Age.

PROVO LEVEL - most prominent level, 4700-4800 feet; controlled by bedrock outlet at Red Rock Pass, southern Idaho. Lake fell below this level several times during Ice Age. BYU upper campus on Provo level.

BONNEVILLE LEVEL - highest level, 5135 feet; lake briefly maintained this level where it found an outlet to its basin in southern Idaho, flowing northward in Red Rock Pass to the Snake River. It cut its outlet rapidly down to a bedrock barrier in the pass which stabilized the lake at the Provo level. Highest power lines above the highest house on east Provo bench are near Bonneville level.

oldest   ALPINE LEVEL - oldest level preserved, 5100 feet. Its hillside lake terraces now present a much dissected appearance because of later washes and gullies. Highest housing development on east Provo bench is on this level.
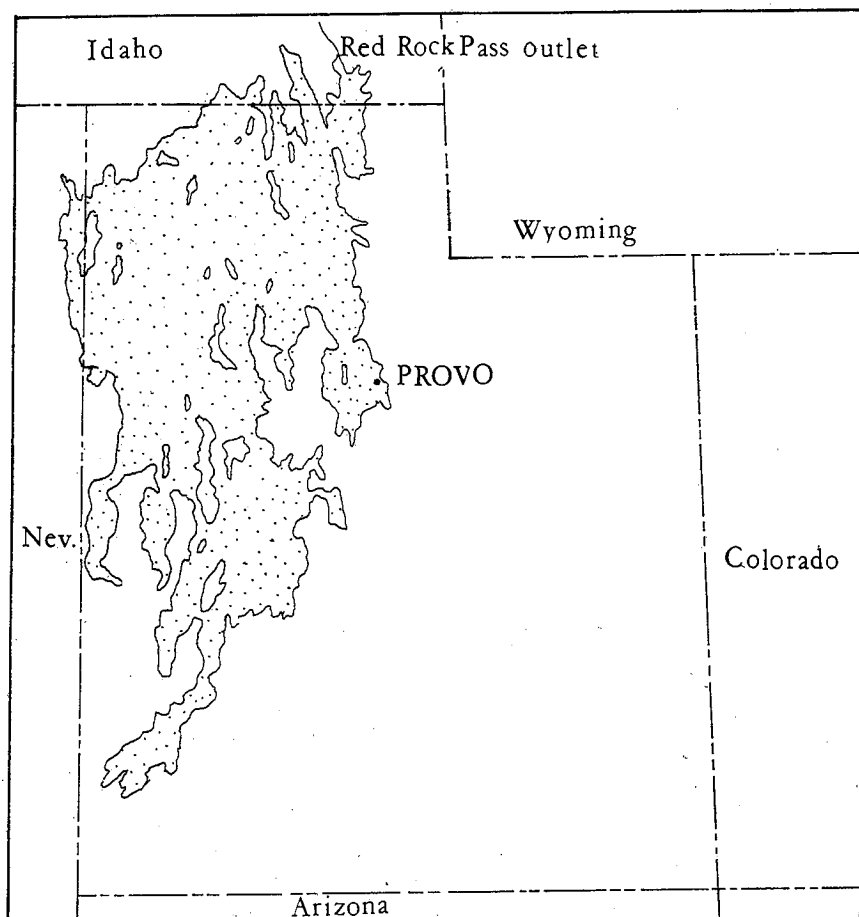
TEXT-FIGURE 5.—Generalized map of Lake Bonneville (stippled) in western Utah, eastern Nevada, and southern Idaho. Red Rock Pass in southern Idaho was the outlet of the lake into the Snake River.

The river removed 30 to 35 feet of gravel and sand from the vicinity of the campus as the river cut down through a delta built into Lake Bonneville from Provo Canyon. The slope off the southern edge of the campus into the lower country of downtown Provo is the original depositional or frontal edge of this delta (Text-figs. 1, 3 and 6).

0.15   0.15   STOPLIGHT. Junction. Southeast of the Wilkinson Center, turn north (left) toward the Smoot Administration Building.

0.15   0.3   CROSSWALK EAST OF WILKINSON CENTER. The low depression or gully east of the Center is a small erosional
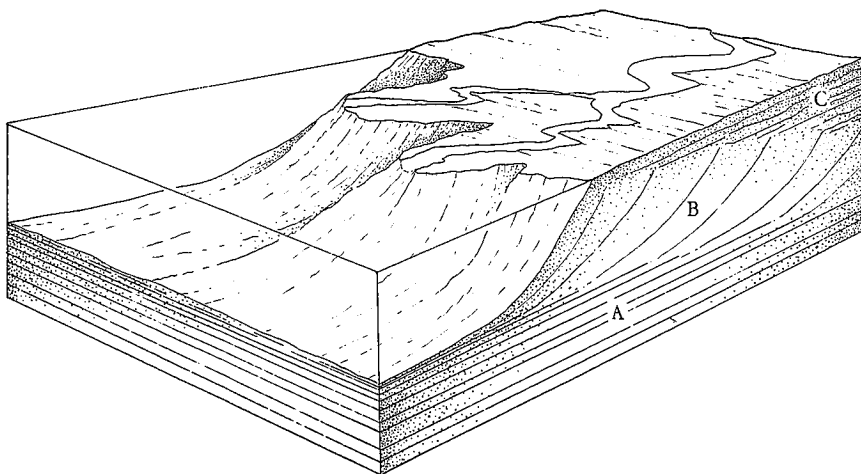
TEXT-FIGURE 6.—Generalized drawing of a characteristic *delta* built into a lake. A, fine clay deposited in front of the advancing delta, termed *prodelta* clay; B, sand of the *foreset beds* of the delta deposited down the advancing sloping front of the delta; C, gravel of the *topset beds* deposited over the top of the foreset beds by the meandering stream.

feature cut into the delta surface as an abandoned channel of Rock Canyon Creek.

0.1   0.4   INTERSECTION HERITAGE WAY - CAMPUS DRIVE at third stoplight. Continue straight ahead along Campus Drive. The hillside northeast of the Smoot Administration Building is the eroded margin of the flat-topped Provo level delta (Text-figs. 1, 3) into which the campus level has been carved. The flat surface to the north, the level of Deseret Towers, is the top of the delta surface and marks the Provo level of Lake Bonneville at 4720 feet (Text-figs. 2, 7).
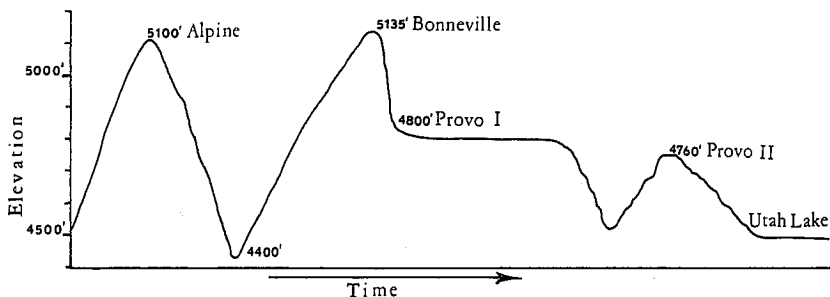
TEXT-FIGURE 7.—Curve of lake level fluctuation of Lake Bonneville showing age relationships of various levels developed during its history.

0.3   0.7   MAIN INTERSECTION OF CAMPUS DRIVE, PHILLIPS LANE ("Entrance Examination"), KEEP TO THE RIGHT (NORTH)—Contine north on 500 East Street.

0.1   0.8   ROAD CUT AT INTERSECTION OF PHILLIPS LANE AND 500 EAST STREET, CONTINUE NORTH ON 500 EAST STREET. A weak soil profile is visible at the top of the cut, developed in coarse gravel of the topset beds of the delta (Text-fig. 6). The sandy beds of the delta show excellent cross-bedding when exposed, suggesting their origin as channel-fillings of deltaic streams or as foreset beds of the delta (Text-fig. 6).

0.1   0.9   INTERSECTION OF 500 EAST AND 1700 NORTH, TURN WEST (LEFT). Continue on 1700 North Street, down the slope of a small alluvial fan formed by Rock Canyon Creek when this was a drainage way into Provo River.

0.4   1.3   INTERSECTION OF CANYON ROAD AND 1700 NORTH STREET, CONTINUE STRAIGHT AHEAD ACROSS CANYON ROAD AND PAST PAGE SCHOOL.

0.1   1.4   INTERSECTION OF UNIVERSITY AVENUE AND 1700 NORTH STREET. TURN RIGHT (NORTH) AND CONTINUE ON UNIVERSITY AVENUE (U. S. HIGHWAY 189) TOWARD PROVO CANYON. Just west of the intersection is the old Provo brickyard. Clay for brick and tile was quarried from prodelta deposits of Lake Bonneville (Text-fig. 6) beneath terrace gravel and recent Provo River fill. Looking north along the highway Mount Timpanogos dominates the skyline. Upper part of the mountain, above the prominent shoulder half way up the slope, is composed of the Pennsylvanian Oquirrh Formation (Text-fig. 8), a series of interbedded limestone and quartzite. The lower part of the mountain, below the shoulder, is composed of the Mississippian Great Blue Limestone. The Manning Canyon Shale which is part Mississippian and part Pennsylvanian age (Text-fig. 8) forms the shoulder.

0.5   1.9   INTERSECTION 2230 NORTH STREET AND U. S. HIGHWAY 189, CONTINUE AHEAD ON U. S. HIGHWAY 189. Provo River, to the west of the highway at present, has cut recent channels through Lake Bonneville sediments. The low ground near river level is its present-day floodplain. The gentle arcuate surface over which we have been riding is the outer or distal edge of an alluvial fan from Rock Canyon. North of the intersection the road dips down nearly to floodplain level. In this general area three levels, or surfaces, can be seen. The lower one is the present floodplain of the river. A low terrace at road level is a river terrace (Text-figs. 9, 10) cut by Provo River as it meandered over the valley floor while eroding downward. The third level is 40 to 50 feet above the road to the east.
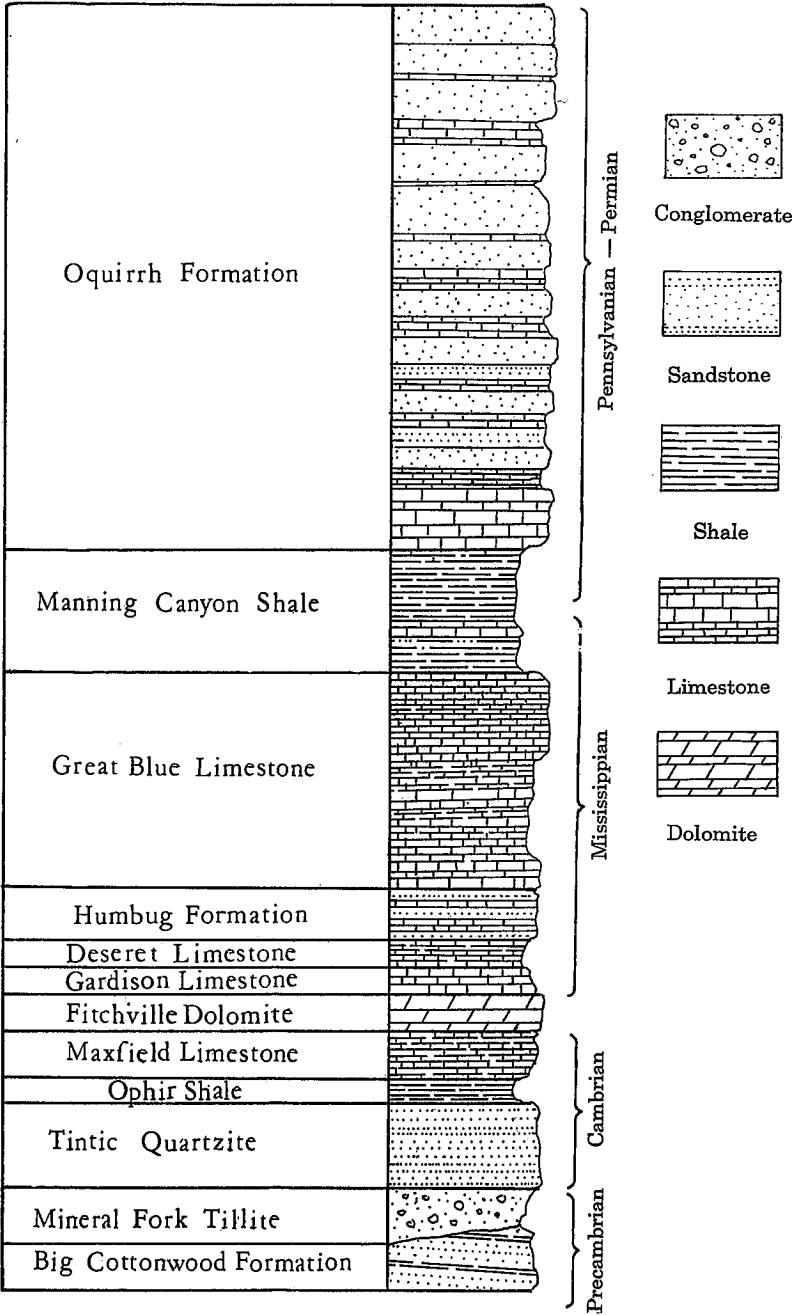
TEXT-FIGURE 8.—Geologic column of rocks exposed in the Wasatch Mountains in the vicinity of Provo.

TEXT-FIGURE 9.—Aerial view of the Provo River valley and the mouth of Provo Canyon as seen from the southwest. The flat benchland on both sides of the entrenched river valley are on the Provo delta surface.
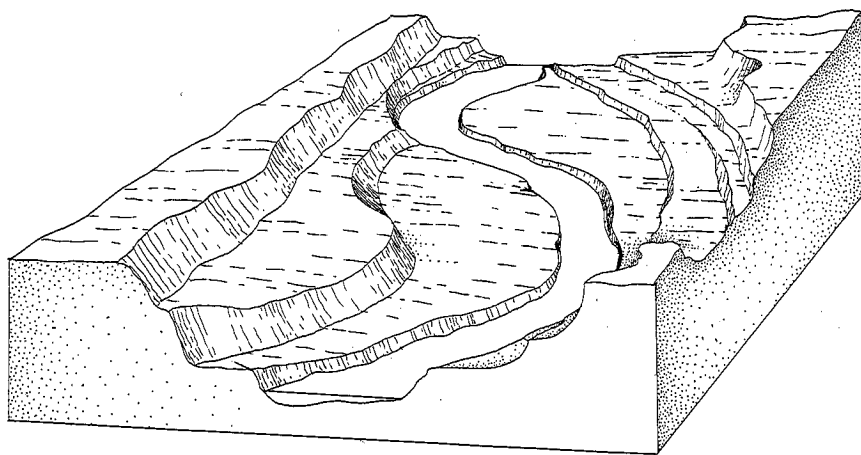
TEXT-FIGURE 10.—Diagram showing development of *river terraces* by a meandering stream which is cutting downward. Small scarps in the valley and along its margins are related to old positions of the stream, positions abandoned as the stream lowers its course by erosion, or shifts from one side of the valley to the other. Similar terraces are visible along the valley of Provo River.

This flat upland, as viewed from here, is the delta surface at the Provo level of Lake Bonneville and is at the same elevation as the upper terrace north of the Smoot Administration Building on the BYU campus.

0.4   2.3   RIVERSIDE COUNTRY CLUB TO WEST (LEFT), CONTINUE AHEAD ON U. S. HIGHWAY 189. The golf course behind the clubhouse is on the floodplain of Provo River. The higher surface immediately east of the highway is the Provo level delta surface. During deposition of the delta Lake Bonneville stood at this elevation, and a continuous sheet of sediments was deposited by Provo River. At that time the Orem Bench, the flat upland to the west across Provo River valley, was continuous with the upland to the east of the highway. As Lake Bonneville dried up, Provo River excavated the broad valley through which it flows here by downcutting to keep pace with lowering of the lake level.

0.8   3.1   INTERSECTION OF UTAH HIGHWAY 78 WITH U. S. HIGHWAY 189, CONTINUE AHEAD ON U. S. HIGHWAY 189. The highway here crosses a former, or abandoned, meander bend of Provo River. River gravel can be seen along the highway. Marshy and spring areas south and north of the intersection represent abandoned channels. The small rise east of the road marks the shore of the river when the meander was in this position.

0.4   3.5   GEOLOGIC STOP 1. River gravel in road cuts east and west of the highway (Text-fig. 11). Poorly sorted (sized) river gravel in the road cut consists mostly of subrounded pebbles and cobbles. Tan quartzite fragments are probably derived from the Oquirrh Formation in Provo Canyon. The gravel also includes a few cobbles and boulders of limestone from the same formation, and a few igneous pebbles probably derived from volcanic rock outcrops near Heber, 20 to 30 miles upstream. This is a characteristic stream-transported series of coarse sediments.

A thin soil layer is developed on top of the gravel. The soil is immature and lacks the distinct horizons characteristic of mature soils. Orchards thrive on well-drained gravelly soil since fruit trees "don't like wet feet."

Continue on north toward Provo Canyon on U. S. Highway 189, built over gravels of the Provo River floodplain.

1.5   5.0   INTERSECTION OF CANYON ROAD WITH U. S. HIGHWAY 189, CONTINUE NORTH ON U. S. HIGHWAY 189. Commercial gravel quarries can be seen northeast of the intersection in one of the higher Lake Bonneville terraces. These gravel deposits are plastered against Mississippian bedrock on the lower slope of the mountain.

TEXT-FIGURE 11.—Road cut in gravel of the Provo River floodplain at Geologic Stop 1. Lack of well-defined bedding or layering, rounding of pebbles and cobbles, and poor size-sorting of fragments are typical of stream-transported gravel deposits. A weak soil horizon is developed on top of these young gravel deposits. The rounded pebbles and cobbles are distinctive of river-transported debris.

0.2 5.2 GEOLOGIC STOP 2. Pull off the road onto shoulder near the high road cuts in bedrock, east of the transformer station. Bedrock exposed in this road cut is in the Mississippian Great Blue Limestone (Text-fig. 8) which here stands at a steep angle and is cut by unusually well-exposed faults (Text-fig. 12). Slickensided surfaces can be observed on the near vertical fault surface. These are the small grooves and scratches on a polished surface produced as the two segments of the earth's crust moved relative to one another. Exposure of faults here is unique along this part of the mountain front since the faults dip eastward *toward* the mountain front, whereas in most other exposures the faults dip away from the mountain. Direction of movement along the fault is indicated by the vertical grooves in the polished slickensided surfaces.

  Excellent examples of breccia, or the rock composed of recemented, crushed and broken fragments, can be seen in outcrops along the fault surfaces. Fragments partially ground by movement along the fault have been recemented with crystalline calcite.
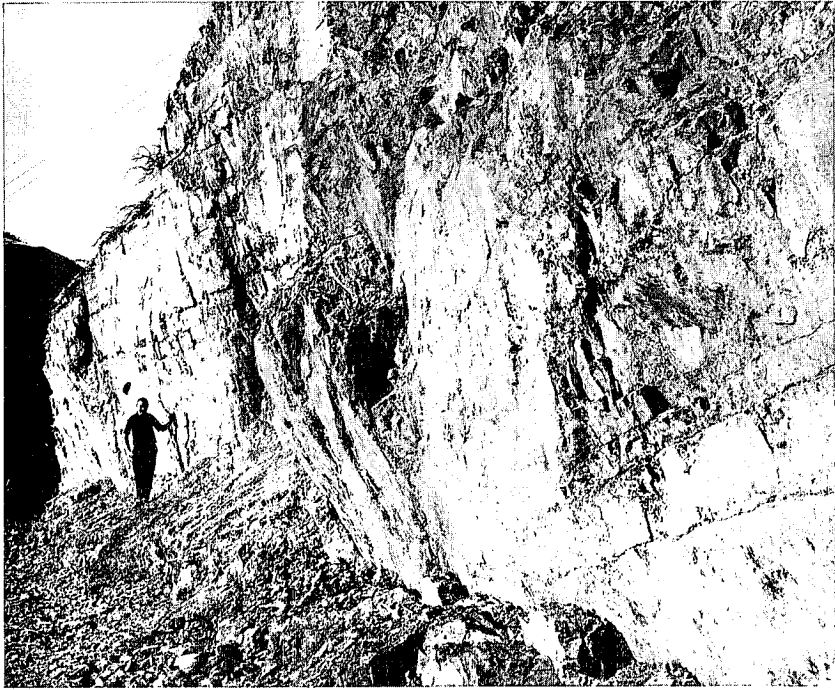
TEXT-FIGURE 12.—Well-exposed fault surface at Geologic Stop 2 on the east side of U. S. Highway 189, near the mouth of Provo Canyon. Vertical grooves and scratches in the surface indicate the direction of movement along the fault. Broken rock fragments, now recemented to form the rock called breccia, can be seen along the fault surface.

Differences between hanging wall and footwall blocks of faults show well here. The wall hanging over the fault exposure is the hanging wall block, while that block on which you are standing, the one beneath the fault surface, is the footwall block (Text-fig. 13).

Return to car and continue north on U. S. Highway 189 into the mouth of Provo Canyon.

0.2   5.4   INTERSECTION OF UTAH STATE HIGHWAY 52, WEST TO OREM, CONTINUE AHEAD ON U. S. HIGHWAY 189. From this point one can look northward toward Mount Timpanogos and the mouth of Provo Canyon. Bedding within the Great Blue Limestone changes in attitude from nearly horizontal in the cliffs at the narrows to a pronounced westward (left) dip at the west end of the exposures. This might be explained as a dragfold (Text-figs. 14, 15) caused by friction along the Wasatch Fault as the valley block dropped relative to the mountain block. Trace of the main Wasatch Fault is concealed under alluvial mate-
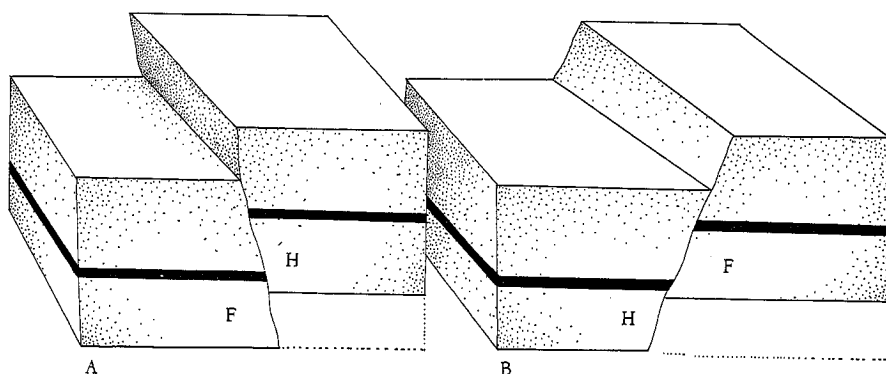
TEXT-FIGURE 13.—Diagrams of faults showing relationships of *hanging wall* and *footwall* blocks in "normal" and "reverse" fault. A: This is a reserve fault. The hanging wall (H) block has moved up relative to the footwall (F) block. The hanging wall is the one above the inclined fault surface and the footwall is below the surface. B: This is a normal fault. The hanging wall (H) block has moved down relative to the footwall (F) block. The hanging wall is still the one above the fault surface.

rial but is probably within one-quarter mile west of this intersection. Many straight fault lines and the broken character of the bedrock show well in outcrops of the Great Blue Limestone at the curve just north of the intersection. The grassy slope above the cliffs of the narrows (Text-fig. 14), immediately above the penstocks, on the north side of the canyon is the expression of the easily eroded Manning Canyon Shale (Text-fig. 8). It is approximately 1000 feet thick here and forms the shoulder at the southwest base of Mount Timpanogos.

0.2   5.6   Fans and slopes of broken rubble, termed talus, are developed over the buried Great Blue Limestone on the south (right) side of the canyon.

0.2   5.8   FOUNTAIN, TURN AROUND WITH CAUTION. GEOLOGIC STOP 3. Rocks exposed in the cliffs to the west and north across the canyon are in the Great Blue Limestone and show the characteristic thin stratification. Accumulations of talus are well exposed at the base of the cliff. These rocks are fragments dislodged from the cliffs above, principally by frost action, and have accumulated on the more gentle lower slope. From here they will be washed away by the river.

The white crystalline fissures cutting across the limestone beds in the cliff to the north were originally cracks opened by faulting and folding of the area and were subsequently filled by calcite crystals.

High talus cones can be seen upstream on the high flanks of Mount Timpanogos at the mouths of very steep canyons and gorges.
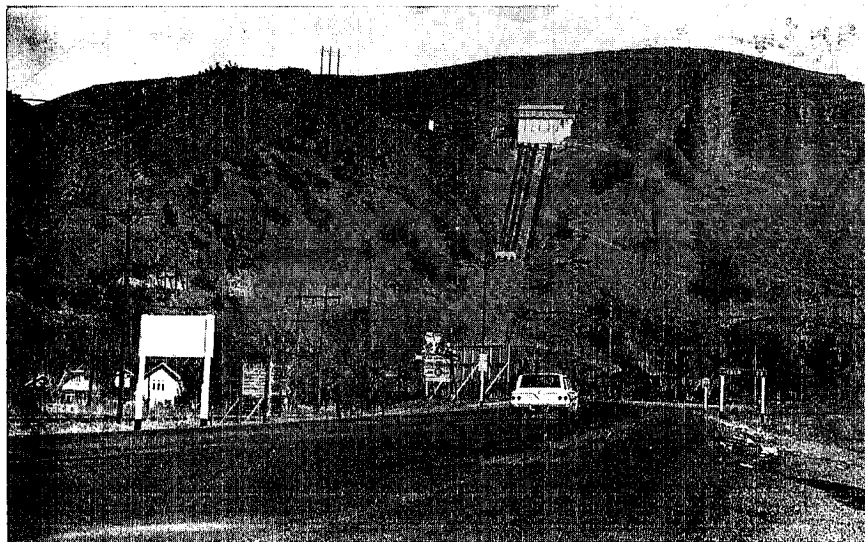
TEXT-FIGURE 14.—Drag fold along the Wasatch Fault as seen from near Geologic Stop 2. Relatively flat-lying Great Blue Limestone in the Narrows (right) is westward dipping near the fault zone (left). Upper grassy slopes above the penstocks are on Manning Canyon Shale.
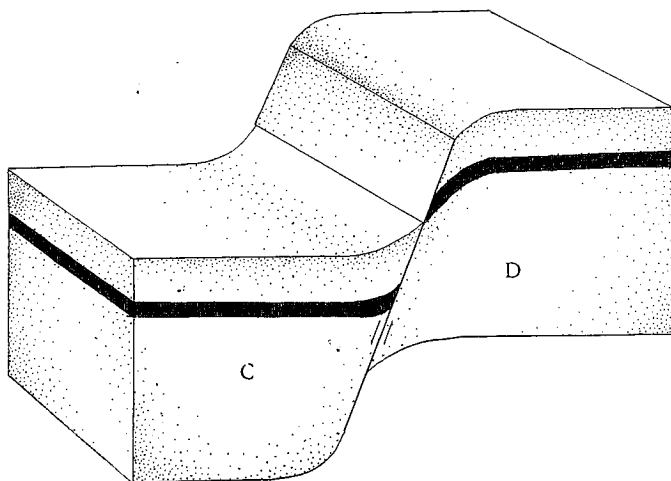

TEXT-FIGURE 15.—*Drag fold* is a fold produced next to a fault as a result of great frictional drag. Such folds commonly develop on both blocks of the fault and can be used to show direction of relative movement. In this diagram the folds have been produced when block C moved down relative to block D.

0.2   6.0   RETURN DOWN CANYON TOWARD INTERSEC-
TION OF UTAH STATE HIGHWAY 52. GEOLOGIC
STOP 4. TURN RIGHT OFF ROAD AND PARK JUST
EAST OF AQUEDUCT AND RAILROAD BRIDGE
OVER PROVO RIVER. Observe the gravel in the channel
of Provo River. Note the shape of the particles; each cobble
is well rounded, a characteristic shape of stream-eroded and
transported material. In contrast, observe the talus accumu-
lations to the north across the canyon and to the east on the
opposite side of the road beyond the road cut. River gravels
are rounded, but the talus blocks are angular, lacking any
rounding. As the talus blocks are carried downstream by
Provo River they become progressively more rounded with
each mile of transport. It is thus possible to make some esti-
mate of distance of transport by running water based upon
the degree of rounding of individual particles.

Sketch two typical river-transported boulders and two typical talus blocks.

0.2   6.2   INTERSECTION OF UTAH STATE HIGHWAY 52
                AND U. S. HIGHWAY 189, TURN WEST, (RIGHT),
                TOWARD OREM AND I-15 ON HIGHWAY 52.

0.1   6.3   CROSS PROVO RIVER AND CANAL, THEN TURN
                NORTH (RIGHT) ONTO SMALL ROAD OPPOSITE
                THE ELECTRIC GENERATING PLANT. Rounded
                boulders show in exposures of Lake Bonneville sediments
                north of the intersection. Compare the particles of this delta
                with those of river gravel and talus accumulations. What is
                the origin of these delta particles?

0.1   6.4   GEOLOGIC STOP 5. DEER CREEK PUMPING STA-
                TION, PULL OFF TO RIGHT IN OPENING AND
                WALK TO THE NORTH ALONG THE ROAD, BE-
                YOND THE PUMPING STATION. Great Blue Limestone
                is exposed in road cuts on the west side of the canyon and
                shows the characteristic beds of limestone 8 to 10 inches
                thick, separated by thinner laminated beds. Folds caused by
                slump or creep of plastic sheets of sediment down slope
                (Text-figs. 16, 17) can be seen in cuts at road level, near
                the crest of the rise in the road, opposite the junction of two
                canals east of the road. These show what appear to be irregu-
                lar bedding at first glance, but careful tracing of individual
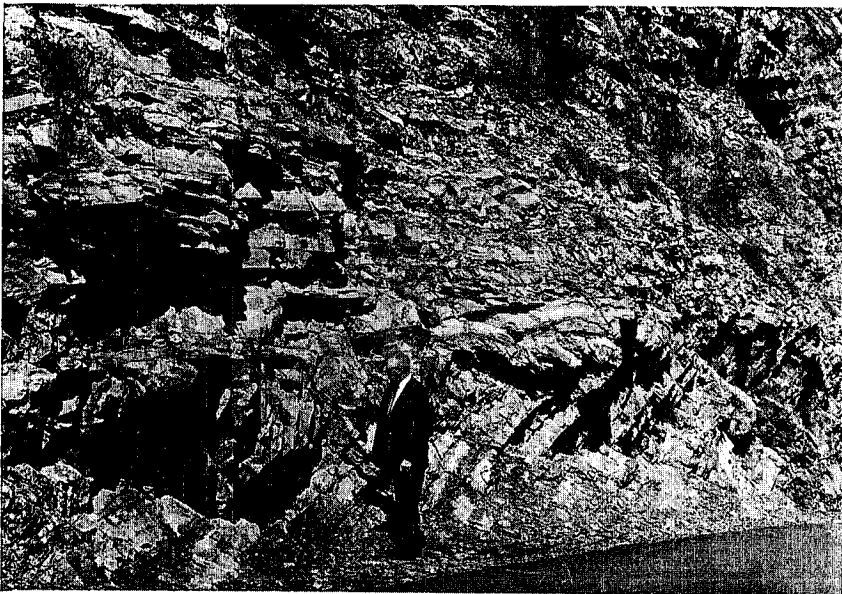
TEXT-FIGURE 16.—*Slump folds* in the Great Blue Limestone exposed on the west side of
the mouth of Provo Canyon, near Olmstead, at Geologic Stop 5. These folds are
formed as soft sediments slid down slope from the east. Individual laminae can be
traced around the crest of the folds.
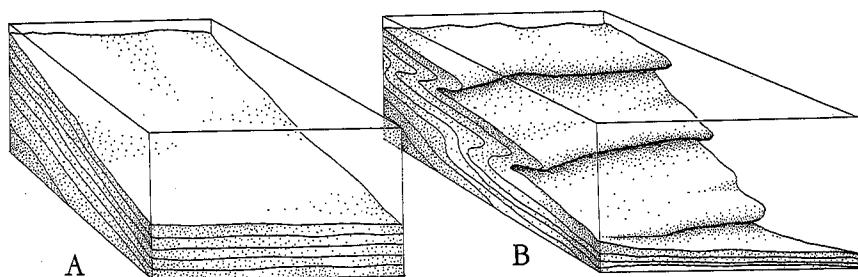
TEXT-FIGURE 17.—Diagram showing possible origin of *slump folds*. A, sediments were deposited in relatively uniform layers on a slope. B, folds were formed within these sediments while they were still soft and plastic as they moved down slope. If they had moved quickly they probably would have been broken into plastic fragments, and if they had been too stiff they would not have moved at all. We can use slump folds to determine direction of slope in even very old rocks.

beds show these to be recumbent anticlines and synclines, folds which are laying on their sides. These folds are interpreted to have been formed while the sediments were still soft and plastic, long before the brittle rocks were fractured by faulting. Similar folds which are interpreted as slump folds are common in rocks of the same general composition and character in other regions of North America. Fine-grained, clayey limestone seems to be particularly susceptible to creep and flow.

Sketch several beds which show the structure of the slump folds particularly well.

Return to cars and then proceed up the road, beyond the road cut, into the community of Olmstead.

0.1   6.5   INTERSECTION AT WEST EDGE OF COMMUNITY OF OLMSTEAD. Talus fans extend down to road level near Olmstead. Do the boulders making up the small protective fence on the north side of the road at the intersection represent predominantly stream gravel or talus blocks? The principle of uniformitarianism is that the present is a key to the past, or that geologic processes acting now probably acted similarly in the past. One might thus interpret the origin of the gravels in the fence. One can tell, even in ancient conglomerate, a rock formed of cemented gravel, the type of transport pebbles and boulders have experienced. TURN AROUND AND RETURN TO INTERSECTION OF UTAH STATE HIGHWAY 52 AND U. S. HIGHWAY 189, HEADING BACK TOWARD PROVO.

0.3   6.8   INTERSECTION OF U. S. HIGHWAY 189 AND UTAH STATE HIGHWAY 52. TURN SOUTH (RIGHT) ONTO U. S. HIGHWAY 189. Exposures of the Great Blue Limestone, across the highway east of the intersection, slightly above and to the left of the circular aqueduct tunnel entrance in the cliffs, exhibit the same type of slump folds seen at Stop 5 across the river. By comparison of similar structures and lithology in the relatively thin disturbed zone, one can correlate, or establish equivalence, between beds across the river whose connection is now buried by Recent river deposits. By correlating the slumped beds one can identify the same horizon on both sides of the river. This is an example of physical correlation where age equivalence is based upon physical evidence rather than on the use of fossils. PROCEED TOWARD PROVO ON U. S. HIGHWAY 189.

0.5   7.3   INTERSECTION OF CANYON ROAD AND U. S. HIGHWAY 189, TURN OFF HIGHWAY ONTO CANYON ROAD, TOWARD EDGEMONT. The road climbs from the floodplain of Provo River up to the terrace at the Provo level of Lake Bonneville.

0.2   7.5   GEOLOGIC STOP 6. TURN OFF ROADWAY TO RIGHT JUST BEYOND CREST OF DUGWAY. View of Provo River valley cut out by downcutting of Provo River through deltaic deposits of earlier river and lake stage. The turn-out is on the Provo level of Lake Bonneville and is at the same elevation as the Orem Bench, visible across the valley one-half mile to the west. During Provo level in the history of Lake Bonneville, these two bench areas were part of one continuous flat surface. The intervening valley of Provo River was cut through the level surface and the

sediments thus removed were transported on out into Utah Valley. Provo River cut down as the lake into which it drained gradually dried up during a shift to a more arid climate, like that at present. River gravel blankets the flood-plain. CONTINUE SOUTH ON CANYON ROAD TO-WARD PROVO.

0.7   8.2   Flat surface at the top of the terrace 200 feet above to the east (left) represents the Alpine level of Lake Bonneville. Edge of the terrace is dissected by small gullies feeding down from the front of the Wasatch Range to the east (Text-fig. 1.)

0.4   8.6   Flat terrace of Alpine level evident to the east (left). The road continues on Provo level sediments.

1.3   9.9   Highway curves westward (right) down off the Provo level, following an abandoned channel of Rock Canyon Creek.

0.3   10.2   Highway curves south (left) around the eroded scarp at the edge of Provo River valley. We are now below the Provo lake level.

0.2   10.4   INTERSECTION OF CANYON ROAD WITH 2230 NORTH STREET. TURN EAST (LEFT) ONTO 2230 NORTH AND CONTINUE EAST. The main road jogs left then right a short distance east of the intersection.

0.4   10.8   ROCK CANYON SCHOOL ON LEFT. The school is situated on the alluvial fan of Rock Canyon. The road ascends the fan which heads into the V-shaped canyon opening directly ahead. Gravelly nature of the soil is typical of alluvial fan deposits. Pebbles and cobbles of the fan are rounded indicating that they have been transported by running water sometime during their development. They may have been transported to their present position by mudflows.

0.4   11.2   INTERSECTION 930 EAST AND 2300 NORTH STREET, CONTINUE STRAIGHT AHEAD, EAST-WARD.

0.1   11.3   Site of Provo Temple to the right.

0.1   11.4   INTERSECTION OF 1200 EAST AND 2300 NORTH STREETS, CONTINUE STRAIGHT AHEAD. We are still climbing the alluvial fan of Rock Canyon which can be seen sloping to the south, toward the campus of Brigham Young University, as well as to the west.

0.1   11.5   INTERSECTION, KEEP TO THE LEFT ON ROAD TO-WARD ROCK CANYON. As we pass the U. S. Forest Service Heliport on the left, we cross a small fault scarp, related to the main Wasatch Fault of the mountain front. The small fault is particularly evident where the fence of the

heliport is sharply bent upward over the break in gradient of the alluvial fan. The fault is relatively young and has offset lake terraces and fan surfaces.

0.3   11.8   INTERSECTION, TURN SOUTH (RIGHT) ON PAVED ROAD LEADING UP ONTO LAKE TERRACE.

0.05   11.85   GEOLOGIC STOP 7. PARK AND WALK BACK TO NORTHWEST EDGE OF THE ROAD CUT. Gravel in the road cut is largely made of limestone cobbles out of Rock Canyon. This represents deltaic deposits built into Lake Bonneville out of Rock Canyon. This delta was subsequently incised by the stream of Rock Canyon, removing the deltaic materials along its course.

From this point we can look eastward toward the mouth of Rock Canyon and observe the anticlinal (uparched) structure of the mountain front. The prominent, orange-colored formation in the canyon mouth is the Tintic Quartzite of Cambrian Age (Text-fig. 8). Beneath it in the mouth of the canyon can be seen an olive-colored rock unit which is the Mineral Fork Tillite of Precambrian Age. Above the Tintic Quartzite are light-colored limestones and dolomites of Cambrian and Mississippian Ages. The boundary between Cambrian and Mississippian rocks lies just above the prominent white band, about a third of the way up the face of Squaw Peak. Along the mountain front, *west* of the exposures of the Tintic Quartzite, can be seen gray slabs of limestone. These limestone masses are of Mississippian Age and are in fault contact with the Tintic Quartzite. These limestones are downfaulted and the fault between them and the quartzite is one of the branches of the Wasatch Fault. Pulverization and brecciation of the Tintic Quartzite (fault gouge) at the fault contact shows up as the light-colored sandy material between the limestone and the quartzite.

The Wasatch Fault consists of a series of parallel faults; some of these can be seen along the mountain front. Others are concealed at the base of the mountain by the Lake Bonneville gravels. Some of the most recent of these faults cut the Lake Bonneville and younger gravels. Prominent limestone masses can be seen low on the hill on the south side of Rock Canyon. These also represent slivers of limestone caught between branches of the Wasatch Fault (Text-fig. 18). Before Wasatch faulting these limestones were continuous with the limestone layers which can be seen high on the mountain to the east.

CONTINUE SOUTH ON TERRACE ROAD.

0.15   12.0   Flat area is a terrace of the Alpine level of Lake Bonneville.
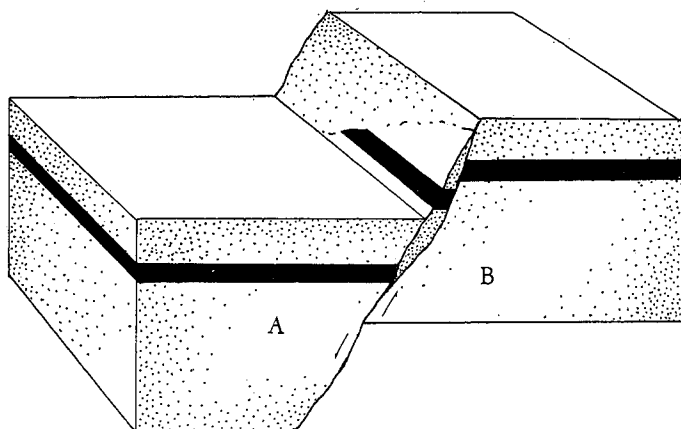
TEXT-FIGURE 18.—Diagram showing relationship of a small block, or *sliver*, isolated along a fault zone. Several of these types of blocks are evident along the Wasatch Fault zone, although most are considerably more complex than the single simple block shown in the diagram.

0.2   12.2   INTERSECTION OF 1850 NORTH AND 1450 EAST STREETS, TURN EAST (LEFT).

0.1   12.3   INTERSECTION OF 1850 NORTH AND 1500 EAST STREETS. TURN NORTH (LEFT) HERE.

0.05   12.35   INTERSECTION OF 1500 EAST AND 1950 NORTH STREETS. TURN EAST (RIGHT) AND PARK IN OPEN AREA. GEOLOGIC STOP 8. A short walk leading towards the water tank on the hill will show several interesting features. Behind the water tank are exposures of Mississippian limestones in the fault slivers along the Wasatch Fault Zone. The fault surface (light-colored), exposed in limestone by the tank, dips westward at about 45 degrees (Text-fig. 19). Ease of running one's hand along the slickensided surface will give indication of the direction of relative movement. This is a normal fault, downdropped on the west. A cave is developed along the fault surface fifty yards south of the tank by ground water dissolving away the crushed rock. The cave entrance is in the bushes just east of the trail. Large boulders in the general vicinity represent rocks which have rolled off the hillside and have come to rest on the less steep slope at the base of the mountain. Note their angular characteristics—obviously not stream boulders. RETURN TO CAR AND CONTINUE SOUTHWARD.

TEXT-FIGURE 19.—Fault surfaces, light colored, exposed in the vicinity of the water tank at Geologic Stop 8. Two areas of fault exposures can be seen along the road south of the tank. A small cave is developed within the limestone sliver, along a minor fault, in the small gully at the right of the picture.

Sketch distribution of fault grooves or slickensides seen at Geologic Stop 8.

0.15 12.5 HIGHEST POINT ON THE ROAD. GEOLOGIC STOP 9. From here, looking southward and eastward, one can see yellow gouge along the Wasatch Fault at the base of Y Mountain, where exposed by the road cuts just east of the power lines. Downhill from the power lines is much angular material which has never been worked by waves or streams. It is slope wash, slump, and slide material which has worked its way down the mountain slopes. Directly to the south can be seen an oak-covered hill with many large limestone blocks; this hill was formed by an ancient landslide. The huge blocks in this deposit had their origin in the large basin above, on the north front of Y Mountain. This landslide was probably of Pleistocene Age when the hillside was more soaked with water than it is at present. Beyond the landslide mass one can see westward dipping bedrock on Y Mountain. The west inclination has resulted from downward drag along the Wasatch Fault.

From this vantage point one can see the many mountains surrounding Utah Valley: directly to the south is Loafer Mountain; to the southwest, Mt. Nebo, across the valley, West Mountain and Lake Mountain; to the northwest the Oquirrh Range and to the north, Mt. Timpanogos. These mountains mostly expose the Pennsylvanian-Permian Oquirrh Formation. The mountains themselves have been elevated along faults similar to the Wasatch Fault of Cenozoic Age. Utah Valley represents a downfaulted block. The bedrock which we see exposed in the mountains is buried beneath Utah Valley by about 6000 to 8000 feet of sediments washed in from the surrounding mountains (Text-fig. 2). Thus, the top of Paleozoic bedrock is now *below sea level* beneath the valley. The difference between the elevation of the bedrock beneath the valley and that exposed in the mountains (which range to almost 12000 feet in elevation) gives some idea of the magnitude of normal faulting which has occurred along the Wasatch Front.

A view toward the south to Loafer Mountain and Maple Mountain shows the triangular facets or spurs along the mountain front. These facets have been formed by repeated movements along the Wasatch Fault. Three, four, and even five sets of faceted spurs may be observed on Maple Mountain.

The road here is on the Bonneville Level, the highest level, of Lake Bonneville. When the lake basin was filled to an elevation of approximately 5200 feet, Utah Valley was filled with a lake approximately 500 feet deep.

0.1 12.6 INTERSECTION, TURN WEST (RIGHT). PROCEED DOWN TO THE ALPINE LEVEL OF LAKE BONNEVILLE AT 1450 EAST STREET.

| 0.1	12.7	TURN NORTH (RIGHT) ONTO 1450 EAST STREET.
0.2	12.9	INTERSECTION 1850 NORTH AND 1450 EAST STREETS, TURN WEST (LEFT).
0.1	13.0	INTERSECTION, OAK RIDGE LANE, 1850 NORTH, PART WAY DOWN STEEP GRADE. We again cross the scarp of the same fault we observed cutting alluvial fan gravel at the heliport in Rock Canyon at mile 11.6. A narrow graben has dropped the lake terrace surface approximately 20 feet, just west of the intersection. The downdropped block is in the region where concrete retaining walls can be seen immediately south of the road. A graben is a downdropped long, linear block, bounded on both sides by normal faults (Text-fig. 20).
0.1	13.1	INTERSECTION OAK LANE, 1950 NORTH STREETS. TURN SOUTH (LEFT) ONTO OAK LANE.
0.1	13.2	Brow of hill proceeding off the Alpine Level. Good exposures of gravel, silt, and sand which make up this level may be seen in the next series of road cuts. Proceeding down the hill notice the well-rounded material which contrasts sharply with the angular slope wash and creep material which we saw above the lake levels along the mountain front at Geologic Stop 9, and the talus accumulation at the mouth of Provo Canyon at Geologic Stops 3, 4, and 5.
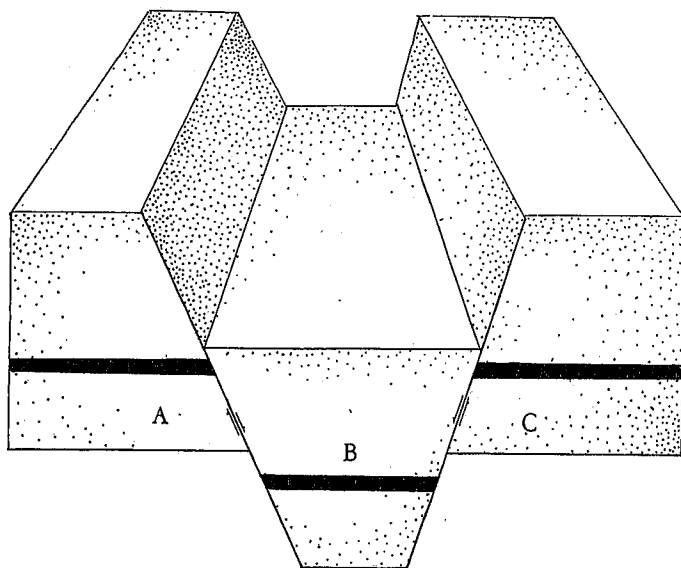
TEXT-FIGURE 20.—Diagram showing relationships of a *graben*, the long downdropped block in the center. A graben is bounded along both sides by normal faults.

0.2   13.4   INTERSECTION, PINE LANE AND OAK LANE. CON-
                 TINUE STRAIGHT AHEAD ON OAK LANE. Good ex-
                 posure of Alpine silt at the base of the Alpine terrace in
                 road cuts to the southeast.

0.2   13.6   INTERSECTION OF OAK LANE AND ELM AVENUE,
                 PROCEED SOUTHWARD (STRAIGHT) ON OAK
                 LANE. On the east side of the road can be seen large
                 angular blocks on top of Alpine silt at the toe of the land-
                 slide that we noted earlier at Stop 9.

0.15   13.75   INTERSECTION OF OAK LANE, BRIAR AVENUE,
                 AND OLD WILLOW LANE. Turn south on Old Willow
                 Lane along toe of landslide to examine landslide debris
                 (Text-fig. 21).

0.15   13.9   Older farmhouses were built by Swiss settlers who moved
                 up on the hillside because it reminded them of their native
                 land. Farmhouse just east of Old Willow Lane is built
                 against an exposure of bedrock, probably Mississippian
                 Shale. This represents the westernmost bedrock exposure in
                 this vicinity, and aids in locating the largely buried Wasatch
                 Fault Zone.

TEXT-FIGURE 21.—*Landslide debris* exposed along the east side of Old Willow Lane, at
    mile 13.8 in the road log. The very large blocks are parts of formations exposed
    high on the mountain to the east but have been transported to their present position
    as part of a large landslide and mudflow.

0.15	14.05	INTERSECTION, TURN EAST. Exposures of limestone and black clay just east of newer houses are bedrock of Mississippian Shale. Bedrock at the toe of the mountains is mostly concealed beneath talus and debris from the landslide.
0.15	14.2	High point on the hill, proceed southward over dirt road with care to paved road rather than up the trail to the Y. Much of the coarse angular material seen here was probably transported to the toe of the mountains by thick viscous mudflows.
0.2	14.4	TURN RIGHT AT INTERSECTION OF 820 NORTH AND OLD WILLOW LANE. PROCEED DOWNHILL.
0.2	14.6	INTERSECTION OF 1250 EAST AND 820 NORTH STREETS. TURN SOUTH (LEFT).
0.1	14.7	INTERSECTION OF 1250 EAST AND 700 NORTH STREETS. TURN WEST. GEOLOGIC STOP 10. Look south over property of the Utah State Hospital. Notice that here the valley floor is inclined toward the east; that is, *toward* the mountain front. Utah State Hospital farmlands occupy what is geologically termed a "sag pond" (Text-fig. 22). Houses built in this general area have had some drain-
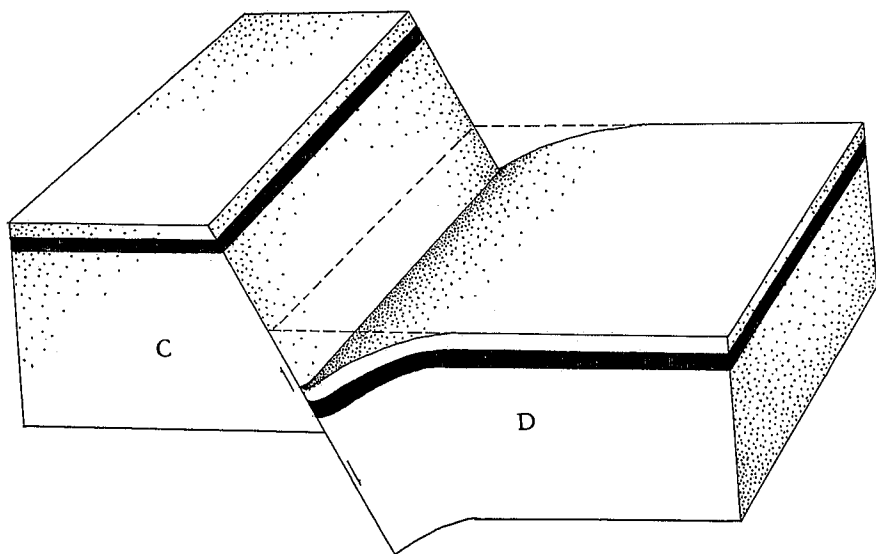
TEXT-FIGURE 22.—Diagram showing the origin of a sag pond adjacent to a fault. When the hang wall block (D) moved down, the part next to the fault sagged, possibly as a response to a curved fault surface. This differs from a drag fold in that here there was apparently little friction between moving blocks. Sag pond folds are not useful in determining direction of fault movement and commonly affect the country some distance away from the fault.

age problems prior to construction of storm sewers because of the unusual slope of the land toward the mountain instead of toward Utah Lake, as in most other parts of Utah Valley.

0.3	15.0	STOPLIGHT INTERSECTION OF 9th EAST AND 7th NORTH. TURN NORTH (RIGHT) AND PROCEED TO BYU CAMPUS. 9th East Street here slopes gently up to the edge of the Provo level delta of Lake Bonneville.
0.3	15.3	INTERSECTION 9th NORTH AND 9th EAST STREETS. TURN WEST (LEFT).
0.3	15.6	PARKING LOT EAST OF EYRING SCIENCE CENTER.

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