FIELD TRIP ROADLOG FOR THE BEAR RIVER LANDSLIDE COMPLEX

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INTRODUCTION

The route from Logan, Utah north to Preston, Idaho traverses the east edge of the Cache Arm of Lake Bonneville. The lake and its predecessors occupied this valley intermittently during the Pleistocene, with the most recent lake cycle (the Bonneville cycle) starting about 32,000 years ago (Currey and others, 1984; Scott and others, 1983; McCoy, 1987). The last rise of Lake Bonneville was caused both by pluvial climates and by the addition of water from Bear River to the Bonneville Basin (Bright, 1963). Bear River, which formerly drained into the Snake River, was diverted to the south by Pleistocene volcanism in Gem Valley, Idaho. The cutting of the deep gorge at Oneida Narrows, Idaho allowed the waters of the Bear to enter Cache Valley.

Where the Bear River entered the rising lake, just north of Preston, Idaho, it deposited a delta, composed of red colored, fine-grained sand, silt and clay. The delta covers an area from the south end of Oneida Narrows to Clifton Hill west of Preston and is up to 155 meters (510 feet) thick near Riverdale.

Lake Bonneville rose to the Bonneville shoreline (5090 ft/1552 m), about 16,000 years ago. The Bonneville Flood occurred between 15,000 and 14,000 years ago when the lake overtopped an alluvial dam near Red Rock Pass, Idaho. The flood rapidly lowered lake level by approximately 350 feet (106 m), from 5090 (1552 m) to about 4740 feet (1445 m), before stabilizing at the Provo level (Maide, 1968). The Provo level was maintained by intermittent overflow at a bedrock lip at Red Rock Pass for about 1,000 years, after which the lake receded rapidly, so that by 11,000 years ago it was at or near its present (Great Salt Lake) level (4200 ft/1280 m) (Currey and others, 1984). The sediments of the Bear River Delta were subsequently dissected as the Bear River adjusted to the lowering of base level.

On a large scale the sediments of the delta fine upwards from gravel and sand to clay. The top of the sequence near Preston consists of a 15m laminated pro-delta clay deposited when the lake was at its maximum level. At a smaller scale, the sediments of the delta contain numerous thin sand and clay couplets and lateral facies changes, which produce thin, confined, and locally perched aquifers.
FIGURE 1: Generalized geologic map of Cache Valley. Field trip stops are in stippled area of Bear River Delta north of Preston.

FIGURE 2: Gravel pit east of Smithfield Utah (mile 9.0). Note westward-dipping coarse foreset beds below the Provo Shoreline.

FIGURE 3: View north of Mt. Smart west of Franklin, Idaho. Boviniosaur is standing at the level of the Provo Shoreline.
The Bear River Landslide Complex occurs where the unconsolidated sediments of the Bear River Delta have been incised to a depth of 350 to 490 feet (106-150 m) north of Preston. The slides are the result of the high pore pressure in confined aquifers in the deltaic sediments. High but variable volumes of groundwater flow and the laterally discontinuous nature of the deltaic sediments result in the varied types of earth movements found within the Landslide Complex. Landslide activity occurs during years of above average precipitation, and has been exacerbated by increased recharge from reservoirs and irrigation canals constructed in the last 100 years.

Refer to Figure 1 for geographic reference in the area of the landslides, and to Mahoney and others (1987, this volume) for a detailed discussion of the history, causes, and attempts at remediation of the Bear River Landslide Complex. This research was funded by Idaho State University Faculty Research Grant #588 to P.K. Link.

**DESCRIPTION OF ROUTE FROM LOGAN TO PRESTON**

<table>
<thead>
<tr>
<th>Mile (Interval)</th>
<th>Description</th>
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<tbody>
<tr>
<td>0.0</td>
<td>The field trip roadlog begins at the parking lot north of the University Inn on the Utah State University campus. The route goes north to just north of Preston, Idaho, where we will examine the Bear River Landslide Complex.</td>
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The University is located on the surface of a large (7 sq km) delta built into Lake Bonneville by the Logan River. The delta surface slopes gently to the west from the Provo shoreline (about 4800 feet, 1463 m). Well logs indicate the delta surface is underlain by 100-115 feet (30-35 m) of coarse gravel, which was deposited by the Logan River during base level readjustment to the Provo level. Underlying the gravel is 165-200 feet (50-60 m) of varved silt and clay, deposited when the lake level was at the Bonneville shoreline (5140 ft/1567 m). This gravel-over-clay geometry creates perched aquifers, springs at the delta margins, and occasional landslide problems when excavations are made near the contact. Deep wells have penetrated pre-Lake Bonneville alluvial gravels at depths over 275 feet (85 m).

The field trip route travels north through Cache Valley. The Bear River Range lies to the east, the Wellsville Mountains to the southwest, the Malad Range to the west, and Oxford Mountain of the Bannock Range to the northwest. The mountains are primarily composed of folded and faulted Paleozoic miogeoclinal strata (Figure 1) (Link and others, 1985).

Leave parking lot, proceed west on 7th North Street
0.2 Turn right (north) onto 8th East Street

0.3 Road descends the front of the Provo delta down to the nearly flat Provo lake bottom. The football stadium on the right was built in an abandoned gravel pit, several more of which can be seen farther east and north along the edge of the delta.

1.1 Turn left (west) onto 14th North Street, continue west.

Water well logs from this area show a sequence typical of the entire valley: 50 feet (15 m) of lake bottom clay and silt, underlain by 10-40 feet (3-12 m) of pre-Bonneville alluvial fan gravels, underlain by 18-24 m of pre-Bonneville lake bottom silts and clays (Little Valley cycle?). Deeper wells show that the lake bottom sediments and alluvial deposits alternate deep into the subsurface (Lowe, in press).

2.3 Turn right (north) onto U.S. Highway 91 and proceed north.

The elevation of the highway here is about 4500 feet. Directly east, the Bonneville shoreline (about 5100 feet) is well exposed as a bench on either side of the mouth of Green Canyon at the front of the Bear River Range. The USU campus is visible to the southeast on the Provo delta.

The Provo Shoreline, at about 4740 feet, is very prominent and forms the break in slope between the flat valley floor and the foothills to the east. Thus, we are about 600 feet (183 m) below the level of Lake Bonneville, and 200 feet (61 m) below the level of Lake Provo.

4.1 Directly to the east, and from here north, the Bonneville shoreline diverges from Paleozoic rocks at the range front and is carved on Tertiary Salt Lake Group, which underlies the more subdued foothills. To the east northeast, pre-Bonneville pediments cut on Salt Lake Group strata above the Bonneville shoreline are displaced by splays of the East Cache Fault.

Straight ahead the highway rises onto the alluvial fan on which Smithfield is located.
DEFORMATION OF THE BONNEVILLE SHORELINE

Ongoing work by McCalpin (in press) on the East Cache Fault has documented an unusual pattern of deformation of the Bonneville Shoreline. As originally described by Crittenden (1963), the shoreline is no longer at the elevation of Red Rock Pass (5090 ft/1552 m) over the entire basin. Isostatic rebound since the lake retreated measures up to 230 feet (70 m) in the center of the basin west of Salt Lake City, and decreases to zero at the lake margins. The Bonneville Shoreline in Cache Valley is affected by this regional-scale unloading, and now slopes northward, measuring 5166 feet (1575 m) elevation at the south end of the valley and 5104 feet (1556 m) at the Idaho-Utah State Line. However, this drop of 62 feet (19 m) does not occur uniformly; 60% of the drop occurs in two short segments which total less than 10% of the total shoreline length in Cache Valley (Figures 4 and 5). At each of these locations (the High Creek-Cherry Creek site in segment A, and the Hyrum site in segment C, Figures 4 and 5), large delta complexes (2.5 km x 3.2 km x 100 m thick) occur graded to the Bonneville or Provo shorelines.

At the other large delta (Logan site in segment B), no sharp shoreline tilt is observed; however, this site is coincident with the only known post-Bonneville surface faulting (Figure 5). It is tentatively proposed that loading by the weight of the delta sediments has induced ductile bending of the range front in segments A and C, where the range-front fault is developed in weak rocks of the Salt Lake Group.

Rheologic modeling of the crust as a 10 km thick beam, subjected to a distributed load similar to delta weight, yields calculated flexures of roughly 6 m, as opposed to 4.3 to 5.3 m measured in the field. In contrast, depositional loading in the central fault segment has resulted in brittle failure of Paleozoic rocks, decoupling of the downthrown and upthrown blocks, and at least two surface faulting events.
FIGURE 4: Sketch map showing the overall pattern of the East Cache Fault Zone (heavy line in center, solid where Bonneville deposits are offset, dashed elsewhere). Qu--Quaternary deposits, undifferentiated; Qd--Quaternary deltaic deposits; Tal--Tertiary Salt Lake Formation; Pu--Paleozoic rocks, undifferentiated. From McCalpin (in press).

FIGURE 5: Elevation profile of the Bonneville Shoreline along the eastern side of Cache Valley, from Franklin, ID (0) to Avon, Ut (5). Elevation measurements (shown by dots) have an uncertainty of plus or minus 0.5m, which is not shown on this plot. Locations of deltas, segment boundaries and towns are the same as on Fig. 4). Height of arrows under "FAULT SCARPS" indicates net surface offset (up to 4.1m) measured from scarp profiles.
To the east, the Bonneville Shoreline is carved on Long Hill (the northern one with the "SV") and Round Hill farther south. Each hill is an outlier from the main body of the Salt Lake Group, separated from it by the East Cache Fault.

Enter Smithfield, Utah (population 4,993), built on the post-Bonneville alluvial fan of Summit Creek. Smithfield is the largest town in Utah without a municipal sewage collection and treatment facility, relying instead on individual septic tanks and leachfields.

Apex of the Summit Creek alluvial fan; Summit Creek flows under the highway in a box culvert.

Leaving Smithfield. To the northeast, the south face of Crow Mountain displays a prominent Bonneville Shoreline. About 350 feet (106 m) below this shoreline, a large gravel pit exposes coarse foreset beds below the Provo Shoreline (Figure 2). The delta front forms a west-facing escarpment approximately 80 feet (25 m) high about 0.6 mile east of the highway.

800 North Street, road to gravel pit on Crow Mountain

To the west is Newton Hill, one of the several peaks named "Little Mountain" in Cache Valley. Newton Hill is 5693 feet (1735 m) high, and displays well-developed shorelines at the Bonneville and Provo levels. The base of the mountain is at 4500 feet (1371 m).

Large blocks of Late Proterozoic-Cambrian quartzite appear on both sides of the highway, probably remnants of a pre-Bonneville landslide off the west face of Crow Mountain. Lake currents were forced to speed up in traversing the Crow Mountain peninsula, leading to relative sediment starvation and a thin, discontinuous cover of lake sediments. From here north to Richmond, the terrain to the east is underlain by conglomerates of the Salt Lake Group, thinly covered with lacustrine shoreline sands and gravels.

Entering Richmond, Utah (1980 population 1,705).

The sharp "hump" in the highway is due to the post-Bonneville alluvial fan upon which the town was built. The Malad Range, composed of lower Paleozoic carbonate strata, lies to the west.
Descend the north side of alluvial fan back onto the Provo lake bottom. The Bonneville Shoreline is carved onto hills to the east at 5125 feet (1563 m).

To the east, the combined Provo deltas of High and Cherry Creeks make a level platform roughly 0.6 miles (1 km) east of the highway, delineated by a west-facing delta front about 80 feet (25 m) high.

Turn-off to Cove, Utah. Richmond Knoll to the east displays Bonneville and Provo shorelines. To the north the Bonneville Shoreline is carved on Mt. Smart, a linear ridge composed of Lower Paleozoic rocks (Figure 3). Mt. Smart is about 600 feet (182 m) high, and was thus almost totally submerged in Lake Bonneville. The Bonneville Shoreline forms the flat bench at the top of the butte, while the Provo Shoreline is about 200 feet (81 m) above the valley floor.

To the northeast and east, the Franklin Ramp is seen in profile. The Ramp is a pre-Bonneville pediment surface eroded onto Salt Lake Group. Above the elevation of the Bonneville Shoreline, the upper half of the Ramp exposes well-developed patterned ground and stone stripes, suggesting that a periglacial/permafrost climate existed when the lake was at its maximum.

Idaho-Utah State Line. Entering Franklin County, Idaho.

Entering Franklin, Idaho (1980 population 423). This is oldest town in Idaho, settled by Mormon pioneers in 1860.

Descend onto the floodplain of the Cub River, one of the few large tributaries to Bear River in Cache Valley. To the northwest is Mt. Smart. The Bonneville Shoreline is displayed roughly 35 feet (10 m) below the summit.

Cross Cub River

Highway 91 curves from north to northwest, heading toward Preston, Idaho. We are traversing the Provo lake bottom, between elevations 4550-4700 ft (1387-1433 m), and will imperceptibly rise onto the surface of the Provo delta of the Bear River.

Sewage treatment plant in the channel of Worm Creek, an intermittent stream on the flank of the Provo delta.
28.1 Merrill's Bar; rise up onto the Provo delta surface.
(1.1)

28.7 Entering Preston, Idaho (1980 population 3,759),
(0.6) elevation 4714 ft (1437 m). The town was constructed on
the smooth surface of the Provo delta.

29.5 Stoplight at the junction of Main and Oneida Streets in
(0.8) downtown Preston.

30.4 Junction of State Highway 34 and U.S. Highway 91. Bear
(0.9) left, staying on Highway 91 heading west. Directly
ahead is Oxford Ridge of the Bannock Range. To the east-
southeast, rolling hills roughly 1.2 miles (2 km) distant mark the remnants of the somewhat higher
Bonneville delta of the Bear River, now severely
dissected by erosion. The road lies on top of the flat
smooth surface of the Provo delta, which contrasts
sharply with the rolling hills of the Bonneville delta.

31.4 Junction with 8th West Street. This road leads north
(1.0) (right) to the area of the "Classic" and the "Complex"
Slides, the third and fourth stops on the field trip.

32.0 Road curves from west to northwest just past the Preston
(0.6) airport on the left. The road descends about 40 feet
(12 m) from the top of the Provo delta to a stream
terrace level at 4660 feet (1420 m). This terrace was
occupied when the Bear River was adjusting to a
lowering of base level due to recession below the Provo
level.

32.2 Road to left provides access to an excellent
(0.2) stratigraphic section incised by the Preston storm sewer
drainage (Figure 7). The section exposes the thick (45
ft/15 m) pro-delta clay that lies at the top of the
Bonneville delta in the Preston area. Unconformably
overlying the clay are post-Provo fluvial sands
and gravels deposited by the Bear River. Post-Provo
erosion has locally removed and/or reworked deltaic and
lacustrine deposits of Lake Provo.
FIGURE 6: Schematic block diagram of Bear River Landslide Complex looking east from above Highway 91.

FIGURE 7: Post-Provo gravels unconformably overlying Bonneville pro-delta clays in Preston Storm Sewer Drain Canyon. Note blowout in gravels and black rippled horizon which marks location of a sand layer which has been washed out by artesian pressure and now liberates free water.
STOP 1--OVERVIEW OF CACHE VALLEY

Pull off at Pioneer Ferry and Bridge Historical Marker on west (left) side of road. The highway descends off the river terrace and down to the floodplain of the Bear River. Clifton Hill ("Little Mountain") rises in the middle of Cache Valley to the northwest. Squaw Hot Springs and Wayland Hot Springs lie along the Bear River just south of Clifton Hill. The springs probably rise along a buried fault which is a continuation of the scarp which forms the east face of Clifton Hill.

The basic setting of the Bear River Landslide Complex is visible to the north and west (Figure 6). The steep sided canyon of the Bear River is cut in unconsolidated deltaic sediments and floored by the broad flood plain of the modern river. East of the highway is an area of springs, small landslides, and thick brush formed where groundwater escapes along the canyon wall.

Clifton Hill is located near the distal terminus of the Bonneville delta, and represents a boundary between deltaic sediments to the east, and lacustrine sediments to the west. Deep Creek drains the west side of Clifton Hill, and is cut in sandy sediments derived from the west and north sides of the valley. Battle Creek, just east of Clifton Hill, is deeply incised into the more clay-rich sediments derived from the Bear River Delta. Both of these creeks occupy steep canyons that are subject to small mass movements. The sandy sediments in Deep Creek are subject to earth falls and dry sand flows, which result from oversteepening of the stream bank by undercutting. Mass movements in the more clay-rich sediments cut by Battle Creek are primarily slump and slump-earth flows.

Return to the vehicles and continue north on Highway 91.

Cross Bear River. To the east and south are the toes of the Classic and Complex slides that will be visited at Stops 3 and 4. Battle Creek enters Bear River from the west just north of the bridge. The active landslide directly west last moved in 1983, and displayed two stages of movement. An initial small earth flow on the north flank weakened lateral support, and instigated a much larger slump failure. Movement occurred over a period of several hours, and blocked both the canal and the access road, requiring extensive repairs.
FIGURE 8: Views of Highway Slide area
A) Aerial view of Highway Slide B
B) Winter grain planted in fall 1985 and displaced by 2m in Spring 1986. This scarp is about 7m east of Highway 91.
C) Damage at Highway Slide B. Cracked pavement in foreground is former roadway that moved 1-2m down in Spring 1983 and 1984.
D) Headscarp of Classic Slide south of Bear River. Note back rotation of slump blocks.
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34.4 Hot Springs Road to the left (west). The canyon of Battle Creek can be seen directly west. Straight ahead (north) is the proposed new right-of-way for Highway 91.

34.9 Cross West Cache Canal. Canal access road on right (east) provides access to exposures of Bonneville delta sediments along the bluffs north of Riverdale. Relocation of this canal and the construction of a new bridge will be major considerations in highway relocation.

35.4 STOP 2--HIGHWAY SLIDES A AND B (See Figure 8) The road here is built on Provo(?) and post-Provo sands and gravels which unconformably overlie fine-grained sediments of the Bear River Delta. Bonneville pro-delta clays lie at a depth of 20-25 feet (6-7 m).

Highway Slide A started encroaching on U.S. 91 during Spring, 1983, when a small mudflow undermined the shoulder of the road near milepost 14.1. Headward expansion of the slide and block type failure near the headscarp eventually disrupted approximately half of the existing roadway. Slope indicator measurements near the head scarp suggest the slide failure plane is 22-27 feet (6-7 m) below the elevation of the road surface. The highway slide is a relatively small movement nested within a much larger slump-earth flow failure. The area has undergone several phases of movement, which have moved down slope and become progressively smaller with each movement (Figures 7 and 8). Highway Slide A was surveyed and observation grid was established in autumn 1986. The grid will be monitored by the Idaho State University Geology Department.

An investigation of the area was initiated by the Idaho Department of Transportation when it became apparent that temporary maintenance measures (patching the road surface, ditchline and culvert maintenance) would not to provide a stable roadway. The results of the investigation coupled with headward expansions of a much more massive slide (Highway Slide B) 800 feet (243 m) north resulted in a temporary shifting of the roadway approximately 25 feet (7 m) into the hillside and the construction of a crude French drain in the ditch in April, 1984. The old road surface can be seen just east of the present highway (Figure 8c).
FIGURE 9: Aerial photo interpretation of Highway Slide A. Numbers refer to sequence of movement (1 is oldest).

FIGURE 10: Oblique aerial photo of Highway Slide A.
The initial slide investigation and observations of other slides near the highway led to the decision to relocate Highway 91. A drilling program was initiated in 1986 in order to characterize the stratigraphy and engineering aspects of the proposed relocation routes. As of February 1987, specific road relocation plans and engineering designs are preliminary. Refer to Mahoney and others (this volume) for a more complete discussion of the highway slides and relocation plans.

Highway Slide B is considerably more worrisome to the Idaho Department of Transportation (Figure 8a). The headwall of this slide has advanced over 1000 feet (305 m) since 1981, and is presently only a few feet from the existing highway. The slide is currently active; grain planted in 1985 has been displaced by about 5 feet (1.5 m) near the head of the slide (Figure 8b). Additional failure within this area will undermine large areas of Highway 91, and will require further road realignment.

The area of the next field trip stop is visible to the south and east across the Bear River (Figure 8d). That area is subject to the most serious and frequent mass movements of the Bear River Landslide Complex.

Return to vehicles, turn around, and head back south across the Bear River, up the hill toward Preston, and onto the Provo delta surface near the airport.

39.1 Turn left on 800 West Street, heading north. We are at (3.7) 4720 feet (1439 m) elevation; the Provo shoreline is just east of the road. The Provo Shoreline divides the extremely flat and smooth Provo delta surface from the rolling hills of the Bonneville delta, visible to the north and northeast.

40.6 House on right, end of paved road. We will drive as (1.5) far as conditions permit.

40.8 End of road. The road formerly continued down the (0.2) bluff, before slide movement made it impassible. Turn right and head northeast into alfalfa field.
FIGURE 11 a and b: Schematic aerial photo interpretation of Complex and Classic Slides. Numbers refer to sequence of movement (1 is oldest). See Figure 8 of Mahoney and others (this volume) for location of slides.
If possible, drive along edge of bluff and get out at head of "Classic" Slide. The original Preston-Riverdale-Mink Creek canal ran along the base of the bluff, but caused continual problems, due to seepage from the canal destabilizing the slopes at their base. The canal was built in 1889, and required constant maintenance due to washouts until it was finally abandoned in 1951.

STOP 3--CLASSIC SLIDE, SOUTH OF BEAR RIVER (Figure 11a)

This mass movement is one of several on the south side of the Bear River and has long been subject to landslides, due to confined and perched aquifers above and below the thick (50 feet/15 m) Bonneville pro-delta clays that underlie the area at a depth of about 10 feet (3 m). The elevation of the field here is about 4740 feet (1445 m), we are at the Provo lake level.

The "Classic" slide is a superb example of a slump-earth flow type failure, with block rotation in the head region, a bulbous toe, numerous transverse and crown cracks, and well-defined margins between zones of movement within the slide. The most recent movement involved failure of a lower saturated horizon, which created a rapid earth flow of semi-liquified sediment that thinned and spread laterally upon reaching the valley floor. Coherent upper units subsided with a back rotation of 45-50 degrees (Figure 8d). It is uncertain whether failure of the lower horizon induced failure of upper units, or visa versa. Movement was very rapid, with the entire slide occurring within two hours.

The slide was surveyed and an observation grid established in Fall, 1986.

If time and weather permit we will proceed back about a mile south and west to the headwall of the Complex Slide.

Start back south toward 800 West Street.

Farmhouse on left (0.5)
42.1 Turn right (west) on farm road, proceed to end of road (0.1) in alfalfa field, and stop.

STOP 4--COMPLEX SLIDE

The Complex Slide is so named because it displays multiple movements which coalesce in a deep narrow gulley in the medial portion of the slide. The most recent movement occurred in 1983-1984, when the slide blocked the Bear River, diverting it into the valley and inundating about 3 acres of farmland.

The failure style of the Complex Slide is similar to that of the Classic Slide. Two separate slump-earth flow movements have occurred recently. The first movement was a viscous earth flow accompanied by major slumping in the head region; displacement on the head scarp is about 15-17 feet (5 m). The second movement was a much more fluid earth flow, which followed gullies developed by the first movement. The amount of time separating the two movements is unknown.

The entire slide region remains quite saturated, with numerous springs and ponds in the poorly drained head region. The resultant instability is evidenced by active flow zones throughout the slide area.

This slide was also surveyed and staked in fall, 1986.

Also visible in this location is the old course of a small canal, and an ill-fated spring-fed cattle watering pond constructed below the edge of the bluff. The pond only served to increase ground water saturation, thereby destabilizing the slope, and had to be abandoned.

END OF FIELD TRIP.
REFERENCES CITED


