Geologic and Hydrogeologic Investigation of the Clark Canyon Landslide, Southwestern Montana

MONTANA BUREAU OF MINES AND GEOLOGY
OPEN-FILE REPORT 442

by
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Introduction

The Clark Canyon landslide, located approximately 17 miles southwest of Dillon, Montana, is an ancient slope failure that has experienced renewed ground movement since 1995. The movement is affecting the Union Pacific Railroad (UP) track, an unpaved state frontage road, and nearby underground utilities. Ground movement has been confined to two small landslides within the much larger ancient landslide. If the size of the small landslides increases and more of the ancient landslide is remobilized, there could be impacts to the Beaverhead River and Interstate 15.

Because of the expense involved in continual repair and reconstruction, UP has considered abandoning this branch line. The Montana Department of Transportation (MDT), the designated state agency for monitoring Montana's rail infrastructure and operations, has also identified this line as being at risk of abandonment because of low traffic density in the 2000 Montana State Rail Plan Update (MDT, 2000). Loss of the line would have significant local and regional economic impacts. The UP is a Class1 railroad that provides the only rail competition for the Burlington Northern-Santa Fe (BNSF) Railroad in Montana. In order to secure and establish more competition for BNSF, the state has already invested local, state, and federal funds in a number of facilities served by UP, including the Port of Montana and a 52-car grain terminal, both located at Silver Bow, west of Butte, MT.

Efforts by UP to stabilize the active landslides have not been completely successful. Therefore, an expanded investigation of the landslide was initiated to gather data needed to determine what factors affect ground movement and what additional remedial measures could be implemented. The investigation is a joint effort involving the UP, Port of Montana, Montana Department of Transportation (MDT), Butte-Silver Bow County, Montana Bureau of Mines and Geology (MBMG), and the Economic Development Administration (grant). Shannon & Wilson, Inc., a geotechnical consulting firm under contract with UP, and MBMG conducted the field investigation.

Purpose and Scope

The purpose of this report is to describe the work completed by MBMG on the geology and hydrogeology of the Clark Canyon landslide. This report was prepared specifically for MDT to assist them in their responsibility for rail programs and planning for the state of Montana. A brief discussion of the subsurface investigation and monitoring is included although that work was primarily conducted by Shannon & Wilson. A separate geotechnical report is being prepared by Shannon & Wilson.

Description of Project Area

The Clark Canyon landslide is located near the mouth of Clark Canyon, approximately one mile north of the Clark Canyon Reservoir (fig. 1). The legal description is the NW¼ of section 33, T. 9 S., R. 10 W. Land ownership includes UP right-of-way, State of Montana, U.S. Bureau of Reclamation, and private. MBMG included an area of

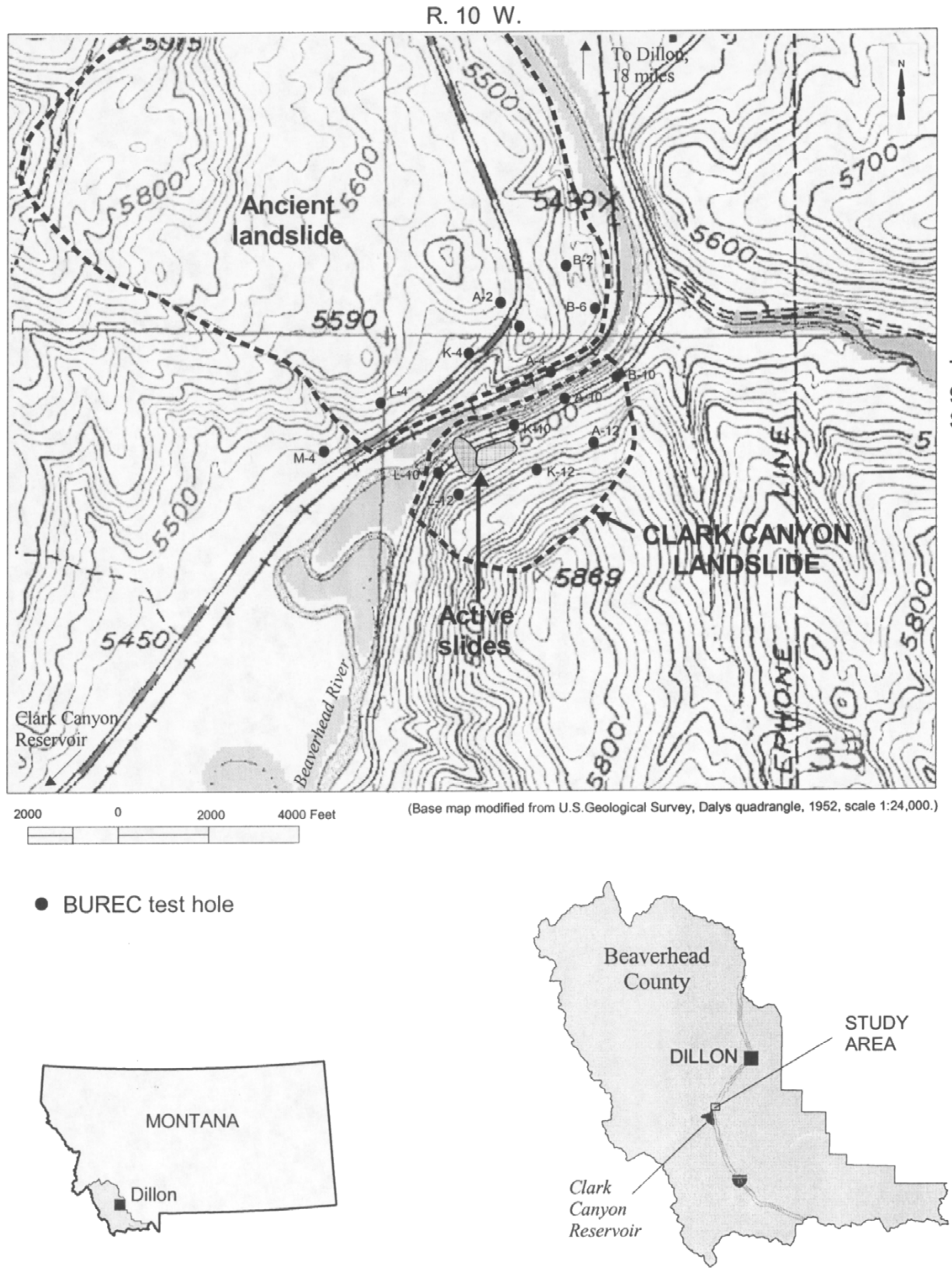

Figure 1. Location of the Clark Canyon landslide and a second inactive landslide, north-northwest of the Beaverhead River south of Dillon, Montana. Base map predates construction of Interstate 15 and UPRR track realignment.

approximately 4 square miles surrounding the landslide as part of the geologic mapping and general hydrogeologic evaluation.

The ancient landslide encompasses approximately 30 acres on a steep, northwest-facing slope adjacent to the Beaverhead River (fig. 2). Total relief on the landslide is approximately 430 feet. The smaller active landslides are each approximately 2 acres in size with less than 80 feet relief. Both are located adjacent to the UP track.

Previous Investigations and Background

The U.S. Bureau of Reclamation (BUREC) first investigated the geology of the Clark Canyon landslide (Elliott, 1958) when it was considered a potential site for the proposed Clark Canyon Reservoir. The site was ultimately rejected because geological and geophysical data indicated a deep Tertiary channel under the site and because both dam abutments would have been on landslide deposits. An alternative location for the dam was selected one mile to the south.

In the early 1960's the UP track was realigned during construction of the dam and the interstate highway. The new route for the railroad crossed the lower portion of the ancient landslide complex. Only minor maintenance problems were reported until 1995 when two small landslides occurred adjacent to the railroad tracks. The first slide (at UP milepost MP309.75) occurred in the spring and resulted in gradual vertical (approximately 18 inches) and lateral (less than 1 foot) deflection of the tracks. UP contracted with Shannon & Wilson, Inc. to investigate the slumping and provide mitigation recommendations. The investigation was conducted in June 1995. In August 1995, approximately one month after the Shannon & Wilson site investigation, a second landslide (at milepost MP309.7) occurred south of the first. Unlike the first slide, the movement at this location was rapid. The ground beneath the track dropped approximately 5 feet overnight, forcing UP to move the track approximately 12 feet into the cutslope. This second slump also affected the frontage road at the toe of the landslide and damaged an underground telephone cable.

Based on the results of their site investigations, Shannon & Wilson (1995) recommended several remedial measures for improving slope stability. In an effort to minimize infiltration of surface water into the active slides, culvert drains and a PVC ditch liner were installed along the east ditch of the tracks. A buttress was constructed along the toe of the MP 309.75 slide. A combination of ballast-filled french drains and regrading was used to increase stability of the MP309.70 slide. The remedial measures were completed in November 1995.

Since 1995 there have been additional stability problems associated with the active slides. In 1998, ground movement along the tracks caused vertical displacement of the tracks and damage to the surface-water drainage system installed in 1995. MBMG visited the site in 1998 and documented damage to the surface drains and ditch liner (fig. 3). New cracks were also observed on the slope above the tracks, indicating the head of the MP 309.75 slide may be migrating upslope to the east. A soldier pile retaining wall was

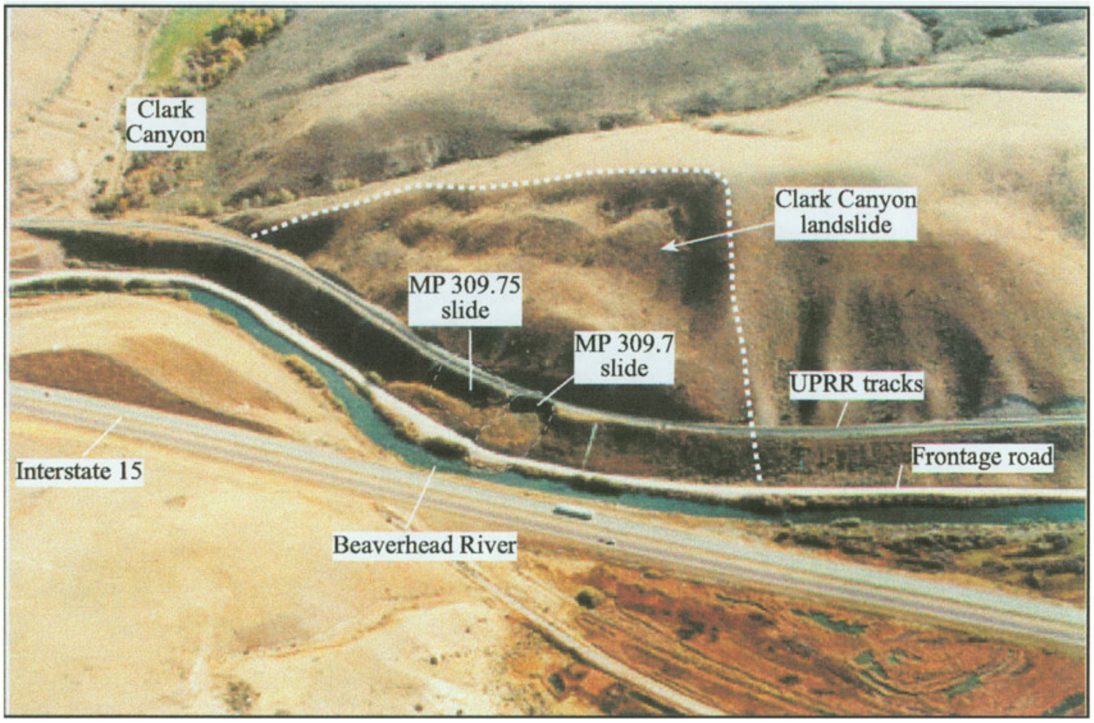

Figure 2. Aerial photograph of the Clark Canyon landslide. The photo was taken in October 1998. The view is toward the east.

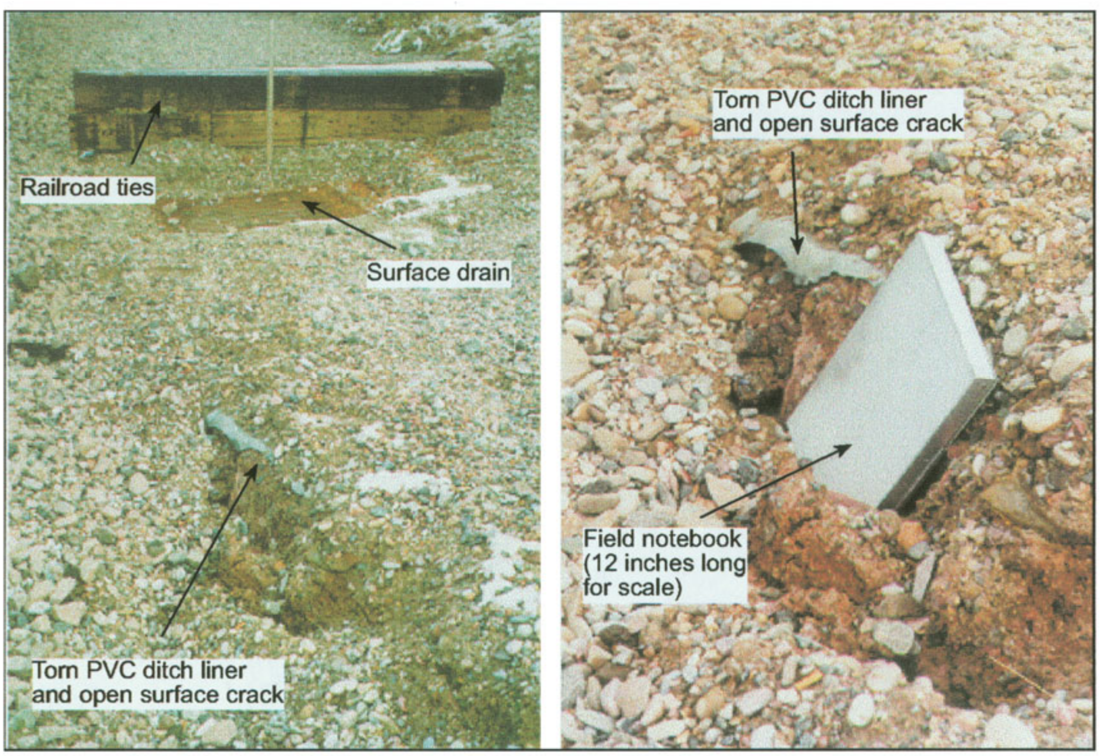

Figure 3. Open-surface cracks and the damaged PVC liner. The PVC liner was installed in 1995 in an effort to redirect suface runoff along the railroad tracks.

installed in 1999 near the head of MP309.7 slide to prevent loss of ballast associated with continued slumping. Since 1995, UPPR has realigned (raised the tracks and added ballast) the track several times (Craig Taylor, UP, oral commun., 2001).

Landslide Surface Features

The primary surface features of the Clark Canyon landslide are shown in figure 4. The main scarp and lateral flanks of the ancient slide are well-vegetated and smooth. The topography below the head scarp is hummocky and slopes to the west. Slopes are steeper in the lower half of the landslide. The toe of the landslide is poorly defined and has probably been modified by the Beaverhead River. A number of isolated patches of serviceberry and wildrye, vegetation that can indicate moist conditions, are present

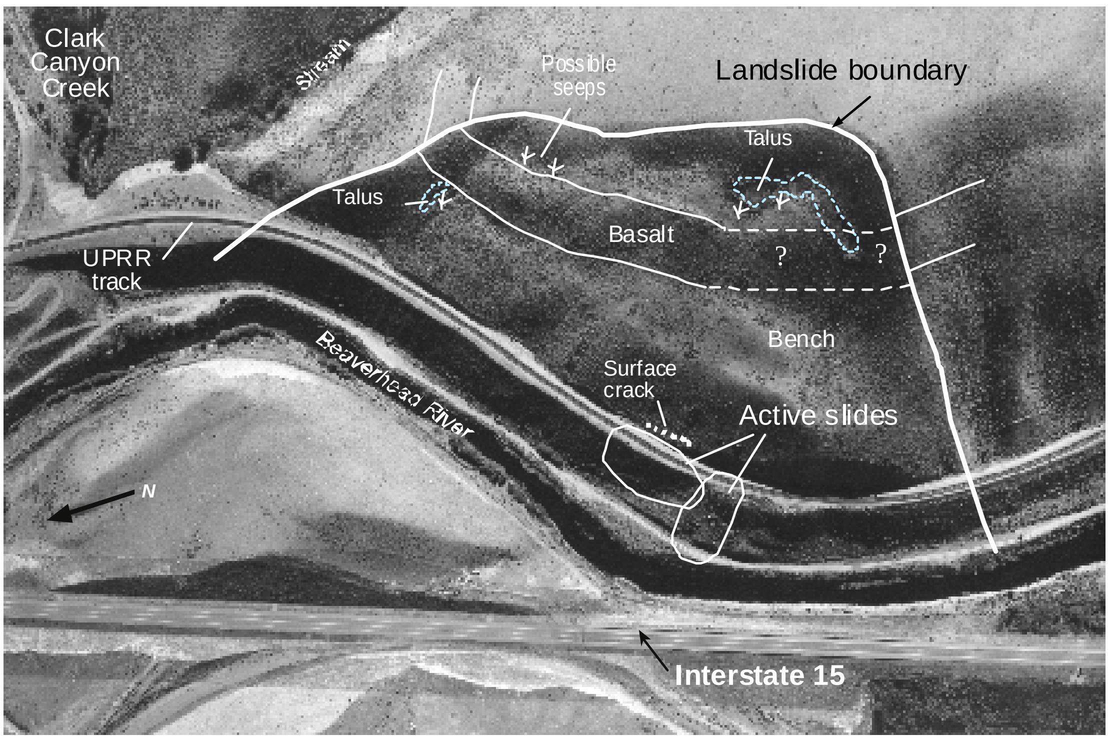

Figure 4. Aerial photograph of the Clark Canyon landslide showing the location of important surface features. The photograph, provided by MDT, was taken in 1977, prior to the slope failures along the railroad tracks.

near the base of the scarp and along the flanks of the ancient slide. Accumulations of talus near the head of the landslide and along the north flank form roughly cresent-shaped features that may have accumulated along surface depressions or cracks. A poorly-exposed outcrop of basalt is present near the head of the ancient landslide. An open surface crack crosses the slope above the head of the active slide at MP309.75.

Geology

The Clark Canyon landslide is located along the Beaverhead River, near the western end of the Blacktail Mountains. The study area (fig. 5) is characterized by folded Paleozoic and Mesozoic sedimentary bedrock overlain by Tertiary basin-fill and coeval volcanic rocks. Bedrock consists of the Mississippian Madison Group, the Upper Cretaceous Beaverhead Formation, and Tertiary volcanic rocks. Important unconsolidated units are the Tertiary Bozeman Group and Quaternary surficial deposits. Mapping for this study was done by MBMG at a scale of 1:24,000. Regional geologic mapping in the Dillon area has been completed by Lowell (1965) and Ruppel and others (1993).

The Madison Group exposed west of the Beaverhead River consists of several thousand feet of gray carbonates, separated into the Lodgepole and Mission Canyon Limestones. The combined thickness of both formations is approximately 3,400 feet (Ruppel and others, 1993). The Armstead Thrust Fault, mapped west of the Beaverhead River, places the Madison carbonates over the Beaverhead Formation.

The Beaverhead Formation is the most widely exposed rock unit in area. It consists of massive, moderately-indurated, boulder, cobble, and pebble conglomerate with some interbedded sandstone and fresh-water limestone. In most places these rocks consist of rounded to subangular fragments of Proterozoic quartzite and Paleozoic carbonate rocks. Minor weathered andesite and other volcanic fragments are present locally.

The Beaverhead Formation is unconformably overlain by a sequence of Tertiary volcanic rocks consisting mainly of basalt and rhyolite lava flows, ash-fall tuffs, and volcaniclastic deposits. Basalt dikes cut the Beaverhead Formation. Unmapped beds of conglomerate containing abundant fresh volcanic fragments and thin, discontinuous ash layers are interbedded with basalt flows near the mouth of Clark Canyon.

The Bozeman Group and related basin-fill deposits consist of pebble- and cobble-conglomerate beds with interbedded tuffaceous sandstone and siltstone. The conglomerate beds contain fresh basalt, rhyolite, and tuff fragments, as well as fragments from the older formations. The sediments were deposited on an erosional surface that truncates all the older rocks (fig. 6).

Quaternary alluvium, colluvium, and terrace deposits are present in valleys of major drainages. These deposits consist of unconsolidated silt, sand, and gravel.

Landslide Geology

A simplified geologic cross section of the landslide is shown in figure 7. Materials in the landslide appear to be derived primarily from the unconsolidated conglomeratic beds of the Bozeman Group and, less commonly, the underlying basalt and unmapped ash beds, and the Beaverhead Formation. The thickness of the ancient landslide deposit and the location of the slide plane are based on data from the BUREC test holes drilled in 1947 and 1948. Bentonitic clay horizons, formed by alteration and weathering of volcanic ash, were identified in the borings in some places.

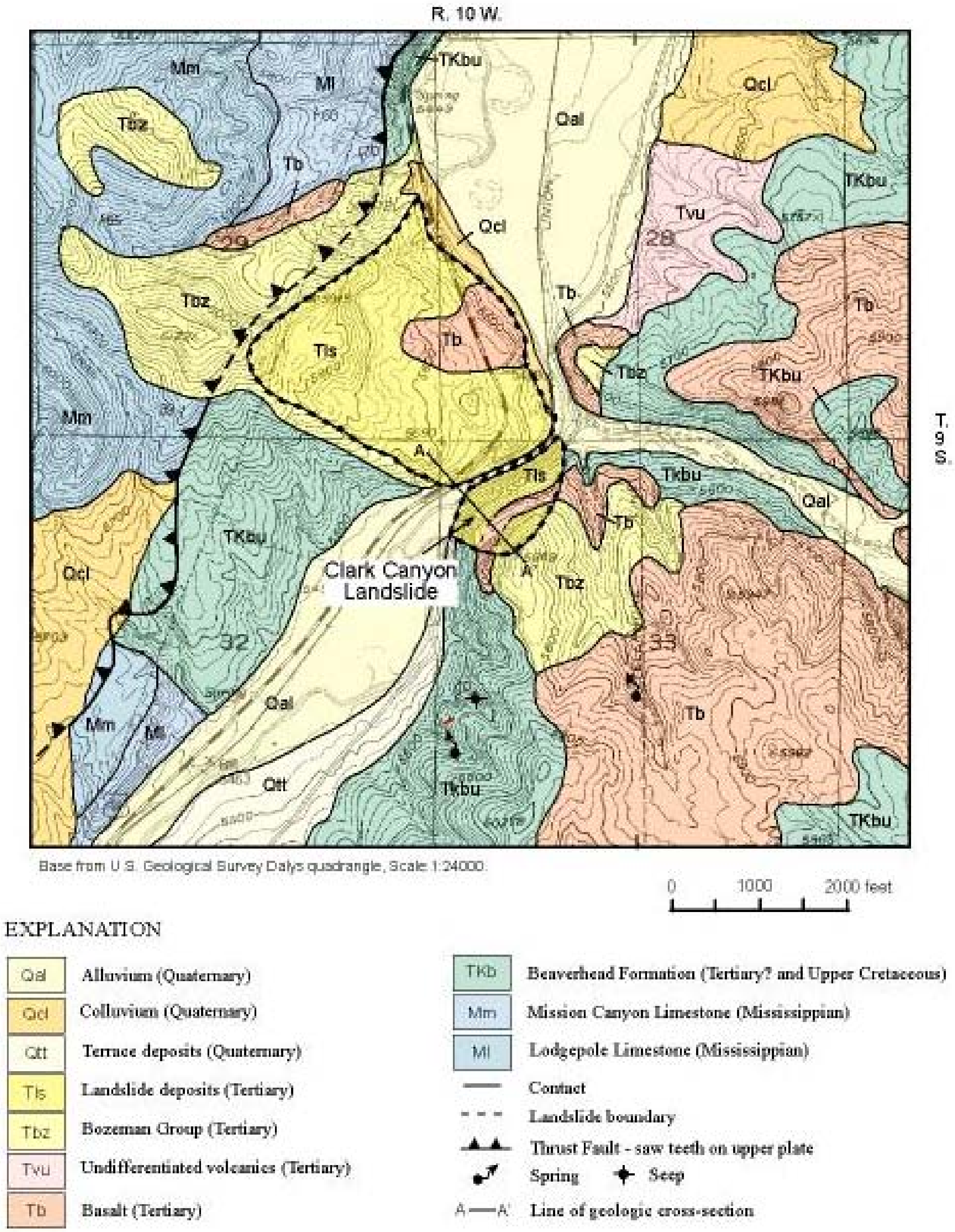

Figure 5. Geologic map of the area around the Clark Canyon landslide (modified from Lowell, 1965).

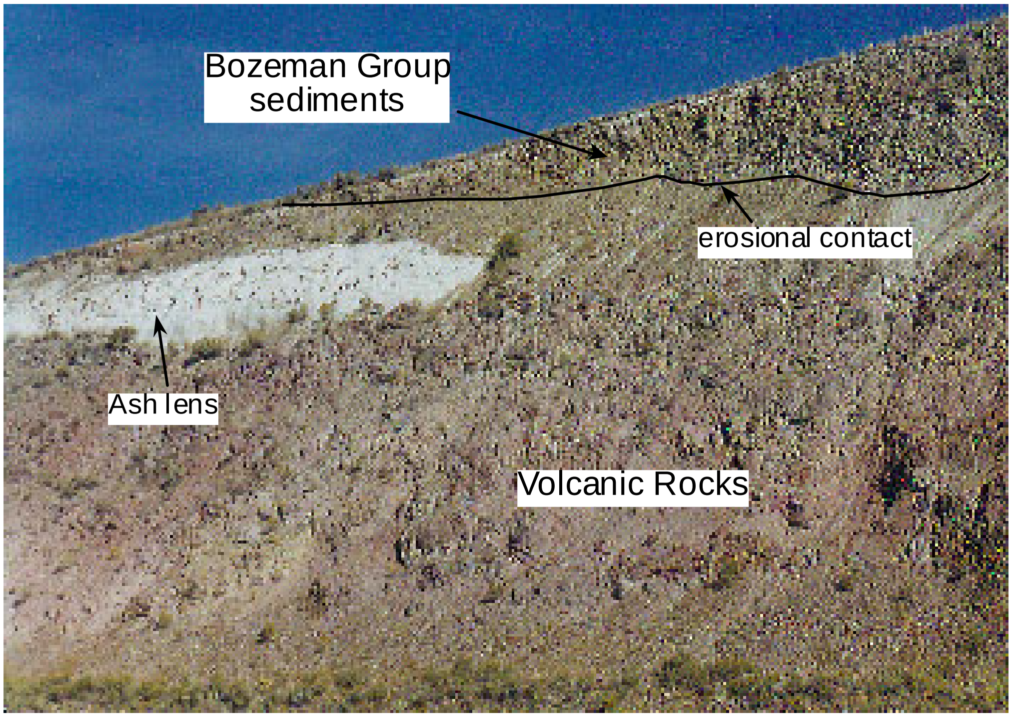

Figure 6. Cutslope exposure showing general stratigraphy of the volcanic and overlying sedimentary bedrock in the area near the Clark Canyon landslide.

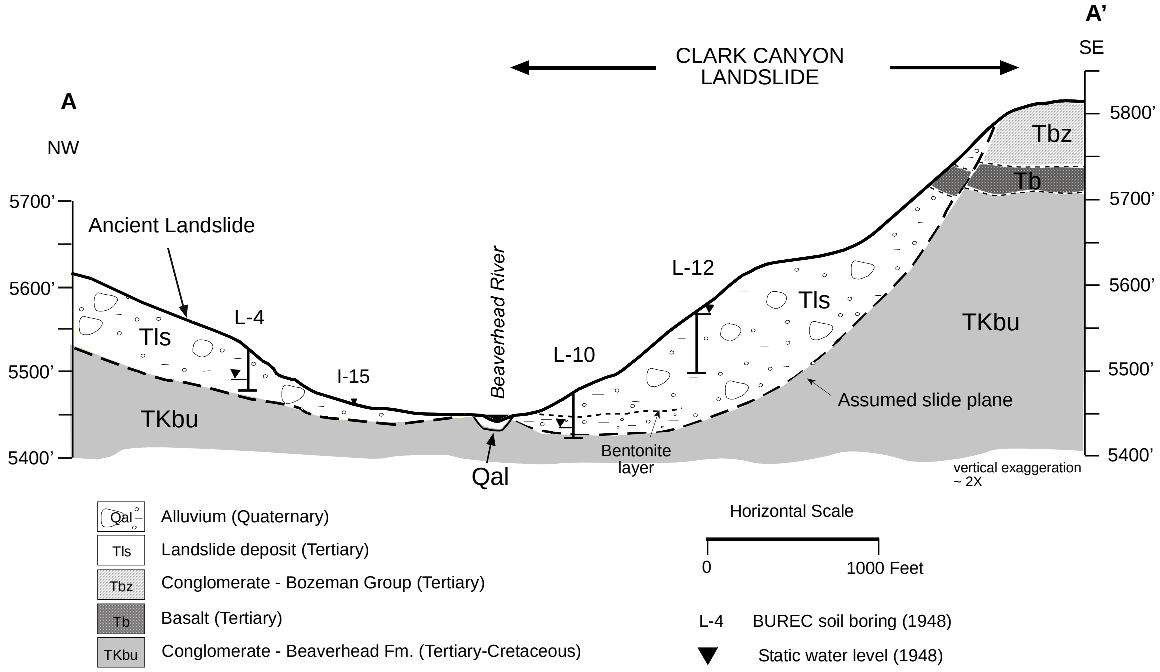

Figure 7. Generalized geologic cross-section through the ancient landslide. The location of the BUREC test holes and the line of the section are shown in figure 5. The active slides (post 1995) are at about the level of holes L-10 and L-12.

A number of other Tertiary landslide deposits in the Blacktail Mountains and surrounding area occur under similar geologic conditions. Notable is the Pipe Organ landslide approximately 5 miles north of the Clark Canyon landslide that was investigated by MDT during construction of Interstate 15 (Williams and Clark, 1970).

Type and Cause of Movement

The Clark Canyon landslide and the two small landslides within the ancient complex all appear to be rotational slides. The presumed cause of the ancient landslide is over-steepened slopes, weakening of volcanic rock units by ground water, and perhaps seismic disturbances. The cause for the recent landslides is probably more complex. Ground water appears to be a key factor because the initial failures in 1995 and subsequent movement in 1997 and 1998 occurred during years with above-normal precipitation (fig. 8). Both slides originated along the grade constructed for the railroad, suggesting that modification of the original slope could be a factor. Although the landslide is in an area with considerable seismic activity (fig. 9), there were no significant seismic disturbances in 1995 that could have triggered the initial ground movement (Mike Stickney, oral commun., 2001).

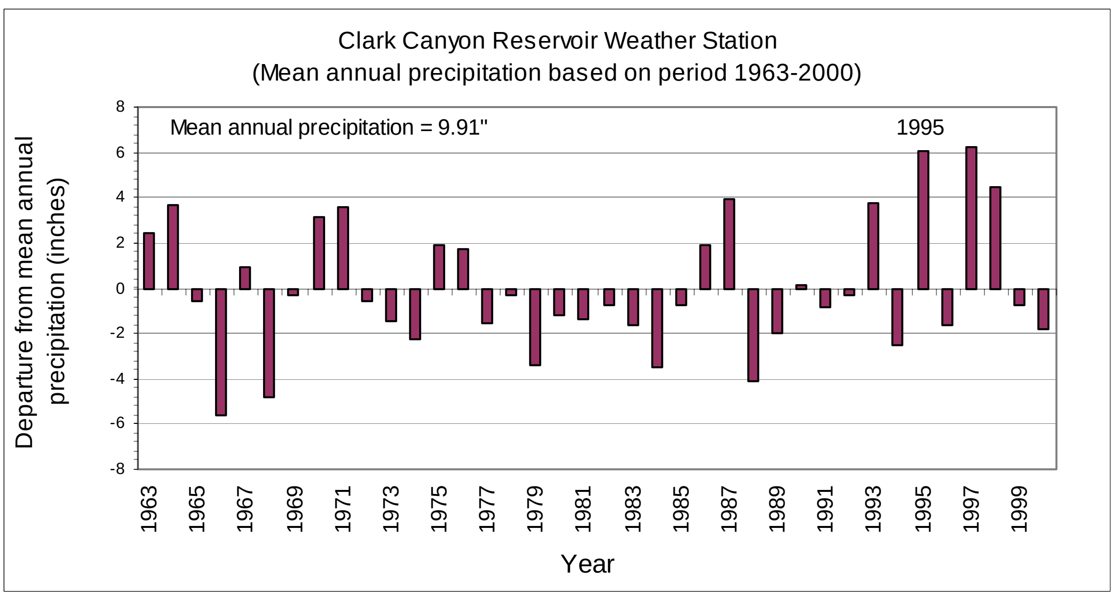

Figure 8. Annual departure from mean annual precipitation at the Clark Canyon Reservoir weather station. The most active periods of slope movement were in 1995, 1997, and 1998. Data from the National Climatic Data Center (2001).

Ground Water

In order to evaluate general ground-water conditions within and around the ancient landslide, MBMG reviewed the historical BUREC drilling data, evaluated well logs and water-levels from private and/or public wells in the area, and collected field data on springs and seeps near the landslide.

BUREC Borings and Other Well Data

During 1947 and 1948, the BUREC completed 15 test holes within the landslide area, and 7 of these were drilled within the Clark Canyon landslide (fig. 1). The information recorded on the logs included daily water levels in the cased holes, remarks on water return, core recovery, and materials encountered. None of the test holes were completed as monitoring wells so the observations discussed below are based on the data collected during drilling and may only be an approximation of actual conditions.

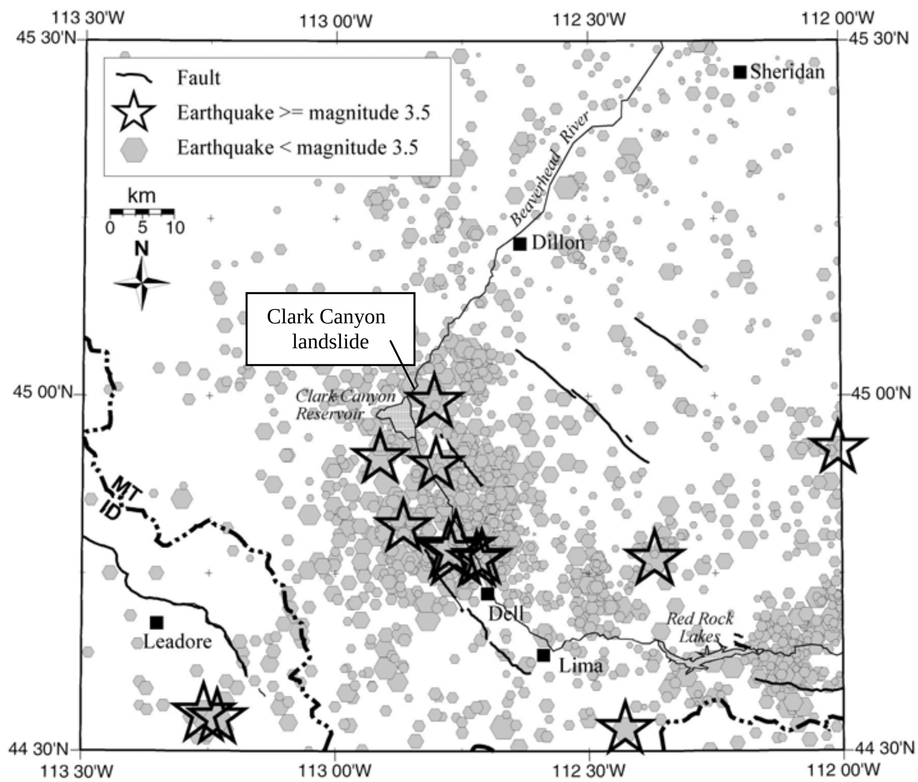

Figure 9. Southwest Montana seismicity since 1982 (Data from the Earthquake Studies Office at MBMG). None of the large (>3.5 magnitude) earthquakes near the Clark Canyon landslide occurred in 1995, the year of the slides discussed in this report. The earthquake shown by the star close to the Clark Canyon landslide was magnitude 3.9 and occurred in 1985.

Ground water was encountered in all borings and it appears that multiple water-bearing zones were present. Water pressure increased with depth in some of the borings (A10 and L10), suggesting that isolated zones of saturated permeable material under elevated pressures were present. Loss of drilling fluid occurred in almost all the borings and is interpreted as an indication of zones of higher permeability. Water levels in wells close to the river were higher than the river water level, indicating that ground water discharges to the Beaverhead River. This would be consistent with a ground-water flow direction to the north-northwest, assumed on the basis of topography.

MBMG conducted a search of the Montana Ground Water Information Center (GWIC) database to locate wells that could provide additional information on local ground-water conditions. Unfortunately, only one well was drilled within a mile of the landslide and it was completed in the shallow alluvium west of the Beaverhead River, and is not representative of subsurface conditions around the landslide.

Springs and Seeps

MBMG located two springs and one ground-water seep along the sides of the ridge behind the landslide (fig. 5). No springs were identified within the landslide although there were areas where vegetation changes indicate potentially elevated soil-moisture levels (fig. 4). The flow rate in the largest spring, located southeast of the landslide, was approximately 15 gpm; flows from the other spring and seeps were too low to measure. The largest spring emanates from a basalt flow and produces a perennial stream that discharges into Clark Canyon Creek. The spring and seep on the west side of the ridge discharge from the Beaverhead Formation.

The springs and seeps, including the potential seeps within the landslide, occur at elevations of between 5,620 and 5,720 feet. This ground-water discharge zone appears to coincide with the upper boundary of saturated conditions (perched water table?) behind the landslide. Based on the assumption that ground water flows north-northwest, a source of ground water to the landslide could be subsurface inflow from the local aquifer(s). Unfortunately, a planned test hole near the top of the ridge to delineate this possible up-gradient ground-water source was not drilled.

Subsurface Investigation and Monitoring

The subsurface investigation was conducted from March 21 to April 4, 2001. The investigation focused on the two active landslides adjacent to the railroad tracks. Shannon & Wilson oversaw the drilling, soil sampling, and installation of monitoring instruments. MBMG provided field assistance when needed and installed a Campbell-Scientific weather station and rain gauge. The subsurface investigation generally went as planned although difficult drilling conditions prolonged the investigation and increased drilling costs. As a consequence, only 5 borings were drilled, rather than 6 as planned. A brief summary of the subsurface investigation and subsequent monitoring is provided below. Shannon & Wilson is preparing a separate report summarizing their work.

Drilling and Instrumentation

Five test holes were drilled in or near the two active landslides (fig. 10). Three were drilled in the MP309.75 slide and two in the MP309.70 slide. The depths of the test holes ranged from 35 feet to 106.9 feet below ground surface (bgs). The material in the subsurface varied laterally and vertically and consisted primarily of silty to gravelly clays and clayey to silty gravels. Cobbles and boulders were common. Soil samples were

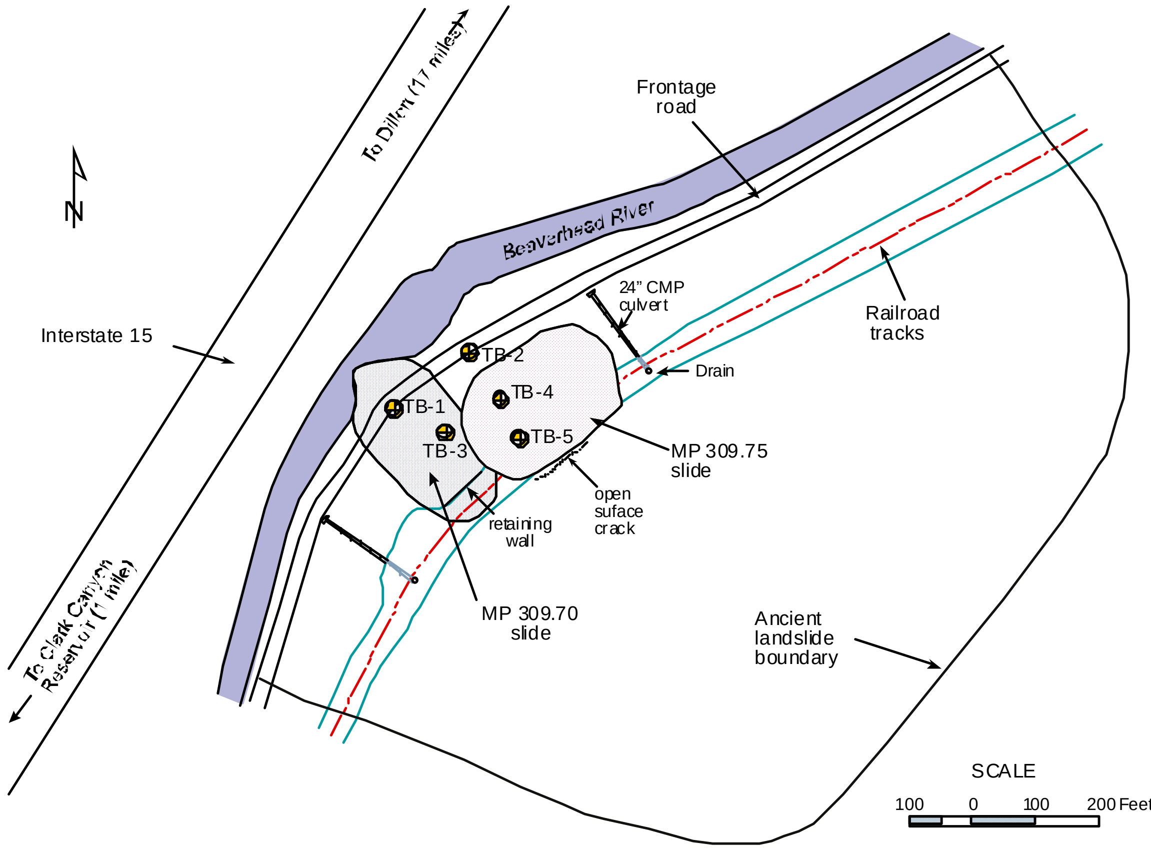

Figure 10. Site map of the Clark Canyon landslide identifying test holes (TB-1 – TB-5) drilled during the 2001 investigation.

collected for geotechnical analyses. Monitoring instruments installed included vibrating-wire piezometers (VWP), standpipe piezometers, and inclinometers. Table 1 summarizes the test hole installations; the drilling logs and water-level results are included in Appendices A and B.

Table 1. Test hole installation summary.

Borehole #	Depth (ft)	Elevation* (ft)	Installation(s)	Comments	Completion Date
TB-1	34.6	933.44	SP @ 15.5 ft	1" diameter slotted pvc	3/12/2001
			VWP @ 25.0 ft		
TB-2	35.0	933.02	SP @ 12.0 ft	1" diameter slotted pvc	3/15/2001
			VWP @ 22.5 ft		
TB-3	60.0	969.94	SI to 60.0 ft		3/16/2001
TB-4	106.9	969.51	SI to 100.0 ft		3/22/2001
TB-5	85.0	1001.31	VWP @ 27.0 ft		3/30/2001
			VWP @ 53.0 ft		

SP – open standpipe VWP – vibrating-wire piezometer SI – slope indicator casing
* Elevations are based on a surveyed control point that was assigned an arbitrary elevation of 1000 feet.

Monitoring

Milepost 309.70 Slide

The MP309.70 landslide extends from the barrow pit adjacent to the railroad track to the Beaverhead River (fig. 10). Test holes TB-1 and TB-3 were completed in this slide. TB-1 was drilled along the frontage road near the toe of the slide and was instrumented to monitor ground-water fluctuations. A 3.9-ft thick clay layer was encountered during drilling; therefore two piezometers were installed in the test hole to measure hydrostatic pressures above and below this potential confining unit. Test hole TB-3 was drilled near the center of the slide to monitor slope movement.

Figure 11a shows the hydrograph of hydrostatic-pressure fluctuations in TB-1 for the shallow and deep piezometers. In both cases, hydrostatic pressures increased during the spring and early summer (by approximately 2.5 feet) and then decreased after mid-July. The increase in pressure generally follows seasonal precipitation patterns (fig. 12). Hydrostatic pressures did not appear excessively high in either well, which may reflect below-normal spring and summer precipitation. The piezometers were not monitored frequently enough to determine if short-term precipitation events affected pressures.

Monitoring for slope movement was done with a borehole probe pipe and a probe inclinometer. The probe pipe was used on a monthly basis (April to October) to detect potential movement. No movement was detected with this method. A probe inclinometer that can detect very small displacements was used twice to monitor slope movement. The readings were taken in March and October, 2001. A comparison of the measurements suggests there was a very small amount of displacement (approximately 0.05 to 0.1 inch) at around 18 feet depth (see appendix C for the inclinometer plot). This depth coincides with a stiff clay layer that could represent the slide plane (fig. 13). Because the inclinometer readings were taken 6 months apart, the timing of the movement and its possible relation to seasonal changes in ground-water conditions is unknown.

Milepost 309.75 Slide

The MP309.75 slide extends from the railroad track to approximately 20 feet above the frontage road based on data collected soon after the slide occurred (Shannon & Wilson, 1995). Two borings, TB-4 and TB-5, are located within the slide; boring TB-2 is below the slide (fig. 10).

Figures 11b and 11c show the hydrographs for test holes TB-2 and TB-5. The shallow piezometer in TB-2 showed little change in water levels from April to October, fluctuating less than 0.25 feet. Water levels in the deeper VWP showed a trend similar to the seasonal pressure changes plotted for the TB-1 piezometers. The lack of variation in the open-standpipe piezometer may indicate poor connection to the shallow saturated zone. The piezometer was developed in late March and the water level did not return to pre-development level. The hydrostatic pressures measured in the two VWP's in TB-5 were consistently low, averaging less than one foot of water above the piezometer. There

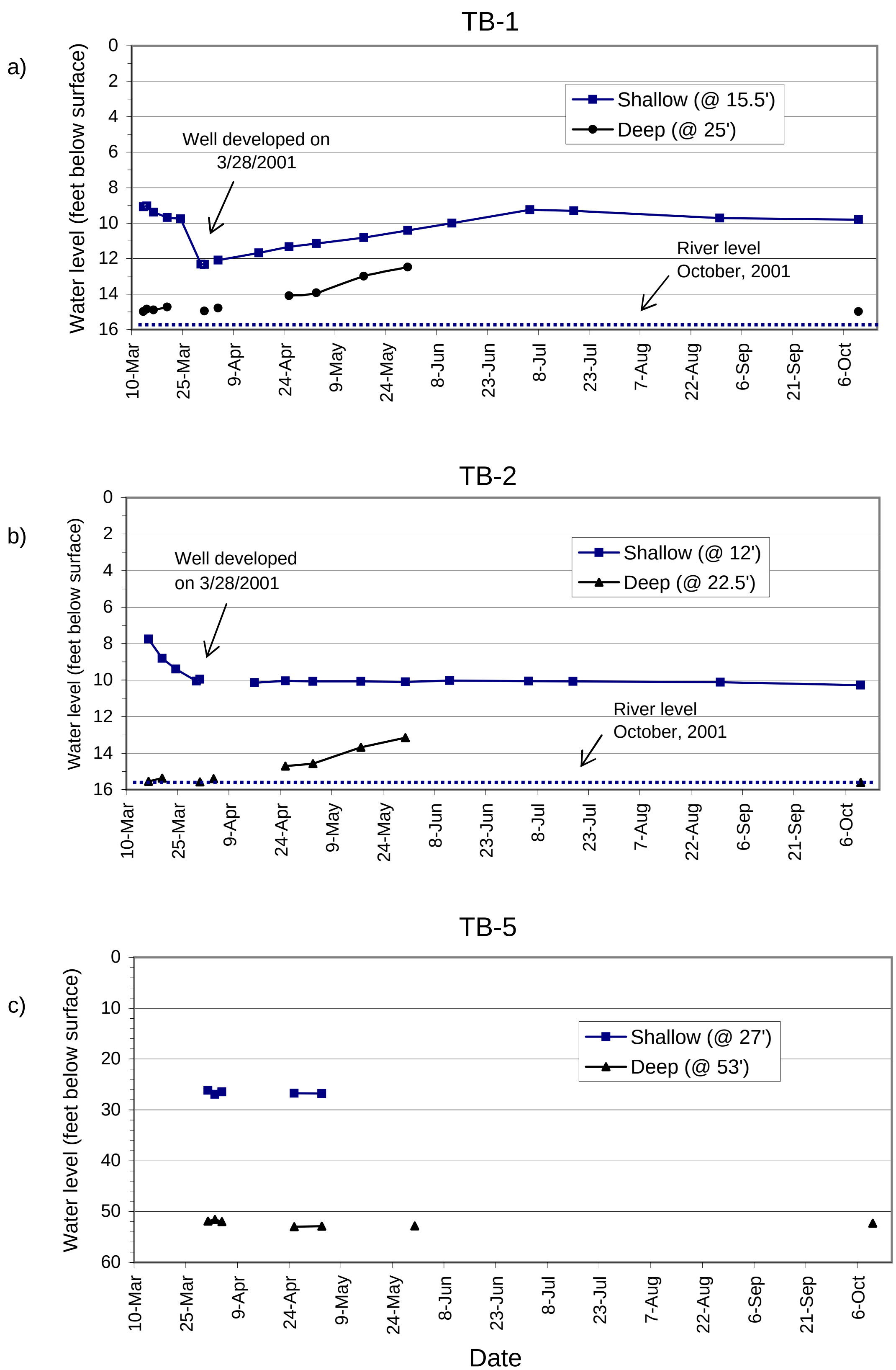

Figure 11. Hydrographs for the piezometers located in the active slides. The 53-ft deep piezometer in TB-5 is approximately 30 feet above the river level.

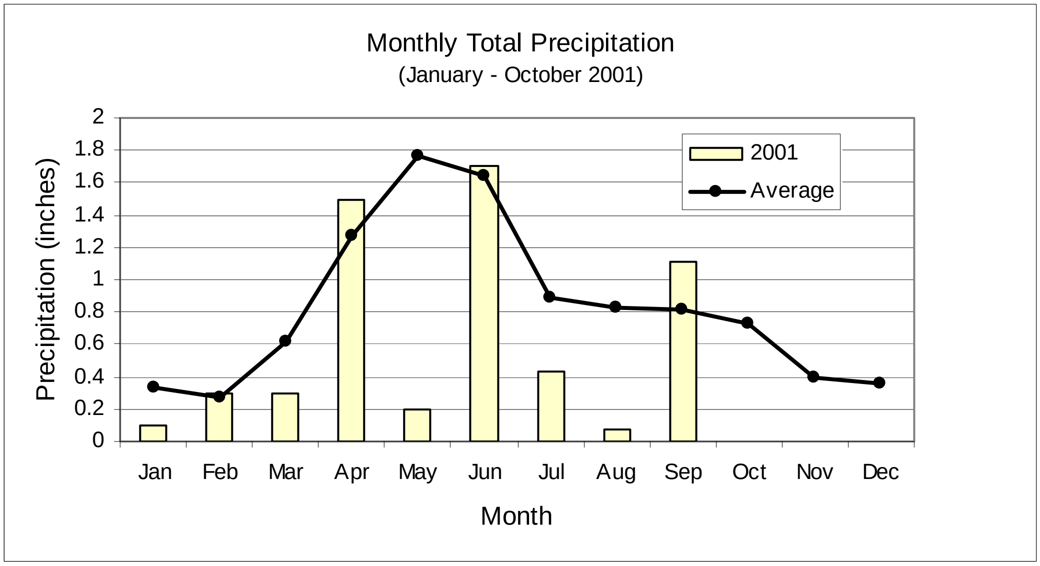

Figure 12. Monthly total precipitation for the landslide. Precipitation totals for January, February, March and parts of April and May are from the weather station at Clark Canyon Reservoir. Average based on 1963-2000 data obtained from the National Climatic Data Center (2001) for the Clark Canyon Reservoir station.

was no measurable water in the shallow piezometer (@ 27 ft bgs) in October, indicating dry (unsaturated) conditions. There was approximately 0.7 feet of water over the VWP at 53 feet bgs.

The inclinometer data for TB-4 (appendix C) showed no apparent movement, suggesting that the rockfill buttress constructed in 1995 has stabilized the slide. However, an open surface crack (approximately 170 feet long) above the slide (fig. 13 and fig. 14) indicates that additional movement is still a concern. A possible shear zone, identified as a hard clay horizon with slickensides, and a zone of potential artesian water pressure were encountered at a depth of around 104 feet bgs in this boring. Unfortunately, the interval was not fully penetrated due to difficult drilling conditions and loss of the drill bit in the boring. This interval may coincide with the failure plane of the ancient landslide.

Discussion

The Clark Canyon landslide is located in a geologic setting that is favorable to landslides. The ancient landslide occurred on a steep slope underlain by interbedded sedimentary and volcanic bedrock. The volcanic tuffs within this sequence are inherently weak because of alteration and weathering. They form clay-rich layers prone to failure. Undercutting along the base of the slope by the Beaverhead River may also have been a factor in the initial slope failure.

Ground water appears to be a key factor affecting stability. The relatively impermeable

Figure 13. **Generalized cross-sections through the active landslides.**

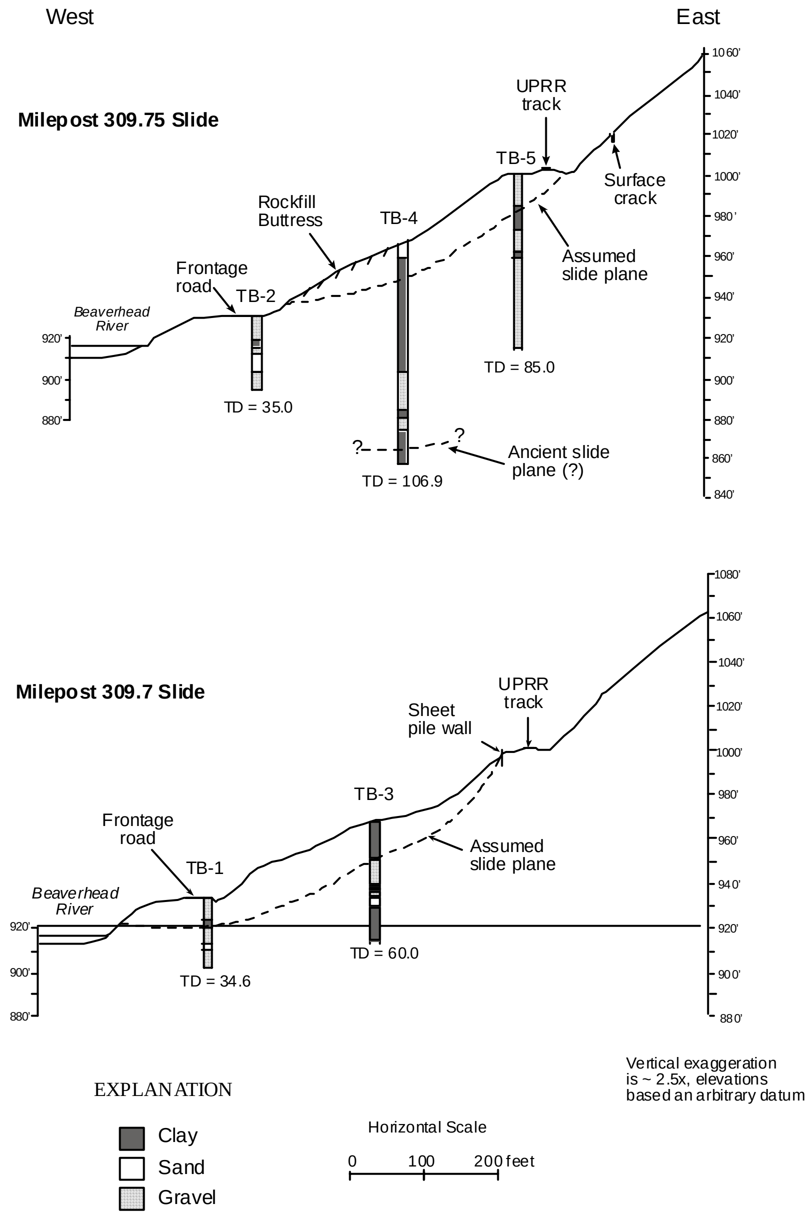

Figure 13. Generalized cross-sections through the two active landslides. Assumed slide plane locations are based on interpretation of subsurface data and information collected by Shannon & Wilson (1995).

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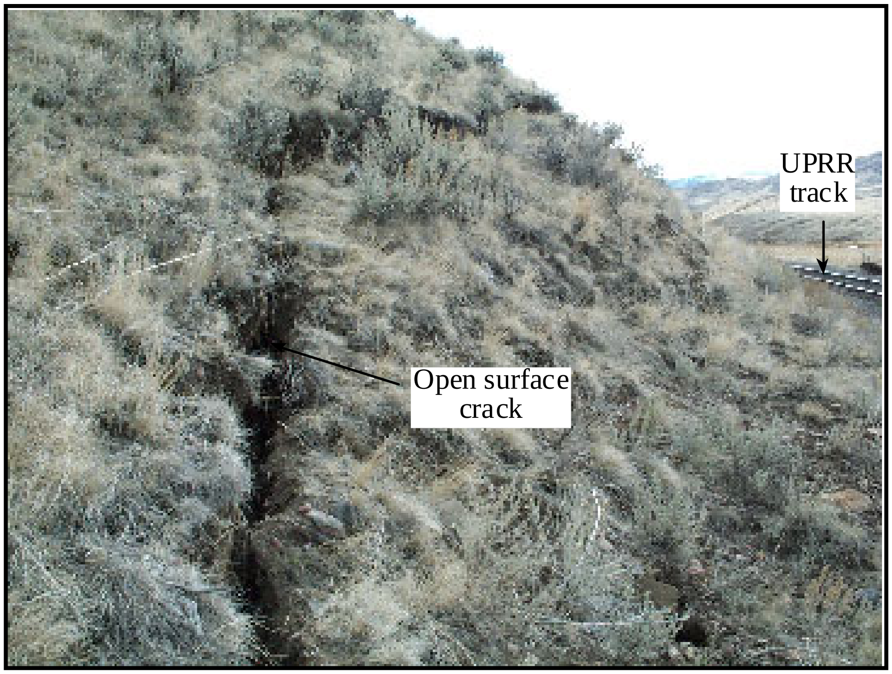

Figure 14. Open surface crack approximately 170 feet in length in the slope above the UP track. Photograph taken in March 2001. Width of crack is approximately 8 inches.

clay layers alternate with permeable beds in the subsurface, creating a complex flow system. Precipitation and runoff contribute local recharge to ground water. Subsurface inflow from local perched aquifers is probably also a significant source of water flowing into the landslide. Ground water was monitored in the active slides from March to October, 2001, for this investigation. The pieziometric data showed that water levels rose during months with higher precipitation and declined during the drier months. None of the piezometers showed excessively high water pressures, possibly because of below-normal precipitation during the spring and summer of 2001.

Ground movement in the recent slides appears to be related to precipitation and changing ground-water conditions. The most active periods of movement correlate with the years of heaviest precipitation. Relatively little activity has been reported over the last few years, which have had below-normal precipitation. The inclinometer data collected in October, 2001, did indicate minor displacement of the slide at MP309.7 sometime during the six months the instruments were monitored. The displacement occurred approximately 20 feet below surface. Although there was no measured movement of the MP309.75 slide, open surface cracks above the slide provide an entry for surface water and indicate future movement is still a concern.

The focus of this investigation was on the active slides that are impacting the UP track. The potential for reactivation of the larger, ancient landslide was not specifically investigated although it should be a concern. The surface cracks above the slide at

MP309.75 indicate ground movement is migrating into the steep slope above the railroad tracks. If this slope fails, the resulting slide could potentially be much larger and would likely impact the Beaverhead River and possibly Interstate 15.

Recommendations

Based on the work done thus far by MBMG, several corrective measures are recommended to help alleviate some of the problems associated with surface-water drainage and ground-water infiltration. Minimizing the amount of water infiltration into the smaller slides is especially important because the slides have relatively small volumes that are more easily saturated, which reduces their stability. The suggested corrective measures are:

1) Inspect the integrity of the surface drainage system installed along the railroad tracks and repair any damaged areas. After it was installed, continued ground movement and surface cracking damaged the system and it no longer directs surface runoff and precipitation away from the landslides.

2) Fill the open cracks above the landslide at MP 309.75 with grouting or sealant to prevent run-off and precipitation from directly infiltrating into the subsurface.

3) Investigate the talus deposits near the head of the ancient landslide. The deposits may have accumulated along old cracks or depressions associated with the ancient landslide and may be surface-water infiltration points.

MBMG also recommends continued monitoring of the landslide. The monitoring for this investigation was done during a dry year and may not be representative of conditions during wet years when stability problems are more likely to occur. Finally, the area outside the landslide perimeter needs to be better characterized to provide comparative data on the stable and unstable portions of the slope. At a minimum, a monitoring well should be drilled near the head of the landslide to better understand local ground-water conditions.

Acknowledgements

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References

Elliott, H.C., 1950, Geologic Report-Clark Canyon Dam Site: U.S. Bureau of Reclamation Report on Three Forks Division, Missouri River Basin Project, Montana, (unpublished).

Lowell, W.R., 1965, Geologic map of the Bannack-Grayling area, Beaverhead County, Montana: U.S. Geological Survey Miscellaneous Investigations Map I-433, scale: 1:31,680.

Montana Department of Transportation, 2000, 2000 Montana State Rail Plan Update, prepared for MDT by R.L. Banks & Associates, Inc., Washington D.C., in association with Harding ESE, Helena, MT: accessed on December 17, 2001 at URL: http://www.mdt.state.us/planning/railplan00.pdf.

National Climatic Data Center, 2001, Clark Canyon Dam station (Co-op ID 241781), accessed October 31, 2001 at URL: http://lwf.ncdc.noaa/oa/ncdc.html.

Ruppel, E.T., O'Neil, J.M., and Lopez, D.A., 1993, Geologic map of the Dillon 1º x 2º quadrangle, Idaho and Montana: U.S. Geological Survey Miscellaneous Investigations Map I-1803H, scale 1:250,000.

Shannon & Wilson, Inc., 1995, Geotechnical Engineering Report, Landslides, Mileposts 309.7 to 309.75, Union Pacific Railroad, Dillon, Montana, August 1995 (unpublished).

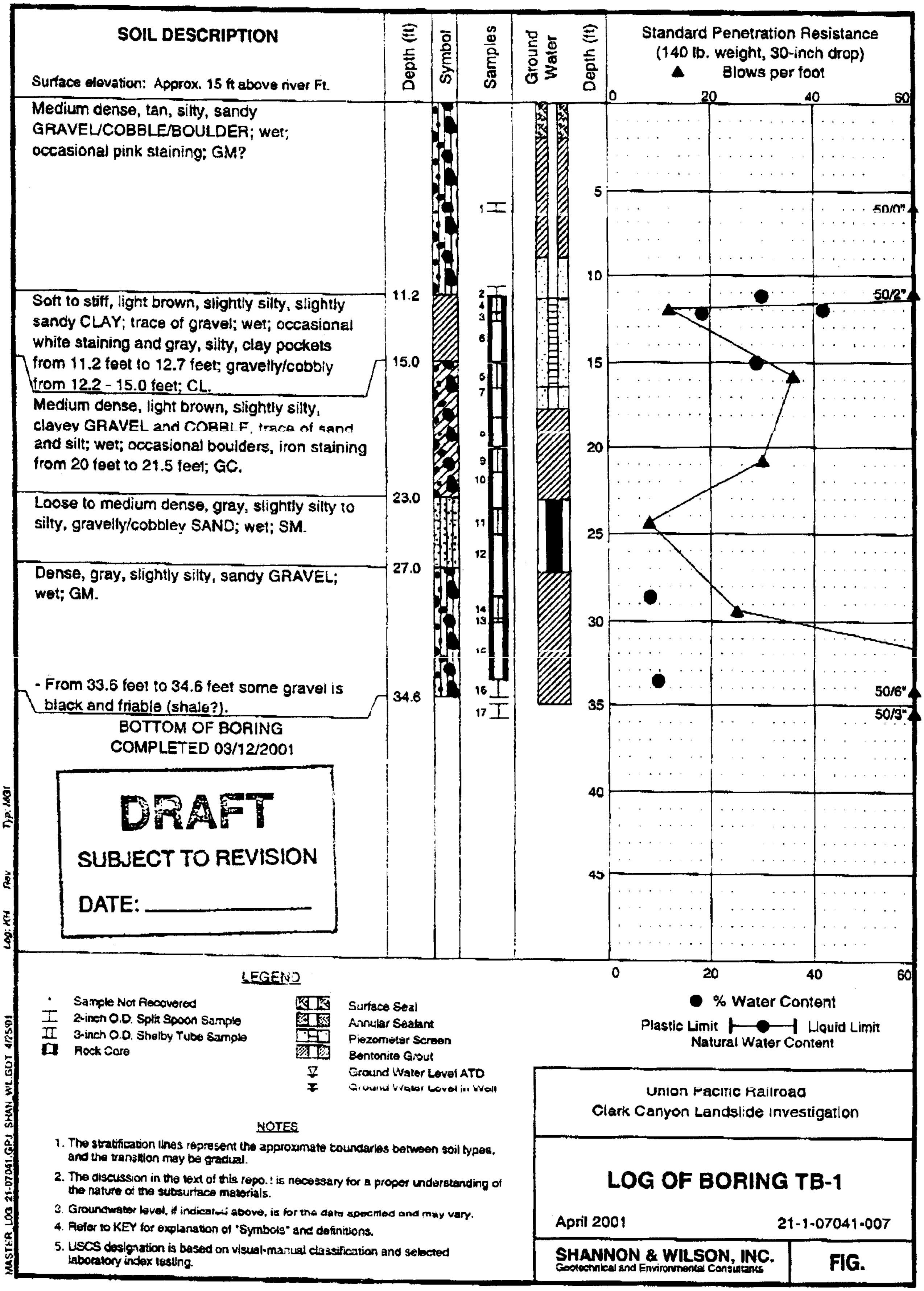
Shannon & Wilson, Inc., 1995, Final Report; Slope Stability Improvements, Mileposts 309.7 to 309.75, Montana Subdivision, Dillon, Montana, November 1995 (unpublished)

Shannon & Wilson, Inc., 1998, Letter report, Site Meeting of February 12, 1998, Landslide, Milepost 309.7, Montana Subdivision, Dillon, Montana, April 1998 (unpublished).

Williams, D.A., and Clark, C.H., 1970, Landslide Research Study, Montana: Montana Highway Commission Report, 109 p.

Appendix A

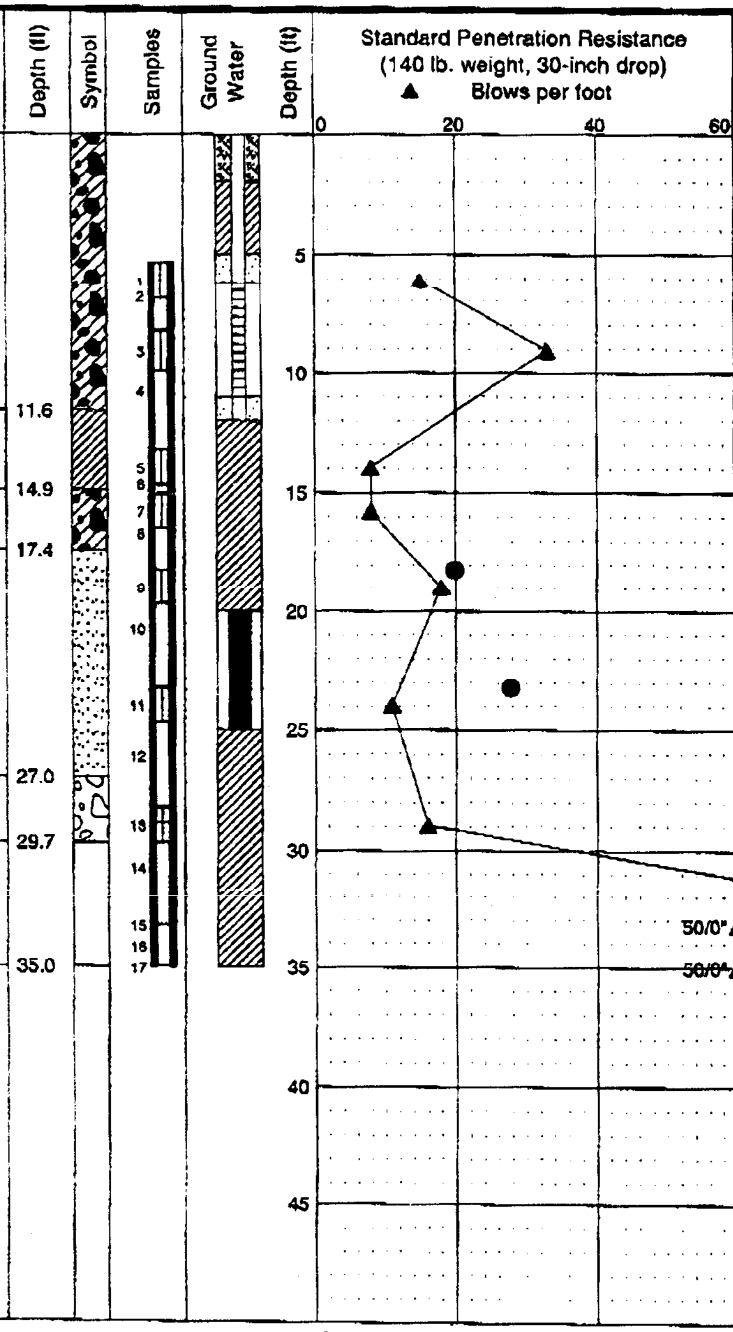
Shannon & Wilson Drilling Logs


SOIL DESCRIPTION
Surface elevation: Approx. 15 ft above river Ft.
Depth (ft)
Symbol
Samples
Ground Water
Depth (ft)
Standard Penetration Resistance
(140 lb. weight, 30-inch drop)
▲ Blows per foot
0 20 40 60
Medium dense, tan, silty, sandy GRAVEL/COBBLE/BOULDER; wet; occasional pink staining; GM?
11.2
Soft to stiff, light brown, slightly silty, slightly sandy CLAY; trace of gravel; wet; occasional white staining and gray, silty, clay pockets from 11.2 feet to 12.7 feet; gravelly/cobbly from 12.2 - 15.0 feet; CL.
15.0
Medium dense, light brown, slightly silty, clayey GRAVEL and COBBLE, trace of sand and silt; wet; occasional boulders, iron staining from 20 feet to 21.5 feet; GC.
23.0
Loose to medium dense, gray, slightly silty to silty, gravelly/cobbley SAND; wet; SM.
27.0
Dense, gray, slightly silty, sandy GRAVEL; wet; GM.
- From 33.6 feet to 34.6 feet some gravel is black and friable (shale?).
34.6
BOTTOM OF BORING
COMPLETED 03/12/2001
DRAFT
SUBJECT TO REVISION
DATE:
5
10
15
20
25
30
35
40
45
50/0"
50/2"
50/6"
50/3"
LEGEND
Sample Not Recovered
2-inch O.D. Split Spoon Sample
3-inch O.D. Shelby Tube Sample
Rock Core
Surface Seal
Annular Sealant
Piezometer Screen
Bentonite Grout
Ground Water Level ATD
Ground Water Level in Well
● % Water Content
Plastic Limit Liquid Limit
Natural Water Content
NOTES
1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of the subsurface materials.
3. Groundwater level, if indicated above, is for the date specified and may vary.
4. Refer to KEY for explanation of "Symbols" and definitions.
5. USCS designation is based on visual-manual classification and selected laboratory index testing.
Union Pacific Railroad
Clark Canyon Landslide Investigation
LOG OF BORING TB-1
April 2001
21-1-07041-007
SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG.

SOIL DESCRIPTION

Surface elevation: Approx. Ft.

Soil Description	Depth (ft)
Medium dense, light gray, slightly silty, clayey GRAVEL and COBBLES, trace of sand, wet; GC.	
Medium stiff, light gray, slightly silty, gravelly CLAY, trace of sand; wet; CL.	11.6
Loose, light gray, slightly silty, clayey GRAVEL, trace of sand; wet; occasional pocket (0.01 foot in diameter) of white silt; GC.	14.9
Medium dense, light brown, fine to medium SAND, trace of silt; wet; SP.	17.4
Medium dense, light brown, slightly silty, fine sandy GRAVEL; wet; GP.	27.0
GRAVEL and COBBLES (matrix, if any, is unknown).	29.7
BOTTOM OF BORING COMPLETED 03/15/2001	35.0



DRAFT
SUBJECT TO REVISION
DATE: ______

LEGEND

- Sample Not Recovered
- 2-inch O.D. Split Spoon Sample
- 3-inch O.D. Shelby Tube Sample
- Rock Core
- Surface Seal
- Annular Sealant
- Piezometer Screen
- Bentonite Grout
- Ground Water Level ATD
- Ground Water Level in Well

● % Water Content

Plastic Limit ├──●──┤ Liquid Limit
Natural Water Content

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of the subsurface materials.
3. Groundwater level, if indicated above, is for the date specified and may vary.
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LOG OF BORING TB-2

April 2001 | 21-1-07041-007

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FIG.

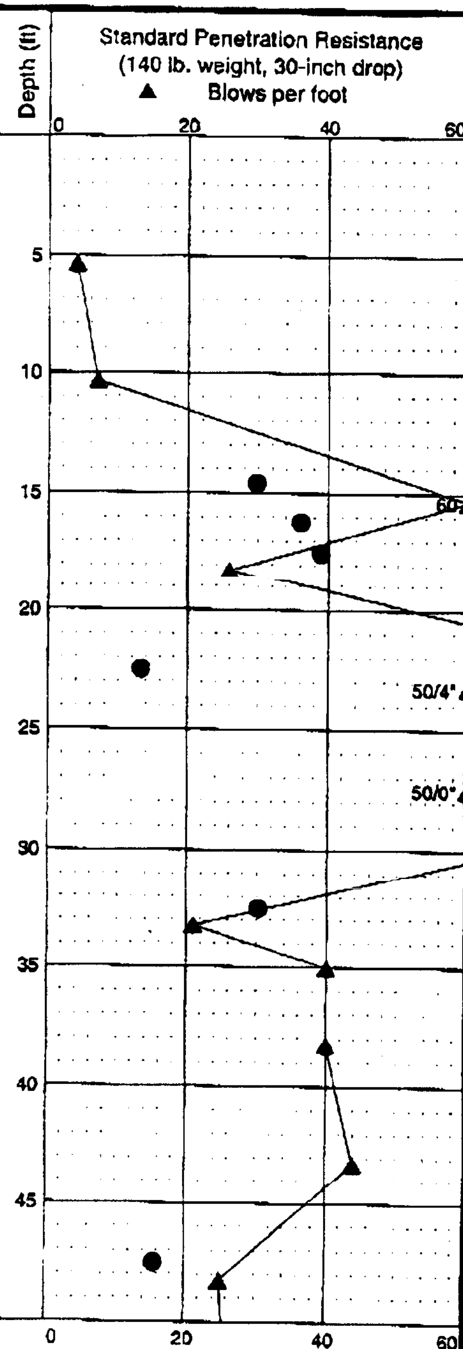
MASTER_LOG 21-07041.GPJ SHAN_WIL.GDT 4/25/01 Log: KH Rev: Typ: MGI

SOIL DESCRIPTION Surface elevation: Approx. ~50 ft above river Ft.	Depth (ft)
Soft, light brown, slightly silty CLAY; wet; CH. - From 0 feet to 8.1 feet, gravelly, with occasional roots. - From 7.9 feet to 12.9 feet, sandy, trace of sand.	
Hard, light green, slightly silty CLAY, trace of sand and gravel; moist; CH.	12.9
Very stiff, light green, clayey SILT with interbeds 0.1 foot to 0.2 foot thick of green, slightly silty CLAY; moist; CL.	16.8
Medium stiff, light green, slightly silty, clayey GRAVEL/COBBLES; GC.	19.5
Very stiff, gray-green, gravelly CLAY; moist; CH.	32.5
Medium dense, light brown, silty fine SAND; moist; gravel interbed at 35 feet; SM.	33.5
Medium stiff, light brown, slightly silty, gravelly CLAY; wet; CH.	35.0
Dense, light brown, silty, gravelly SAND; wet; SM.	37.5
Medium stiff, light brown, slightly silty, slightly gravelly/cobbley CLAY, trace of sand; wet; iron staining; CL.	42.5

DRAFT
SUBJECT TO REVISION
DATE: ____________

CONTINUED NEXT PAGE

Samples: 1–18



LEGEND

- * Sample Not Recovered
- 2-inch O.D. Split Spoon Sample
- 3-inch O.D. Shelby Tube Sample
- Rock Core
- Ground Water Level ATD

● % Water Content

Plastic Limit ├─●─┤ Liquid Limit
Natural Water Content

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of the subsurface materials.
3. Groundwater level, if indicated above, is for the date specified and may vary.
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5. USCS designation is based on visual-manual classification and selected laboratory index testing.

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Clark Canyon Landslide Investigation

LOG OF BORING TB-3

April 2001 21-1-07041-007

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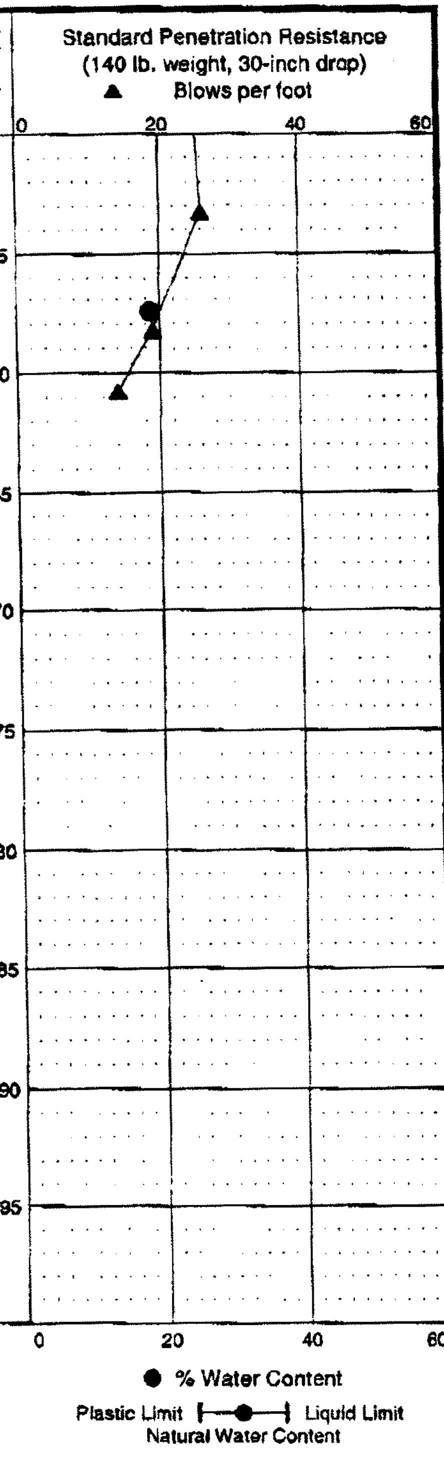
FIG.
Sheet 1 of 2

MASTER LOG 21-07041.GPJ SHAN_WIL.GDT 4/25/01 Log: KH Rev: Typ: MGI

SOIL DESCRIPTION	Depth (ft)	Symbol	Samples	Ground Water	Depth (ft)
Surface elevation: Approx. ~50 ft above river Ft.					
			19, 20, 21, 22, 23		55
BOTTOM OF BORING COMPLETED 03/16/2001	60.0		24		60



DRAFT

SUBJECT TO REVISION

DATE: ____________

LEGEND

- Sample Not Recovered
- 2-inch O.D. Split Spoon Sample
- 3-inch O.D. Shelby Tube Sample
- Rock Core
- Ground Water Level ATD

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of the subsurface materials.
3. Groundwater level, if indicated above, is for the date specified and may vary.
4. Refer to KEY for explanation of "Symbols" and definitions.
5. USCS designation is based on visual-manual classification and selected laboratory index testing.

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Clark Canyon Landslide Investigation

LOG OF BORING TB-3

April 2001 21-1-07041-007

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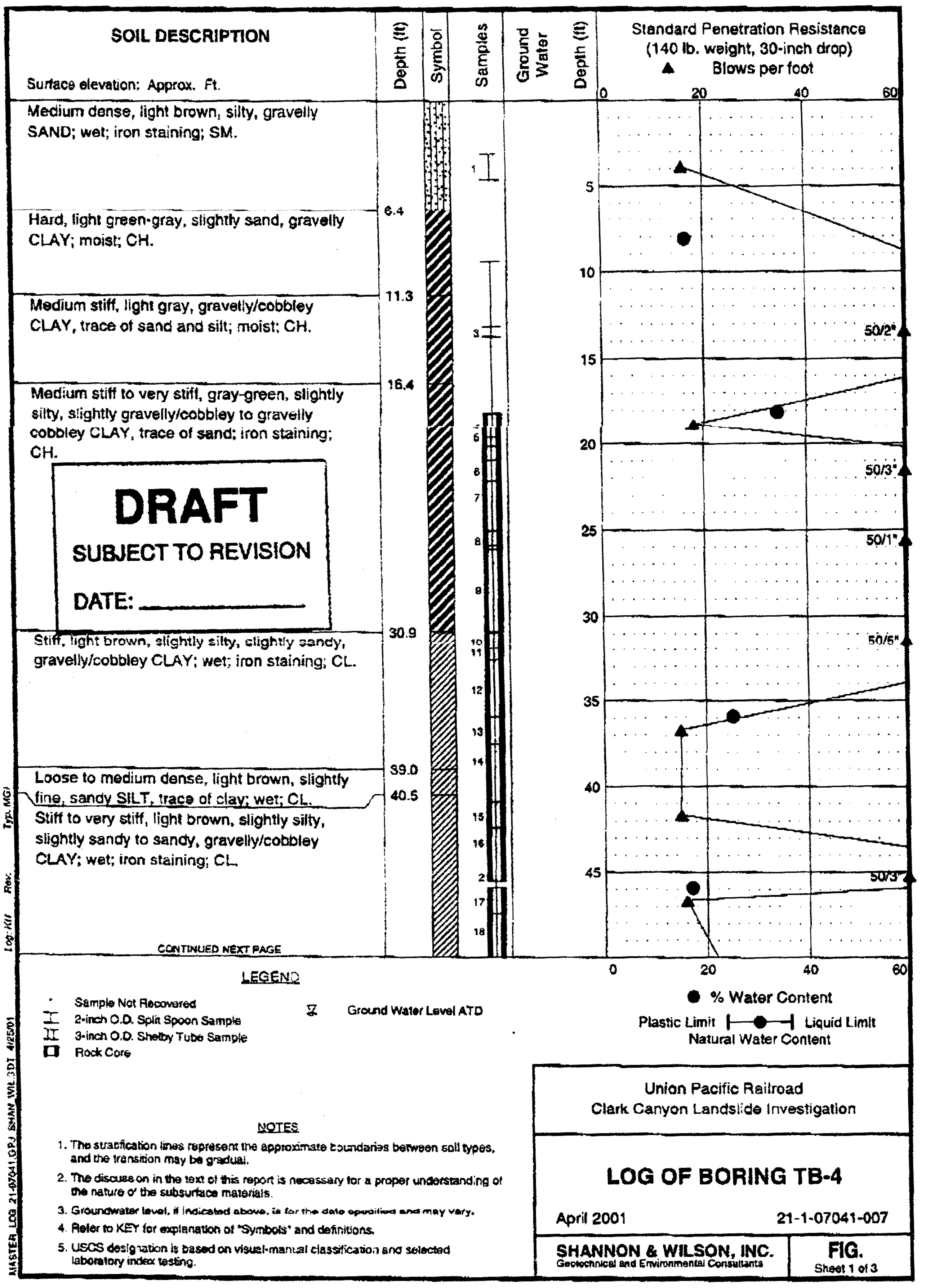
FIG.
Sheet 2 of 2

MASTER_LOG 21-07041.GPJ SHAN_WIL.GDT 4/25/01 Log: KH Rev: Typ: MGI


SOIL DESCRIPTION
Surface elevation: Approx. Ft.
Depth (ft)
Symbol
Samples
Ground Water
Depth (ft)
Standard Penetration Resistance
(140 lb. weight, 30-inch drop)
▲ Blows per foot
Medium dense, light brown, silty, gravelly SAND; wet; iron staining; SM.
6.4
Hard, light green-gray, slightly sand, gravelly CLAY; moist; CH.
11.3
Medium stiff, light gray, gravelly/cobbley CLAY, trace of sand and silt; moist; CH.
16.4
Medium stiff to very stiff, gray-green, slightly silty, slightly gravelly/cobbley to gravelly cobbley CLAY, trace of sand; iron staining; CH.
DRAFT
SUBJECT TO REVISION
DATE:
30.9
Stiff, light brown, slightly silty, slightly sandy, gravelly/cobbley CLAY; wet; iron staining; CL.
39.0
Loose to medium dense, light brown, slightly fine, sandy SILT, trace of clay; wet; CL.
40.5
Stiff to very stiff, light brown, slightly silty, slightly sandy to sandy, gravelly/cobbley CLAY; wet; iron staining; CL.
CONTINUED NEXT PAGE
50/2"
50/3"
50/1"
50/6"
50/3"
0 20 40 60
% Water Content
Plastic Limit Liquid Limit
Natural Water Content
LEGEND
Sample Not Recovered
2-inch O.D. Split Spoon Sample
3-inch O.D. Shelby Tube Sample
Rock Core
Ground Water Level ATD
NOTES
1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of the subsurface materials.
3. Groundwater level, if indicated above, is for the date specified and may vary.
4. Refer to KEY for explanation of "Symbols" and definitions.
5. USCS designation is based on visual-manual classification and selected laboratory index testing.
Union Pacific Railroad
Clark Canyon Landslide Investigation
LOG OF BORING TB-4
April 2001
21-1-07041-007
SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG.
Sheet 1 of 3

SOIL DESCRIPTION Surface elevation: Approx. Ft.	Depth (ft)	Symbol	Samples	Ground Water	Depth (ft)	Standard Penetration Resistance (140 lb. weight, 30-inch drop) ▲ Blows per foot
			19			
Medium stiff, light brown, slightly silty, slightly sandy to sandy CLAY; wet; iron staining; CH.	52.4		20, 21, 22, 23		55, 60	50/0", 50/1"
COBBLES and GRAVEL (River sediment?), or perhaps matrix washed away during coring.	62.0		24, 25, 26, 27, 28, 29		65, 70, 75	50/5"
Hard, gray, sandy, clayey SILT; wet; iron staining, pockets of gray clay, possible sheared; CL.	80.4		30		80	50/5"
Dense, light brown, slightly silty to silty, slightly sandy to sandy COBBLES/BOULDERS; wet; iron staining; GM.	81.9		31, 32, 33		85	50/5"
Hard, gray, silty CLAY, trace of gravel; moist; CH.	90.9		34		90	50/5"
Dense, gray, slightly clayey, silty COBBLES; moist.	92.4		35		95	
Hard, gray, slightly clayey SILT, trace of gravel; moist; CL.	95.9		36			70
	98.1		37			

CONTINUED NEXT PAGE

LEGEND

- * Sample Not Recovered
- 2-inch O.D. Split Spoon Sample
- 3-inch O.D. Shelby Tube Sample
- Rock Core
- Ground Water Level ATD

● % Water Content

Plastic Limit ├──●──┤ Liquid Limit
Natural Water Content

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of the subsurface materials.
3. Groundwater level, if indicated above, is for the date specified and may vary.
4. Refer to KEY for explanation of "Symbols" and definitions.
5. USCS designation is based on visual-manual classification and selected laboratory index testing.

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DATE: ______

Union Pacific Railroad
Clark Canyon Landslide Investigation

LOG OF BORING TB-4

April 2001 | 21-1-07041-007

SHANNON & WILSON, INC.
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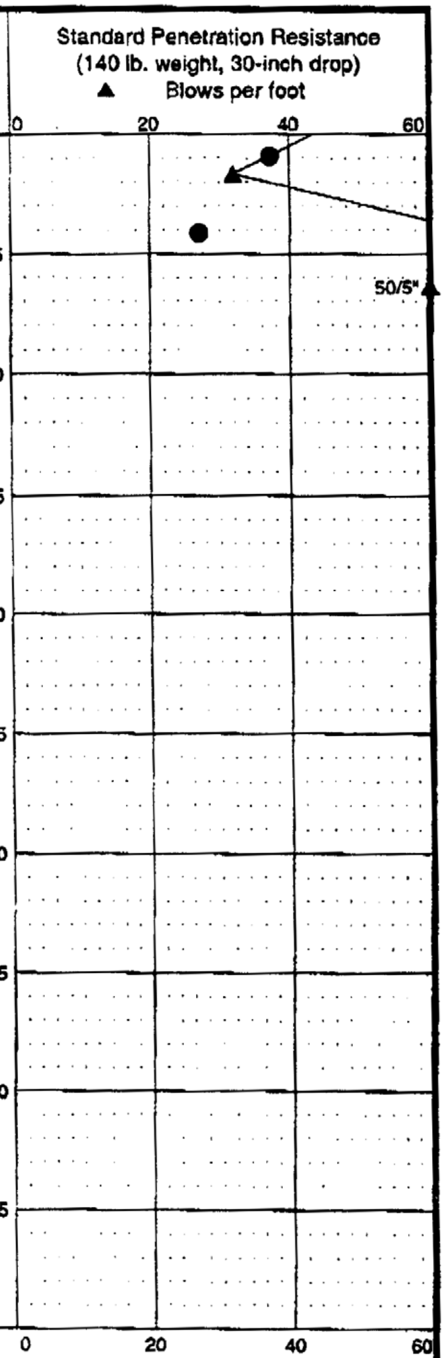
FIG.
Sheet 2 of 3

MASTER_LOG 21-07041.GPJ SHAN_WIL.GDT 4/25/01 Log: KH Rev: Typ: MGI

SOIL DESCRIPTION Surface elevation: Approx. Ft.	Depth (ft)	Symbol	Samples	Ground Water	Depth (ft)
Soft to hard, gray, gravelly CLAY, trace of silt and sand; wet; CH.	100.9		38		
Very soft, gray, slightly clayey SILT, trace of sand; wet; CL.	101.4		39		
Hard, gray, slightly silty CLAY, trace of sand; moist; slickensided; gravelly from 102.1 to 104.1, occasional organics from 104.1 to 106.9; CH.	106.9		40		105
BOTTOM OF BORING COMPLETED 03/22/2001					110
					115
					120
					125
					130
					135
					140
					145

DRAFT
SUBJECT TO REVISION
DATE: ______________



0 20 40 60

● % Water Content
Plastic Limit ├──●──┤ Liquid Limit
Natural Water Content

LEGEND

- Sample Not Recovered
- 2-inch O.D. Split Spoon Sample
- 3-inch O.D. Shelby Tube Sample
- Rock Core
- Ground Water Level ATD

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of the subsurface materials.
3. Groundwater level, if indicated above, is for the date specified and may vary.
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Union Pacific Railroad
Clark Canyon Landslide Investigation

LOG OF BORING TB-4

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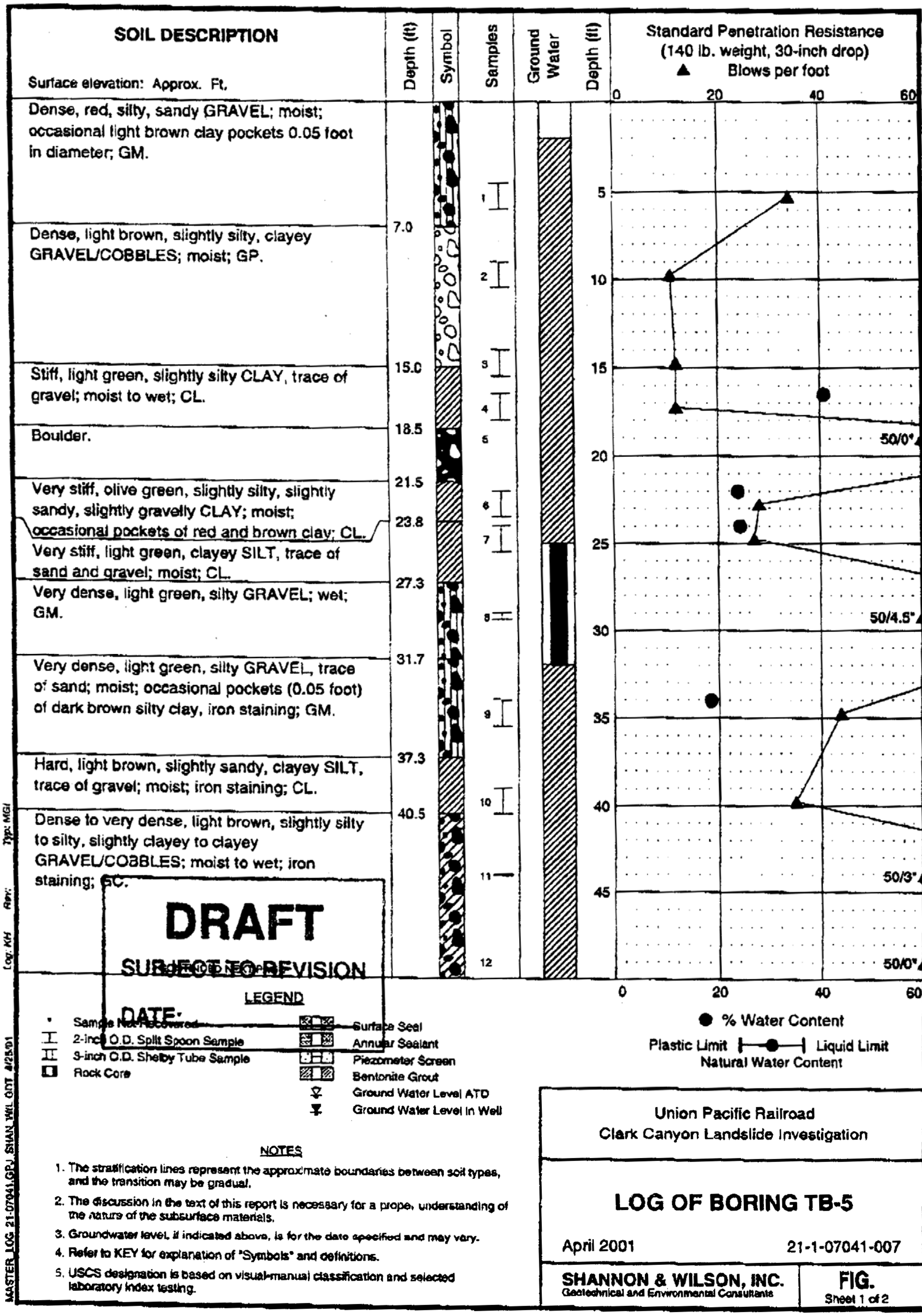
FIG.
Sheet 3 of 3

MASTER_LOG 21-07041.GPJ SHAN_WIL.GDT 4/25/01 Log: KH Rev: Typ: MGI


SOIL DESCRIPTION
Surface elevation: Approx. Ft.
Depth (ft)
Symbol
Samples
Ground Water
Depth (ft)
Standard Penetration Resistance
(140 lb. weight, 30-inch drop)
▲ Blows per foot
0 20 40 60
Dense, red, silty, sandy GRAVEL; moist; occasional light brown clay pockets 0.05 foot in diameter; GM.
7.0
Dense, light brown, slightly silty, clayey GRAVEL/COBBLES; moist; GP.
15.0
Stiff, light green, slightly silty CLAY, trace of gravel; moist to wet; CL.
18.5
Boulder.
21.5
Very stiff, olive green, slightly silty, slightly sandy, slightly gravelly CLAY; moist; occasional pockets of red and brown clay; CL.
23.8
Very stiff, light green, clayey SILT, trace of sand and gravel; moist; CL.
27.3
Very dense, light green, silty GRAVEL; wet; GM.
31.7
Very dense, light green, silty GRAVEL, trace of sand; moist; occasional pockets (0.05 foot) of dark brown silty clay, iron staining; GM.
37.3
Hard, light brown, slightly sandy, clayey SILT, trace of gravel; moist; iron staining; CL.
40.5
Dense to very dense, light brown, slightly silty to silty, slightly clayey to clayey GRAVEL/COBBLES; moist to wet; iron staining; GC.
1
2
3
4
5
6
7
8
9
10
11
12
5
10
15
20
25
30
35
40
45
50/0"
50/4.5"
50/3"
50/0"
DRAFT
SUBJECT TO REVISION
DATE:
LEGEND
Sample Not Recovered
2-inch O.D. Split Spoon Sample
3-inch O.D. Shelby Tube Sample
Rock Core
Surface Seal
Annular Sealant
Piezometer Screen
Bentonite Grout
Ground Water Level ATD
Ground Water Level in Well
● % Water Content
Plastic Limit Liquid Limit
Natural Water Content
NOTES
1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of the subsurface materials.
3. Groundwater level, if indicated above, is for the date specified and may vary.
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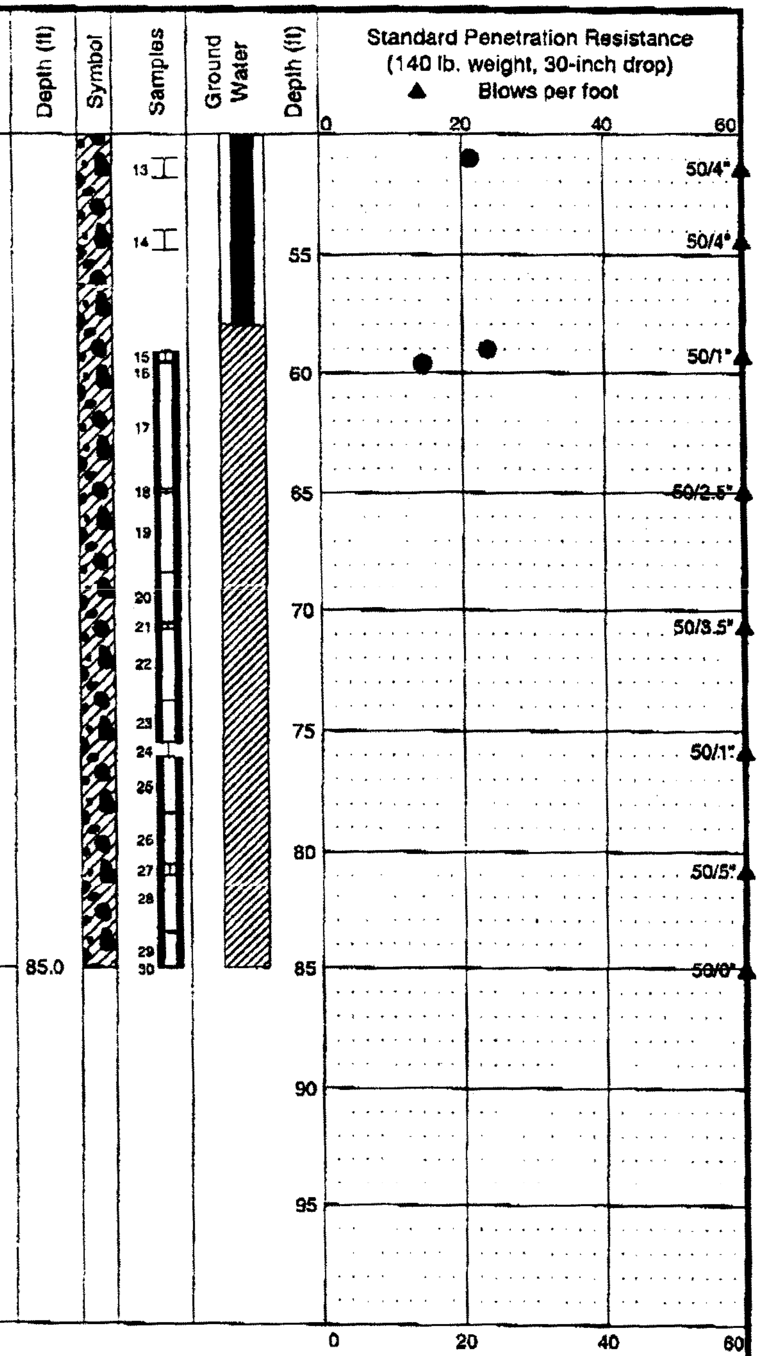
Union Pacific Railroad
Clark Canyon Landslide Investigation
LOG OF BORING TB-5
April 2001
21-1-07041-007
SHANNON & WILSON, INC.
Geotechnical and Environmental Consultants
FIG.
Sheet 1 of 2
MASTER LOG 21-07041.GPJ SHAN WIL.GDT 4/25/01
Log: KH Rev: Typ: MGI

SOIL DESCRIPTION

Surface elevation: Approx. Ft.



BOTTOM OF BORING
COMPLETED 03/30/2001

DRAFT
SUBJECT TO REVISION
DATE: ____________

LEGEND

- • Sample Not Recovered
- 2-inch O.D. Split Spoon Sample
- 3-inch O.D. Shelby Tube Sample
- Rock Core
- Surface Seal
- Annular Sealant
- Piezometer Screen
- Bentonite Grout
- ∇ Ground Water Level ATD
- Ground Water Level in Well

● % Water Content

Plastic Limit ├─●─┤ Liquid Limit
Natural Water Content

NOTES

1. The stratification lines represent the approximate boundaries between soil types, and the transition may be gradual.
2. The discussion in the text of this report is necessary for a proper understanding of the nature of the subsurface materials.
3. Groundwater level, if indicated above, is for the date specified and may vary.
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Clark Canyon Landslide Investigation

LOG OF BORING TB-5

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FIG.
Sheet 2 of 2

MASTER_LOG 21-07041.GPJ SHAN_WIL.GDT 4/25/01 Log: KH Rev: Typ: MGI

Appendix B

Ground-Water Monitoring Data

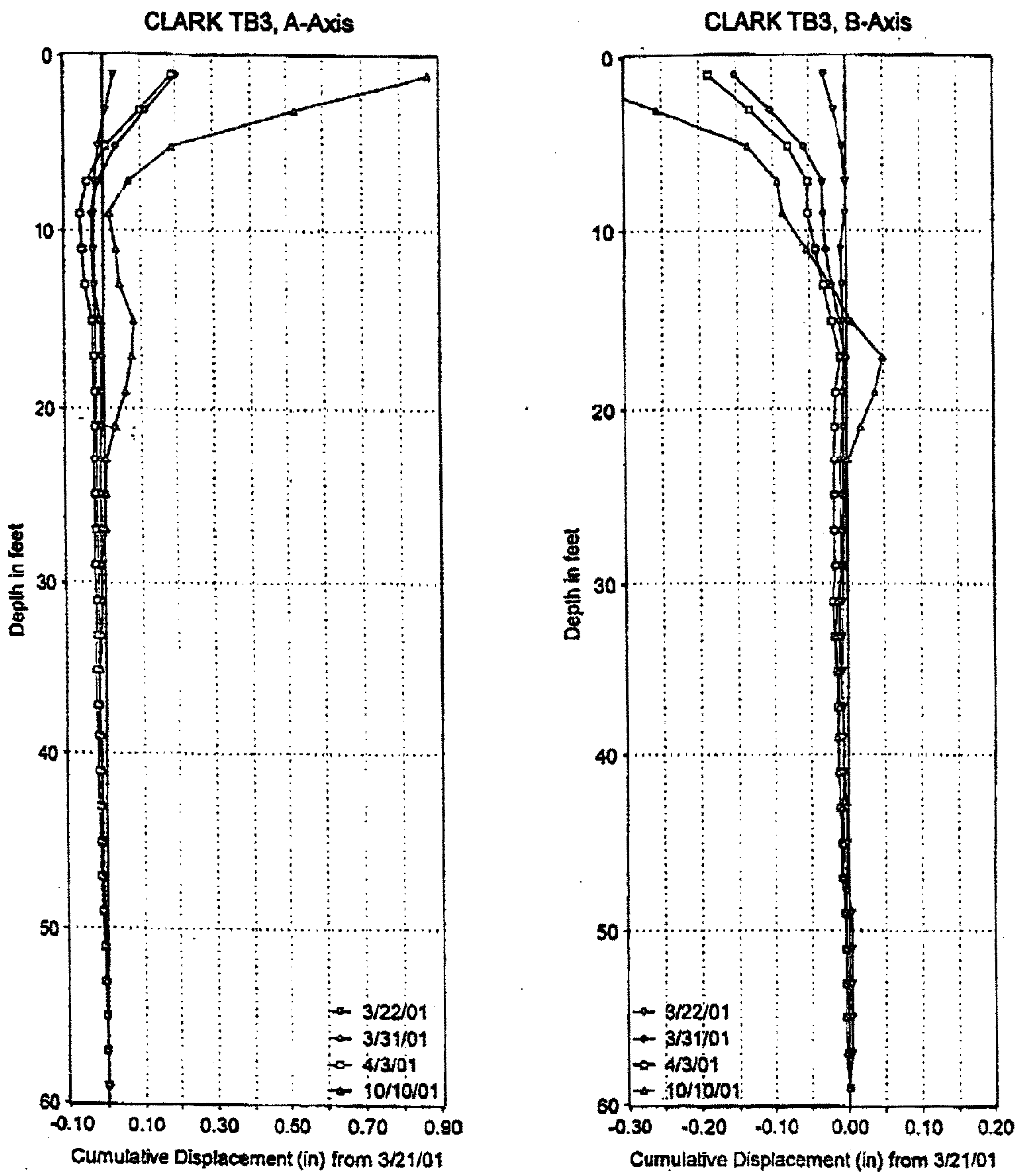
WATER LEVEL (depth in feet below land surface)

Boring #	**TB-1**		**TB-2**		**TB-5**	
DATE	Standpipe @15.5 ft	VWP @ 25.0 ft	Standpipe @ 12.0 ft	VWP @ 22.5 ft	VWP @ 27.0 ft	VWP @ 53.0 ft
03-13-01	9.08	10.01	--	--	--	--
03-14-01	9.03	10.14	--	--	--	--
03-16-01	9.38	10.10	7.75	15.55	--	--
03-20-01	9.68	10.27	8.80	--	--	--
03-24-01	9.76	--	9.40	--	--	--
03-30-01	12.32	--	10.06	--	--	--
03-31-01	12.33	10.04	9.95	15.58	26.13	51.88
04-02-01	--	--	--	--	26.92	51.58
04-04-01	12.08	10.22	--	15.40	26.46	51.99
04-16-01	11.68	--	10.15	--	--	--
04-25-01	11.33	10.91	10.04	14.71	26.71	52.97
05-03-01	11.15	11.08	10.07	14.58	26.80	52.86
05-17-01	10.82	12.01	10.07	13.69	Dry	Dry
05-30-01	10.41	12.52	10.10	13.15	Dry	52.81
06-12-01	10.00	--	10.03	--	--	--
07-05-01	9.25	--	10.05	--	--	--
07-18-01	9.30	--	10.07	--	--	--
08-30-01	9.71	--	10.12	--	--	--
10-10-01	9.81	10.02	10.27	15.60	Dry	52.29

(Water level data shown in hydrographs in figure 14. VWP, vibrating-wire piezometer; -- , no data. Water pressures measured in the vibrating-wire piezometers were converted to equivalent water depths.)

Appendix C

Inclinometer Displacement Plots



UPRR Clark Canyon Landslide Investigation

INCLINOMETER PLOT
TB-3

November 2001 21-1-07041-007

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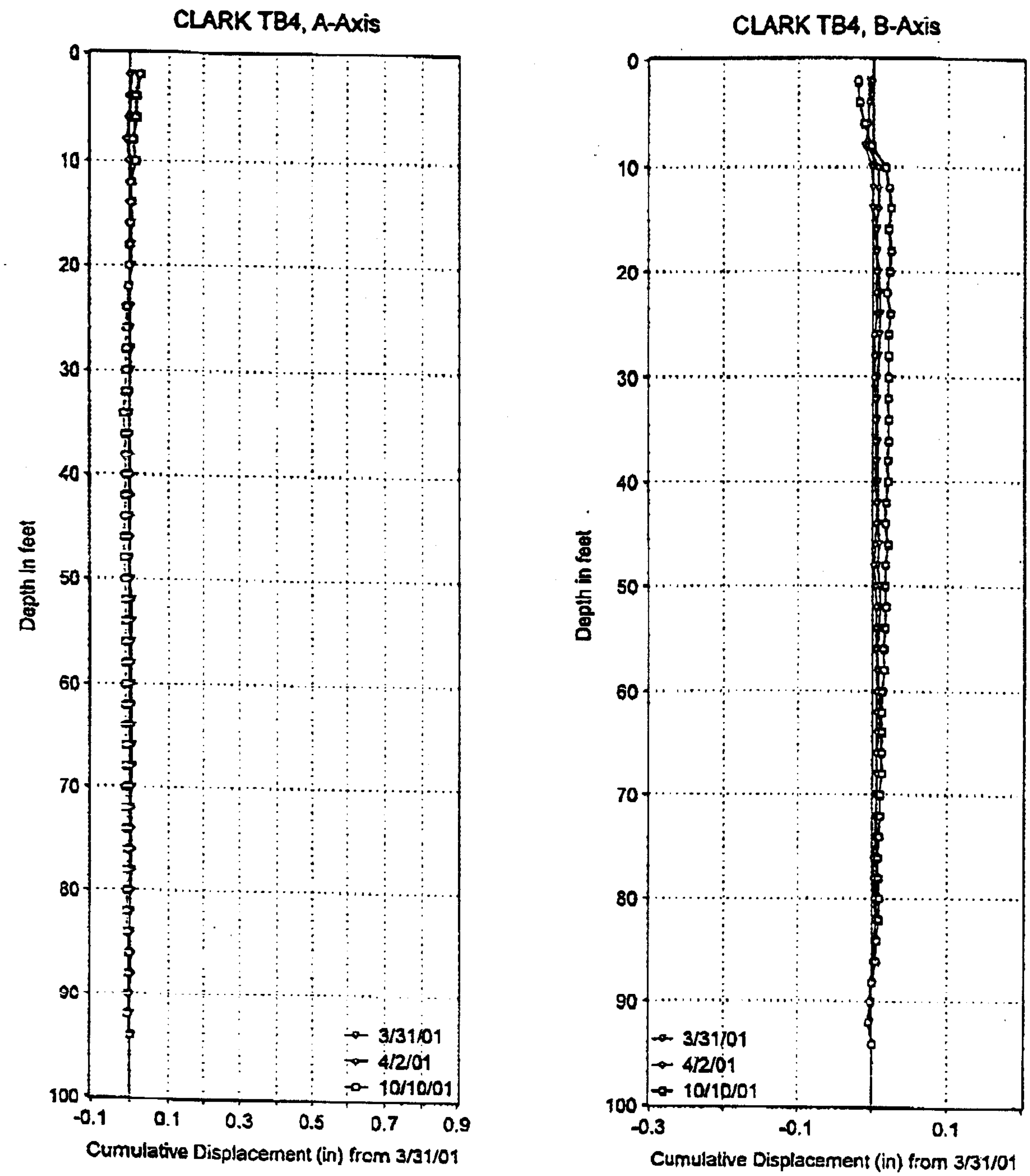
FIG. 6



UPRR Clark Canyon Landslide Investigation

INCLINOMETER PLOT
TB-4

November 2001 21-1-07041-007

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FIG. 7

File: I:\Drafting\21\07041-007\21-1-07041-007 Inclin Plots.dwg Date: 11-07-2001 Author: LR