Reconnaissance Engineering Geology of the Mill Creek Landslide of January 24, 1997

U.S. Highway 50, El Dorado County, California

ROBERT H. SYDNOR, Senior Engineering Geologist
California Department of Conservation, Division of Mines and Geology

The Mill Creek landslide (initially called the 1997 White Hall landslide) closed State Highway 50 for 27 days in January and February 1997. California Department of Conservation, Division of Mines and Geology staff assisted in the evaluation of the slide and are now under contract with the California Department of Transportation to map landslides in the Highway 50 corridor. This article is a modification of a January 31, 1997 report by Robert Sydnor...editor

A large fast-moving landslide occurred on Eldorado National Forest land around 11:20 PM on Friday, January 24, 1997 near the village of White Hall in central El Dorado County within steep terrain of the Sierra Nevada (Photo 1, Figure 1). The landslide is within the canyon of the South Fork American River, at an elevation of about 3,400 feet (1,036 m). Known as the Mill Creek landslide, it buried Highway 50 under 75 feet (23 m) of fluid mud in a swath about 800 feet (245 m) wide along the highway and briefly dammed the river. The landslide dam breached slowly enough that no local downstream flooding occurred. There were no fatalities.

This article is a summary of brief reconnaissance-level geologic field work on January 27 and 30, 1997, which included a helicopter flight. Field work was performed with the cooperation of U.S. Forest Service (USFS) and California Department of Transportation (Caltrans) engineering geologists and geotechnical engineers and landslide consultants from the U.S. Geological Survey (USGS). Because this geologic information is preliminary, it is likely to be refined and modified by subsequent

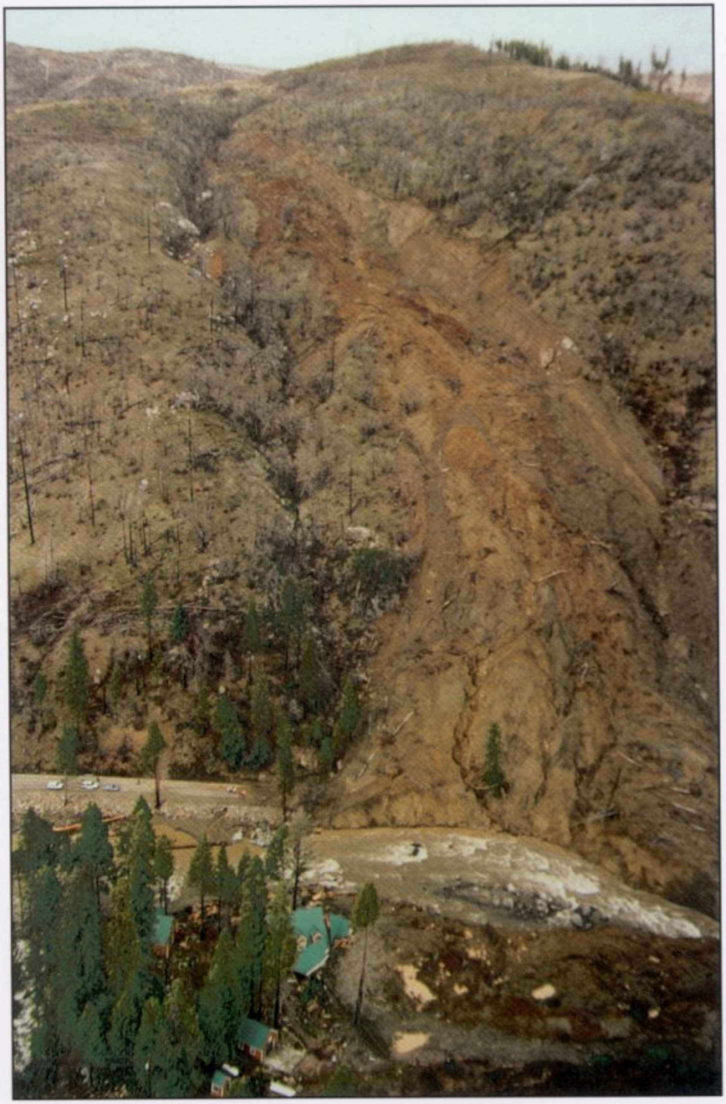

Photo 1. January 27, 1997 view northward of entire Mill Creek landslide, 1,120 feet (340 m) high and 3,100 (945 m) long. *Photo by Robert H. Sydnor.*

investigations by the California Department of Conservation, Division of Mines and Geology (DMG).

DMG has done both regional geologic mapping for the Sacramento 1:250,000 quadrangle (Wagner and others, 1981), and specific engineering geologic mapping of the 1983 Highway 50 landslide in the White Hall area in cooperation with USFS (Kuehn and Bedrossian, 1987). The 1983 Highway 50 landslide is about 0.6 miles (965 m) east of the 1997 Mill Creek landslide (Figure 1).

LANDSLIDE CLASSIFICATION

The Mill Creek landslide is best classified as an active, rapid debris slide composed principally of very wet sandy colluvium (Turner and Schuster, 1996). The movement was principally translational, with little or no backward rotation of colluvial blocks below the head scarp. The first movement is inferred to have been rapid to very rapid (6 feet per hour to 16 feet per second [1.8 m/hr - 5 m/sec]), but because it occurred shortly before midnight, there were no known eyewitnesses. The second phase of landslide movement (days 2 to 6) was of moderate velocity (43 feet per month to 6 feet per hour [13m/mo - 1.8 m/hr]). The water content diminished from very wet to moist-to-wet within the first week. The lower portion of the landslide appears to have changed in character to a debris flow as evidenced by its broadening from about 400 feet (37 m) to about 800 feet (245 m) at the river, and fanning outward, both up-river and down-river in the manner of a viscous liquid. At this location, there is no evidence of a pneumatic concussion or significant

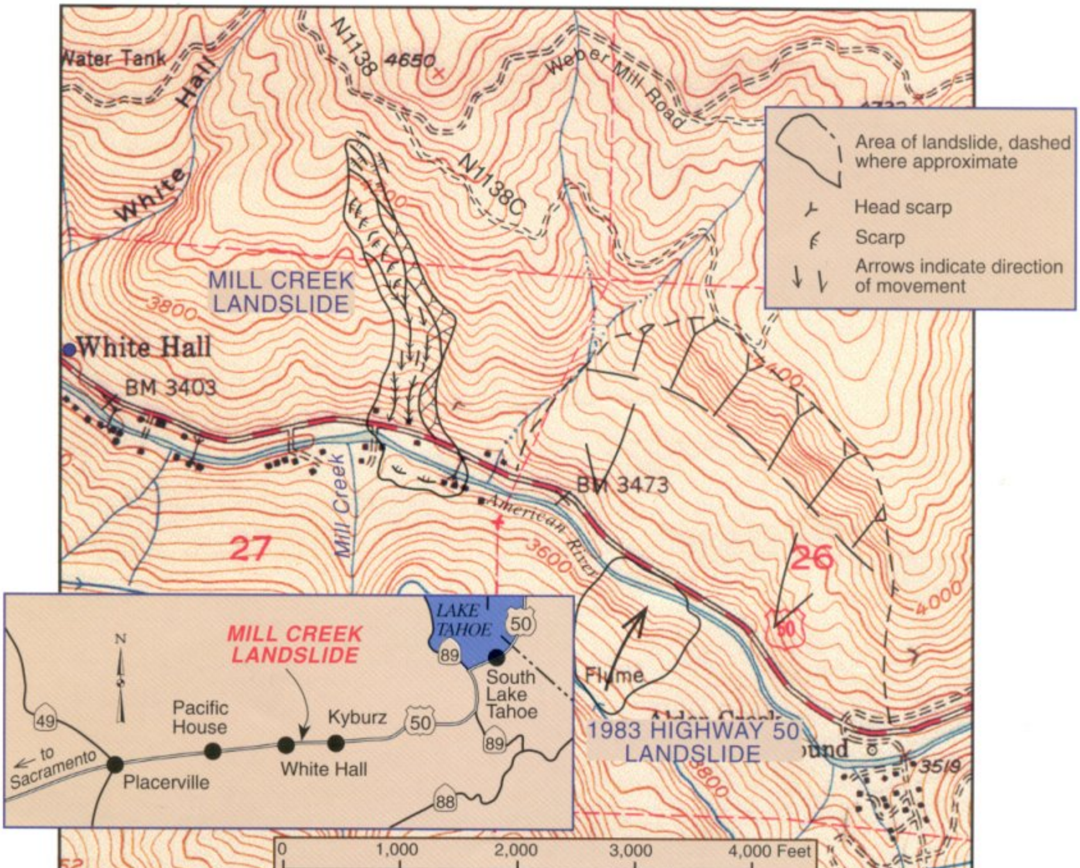

Figure 1. Map of landslides in the White Hall area along U.S. Highway 50 corridor in El Dorado County. *Base map enlarged from USGS 1950 Riverton Quadrangle.*

water splash beyond the farthest limits of sandy mud, as evidenced by undamaged, vertically-standing burned snags that could have easily been knocked down. Based on this evidence, the landslide is not considered to be a debris avalanche, although movement at the toe is inferred to have been very rapid during the initial phase of mobilization. At the time of the inspection, there were no intact slide blocks visible in the lower third of the landslide, which was heavily rilled by rapid dewatering of the fluidized mass.

LANDSLIDE DIMENSIONS

The landslide is 800 to 900 feet (245-275 m) wide where it blocked Highway 50. The main body of the landslide is about 400 feet (120 m) wide and the length from the head scarp to the toe on the opposite canyon wall is about 3,400 feet (1,036 m) (Figure 2). The head scarp is about 1,100 vertical feet (335 m) above the river (elevation ±3,420 feet [980 m]).

The highly fluid toe of the landslide crossed the river, flowed up the south slope about 50 vertical feet (15 m), and veered westward (Photo 2). The toe of the landslide on the south bank of the river is 600 to 700 feet (180-215 m) wide at the highest elevation of run-up.

LOSS OF CABINS

All the cabins on the south bank of the American River in this area were burned by the 1992 Cleveland Fire. Two newly rebuilt cabins were destroyed by the 1997 Mill Creek landslide along with one rebuilt cabin on the north side of the river.

VARIABLE FLOW DIRECTIONS

The upper half of the Mill Creek landslide mobilized as a translational debris slide in a southwest direction which is slightly oblique downhill at an apparent slope angle of about 22 degrees. Near the 3,840-foot (1,170-m) contour, the landslide turned about 30 degrees westward. The lower half of the landslide evidently had a much higher moisture content, apparently moved faster, and may have evolved from a debris slide to a debris flow. The lower half of the landslide flowed directly downhill. Just above the highway the slope angle steepens to 30 to 32 degrees. Surprisingly, a lone tree is still standing at the shoulder of Highway 50; the saturated sandy mud evidently flowed around it.

BREACHED LANDSLIDE DAM

The 11:20 PM landslide dammed the South Fork American River. Floating logs accumulated at the southeast corner of the landslide toe. The river slowly eroded the soft sandy material composing the debris slide, breaching the dam by 4:30 the next morning (Lakey, 1997). The river channel is in hard diorite bedrock, although the thalweg (deepest line of stream channel) was temporarily deflected southward.

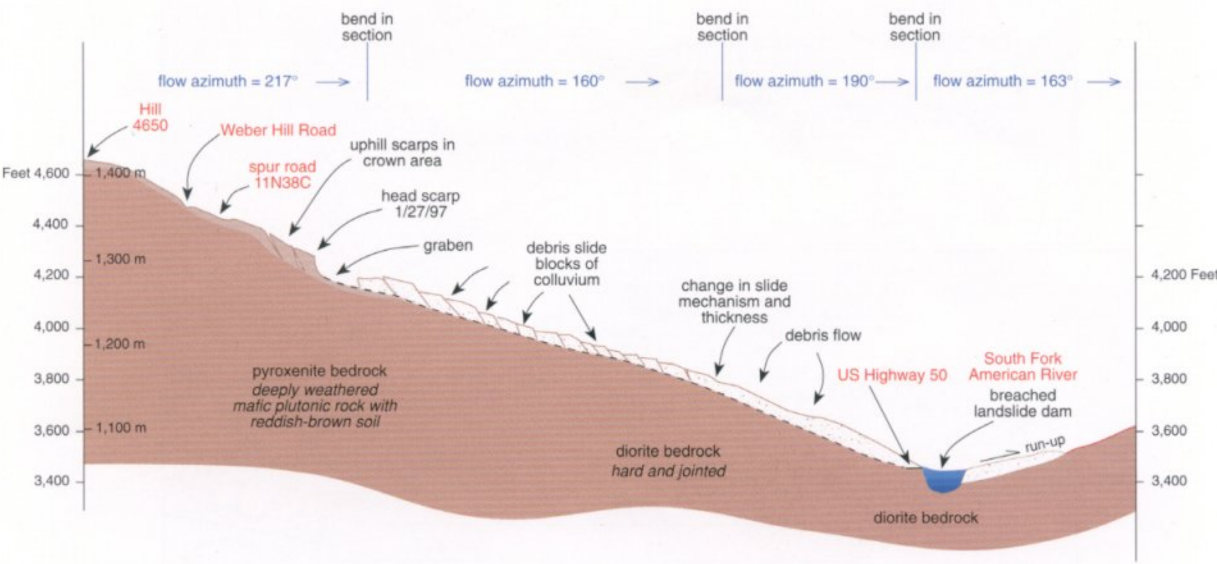

Figure 2. Schematic geologic cross section of the Mill Creek landslide, approximately down the center of the debris slide and parallel to the direction of flow (note three bends in the section).

Photo 2. View westward down the South Fork American River showing the breached landslide toe and about 800 lineal feet (245 m) of U.S. Highway 50 buried. *Photo by Robert H. Sydnor.*

PREVIOUS FOREST FIRES

The entire region surrounding the Mill Creek landslide was burned in the 1959 Icehouse Fire and September 1992 Cleveland Fire. The 1992 fire was a moderately hot, fast-moving fire that left little vegetation in the upper and intermediate slopes within the South Fork American River canyon. Following the fire, USFS seeded the burned area prior to the first rains so that ground cover over much of the burned area was quickly reestablished. In addition, native vegetation resprouted. There are isolated groves of trees on the east side of the landslide and along the immediate Highway 50 corridor. USFS has prepared a map showing the perimeter of the 1992 Cleveland Fire and has classified various areas by the relative intensity of that burn; this map will be useful in future assessment of landslide hazards.

BEDROCK PETROLOGY

The Mill Creek landslide is underlain in the head scarp area by mafic plutonic rocks of Mesozoic age, principally pyroxenite and diorite. Mafic plutonic rocks (gabbro) were previously mapped in 1979 reconnaissance work by McJunkin and Taylor (1989) in the Robbs Peak 15-minute quadrangle for the compilation of the 1:250,000-scale Sacramento Quadrangle (Wagner and others, 1981).

The pyroxenite is coarse-grained and contains mostly pyroxene, with minor hornblende. It weathers easily and is notable in the field for the distinctive reddish-brown residual and colluvial soil caused by a typically high iron oxide content (Photo 3). The pyroxenite is exposed along road cuts in Weber Mill Road near the fork of USFS roads N1138 and N1138C. A few small boulders of reddish-brown pyroxenite were observed as float within intact landslide blocks in the upper third of the debris slide. Otherwise this unit is seldom exposed in natural outcrop and is characterized by subdued topographic form with reddish brown soils on the order of 6 to 10 feet (2-3 m) thick. The pyroxenite appears to be the uphill parent material for the large quantity of sandy colluvial soil forming this landslide.

The middle and southwestern portions of the landslide appear to be underlain by fine-grained dark-gray diorite which is typically very hard and resistant to weathering. Intact exposures of diorite within the flanks of the landslide indicate very little weathering of the hard diorite despite burial under 6 to 9 feet (2-3 m) of sandy reddish-brown colluvium. The hard diorite forms ridge crests and is also well exposed along the bank of the river at the western edge of the foot of the landslide (at Caltrans milepost #42+88). The hard diorite has thinner (0 to 1.5 feet [0-45 cm]) discontinuous soils. Gneiss, quartz-

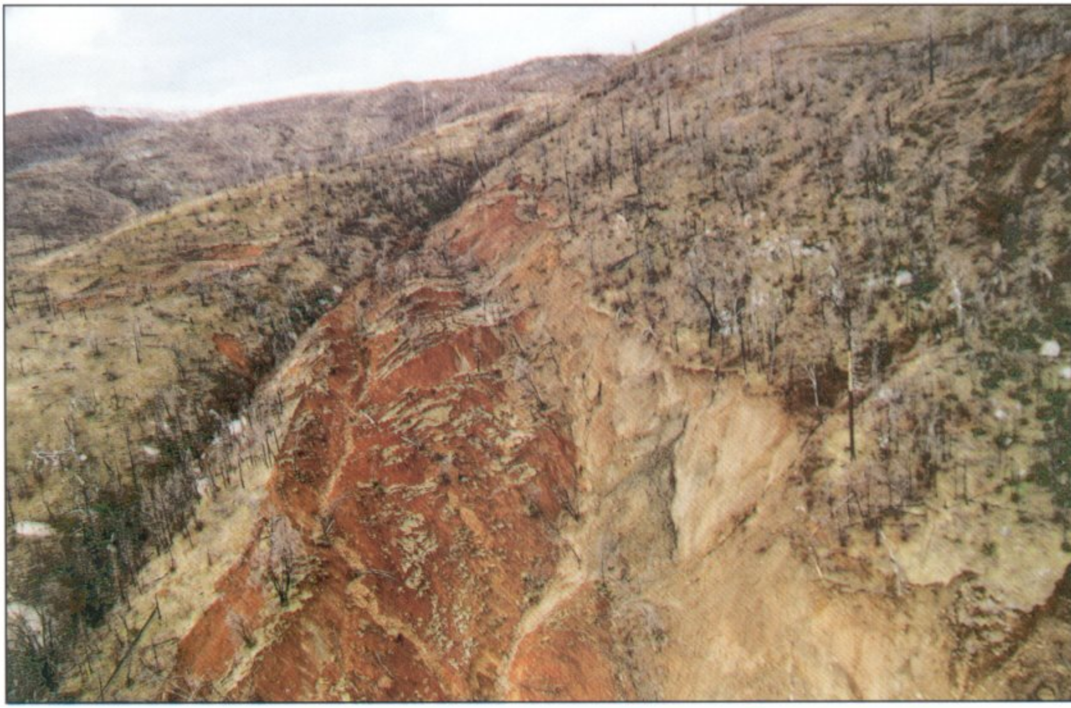

Photo 3. Axial view N20°W of the upper half of Mill Creek landslide showing debris slide blocks and translational movement. Note structural control of west side of landslide (at left) and asymmetric tilt of slide mass. Prominent joint-controlled bedrock gully at left. Reddish-brown colluvium (derived from pyroxenite) within the debris slide contrasts in color with gray colluvium derived from diorite and schist at right side. *Photo by Robert H. Sydnor.*

biotite schist, and granodiorite are discontinuously exposed along the eastern flank of the landslide.

BEDROCK STRUCTURE

The morphology of the Mill Creek landslide appears to be significantly controlled by the geologic structure of the bedrock. Preliminary geomorphic analysis indicates a near-vertical joint system trending north-south (Figure 3). On the south side of the South Fork American River, this joint set evidently controls the course of Mill Creek, which runs nearly straight for about 1.2 miles (1.9 km). Mill Creek intersects the river at nearly 90 degrees, rather than a more typical 60- to 70-degree angle. This near-vertical joint set is exposed in hard diorite on the north bank of the river at Caltrans milepost 42+88, and continues northward for at least 0.5 mile (800 m), forming a straight gully. This joint set appears to control the west edge of the upper half of the Mill Creek landslide.

The second joint set is estimated to be about N30°W, 40°SW, and is inferred from the smooth bedrock surface exposed in the northeast flank of the upper half of the landslide. The two intersecting joint sets appear to form an asymmetric trough as shown in Figure 3. The western edge of the landslide is apparently steep and the landslide is inferred to be thickest (roughly estimated 40 to 50 feet [12-15 m]) at the western edge of the upper half of the landslide.

COLLUVIUM

The landslide mass is composed principally of reddish-brown to gray-brown sandy colluvium. An unusually thick regolith formed from the parent bedrock and was deposited in the trough by a combination of sheetwash and gravity. The texture is uniformly sorted (poorly graded) fine to coarse sand with some silt. There are few cobble or rock fragments, but abundant small shiny flecks of weathered biotite or sericite. The sandy colluvium, which was moist to wet, appears to lack any significant clay content and is inferred to have a relatively high void ratio. The landslide mass has minimal organic content, except for scattered logs and remnants of burned snags from the 1992 Cleveland Fire.

Along Highway 50 the landslide material is very dark grayish brown. In the upper elevations of the landslide, the colluvium is distinctly reddish-brown, suggesting proximity to the parent bedrock, inferred to be chiefly pyroxenite with decomposed granite, schist, and gneiss to the east.

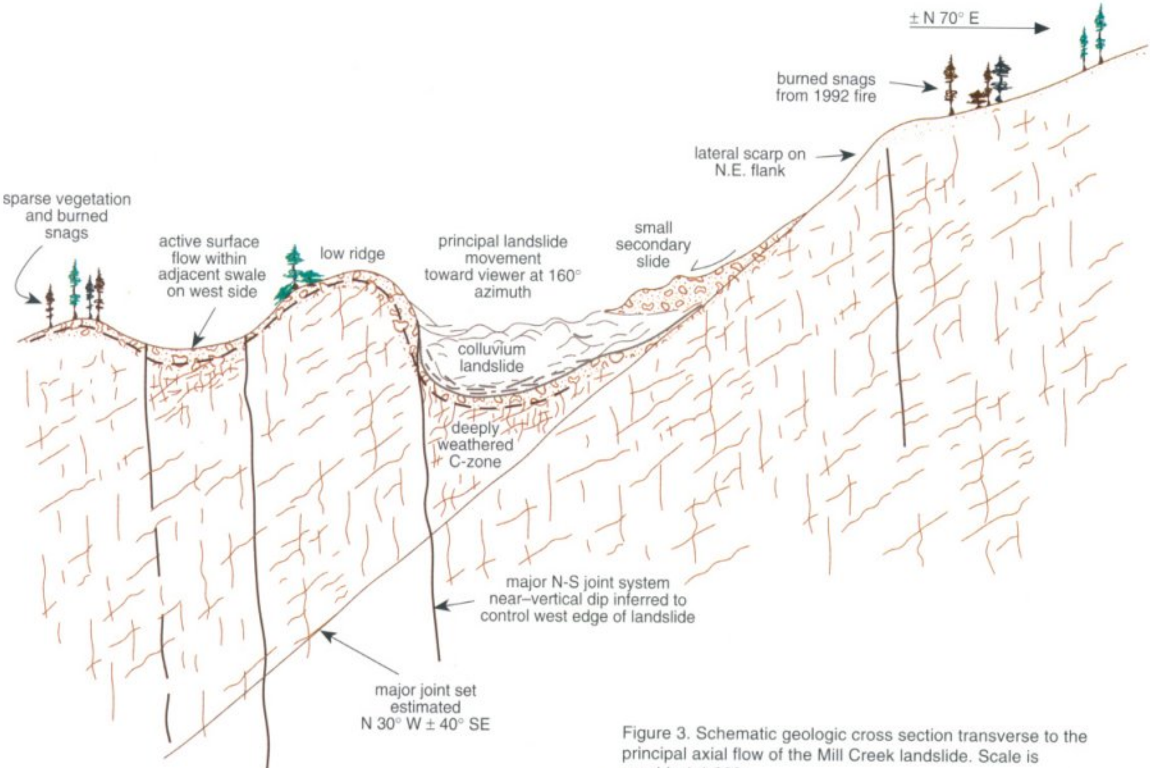

Figure 3. Schematic geologic cross section transverse to the principal axial flow of the Mill Creek landslide. Scale is roughly 1:1,200.

INTENSE RAINFALL OVER EXISTING SNOW

Two distinct episodes of flooding occurred in the White Hall area during January 1997 as a result of intense rainfall over existing snow. On December 25, 1996, about 1 foot (30 cm) of snow had accumulated in the White Hall to Kyburz area and about 6 feet (2 m) at Echo Summit. It rained some on December 26 and 27, and then, on December 31 and January 1, an unusually warm tropical storm dropped sustained heavy rain in central El Dorado County with severe flooding along the South Fork American River. Several private bridges spanning the river from Highway 50 to the Randall Tract on the south bank (near Mill Creek) were destroyed in this January 1 flooding. This is immediately southwest of the current Mill Creek landslide.

There were several additional heavy rainstorms in mid-January and the snow in the White Hall to Kyburz area rapidly melted. Rainfall continued during the week before the January 24 landslide. There is a gauging station at the intake of the El Dorado Ditch near Silver Fork (Section 29, Kyburz Quadrangle) about 5 miles up-river from the Mill Creek landslide. However, according to Anne Boyd, USFS geologist, it was damaged and rendered inoperable by the January 1 flood. The 49-year mean annual precipitation is 41 inches (1 m) at Pacific Gas & Electric's (PG&E) rain gauge at the power intake near Kyburz.

The 122-year mean annual rainfall for Placerville (about 25 miles [40 km] west and 1,900 feet [580 m] lower elevation) is 39.64 inches (100.7 cm). The rainfall from July 1996 through January 29, 1997 was 46.46 inches (118.0 cm), already 117 percent of the annual mean. For the first 29 days of January 1997, 19.22 inches (48.8 cm) of rain fell in Placerville, far greater than the 122-year mean for January, just 7.56 inches (19.2 cm).

Rainfall data from the Fresh Pond gauge station near the slide show the monthly precipitation for this area to be 32.59 inches (82.78 cm) in December 1996, and 24.30 inches (61.72 cm) in January 1997.

USFS GEOLOGIC MAPPING OF LANDSLIDE SCARPS IN MAY 1996

Anne Boyd has routinely mapped landslide scarps in the canyon of the South Fork American River and related areas affected by the 1992 Cleveland Fire. In early May 1996, she observed and photographed significant arcuate tensional landslide scarps near the 3,800- to 4,200-foot (1,160- to1,275-m) level in the Mill Creek landslide and in similar areas within the canyon. DMG and USFS continue geologic mapping, and USGS is assisting USFS and Caltrans in monitoring additional areas of known active sliding along Highway 50.

GROUND WATER AND SURFACE WATER

The head scarp of the Mill Creek landslide is on the south flank of a spur ridge at 4,650 feet (1,417 m) elevation, and there is no higher catchment area for surface water. About 200 feet (60 m) west of the Mill Creek landslide is a straight (joint-controlled) gully that has surface water flow following heavy precipitation. It was actively flowing about 200 gallons per minute (13 l/s) on January 27, 1997, but this decreased to about 100 gallons per minute (6 l/s) by January 30. Local surface water flowed into the head scarp at 50 gallons per minute (3 l/s), as estimated on January 30. An earth berm was constructed below the scarp to divert as much surface water as possible into the bedrock gully on the western side and away from the landslide mass. Considerable ground water was seeping from the exposed bedrock/colluvium interface on the northeast flank of the landslide. Also, there are some springs on the hill above the landslide. It is believed that buildup of pore-water pressure along the soil/bedrock interface mobilized the thick deposit of saturated colluvial material in the narrow wedge-shaped trough. If pore-water pressure were the triggering mechanism, then diverting ground water and surface water near the crown of the landslide will be an essential component of an overall remediation strategy for the upper mass of the Mill Creek landslide, which is still in place.

REMEDIAL REPAIR AND ECONOMIC COST

Highway 50 was closed for 27 days during landslide removal and remedial grading operations (Photos 4 and 5). Remedial landslide repair options were developed by a team of engineering geologists and geotechnical engineers from Caltrans. The repair schedule was of keen interest because it had a salient impact on the economic recovery of El Dorado County and South Lake Tahoe (California and Nevada sides). Many agencies in the public and the private sectors were dependent upon the reopening of Highway 50. Foremost among these were Pacific Bell

Photo 4. Heavy equipment removing an estimated 250,000 to 300,000 cubic yards (190,000-230,000 m^3). *Photo by Robert H. Sydnor.*

Photo 5. Caterpillar tractors push landslide debris downslope toward two sets of track-mounted loaders at the toe of Mill Creek landslide. The roadbed was found to be intact after 27 days of excavation. *Photo by Robert H. Sydnor.*

telephone operations and PG&E electrical power supply, whose lines were truncated by the Mill Creek landslide.

Some meaningful insights can be gained from the direct cost and indirect total economic impact of the 1983 Highway 50 landslide that closed Highway 50 for 75 days. Schuster (1996) cited estimates of the area's economic loss from the 1983 landslide as $3.6 million for highway repairs (Walkinshaw, 1992) and $70 million for economic loss (*San Francisco Chronicle*, 1983).

PRELIMINARY SUMMARY OF THE GEOLOGIC CONDITIONS RELATED TO THE MILL CREEK LANDSLIDE

The geologic factors that sequentially combined to initiate catastrophic movement of the Mill Creek landslide are:

- Steep slopes of the canyon of the South Fork American River.
- Deeply weathered mafic plutonic bedrock (chiefly pyroxenite) that produced an unusually thick sandy colluvial soil that lacks a cohesive clayey matrix. This type of colluvium typically has a high void ratio and can have an unusually high moisture content.
- Structural control by two intersecting bedrock joint planes, creating an inclined asymmetric trough-like structure (like a half-open and tilted book) that collected a particularly thick prism of colluvium over geologic time.
- Possible effects of the 1992 Cleveland Fire.
- Landslide creep observed in May 1996, creating tension cracks in the head scarp area.
- December snowfall, then rapid melting due to the January 1, 1997 tropical thunderstorms with relatively warm rain. The colluvium reached field capacity and became saturated with this antecedent rainfall.
- Sustained rainfall on a weekly basis in January 1997.

In summary, geologic field evidence indicates the Mill Creek is a naturally-occurring landslide, due to a highly unfortunate combination of geological field conditions, and an unusual sequence of adverse meteorological events.

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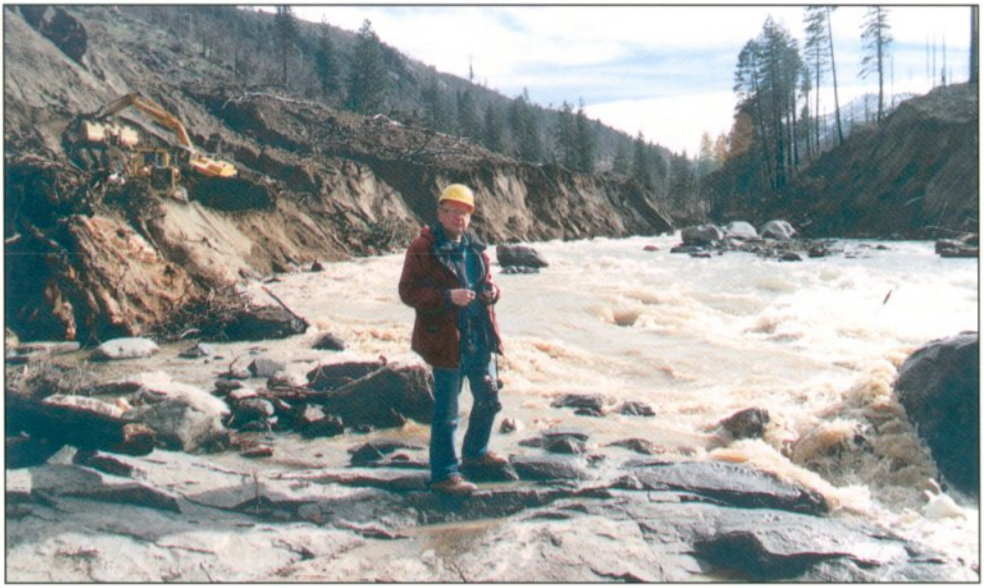

Photo 6. The breached landslide dam along the South Fork American River is inspected on January 30, 1997 by Robert L. Schuster, engineering geologist, USGS, Denver. Within about 5 hours the river quickly cut the sandy colluvium to its original base level in hard diorite shown in the foreground. *Photo by Robert H. Sydnor.*

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