Geology and Slope Stability Along Highway 50

El Dorado County

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Following the Mill Creek landslide (see May/June 1997 CALIFORNIA GEOLOGY [CG] by R. Sydnor) that closed Highway 50 in 1997, the California Department of Transportation (Caltrans) contracted with the California Department of Conservation's Division of Mines and Geology (DMG) to map the geology and identify landslides and potentially unstable earth materials along a section of the American River Canyon. This study was to determine the influence the geology and geologic structure have on slope stability, thereby providing information to assess potential impacts that landslides have on Highway 50. This article summarizes the findings of that study...*authors' note*

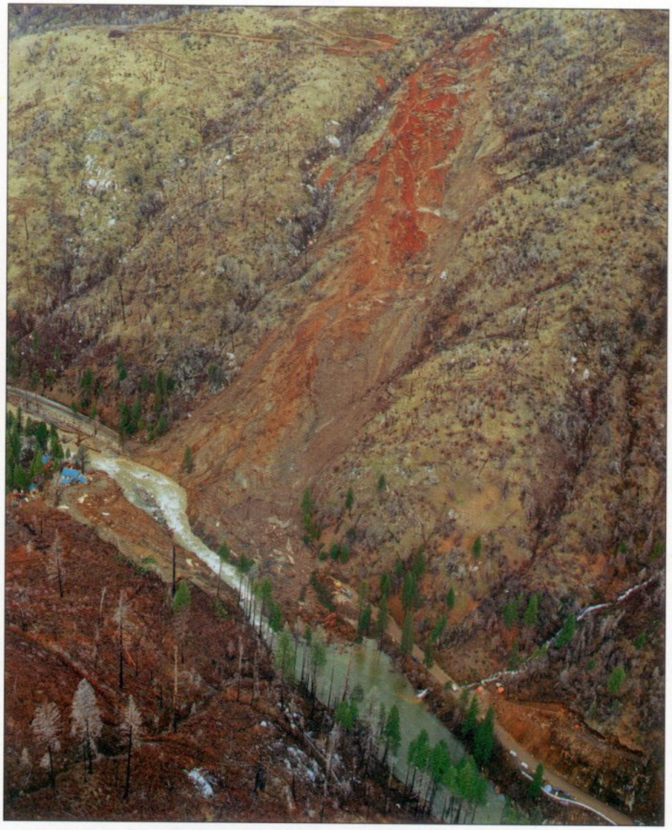

Photo 1. View of the Mill Creek landslide on a steep, south facing slope of the American River Canyon. The slide occurred (January 24, 1997) along the contact between the gray colored granitic bedrock and the reddish colored ultramafic bedrock. *Photo courtesy of Caltrans. Photo by Lynn Harrison. Taken 1/27/97.*

INTRODUCTION

Landslides are natural geologic phenomena that can have devastating effects on human lives. During intense and long storms that pound California during wet years, such as the current El Niño season, people are killed and millions of dollars lost due to landslides. Loss of business income can be substantial when landslides close highways, such as U.S. Highway 50, a major route between Sacramento and South Lake Tahoe (Photos 1 and 2).

As California's population and commerce continue to increase and expand into landslide-prone mountainous areas, our encounters with landslides become more common and more costly. Preventing these natural hazards often is not feasible. However, a better understanding of where landsliding has occurred will aid planners in avoiding, where possible, unstable areas and where avoidance is not an option, developing plans for mitigating potential impacts. Geologic investigations are being conducted throughout the state by private sector and government alike to reduce the threats to lives and property from slope failures and other geologic hazards. One such investigation is along Highway 50 (Figure 1).

Periods of road closure along this route due to landsliding occur almost every winter. Ever since this route was established over 100 years ago, landslides have presented a hazard for travelers, an economic hardship for businesses, and a significant maintenance expense for California taxpayers. The most recent catastrophic slope failure (January 24, 1997 Mill Creek landslide) closed Highway 50 for 27 days while construction crews removed 350,000 cubic yards of landslide debris. A much

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Terms in **boldface type** are defined in glossary on pages 15 and 16.

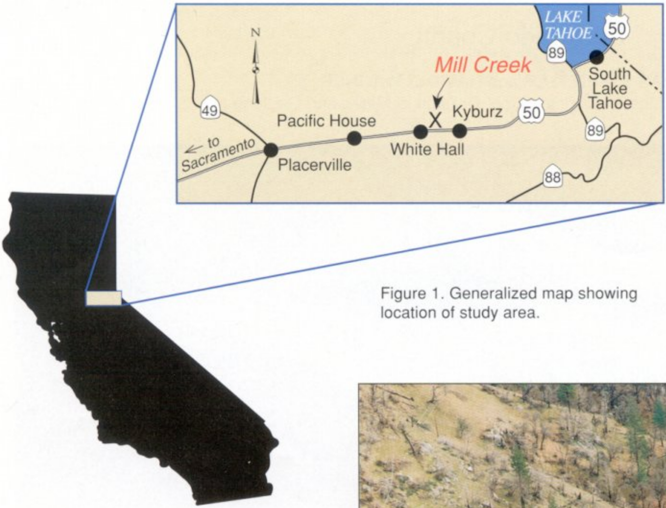

Figure 1. Generalized map showing location of study area.

longer closure occurred (75 days), after the 1983 Highway 50 landslide (Kuehn and Bedrossian, 1987).

The Study Area

The study area extends for about 15 miles between Riverton and Strawberry where Highway 50 follows the South Fork of the American River through a steep-walled 2,000-to-3,000 foot deep canyon. The hillslopes that were investigated extend about 1 mile north and south of the highway between Riverton and Kyburz and 1 mile north of the river between Kyburz and Strawberry. Mapping was conducted at a scale of 1:12,000 (1 inch=1,000 feet). More detailed results of this study with full-scale maps (Plates 1-4 in the report) are available in DMG Open-File Report 97-22, *Landsliding Along the Highway 50 Corridor: Geology and Slope Stability of the American River Canyon between Riverton and Strawberry, California* (see release announcement on page 2 in this issue). Plates 2 and 3 in OFR 97-22 are reproduced here at a smaller scale as Figures 2a (geologic map) and 2b (landslide map).

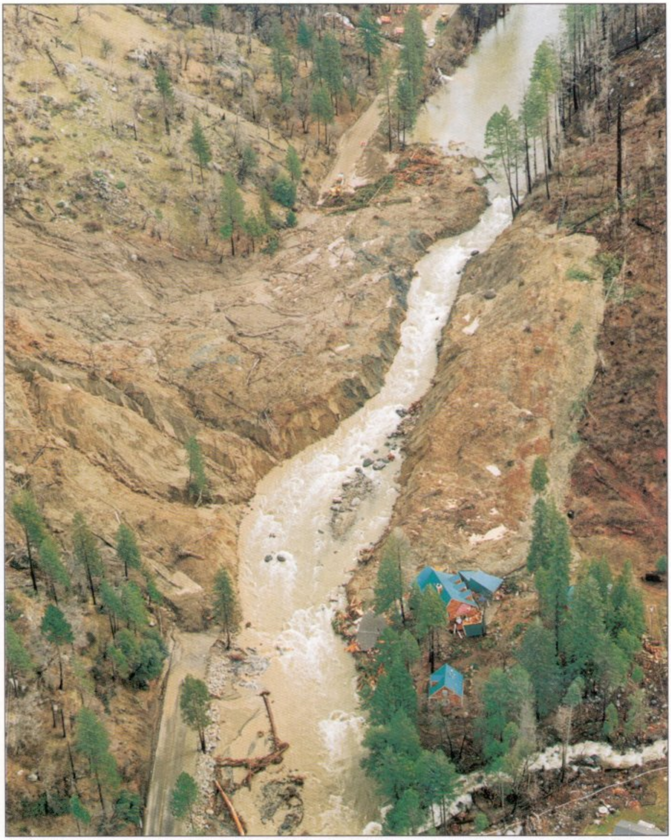

Photo 2. Oblique aerial view eastward up the South Fork American River showing the breached Mill Creek landslide of January 24, 1997. About 800 feet of U.S. Highway 50 was buried and the river blocked for about 5 hours before the landslide debris dam was breached. *Photo courtesy of Caltrans. Photo by Lynn Harrison. Taken 1/27/97.*

A common perception of many people, geologists included, is that the Sierra Nevada is relatively free of landslides, being composed of unweathered, glaciated **granitic** rock that forms domes and spires. However, in much of the range there were no glaciers to scour away deeply weathered, weak rocks. During wet years, weak rocks and unconsolidated surficial deposits become water-saturated and may fail as landslides. Even in the glaciated granitic rock of Yosemite Valley, mass wasting is common (Wieczoreck and others, 1989). Landsliding is a natural erosional process in all upland areas, and the canyon of the South Fork of the American River is no exception. Variations in rock strength, slope steepness and configuration, surface and ground water flow, type and density of vegetation, and land use all may affect when and where a landslide happens. An understanding of the geologic setting of the Sierra Nevada and more specifically the American River Canyon is a starting point for understanding slope stability and landslides affecting the Highway 50 corridor.

GEOLOGY

The geologic history of the Sierra Nevada can be divided into three broad phases. During the first phase in the Paleozoic Era (570-245 million years ago), sediments and **volcanic ejecta** (ash deposits similar to those laid down by the eruption of Mount Saint Helens) that were destined to become the **metamorphic rocks** of the Sierra Nevada, were deposited in an ancient ocean. In the second phase, during the Mesozoic Era (245-65 million years ago), molten rock intruded and metamorphosed the Paleozoic rocks far below the earth's surface. When cooled, these became the granitic rocks of the Sierra Nevada **Batholith**. By the earliest part of the Cenozoic Era (65 million years ago to the present), tectonic forces led to uplift and tilting of the range, resulting in the stripping away of miles of the earth's crust through erosion, eventually exposing the granitic and metamorphic rocks we now see in the Sierra. Later during the Cenozoic, west-flowing rivers cut valleys into an ancestral Sierra Nevada. The newly formed landscape was then filled by volcanic debris and lava ejected from volcanoes along and east of the crest of the range. Within the last 3 to 4 million years as uplift continued, rivers cut new canyons. Ice age glaciers during Pleistocene time (2 million to 11,000 years ago) put the finishing touches on the spectacular Sierra Nevada landscape of today. The following section presents brief descriptions of the geologic units (including abbreviated formation names) mapped in the study area and shown in Figure 2a.

Metamorphic Rocks (pKm)

The oldest rocks in the study area are exposed in three north-trending masses of metamorphic rock mostly on the north side of the highway (Figure 2a). Dominant rock types are **quartz mica schist** and **gneiss**, with lesser amounts of **quartzite**. These rocks are completely recrystallized with none of the original textures remaining and are considered to be part of the early Paleozoic Shoo Fly Complex (Clark, 1976; Schweickert, 1981). They are highly deformed, especially along contacts with the granitic rocks, with a strong **foliation** defined by alignment of platy minerals and compositional layering. Near contacts with the granitic rocks, the metamorphic rocks are highly weathered which may weaken them and explain this unit's moderate-to-high suseptibility to slope failure observed in those areas. Both the Cleveland Corral and Silver Fire landslides occur along such contacts (Figure 2a). Outcrops are sparse except in roadcuts (Photo 3).

Photo 3. Exposure of the deeply weathered, reddish metamorphic rock. The reddish color is due to iron oxidation of biotite in the rock. *Photo by Dave Wagner.*

Ultramafic-mafic Complex (Jum)

An assemblage of ultramafic and mafic igneous rocks (dark colored rocks with a high component of magnesium and iron-rich minerals) was mapped in three places north of Highway 50 between Riverton and Kyburz. The complex is associated with the older granitic rocks but its structural relationship to them is uncertain. The age and origin of this unit are not known, although it is similar in many respects to the Emigrant Gap Complex to the north. The Emigrant Gap Complex is believed to be part of an older system rather than part of the Sierra Nevada Batholith (Hanson and others, 1993). A **pyroxenite** member of the complex lies immediately above the Mill Creek landslide. Because pyroxenite is rich in iron, it weathers to a bright red soil. Pyroxenite detritus and red soil were shed downslope over the area that failed on January 24, 1997, giving the Mill Creek landslide its brilliant red colors (Photo 1). Extensive, largely dormant landslides are associated with the ultramafic-mafic complex.

Granitic Rocks (Kgr)

The most common rock types in the study area are two groups of granitic rocks: an older, dark colored, deformed **quartz diorite** to **diorite** in the western part of the study area and a younger, light colored, less deformed **granodiorite** to **monzonite** to the east. The dioritic rocks are often brecciated (broken) and intruded by younger granitic rocks. Well developed foliations defined by alignments of platy and tabular minerals, as well as a pervasive penetrative shear foliation, affect

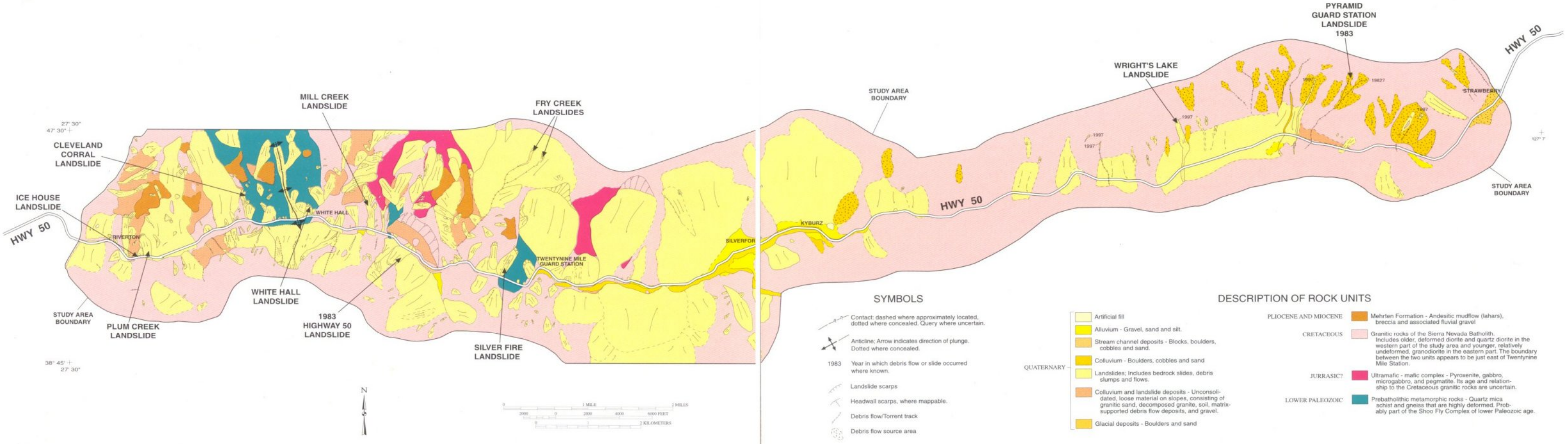

Figure 2a. Geologic map. *Modified from Wagner and Spittler (1997) Plate 2.*

Figure 2b. Landslide map. *Modified from Wagner and Spittler (1997) Plate 3* .

the dioritic rocks. Weathering has apparently proceeded preferentially along more intensely sheared zones resulting in resistant angular slabs separated by soft topography underlain by decomposed granitic rock (grus).

The younger granodiorite to monzonite frequently has a speckled appearance from inclusions of older rock (xenoliths) or accumulations of dark colored minerals (schlieren). A weak **magmatic** foliation and penetrative shearing is occasionally present. This rock type forms imposing domes and spires, such as Sugarloaf near Silver Fork and Eagle Rock near Kyburz.

In places, the granodiorite is deeply weathered to grus. There are many pockets of disaggregated weathered granitic material on slopes underlain by this unit. Where observed, the pockets have been mapped as colluvium on the geologic map (Figure 2a). Unfortunately, these pockets are obscured by dense forest and can only be observed in burned areas, where vegetation is more sparse.

Joints are especially prominent in the granodiorite. There are two dominant sets of north trending joints. One set dips at gentle angles to the east and the other is nearly vertical. A third prominent set of planar surfaces that affects the stability of the granitic bedrock is caused by **exfoliation** planes that are parallel to the slopes of the river canyon. There are also numerous, less prominent joint sets that may locally affect slope stability.

Mehrten Formation (Tm)

Andesitic volcanic **breccias**, **mudflows**, and associated **volcaniclastic** sand and gravel of the Miocene to Pliocene age Mehrten Formation (Photo 4) are part of the voluminous andesitic material that erupted from volcanoes along the crest of the Sierra Nevada from 18 to 4 or 5 million years ago. The volcanic material flowed westward into the ancestral Great Valley, inundating most of the landscape of the northern and central Sierra Nevada. New drainages were established, while the rivers cut new canyons and left remnants of the volcanic rock as caprocks on the ridges.

The study area does not extend to the ridgetop, therefore the volcanic caprocks do not appear on the geologic map. There are, however, isolated bodies of Mehrten Formation mapped in the river canyon between Riverton and Twentynine Mile Station. These occurrences of the Mehrten are significant because they provide insights to landslide processes that have operated in the American River Canyon. Based on regional mapping (Jennings, 1978; Wagner and others, 1981), our interpretation is the American River Canyon did not exist when the andesitic mudflows of the Mehrten Formation were deposited. If the canyon had existed at that time, it would have been filled with andesitic volcanic deposits. Remnants of these volcanic rocks would be fairly common in this and other canyons today, but they are not. In fact they are quite rare. It is our interpretation that the masses of Mehrten found in the canyon between Riverton and Twentynine Mile Station have been displaced by ancient landsliding, some 2,000 to 5,000 feet downslope from the ridge top into the canyon. It is also our interpretation that the present location of Mehrten volcanics in the study area are now relatively stable. For a more detailed discussion of the Mehrten Formation see DMG OFR 97-22.

Photo 4. Exposure of volcanic mudflow deposits (lahars) of the Mehrten Formation. *Photo by Dave Wagner.*

Glacial Deposits (Qg)

Glacial deposits consisting of boulders, cobbles and sand were mapped by Warhahftig (1965) along the eastern edge of the area at Strawberry. Warhahftig attributed them to the Tahoe glaciation, approximately 118,000 years ago (Bursik and Gillespie, 1993). Warhahftig's map shows the present configuration and depth of the American River Canyon had been established by that time because the river had not cut appreciably below the glacial material underlying the meadow at Strawberry.

Landslides (Qls)

Landslides and landslide deposits include accumulations of poorly sorted, disrupted materials that have been transported by **debris flows**, as well as larger, more coherent areas where bedrock units have been transported downslope. The largest of the mapped landslides is over 1 mile long and 1 mile across.

Colluvium and Grus (Qcl, Qc)

Geologic mapping for this project revealed mappable deposits of poorly consolidated granitic **colluvium**, decomposed granite, soil, **matrix supported debris flow** material, and cobble/boulder gravel that had not been mapped previously. Where this

Photo 5. Outcrop of unconsolidated colluvium and landslide deposits. These deposits are composed of decomposed granite, granitic colluvial sand as in this outcrop, thick soil horizons, and debris flow deposits. *Photo by Dave Wagner.*

material is present on steep slopes it is unstable. Many of the landslides triggered by the 1996-97 storms, from small roadcut slumps to large landslides, occurred in this material (Photo 5). The most common constituents of these deposits are granitic colluvium and decomposed granite. In addition, cobbles of andesite derived from the Mehrten Formation are also present. The Ice House and Mill Creek landslides are composed of granitic sand (colluvium or decomposed granite) that disaggregated during the sliding. The headwall of the Cleveland Corral landslide occurs within these deposits. An enigmatic component of these deposits in the western portion of the study area, west of Twentynine Mile Station, are thick highly oxidized soil horizons. Debris flow deposits consisting of a silty sand matrix, supporting pebbles and cobbles are also found in this unit.

The origin of these deposits and the associated soil in the western portion of the study area are complex and not precisely understood. Because the decomposed granite and the thick oxidized soil horizons are in close association with Mehrten Formation rocks, we thought these deposits could be remnants of a deeply weathered bedrock surface that developed on the ancient topographic surface beneath the Mehrten Formation. However, where the basal contact of the Mehrten was observed in place, andesitic gravel rests on relatively fresh granitic bedrock. This leads us to postulate that the material locally represents remnants of ancient landslides whose morphologies have been eroded.

In the eastern portion of the study area, accumulations of granitic sand, cobbles and boulders are mapped as colluvium. They are best observed in areas where vegetation is less dense (a result of wildfires). Areas where the granitic sand occurs are considered to be potential debris flow source areas. An example is the Wright's Lake landslide that failed in colluvial grus.

Alluvium and River Gravel (Q, Qr)

Alluvium composed of boulder gravel, sand and silt was mapped on benches along the river. The most extensive accumulations of alluvium are at Silver Fork and Kyburz. River gravel consisting of boulders and sand occurs all along the American River but it was mapped only from about Twentynine Mile Station to Kyburz where exposures are extensive. River gravel, alluvium and bedrock benches are scarce between Riverton and Twentynine Mile Station. This may be due to the frequency of landslides occurring along this section of the river. When large landslides such as the 1997 Mill Creek and the 1983 Highway 50 occur, river gravel or alluvium are pushed into the river and washed downstream. Apparently the frequency of landslides along this section of the river is high enough to prevent both the accumulation of significant amounts of sand and gravel and the formation of bedrock benches. Upstream, at Silver Fork and Kyburz where wide bedrock benches are overlain by gravel and alluvium, large landslides are dormant.

SLOPE STABILITY AND LANDSLIDING

Over 600 landslides have been identified along the Highway 50 corridor between Riverton and Strawberry (Figure 2b). These landslides range from small, recently active **debris slides** and debris flows (Photo 6) to dormant **rotational landslide** complexes, perhaps inactive for thousands of years. The mapped landslides include rapid debris slides and debris flows, such as the 1997 Mill Creek landslide, relatively slow-moving rotational or translational landslides, such as the 1983 Highway 50 landslide (Photos 7 and 8), and highly viscous, slow moving **earthflows**. Potential debris flow source areas, accumulations of colluvium on relatively steep and concave slopes, are also mapped within the corridor.

We mapped the landslides in two ways. Wagner mapped the geology, including those landslides that affect the distribution of geologic units and Spittler identified landslides from an interpretation of stereographic aerial photographs. The photo-interpreted landslides were then field checked and modified as needed. Our confidence in the mapping is bolstered by the correlation in landslide pattern and relative density between the two different mapping techniques.

The mapping of landslides is possible because they typically have distinc-

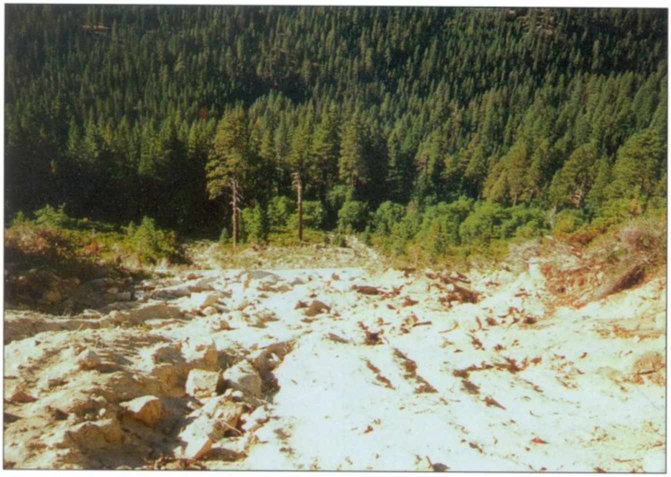

Photo 6. View looking downslope of a debris flow. It is derived from granitic colluvium and traveled at speeds of several feet per second. *Photo by Tom Spittler.*

tive surface features. Over time, erosion degrades the surface expression. Based upon the relative freshness of each landslide feature, we classified it into one of five groups.

Group A includes landslides that moved during the winter of 1996-97. More than 50 landslides were identified. Most of these are small (less than 1/4 acre) debris flows and debris slides that transported material downslope, but had no significant impact on Highway 50. However, eight of these landslides required road maintenance or grading, and one, the Mill Creek landslide, closed the highway for nearly a month. Group A landslides include those that may pose chronic problems unless remedial work is performed, as well as the scars left behind following the failures of debris flows.

Group B landslides are those that appear to be unstable under current conditions or that have distinct surface features, but did not move during 1996-97. This includes historic landslides such as the 1983 Highway 50 landslide. These landslides have distinct geomorphic expression. In general, Group B rotational or translational landslides and earthflows appear to be intermittently active with episodes of relatively slow, incremental movement separated by periods of dormancy. Movement of these landslides is typically triggered by high precipitation. Group B debris flows and debris slides include both those that have recently failed, as determined from aerial photographs, and well defined, discrete colluvial source areas that appear to be highly unstable. As with the Group A landslides, Group B debris flows and debris slides may be extremely unstable, or they may be the scar left following the failure of the unstable materials. They can pose significant problems to Highway 50 during intense rain.

Landslides in Group C are those that may be unstable under current conditions. Relative to Groups A and B, these landslides are not as likely to fail.

Landslides falling into Group D are those that have been identified based on their relatively distinct landslide geomorphology. However they do not show evidence of active instability.

Group E includes slopes with possible landslide geomorphology or areas where geologic exposures indicate landslide displacement.

Groups D and E are dormant features that have been modified by post-failure erosion. They are not presently active, but their stability could be affected by grading or other land use activities.

In addition to landslides (Figure 2b), potential debris flow source areas were identified. These are areas of colluvial accumulation on steep slopes with local areas of topographic convergence that could concentrate runoff or ground water. Although these features are not in themselves landslides, they represent areas where debris flows or debris slides are most likely to occur. Stream channels or topographic draws below potential debris flow source areas are most likely to be impacted by debris flows.

The distribution of landslides is not uniform throughout the Highway 50 corridor. Because of this, the area can be subdivided into three distinct landslide domains based upon the types and frequency of landslides:

Riverton to Twentynine Mile Station

This domain includes a large number of different types of landslides underlain by complex geology, unstable surficial materials, and highly deformed weakened bedrock. Geologic structure strongly influences slope stability in this area. Active landslides include the Ice House, Cleveland Corral, White Hall, Mill Creek, Fry Creek and Silver Fire, all of which appear to have moved during the 1996-97 winter, as well as numerous other unnamed active slides both north and south of the American River. The 1983 Highway 50 landslide is also in this domain.

The Ice House landslide has been a maintenance problem along Highway 50. Failure appears to be dominantly translational, with offset along jointing within the underlying granitic bedrock. The Cleveland Corral landslide, which is about 1.5 miles long and about 0.5 mile across, is complex in its mode of failure, and includes rotational, translational and earthflow characteristics. The landslide has developed along the contact between granitic and metamorphic bedrock units. The White Hall landslide is also a complex landslide with rock block glide translational failure and rotational slumping; both apparently actively operating. Analogous to the Icehouse landslide, foliation within the metamorphic bedrock appears to be one of the dominant controlling factors in the White Hall landslide.

The 1997 Mill Creek landslide failed as a joint controlled rock block glide that initially disaggregated into a debris slide high on the slope. The landslide material appears to have rapidly mobilized as a debris flow below the source area, burying the highway and damming the American River. Sydnor (1997) provides a more complete description of this failure.

The Silver Fire landslide is a rotational slump within deeply weathered granitic bedrock. Recent failure has been episodic and relatively minor in extent. The 1983 Highway 50 landslide is also a rotational landslide that failed within deeply weathered granitic bedrock from the toe of a much larger ancient landslide complex on the north-facing slope south of the American River. Kuehn and Bedrossian (1987) report that movement was relatively slow and occurred following 40 inches of precipitation during the preceding 2 months.

Twentynine Mile Station to Kyburz

This domain is underlain by granodiorite and, in the western part, by rocks of the ultramafic-mafic complex. This appears to be the most stable of the domains along the Highway 50 corridor in the study area. The large bedrock landslides in this domain appear to be dormant but they do exhibit well defined landslide morphology such as head wall scarps, closed depressions and poorly drained areas.

Kyburz to Strawberry

This domain is underlain by granodiorite. Extensive debris flows have occurred, including this past winter's Wright's Lake landslide and numerous other unnamed debris flows. On June 4, 1983, rapid melting of the deep snowpack triggered the Pyramid Guard Station landslide (Connelly, 1988). These landslides are debris flows that failed from colluvial soils within topographic swales on the upper sections of the mountain slopes. Areas with similar slopes and materials are mapped as potential debris flow source areas.

FACTORS INFLUENCING SLOPE STABILITY

Slope inclination, bedrock geology, geologic structure, geomorphology, weathering, vegetation and precipitation all influence the stability of the slopes along the Highway 50 corridor.

Slope Inclination: The American River Canyon along the Highway 50 corridor is relatively steep, with slope inclinations typically ranging from 40 to 70 percent (18 to 31.5 degrees). Between Riverton and Twentynine Mile Station, the slopes tend to be steeper along the lower slopes. Slope angles between Twentynine Mile Station and Kyburz, tend to be less steep and more

Photo 7. The 1983 Highway 50 landslide pushed slowly into the South Fork of the American River and up over the highway damming the river. The landslide, which closed Highway 50 for 75 days, was a 1 million cubic yard, 22 acre, rotational failure originating in decomposed granitic rock. Trees up to 4 feet in diameter were toppled and splintered. *Photo by Trinda Bedrossian.*

Photo 8. The 1983 Highway 50 landslide 15 years later. The lower bench formed when a mass of earth slowly moved downslope while rotating back. *Photo by Tom Spittler.*

subdued. East of Kyburz, the canyon has more of a U-shape, with the steeper ground high on the ridges, and relatively broad flats at the base of the slopes. In combination with the other conditions, the slope angle is a major determinant in the stability of the corridor.

Bedrock Geology: Bedrock geology, particularly the contact between different geologic units, is a principal factor of landsliding in the area. Two large active features, the Cleveland Corral and the Silver Fork landslides, as well as a host of smaller failures, occur along the contact between the metamorphic and granitic rocks. Along this contact, the rock units are frequently sheared and deeply weathered, resulting in weakened material. The contact between the Mehrten Formation and underlying granitic and metamorphic rocks is commonly a locus of landslides. Ground water rapidly permeates through the coarse Mehrten volcanic rocks until it reaches the contact with the crystalline bedrock. Lateral migration of ground water along the contact supports the large number of springs that occurs along these zones. Warhahftig (1965) showed that decomposition of granitic rock occurs preferentially beneath andesitic volcanic caprock because the underlying rock does not dry out. The combination of deep weathering along the contact and the high pore water pressure is hypothesized to be a control on landslide frequency. The relationship between landslide frequency and geologic contacts has been observed in this portion of the Sierra Nevada by Trinda Bedrossian (personal communication, 1997, DMG) and U.S. Forest Service (USFS) staff (Anne Boyd written communication, 1997).

Geologic Structure: The structure of the bedrock geologic units also plays an important role in the stability of the slopes. Where foliations in metamorphic rocks or joints in granitic rocks parallel the slopes, a dipslope condition may exist where rock masses may project out-of-slope. About 1/2 mile west of White Hall, the metamorphic rocks are folded into a south plunging anticline. The metamorphic rocks have a pronounced parting parallel to the foliation that is defined by compositional layering. The rocks are typically fractured along the crest of the anticline. Not surprisingly, there is a long, narrow landslide along the trace of the fold axis, probably due to the fracturing of the rocks and the out-of-slope character of the foliation. The active White Hall landslide has developed upon foliations along a margin of the anticlinal fold. The intersection of joint sets within the granitic rocks has locally developed V-shaped wedges of bedrock that project out-of-slope and are locally unstable.

Geomorphology: Topographic swales are commonly the sources of material for debris flows in the area. The granitic bedrock is typically deeply weathered to grus (decomposed granite) within these swales. It appears that the swales are often controlled by the intersecting joint sets in the underlying bedrock (Figure 3). The combined influence of the out-of-slope projection of the joint-defined wedges, the weakening of the bedrock through decomposition, and relatively steep ground have resulted in unstable slopes. Bedrock jointing and weathering apparently controlled the Mill Creek landslide (Sydnor, 1997). The Wright's Lake landslide also appears to have been controlled by jointing at the source area. Most of the other debris flows had source areas in the colluvium filled swales, many of which developed above intersecting joint sets.

Weathering: The weathering of bedrock to colluvium and soil has resulted in a significant reduction in material strength. As a result, these weathering by-products (colluvium and soil) are frequently the source of rapidly-moving debris flows, such as the Pyramid Guard Station landslide.

Vegetation: Vegetation is a factor on the distribution of landslides in the Highway 50 corridor. Although many of the active landslides occurred within areas that had recently burned, debris flows failed from unburned areas as well. While most of the research has been associated with clear-cut logging practices, high intensity wildfires, such as in the Highway 50 corridor, will often result in an analogous die back of tree roots. The effects in burn areas will likely be greater, because wildfires are often much larger than prescribed timber harvests, and because regeneration of forest is often more difficult on large, harsh burn areas. The Cleveland (1992), Wright's (1981), Pelliken (1973), Icehouse (1959) and Long Canyon (1932) fires denuded large areas within the study area.

On April 15, 1997, State Geologist James F. Davis notified Caltrans, the USFS, and the Governor's Office of Emergency Services (OES) of DMG's concerns about homes directly beneath known active landslides, particularly those between Riverton and Kyburz. The USFS subsequently advised local residents of ongoing efforts to monitor and map landslides in the area (Smart, 1997). In addition, following the 1997 Mill Creek landslide, monitoring devices were installed by Caltrans [US Geological Survey (USGS) provided technical expertise] on five known active landslides along the corridor (see page 17). Following completion of DMG's study, copies of DMG Open-File Report 97-22 were also sent to regional and local offices of Caltrans, OES, USFS, USGS, El Dorado County and the Placerville Sheriff's Office.

Precipitation: The Sierra Nevada forms a barrier to moist Pacific storms moving eastward. As storms pass over the mountains, they cool and drop much of their moisture as rain and snow. While the 49-year mean annual precipitation at Kyburz is 41 inches (Sydnor, 1997), precipitation in 1983 was 176 percent of normal (Keuhn and Bedrossian, 1987) and in January 1997 the cumulative precipitation for the winter was 235 percent of normal at Fresh Pond, about 7 miles west of Riverton (Anne Boyd, written communication, 1997). Shallow debris flows, including the Pyramid Guard Station landslide and the 1983 Highway 50 landslide, occurred during periods of rapid snowmelt in 1983. The Wright's Lake landslide failed during the high-intensity rain-on-snow event of New Year's Eve, 1996, and the Mill Creek landslide failed just over 3 weeks following the New Year's Eve event. In these cases the landslides were triggered by a rapid input of water. Landslides can be expected during periods of heavy, sus-

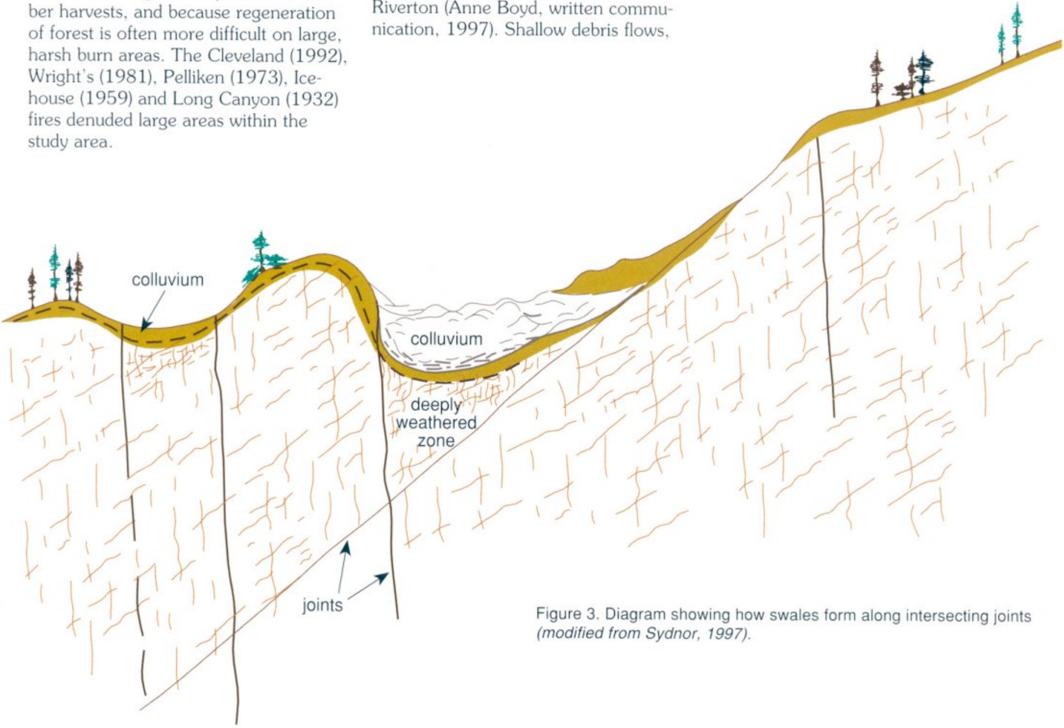

Figure 3. Diagram showing how swales form along intersecting joints *(modified from Sydnor, 1997).*

tained rainfall and following abnormally wet winters when the ground remains saturated later in the year after the rainy season has ended. Rapid melting of major snowpacks and high intensity and duration storms will also trigger new or accelerated failures, especially when the ground is saturated.

Impacts to Highway 50 and Structures

Twenty-four landslides and landslide source areas appear most likely to impact Highway 50 (Figure 2b). Each of the 24 landslides and source areas is tabulated in a matrix contained in DMG OFR 97-22 showing size, probable relative rate of movement and potential for impacting Highway 50. What is not known is the timing of the next precipitation/snowmelt event that could trigger landsliding.

During the 1996-97 winter storms, several homes and private bridges in the Randall Tract-White Hall area were damaged or destroyed by landslides and flooding. Although there is a potential for landslide damage to homes throughout the canyon, the problem is most acute in this area. Several active debris flows and deep-seated landslides mapped on the north-facing slopes above Randall Tract have a low potential for impacting the highway, but they could pose a significant threat to structures directly below. The White Hall landslide also could impact the highway and structures near White Hall. Structures along the South Fork of the American River in the study area may be affected by flooding associated with landslides that are not highlighted as likely to impact Highway 50. Flood damage could result from landslide dams downstream from structures, or from the breeching of landslide dams upstream.

Limitations of the Mapping

The landslide and bedrock geology mapping was conducted on photographically enlarged topographic base maps and large-scale aerial photographs. The geologic features were plotted on the maps by the geologists doing the work. Because none of the landslides were surveyed, map locations are no better than the quality of the original topographic maps. Landslides are modified by erosion following failure; therefore, the older and less active the landslide, the greater the probability of error in size, location and type of failure. Landslides are often obscured by forest cover. Therefore, because of limits on field mapping time, additional small, active landslides most likely exist within the portions of the study area that were not recently burned. Finally, landslides do occur in areas where surface features do not indicate unstable conditions. It is possible that failures will occur where no surface evidence exists.

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GLOSSARY

Andesitic: Pertaining to a dark-colored, fine-grained volcanic extrusive rock.

Batholith: A large plutonic mass that is believed to involve magmatic processes.

Breccia: A coarse-grained rock, composed of angular broken rock fragments held together by mineral cement.

Colluvium: A general term for any loose mass of soil material and/or rock fragments deposited by rainwash.

Diorite: A group of plutonic rocks containing essentially the minerals plagioclase and hornblende.

Exfoliation: The process by which concentric plates are stripped from the bare surface of a large rock mass.

Foliation: A general term for a planar arrangement of textural or structural features in any type of rock.

Gneiss: A foliated rock formed by regional metamorphism.

Granitic: Pertaining to granite, a crystalline quartz-bearing plutonic rock.

Granodiorite: A group of plutonic rocks that has an intermediate composition between granite and diorite.

Joints: A surface of fracture or parting in a rock, without displacement.

Magmatic: Pertaining to magma, a naturally occurring mobile rock material generated within the earth that produces igneous rocks.

Metamorphic rock: Rock derived from pre-existing rocks by mineralogical, chemical, and/or structural changes in response to marked changes in temperature, pressure, shearing stress and chemical environment.

Monzonite: A group of plutonic rocks intermediate in composition between syenite and diorite.

Pyroxenite: An ultramafic rock chiefly composed of pyroxene, with accessory hornblende, biotite or olivine minerals.

Quartz mica schist: A strongly foliated crystalline rock that contains the dominant minerals, quartz and mica. It is formed by dynamic metamorphism, that can be readily split into thin flakes or slabs.

Quartzite: An (granoblastic) equal-grained metamorphic rock consisting mainly of quartz and formed by recrystallization of sandstone or chert.

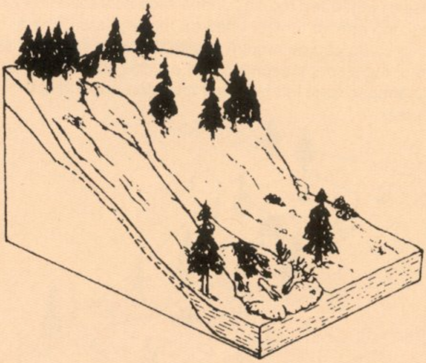
Quartz diorite: A group of plutonic rocks having the composition of diorite but with an appreciable amount of quartz.

Volcanic ejecta: Material thrown out by a volcano.

Volcaniclastic: Pertaining to clastic rock containing volcanic material in whatever proportion, and without regard to its origin or environment.

LANDSLIDE DEPOSITS

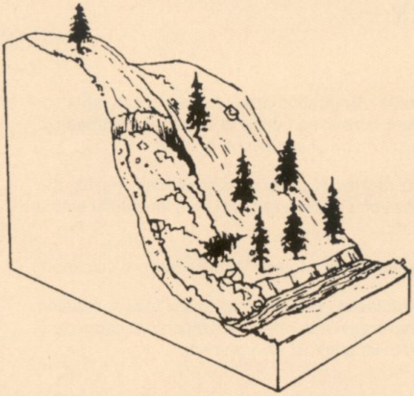
A general term covering a wide variety of mass-movement landforms and processes involving the downslope transport of soil and rock. Landslide types are defined as the following:



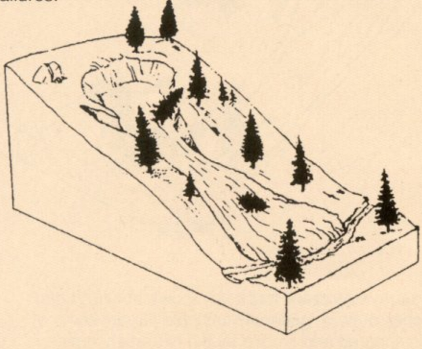
Debris flows/torrent track (as shown above)**:** Long stretches of bare, generally unstable stream channel banks scoured and eroded by the extremely rapid movement of water ladened debris, commonly caused by debris sliding or road stream crossing failure in the upper part of the drainage during a high intensity storm.

more. . .

Glossary continued. . .



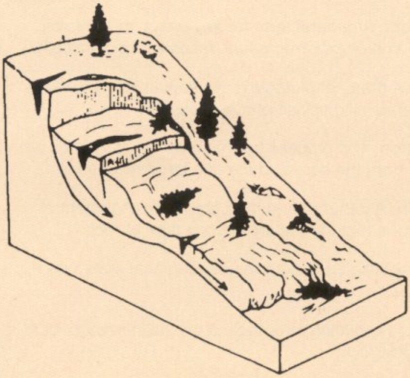
Debris slide (as shown above)**:** Unconsolidated rock, colluvium, and soil that have moved slowly to rapidly downslope along a relatively shallow translational failure plane. Debris slides form steep, unvegetated scars in the head region and irregular hummocky deposits (when present) in the toe region. Debris slide scars are likely to ravel and remain unvegetated for many years. Revegetated scars can be recognized by the even-faceted nature of the slope, steepness of the slope, and the light-bulb shaped form left by many mid- and upper-slope failures.



Earthflow (as shown above)**:** Mass movement feature resulting from slow to rapid flowage of saturated soil and debris in a semi-viscous, highly plastic state. After initial failure, the flow may move, or creep, seasonally in response to destabalizing forces.

Matrix supported debris flow: A debris flow made up of a muddy matrix which supports large rocks and debris.

Mudflow: A general term for a mass movement landform and a process characterized by a flowing mass of predominantly fine-grained earth material possessing a high degree of fluidity.



Translational/rotational landslide (as shown above)**:** A landslide is characterized by a somewhat cohesive slide mass and a failure plane that is relatively deep when compared to that of a debris slide of similar areal extent. Failure plane depth may approach 50 percent of the slide's greatest horizontal dimension. The sense of the motion is linear in the case of a translational slide and arcuate or "rotational" in the case of the rotational slide. Complex versions involving rotational heads and toes with translation in between are quite common. When movement occurs along a planar joint or bedding plane discontinuity, the translation may be referred to as a block glide.

Landslide definitions and figures from July 1983 CALIFORNIA GEOLOGY by T.L. Bedrossian. Also refer to DMG OFR 97-22, Plate 1.