SPECIAL REPORT 186

LANDSLIDES IN THE HIGHWAY 60 CORRIDOR
SAN TIMOTEO BADLANDS
RIVERSIDE COUNTY, CALIFORNIA

Prepared for

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by

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DEPARTMENT OF CONSERVATION

CALIFORNIA GEOLOGICAL SURVEY

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INTRODUCTION

Highway 60, the “Moreno Valley Freeway”, is a major east-west trending highway located in Riverside County in southern California. The highway connects the Los Angeles area with the “Inland Empire” and extends east from Moreno Valley to connect with Interstate Highway 10 at Beaumont. East of Moreno Valley, the highway passes through an area of northwest-trending hills of moderate to steep relief known as the San Timoteo Badlands (Figure 1). The segment of the highway between Gilman Springs Road and Jack Rabbit Trail is largely undeveloped and underlain by the weakly consolidated San Timoteo Formation, which is prone to slope movements. Erosion and landslides on very steep slopes along the highway during times of severe rainfall has led Caltrans to investigate stabilization options to keep the highway safe for travel.

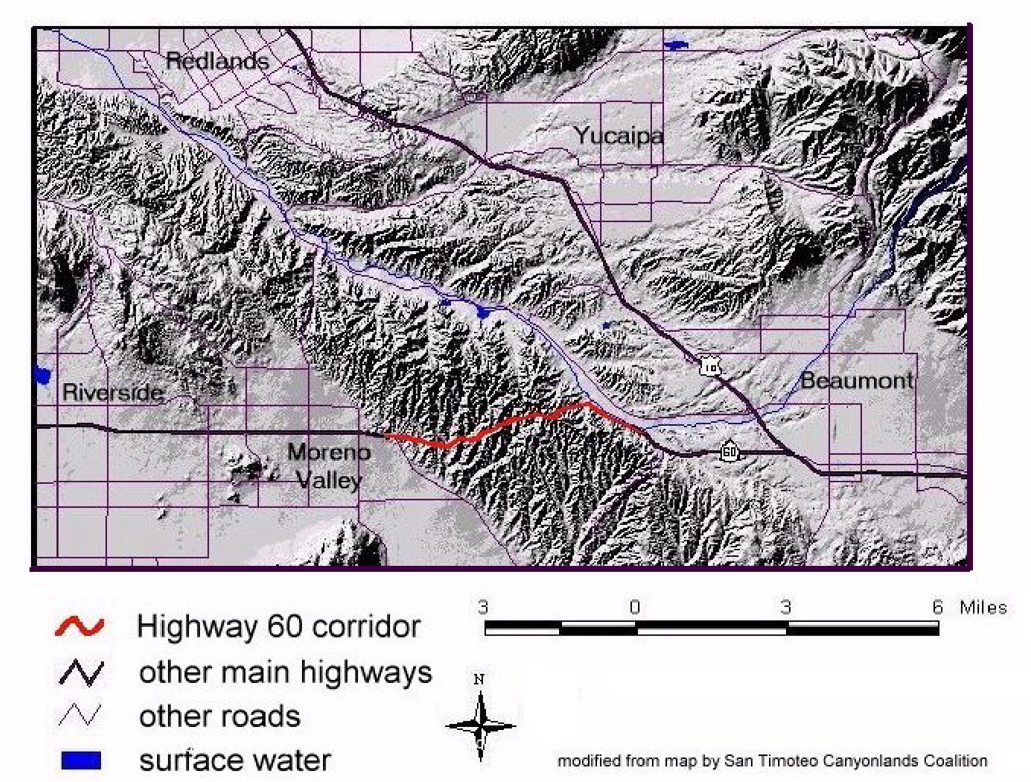


Figure 1. Relief map of the Highway 60 corridor through the San Timoteo Badlands.

To place the landslides of the badlands in regional perspective, and to provide background data for potential stabilization projects, the California Department of Transportation, Office of Infrastructure Research contracted with the California Department of Conservation's California Geological Survey (CGS) to prepare maps of the Highway 60 corridor between Gilman Springs Road and Jack Rabbit Trail (postmile 20 to p.m. 30). These maps include a geologic map, a map of landslides in the highway corridor, and maps of those landslides most likely to affect the highway. The mapping area includes the highway alignment and the surrounding area generally up to 1/2 mile to the north and south of the roadway. The maps do not indicate the probability of movement of any individual landslide or the stability of areas outside of mapped landslides. However, the characteristics of each mapped landslide and physical properties of the geologic units can be used by engineers and geologists at Caltrans in the planning of more detailed evaluations for roadway improvement projects.

The maps presented here were prepared at a scale of 1:12,000 (1 inch = 1000 feet) by compilation of previous mapping, interpretation of aerial photographs and original field mapping. These maps were prepared using a computer geographic information system (ArcView v. 3.2) on scanned images of USGS 7.5-minute topographic quadrangles. Portions of the El Casco and Sunnymead quadrangles form the base map of Plates 1 and 2. The geologic and landslide maps were drawn in the computer GIS, which includes database tables describing each feature mapped.

REGIONAL OVERVIEW

Highway 60 is located in the northern part of the Peninsular Ranges geomorphic province that extends for about 125 miles within California from the border with Mexico north to the Los Angeles Basin (Figure 2). The province is generally characterized by northwest-southeast oriented mountain ranges and valleys bounded by major right lateral strike slip fault zones; the San Andreas on the east and the San Jacinto and Elsinore through the center of the province.

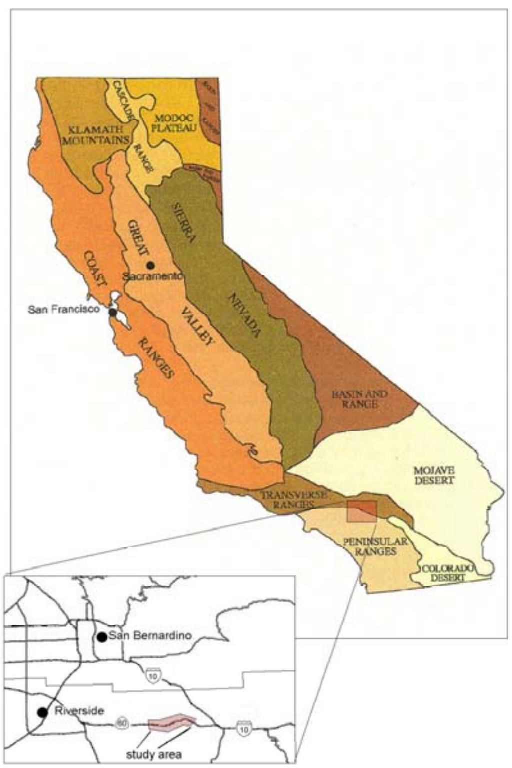


Figure 2, Index map showing Hwy 60 corridor at northern edge of Peninsular Ranges.

Rocks of the Peninsular Ranges are typically Cretaceous igneous rocks and marine sedimentary rocks. Post-Cretaceous rocks of volcanic, marine and non-marine origin lie unconformably on either the Cretaceous sedimentary rocks or on the basement. Within the Highway 60 corridor, the upper Pliocene San Timoteo Formation, composed of a thick sequence of weakly consolidated, nonmarine, siltstone, sandstone, and conglomerate, is the only bedrock unit exposed.

STUDY AREA

The route now followed by Highway 60 was originally commissioned as part of U.S. Highway 60 in 1926. It was changed to a state highway in 1964, but remains a major travel route between the Los Angeles basin and the San Gorgonio Pass and to the east.

The Highway 60 corridor through the badlands extends from p.m. 20 to p.m. 30.

Steep slopes of the San Timoteo Badlands extend from p.m. 21.4, just west of the highway overpass at Gilman Springs Road to p.m. 28, at Jack Rabbit Trail on the east. The badlands rise from an elevation of about 1720 feet in the Moreno Valley to over 2625 feet. Hill slopes are typically about 200 feet high and steeper than 1/1. Several cut slopes are 50 to 100 feet high above the highway and extensive fills have been built across canyons. The hills have a steep, short ridges separated by ephemeral streams, typical of badland topography. Vegetation consists of coastal sage scrub on north-facing slopes and sparse coastal sage scrub and grasses on south-facing slopes. North of the highway, much of the study area is located within the Norton Younglove Reserve, a county park.

GEOLOGIC MAPPING

The geologic map (Plate 1) was prepared by compiling published and unpublished geologic maps and performing additional interpretation of aerial photographs and field mapping. We obtained digital versions of the geologic maps of the Sunnymead and El Casco Quadrangles from Douglas Morton of the USGS. We digitally clipped and copied those portions of the maps that covered the field area, spliced the digital files together to create the geologic map of the corridor, then added our additional interpretation of landslide deposits.

Geologic units

This highway corridor contains only one type of bedrock, a sequence of sandstone, siltstone and conglomerate originally deposited in alluvial fan and floodplain environments and now uplifted and warped due to deformation along the San Jacinto fault. This unit is referred to as the San Timoteo formation. These sedimentary rocks were originally described by Frick (1921) and mapped in more detail by English (1953), Shuler (1953), Morton (1999) and Morton and Matti (2001).

The San Timoteo Formation

The San Timoteo formation (Tstm, Tstd, QTstu) is a widespread deposit of sands, gravels, and clays that extends northward from the foothills of the San Jacinto Mountains for a distance of nearly 20 miles. It has been divided by Morton (2001) into five sub-units, three of which crop out along this highway corridor. The majority of the badlands area is developed in the middle member of the San Timoteo Formation (Tstm and Tstd). Most of the middle member is a light-gray pebbly to cobbly medium- to coarse-grained sandstone with conglomerate beds. Shuler (1953) notes that the middle member contains more clay and silt that other members, but does not give percentage values. Sandstone of the middle member of the San Timoteo formation is described as varying from well-cemented to friable (can be crumbled by hand pressure), and siltstone interbeds are noted as being locally fragmented material that is prone to slumping and raveling (Gamble, 1974). Within the middle member, Morton (1999) mapped a distinctive unit composed of highly deformed, sandstone, pebbly sandstone and conglomerate (Tstd). This units crops out in the western part of the corridor, adjacent to the Claremont fault (a strand of the San Jacinto fault zone). Morton (1999) mapped outcrops of the upper member of the San Timoteo formation (QTstu) on the north side of San Timoteo Creek and its southeastern tributary. This unit is described by Morton (1999) as interbedded sandstone and conglomerate. The upper member of the San Timoteo formation underlies the roadway only at the extreme eastern limit of the study area, in low, gently sloping terrain and therefore is unlikely to contribute to landslide hazards in the area. The upper member of the San Timoteo formation, therefore was not mapped or described in the field for this project.

The San Timoteo formation contains fossils of land animals and represents sediments deposited from about 3.5 to 0.7 million years ago, during Late Pliocene to middle Pleistocene time (Albright, 1999). The presence of non-marine fossils within a sequence of rocks spanning such a long time has lead to several studies of the depositional environments and paleontology of the formation.

The San Jacinto fault crosses Highway 60 at the west end of the San Timoteo badlands. Compressional tectonics related to movement on the San Jacinto and associated faults has uplifted the badlands and created a broad anticline (known as the San Timoteo Anticline) within the study area. Uplift of the weak San Timoteo Formation has lead to high rates of erosion, oversteepened slopes and a complex drainage network, which are all characteristic of badlands topography.

Quaternary very old alluvium

Very old alluvial fan deposits (Qvof1, Qvof) overlie the upper member of the San Timoteo formation on the north side of San Timoteo Creek. These deposits are of early Pleistocene age (Morton, 1999). Alluvial fan remnants that may be correlative are found on two ridgetops on the south side of the creek, above the highway (Qvof1). This material is described as reddish-brown gravel, sand, and silt. Only the two small ridgetop exposures are near the highway, and these are too small to affect the slope stability along the highway, so this unit was not examined in the field.

Quaternary older alluvium

Older alluvium (Qof) is described by Morton (2001) as indurated, sandy and gravelly alluvial fan deposits. These deposits underlie an extensive area on the north side of San Timoteo Creek and isolated small areas on the west edge of the Badlands. None of these the outcrops of older alluvium are located in areas or on slopes where they would affect the slope stability along the highway, so this unit also was not examined in the field.

Quaternary Alluvium

Alluvial deposits are found in the channels of numerous ephemeral drainages that occur in the study area and on the alluvial fans on both sides of the badlands. These deposits are divided by Morton (2001) into axial channel deposits (Qyw and Qw) and alluvial fan deposits (Qyf and Qf). These young deposits are subdivided into deposits in the active channels and fans (Qw and Qf) and young, but not currently active deposits (Qyw and Qyf). The alluvial deposits consist of unconsolidated sand and sandy gravel with some layers of finer-grained materials.

Landslide deposits

The landslide deposits shown on the geologic map are the larger and deeper slides from the landslide map. Landslide areas are divided into landslides (Qls) and questionable landslides (Qls?) reflecting the designation from the landslide map described below. Definite and probable landslides are designated Qls, while questionable landslides are designated Qls?. The materials in the landslide deposit are highly variable, depending on the source material and range from nearly intact sandstone to completely disrupted clay soils.

LANDSLIDES

More than 8500 landslides were mapped in the Highway 60 corridor area between Gilman Springs Road and Jack Rabbit Trail (Plate 2). Although we have attempted to show all landslides, there may be some small shallow slides that occurred within the past four years (the most recent aerial photographs used in this study were taken in 1997). This area is notable for the abundance of debris flows, which have occurred during extreme rainfall in three major storms, in 1938, 1969, and 1998. We have no records of the 1938 storms, but Morton (unpublished) mapped debris flows following the 1969 and 1998 storms. Within the area shown on Plate 2, Morton mapped 1870 individual debris flow tracks from the 1969 storms and 947 from the 1998 storms. Morton did not map all the debris flows from 1969, however, because he did not have aerial photos for a central part of the area. In mapping just those debris flows on the slopes adjacent to the highway, we have mapped 493 debris flows that occurred in the 1969 storms, many of which fall in the gap in Morton's aerial photo coverage.

The landslide map (Plate 2) was prepared primarily by interpretation of aerial photographs, with review of previous reports and field checking. Landslides shown on previous maps (Morton, 1999, and unpublished) and in reports prepared for Caltrans were checked on aerial photos and in the field, if possible. The boundaries of landslides from previous work were revised and additional landslides were added based on geomorphic interpretation for this investigation.

In this study we have recognized, classified and mapped landslides based on their geomorphology. Landslides displace parts of the earth's surface in distinctive ways, and the resulting landforms can show the extent and characteristics of the landslide. Recognition of these landforms (scarps, troughs, benches and other subtle topographic features) allows the geologist to recognize, map and classify most landslides. For this study, landslides were recognized by their topographic expression, as interpreted from topographic maps and aerial photographs, and seen in the field. For each landslide we have attempted to record the characteristics of the slide, generally following the recommendations of Wieczorek (1984). Portrayal of landslides on the map includes a pattern, which designates the type of slide (materials and type of movement). The color of the slide area signifies its level of activity, and the thickness of the outline signifies the confidence of our interpretation as described below.

Types of landslides

Each landslide is classified according to the materials involved and the movement type, as deduced from the associated landforms. A two-part designation is given to each slide, based on the system of Cruden and Varnes (1996). Materials are called either rock or soil, and soil is subdivided into fine-grained (earth) and coarse-grained (debris). This system was designed to allow a series of names that completely describes the materials and processes involved in a landslide. We have simplified the system slightly to use it in preparing an inventory map of an area. We use the terms and definitions of Cruden and Varnes, but have attempted to simplify the designations by listing only the primary classification of a given landslide. For example, our example diagram of a rock slide, (see below), is a rotational rock slide-flow in which the upper part of the slide has moved by sliding, but the lower part has disaggregated and is flowing. On this map this type of slide is shown simply as a rock slide. Using the Cruden and Varnes system to classify rock versus soil is also complicated by the various vague and overlapping meanings of those terms in common usage. In California, many geologic formations are not hard or indurated rock and it is possible to find all gradations between weak, soil-like, and hard rocks. Our general system is to call material “rock” if it has a geologic formation name and the original geologic structure can be discerned. By these criteria, a weak, poorly consolidated formation such as the San Timoteo formation is classified as “rock” although parts of the formation could be classified as soil in engineering terms.

Applying the system of Cruden and Varnes (1996), with the criteria described above, there are four predominant types of landslides in this study area.

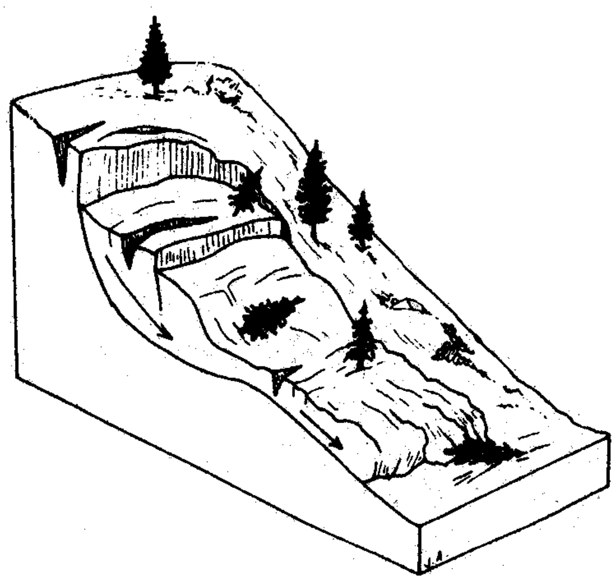


diagram by J. Appleby, R. Kilbourne, and T. Spittler after Varnes, 1978

ROCK SLIDE: A slide involving bedrock in which much of the original structure is preserved. Strength of the rock is usually controlled by zones of weakness such as bedding planes or joints. Movement occurs primarily by sliding on a narrow zone of weakness as an intact block. Typically these landslides move downslope on one or several shear surfaces, called slide planes. The failure surface(s) may be curved or planar. In some older classification systems, slides with curved failure surfaces are commonly referred to as slumps, while those with planar failure surfaces are called block glides.

Rock slides commonly occur on relatively steep slopes in competent rocks. Slopes are commonly from 35 % to as steep as 70%. Movement of an intact rock mass along a curved slide plane leads to a steep headscarp at the upper boundary of the slide.

Immediately below the headscarp is a block that is commonly rotated so that it is less steep than the surrounding hill slopes. Below the bench, the slide mass may be intact and similar gradient to the surrounding slopes or may have additional scarps and benches. The lower parts of the slopes may bulge outward and be steeper that the surrounding slopes.

The rotation of the block that typically occurs in the upper part of a “slump” rock slide leads to a less steep area or in some cases a closed depression. These areas drain more slowly and may accumulate and hold water more than the surrounding slopes. Recognition of landslides is aided if the accumulated water leads to significantly different vegetation, especially phreatophytic (water loving) vegetation common in such areas. The improved water-retention capacity of these areas also decreases the overall stability of the slide mass by allowing water more time to infiltrate the slide.

The larger and deeper rock slides are sensitive to conditions that affect the entire slope. A rise in the water table that may occur in high rainfall years may decrease the overall stability. Undercutting of the base of slope by streams or waves or by road construction, or addition of fill to the upper slope all tend to destabilize an existing slide. Conversely, adding fill at the base of a slope may increase stability. Movement is usually slow, on the order of millimeters per year, and incremental, sometimes only occurring in response to triggering events such as higher-than-normal rainfall. Movement can accelerate in some cases to the point that the mass fails more rapidly, moving several meters in the course of a few days, or by breaking up into smaller rock falls and debris slides, which can move several meters in a few moments.

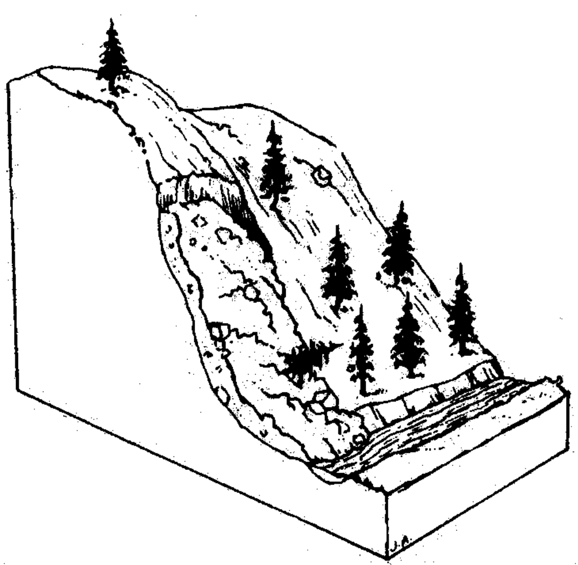


diagram by J. Appleby, and R. Kilbourne, after Varnes, 1978

DEBRIS SLIDE: A slide of coarse grained soil, commonly consisting of a loose combination of surficial deposits, rock fragments, and vegetation. Strength of the material is low, but there may be a very low strength zone at the base of the soil or within the weathered bedrock. Debris slides typically move initially as shallow intact slabs of soil and vegetation, but break up after a short distance into rock and soil falls and flows.

Debris slides commonly occur on very steep slopes, usually greater than 60% in an area where the base of a slope is undercut by erosion. They are most common in unconsolidated sandy or gravelly units, but also are common in residual soils that form from the in-place weathering of relatively hard rock. Movement of the slide mass as a shallow slab leads to a smooth, steep, commonly curved scar. The debris is deposited at the base, as a hummocky mass, although the deposit may be rapidly removed by erosion. Debris slides form steep, unvegetated scars. Debris slide scars are likely to remain unvegetated for years. Revegetated scars can be recognized by the even steep slopes, and the shallow amphitheater shape of many scars.

Because debris slides are relatively shallow they are sensitive to changes that are smaller and may occur over shorter times than those that affect deeper slides. A single heavy rainstorm or series of storms may deliver enough rain to trigger debris slides. Individual debris slides may move at rates ranging from meters per day to meters per minute. Debris slide scars are extremely steep and therefore are very sensitive to renewed disturbance. Natural erosion at the base of debris slide scars may trigger additional slides. Cutting into the base of a debris slide scar during road construction may also trigger renewed slides. Even without additional disturbance, debris slide scars tend to ravel and erode, leading to small rock falls and debris slides from the same slope.

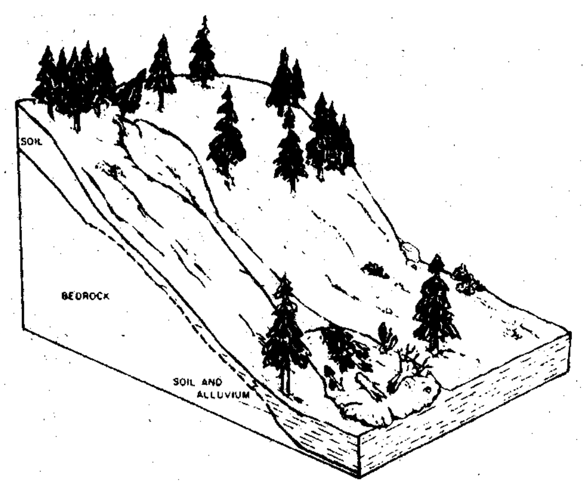


diagram by J. Appleby, and R. Kilbourne, CDMG

DEBRIS FLOW: A landslide in which a mass of coarse-grained soil flows downslope as a slurry. Material involved is commonly a loose combination of surficial deposits, rock fragments, and vegetation. High pore water pressures, typically following intense rain, cause the soil and weathered rock to rapidly lose strength and flow downslope.

Debris flows commonly begin as a slide of a shallow mass of soil and weathered rock. Their most distinctive landform is the scar left by the original shallow slide. The path of the debris flow may be marked by a small drainage that has been stripped of vegetation. The debris flow may not leave any deposit if it flows directly into a larger creek and is immediately eroded away. Many debris flow deposits are ephemeral, but in some cases successive debris flows may deposit material in the same area thereby forming a debris fan, which resembles a small, steep alluvial fan.

Because debris flows are relatively shallow they are sensitive to changes that are smaller and may occur over shorter times than those that affect deeper slides. Debris flows are especially sensitive to changes in water conditions in slopes. They are triggered in natural conditions by factors that increase the pore pressures in the shallow subsurface, commonly at the base of the soil. A single heavy rainstorm or series of storms may deliver enough rain to trigger debris flows, especially after a hot fire has burned over the hill slope. Individual debris flows may move at rates ranging from meters per hour to meters per second. Works of man that tend to concentrate water on steep slopes have to be carefully designed to avoid increasing the potential for debris flows.

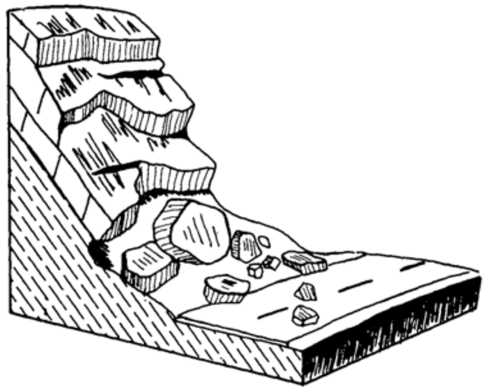


diagram after Colorado Geological Survey, 1989

ROCK FALL: A landslide in which a fragment or fragments breaks off of an outcrop of rock and falls, tumbles or rolls downslope. Rock falls typically begin on steep slopes composed of hard rocks and result in piles of loose rubble at the base of slope.

Rock falls occur on steep slopes of hard, fractured rock. The scar left by a rock fall on the slope may be no more apparent than an area of rock that is less weathered than the surrounding rocks. Rock fall deposits are loose piles of rubble that may be easily removed by erosion. Because neither the scar nor the deposit are distinctive, and because rock falls are typically small, individual rock falls are usually not shown on regional-scale (1:24,000 and smaller) landslide maps. Rock falls in this corridor appear to be very small and primarily related to cut slopes. Because of their small size they are not shown on the accompanying maps.

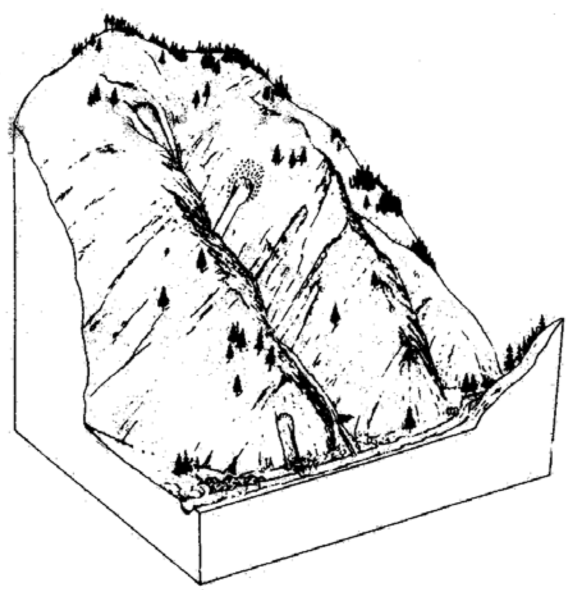


diagram by J. Appleby, and R. Kilbourne CDMG

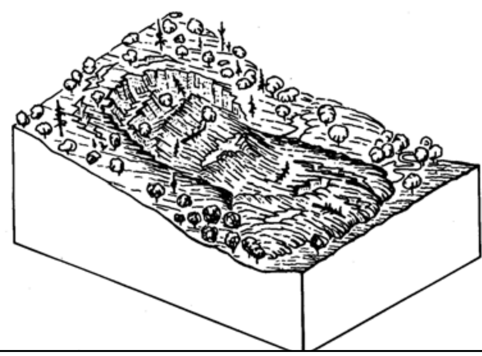
DEBRIS SLIDES and DEBRIS FLOWS are commonly found on a landform called a DEBRIS SLIDE SLOPE, which represents the coalesced scars of numerous landslides that are too small to depict on a map of this scale. These landforms are generally very steep, and have developed in areas of weak bedrock mantled with loose, thin soils and covered with sparse vegetation.

Debris slide slopes are typically very steep; 60% and steeper is common. Areas in which the dominant form of erosion is by debris slides and debris flows are have very steep slopes, commonly with each small canyon having rounded amphitheater-shaped heads.

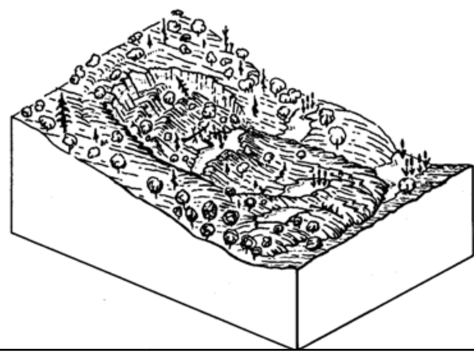
Because virtually all of the slopes within the San Timoteo badlands are primarily shaped by debris slides and debris flows, almost all are debris slide slopes. Debris slide slopes are not shown on the landslide maps in this report for clarity.

Activity of landslides

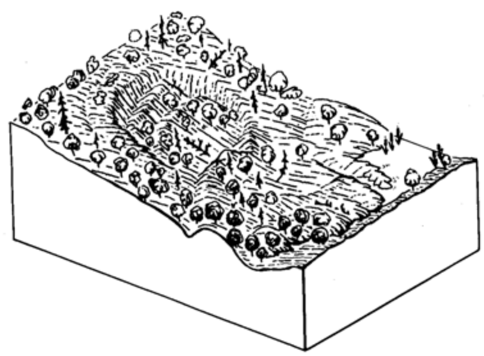
Each landslide is classified based on the recency of activity into one of four categories based on the system of Keaton and DeGraff, (1996). The diagrams below illustrate levels of activity (diagrams from Wieczorek, 1984).



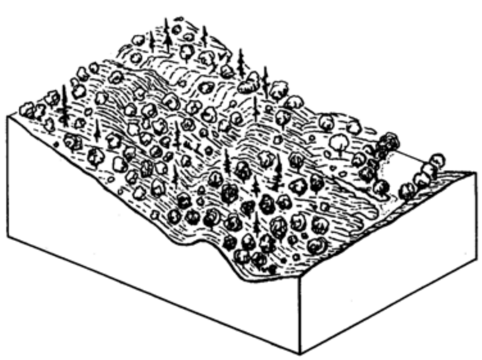
active or historic: The landslide appears to be currently moving or movements have been recorded in the past. Fresh cracks, disrupted vegetation or displaced or damaged man-made features indicate recent activity. Water may be ponded in depressions created by rotation of the slide mass or blockage of stream drainage.



dormant-young: The landforms related to the landslide are relatively fresh, but there is no record of historic movement. Cracks in the slide mass are generally absent or greatly eroded; scarps may be prominent but are slightly rounded. Depressions or ponds may be partly filled in with sediment, but still show phreatophytic vegetation.



dormant-mature: The landforms related to the landslide have been smoothed by erosion and re-vegetated. The main scarp is rounded, the toe area has been eroded and some new drainages established within the slide area. Benches and hummocky topography on the slopes are subdued and commonly obscured by dense, relatively uniform vegetation.



dormant-old: The landforms related to the landslide have been greatly eroded, including significant gullies or canyons cut into the landslide mass by small streams. Original headscarp, benches and hummocky topography are now mostly rounded and subtle. Closed depressions or ponds now filled in. Vegetation has recovered and mostly matches the vegetation outside the slide boundaries.

Confidence of Interpretation

Each area is classified as a definite, probable or questionable landslide. Because landslides are mapped based on their landforms, the confidence of identification is dependent on the distinctness of those landforms as visible from available aerial photos and in the field. Confidence of interpretation is classified according to the following criteria:

DEFINITE LANDSLIDE. Nearly all of the diagnostic landslide features are present, including but not limited to headwall scarps, cracks, rounded toes, well-defined benches, closed depressions, springs, and irregular or hummocky topography. These features are common to landslides and are indicative of mass movement of slope materials. The clarity of the landforms and their relative positions clearly indicate downslope movement.

PROBABLE LANDSLIDE. Several of the diagnostic landslide features are observable, including but not limited to headwall scarps, rounded toes, well-defined benches, closed depressions, springs, and irregular or hummocky topography. These features are common to landslides and are indicative of mass movement of slope materials. The shapes of the landforms and their relative positions strongly suggest downslope movement, but other explanations are possible.

QUESTIONABLE LANDSLIDE. One or a few, generally very subdued, features commonly associated with landslides can be discerned. The area typically lacks distinct landslide morphology but may exhibit disrupted terrain or other abnormal features that strongly to vaguely imply the occurrence of mass movement.

Each landslide is also classified by a number of other factors not portrayed on the map, but listed in the accompanying database table. The records in the database table include a unique number for each landslide in each quadrangle and a listing of the quadrangle. Other factors recorded for each landslide are listed in Table 1 below.:

Table 1, Additonal attributes recorded for landslides in the Highway 60 corridor

FIELD	VALUES	NOTES
Depth	s,m,d	As interpreted from the geomorphology and classified into one of the following three categories: shallow <3 m, medium 3-15 m, deep >15 m.
Direction of movement	azimuth	North is zero degrees, rotation clockwise.
Primary geologic unit	Tstm	The geologic unit from the geologic map. In this area most landslides involve either Tstm, San Timoteo formation, middle member, or Tstd, Sam Timoteo formation, deformed sediments.
Primary lithology	ss, sh, ss-sh	Corresponding to the unit on the geologic map. In this area the lithologies are ss, sandstone, sh, shale and ss-sh, sandstone with lesser shale.
Secondary geologic unit	Tstd	If a landslide involves two bedrock geologic units
Secondary lithology	ss, sh, ss-sh	If a landslide involves two bedrock geologic units
Source of geologic data	Morton, 1999	Reference of previous geologic map containing strike and dip information or field locality number where strike and dip measured
Photo year	1953	Date of aerial photographs

FACTORS INFLUENCING SLOPE STABILITY IN THIS HIGHWAY CORRIDOR

The inclination of slopes, their underlying rock types and geologic structures, landforms, and rainfall all influence the slope stability along the Highway 60 corridor between Gilman Springs Road and Jack Rabbit Trail.

Slopes along the Highway 60 corridor range from gentle to extremely steep (in particular very high roadcuts). Most landslides on these very steep slopes involve shallow soil and loose rocks, moving as debris slides and rock falls.

Bedrock geology also has a very strong influence on the types and activity of landslides. In this region, loose erodible soils and bedrock lead to development of badlands topography and debris flows. Deeper landslides are more abundant in the western part of the corridor and appear to be concentrated in the area mapped as the "deformed beds" within the middle member of the San Timoteo formation (Tstd) by Morton (1999). More extensive deformation or fracturing of this part of the San Timoteo formation may result in weaker rocks and therefore more abundant landslides.

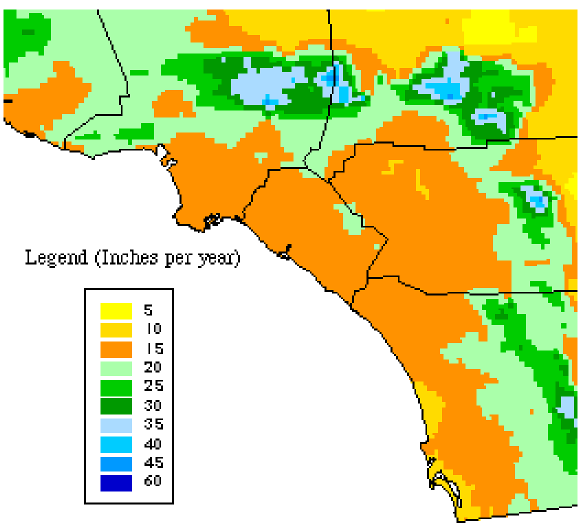


Figure 3. Average annual rainfall in coastal Southern California for the period 1961-1990. Map by Oregon climate Service.

Precipitation is a major factor influencing landslides. According to the Oregon Climate Center, the Highway 60 corridor averaged less than 15 inches of rainfall per year between 1961 and 1990 (Figure 3). The rainfall in this area, however comes as very intense storms of short duration. Although the average rainfall for any day of the year is less than 0.4 inches, extreme events may result in up to 4 inches of rainfall in 24 hours (Figure 4). These shorter term, but very intense rain storms tend to de-stabilize the shallower types of landslides, such as debris slides and debris flows.

The occurrence of wildfires appears to have a significant effect on the number of debris flows in this corridor, as it does in other parts of southern California. The effect is opposite of what is commonly seen, however. In areas covered by dense chaparral, a hydrophobic soil layer may form after a wildfire, causing more rapid runoff and a greater potential for mobilization of debris from lower slopes and small channels. Morton (1989) found that a hydrophobic soil layer formed in areas or the San Timoteo badlands burned by a wildfire in 1968, but that far *fewer* debris flow scars were found on burned than unburned slopes after the major storms of 1969. In this area of short, very steep slopes with relatively little debris stored in the channels, the faster runoff due to lack of

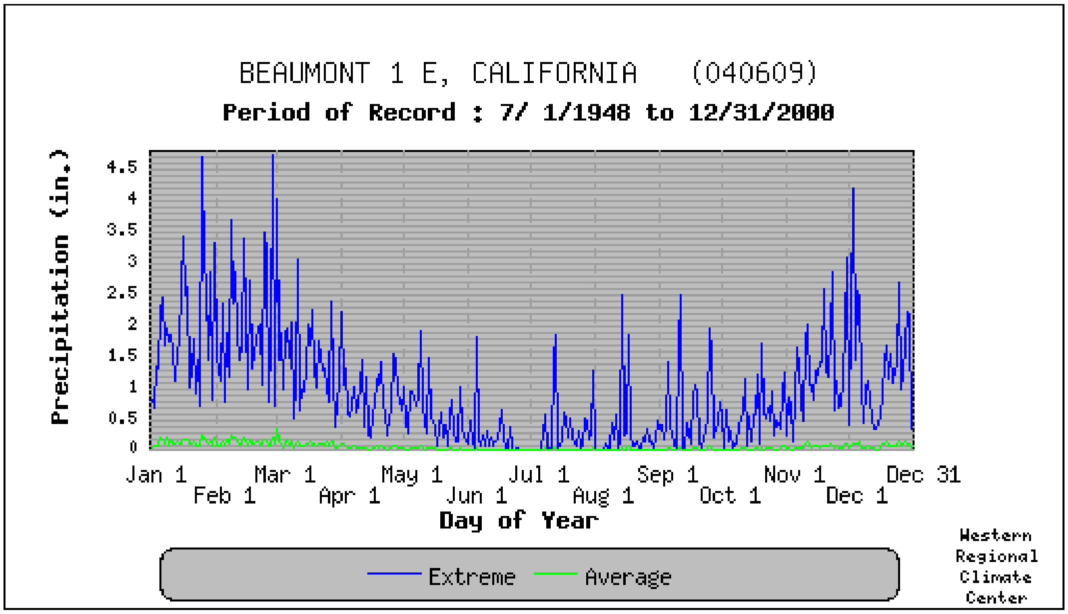


Figure 4, Average and extreme daily rainfall for Beaumont, California, east of the Highway 60 corridor. Note that average daily rainfall is rarely over 0.2 inch, but extremes reach nearly 5 inches. From USDA western region climate center.

vegetation and presence of the hydrophobic layer may decrease the potential for debris flows.

The geologic structure of the San Timoteo Badlands does not appear to have a significant influence on the distribution of landslides. There does appear to be a slightly greater abundance of slides in the western part of the area (west of p.m. 23). This corresponds to the deformed beds within the middle member of the San Timoteo Formation mapped by Morton (1999), and Morton and Matti (2001). The slightly greater density of landslides may be related to the weaker, sheared or deformed rock, or to the presence of shear zones related to faulting. In the majority of the badlands, similar orientation of bedding, shear zones and faults locally controls the trend of ridges and stream valleys. Bedding and shear zones dip to both northeast and southwest, leading to planes of weakness that favor landslides that move in those directions. The overall structural grain and orientation of common planes of weakness may lead to relatively common landslides on slopes that face northeast and southwest.

POTENTIAL FOR LANDSLIDES ALONG HIGHWAY 60

Landslides can and do damage and close roads, resulting in significant repair and maintenance costs. Economic losses can be significant to an entire region of the state if a major route is closed for a significant period. Besides the costs associated with landslide damage, some types of landslides pose a risk to the safety of the traveling public. None of these risks can be eliminated. If roads are to pass through regions like the San Timoteo Badlands, where landslides are common, they will be exposed to some risk.

An evaluation of the potential consequences of landslides along Highway 60 between Gilman Springs Road and Jack Rabbit Trail can help Caltrans plan for future landslide mitigation projects and prioritize more detailed studies of individual landslides. A thorough evaluation of the probabilities of landslide movement, or of the economic consequences of that movement is beyond the scope of this study. We do not have the detailed geotechnical data to evaluate the probability of movement of landslides, nor the economic data to measure their consequences. We can, however, assess the types of landslides and the general consequences of movement of those types of landslides. In the table below are the size, movement type, materials and activity level of a landslide, the velocity of movement that is typical of a type of landslide, and the proximity to the highway. One can assume that those landslides that have moved most recently are the most likely to move in the future, and that the types of movement that have occurred in the past will continue.

The consequences of landslide movement are related to the size of a landslide, and the amount and velocity of movement. Larger slides may displace more of a roadway, resulting in greater repair costs. Larger displacements also translate to greater repair costs. If large movements accumulate slowly, over years or decades, they may be a continuing maintenance problem where cracks are filled and pavement re-leveled frequently. Large, rapid, displacements of even small volumes of material may undermine the road or deposit material on the road sufficient to close or partially close the roadway. These smaller volume but rapidly moving slides are the most likely to pose a safety risk to the travelling public. Movement of large, deep landslides is less likely to occur rapidly, but could have particularly severe consequences. Large displacements of large, deep landslides may result in the roadway being closed for repair, or in the worst case closed for long periods for reconstruction or rerouting.

There are only a few large or deep landslides in the Highway 60 corridor through the San Timoteo Badlands. Of those listed below and in Table 2, only the moderately sized rock slide at p.m. 24.7 appears to be both historically active and adjacent to the roadway. Even there, however, it appears that the historically active part of the landslide is just beyond the base of the highway fill, and older parts of the slide may by buried and in part buttressed by the fill. The larger landslides that are in a position to damage the roadway are listed below from west to east, with a discussion of their extent and evidence for their recency of movement.

P.M. 21.8

A large area mapped as a questionable, dormant-old rock slide underlies the highway and interchange at p.m. 21.8 (Figure 5). If this area of irregular topography is related to landsliding, it appears that there has not been significant movement in the recent past hundreds to thousands of years. The rocks of the area may be weaker than the surrounding rocks, as suggested by the relative abundance of smaller, more recent landslides in the older, questionable landslide area.

P.M. 22.5
A small probable, dormant mature, rock slide is adjacent to the highway at p.m. 22.5 (Figure 5). this slide may include part of the cut slope above the highway and the slope below the highway. Movement of the slide is due west, parallel to the road, so renewed movement is unlikely to extend beneath the roadway.

P.M. 22.8
A large probable dormant-mature rock slide is adjacent to the south side of the highway at p.m. 22.8 (Figure 5). This slide has moved parallel to the highway in its upper part and into a small canyon between the highway and the slide over most of the slide mass. There is some potential for the upper part of the highway expanding laterally to affect the roadway, but the majority of the slide movement will be in the lower part which is unlikely to affect the highway.

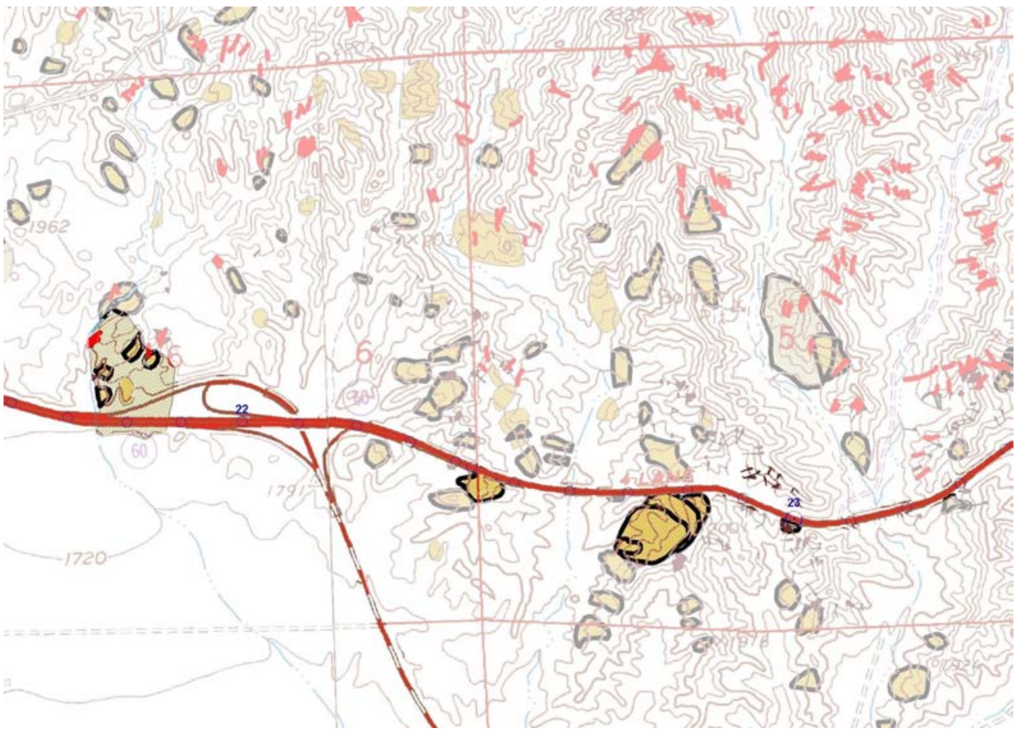


Figure 5. Landslides under or adjacent to Highway 60 include the questionable old slide area at p.m. 21.8 and probable dormant-mature slides at p.m. 22.5 and 22.8

P.M. 24.7
A definite, historic rock slide has formed since 1969 just south of the highway at p.m. 24.7. The historic slide has re-activated a part of a larger, dormant mature rock slide that is larger and extends closer to the roadway. The larger, dormant slide appears to extend beneath the fill that extends across a canyon. It may be that this fill has effectively buttressed this part of the slide, making reactivation less likely.

P.M. 25.2

Landslides flank both sides of a drainage north of the highway at p.m. 25.2. On the west side of the canyon a probable, dormant-mature, rock slide has moved parallel to the highway, extending eastward into the canyon. On the opposite side of the canyon a larger and deeper probable, dormant-mature, rock slide has moved westward. The toes of both of these slides appear to be partly buried in the large area of fill north of the highway across this canyon. Neither slide appears to have had recent movement, placement of fill may have made movement less likely in the future.

Debris flow areas

The most common landslide related hazards in this highway corridor are due to small, fast-moving debris flows which will be mobilized during exceptionally heavy rainfall. Virtually all of the slopes in the San Timoteo Badlands have been shaped by debris flows (the only exceptions being the canyon bottoms and the roadway surface, cuts and fills). There do appear, however, to be several areas where debris flows have been more abundant in the 1969 and 1998 storms. Because of the steepness of slopes near the road and past abundance of debris flows, these areas may be the most likely sources of debris flows that impact the highway.

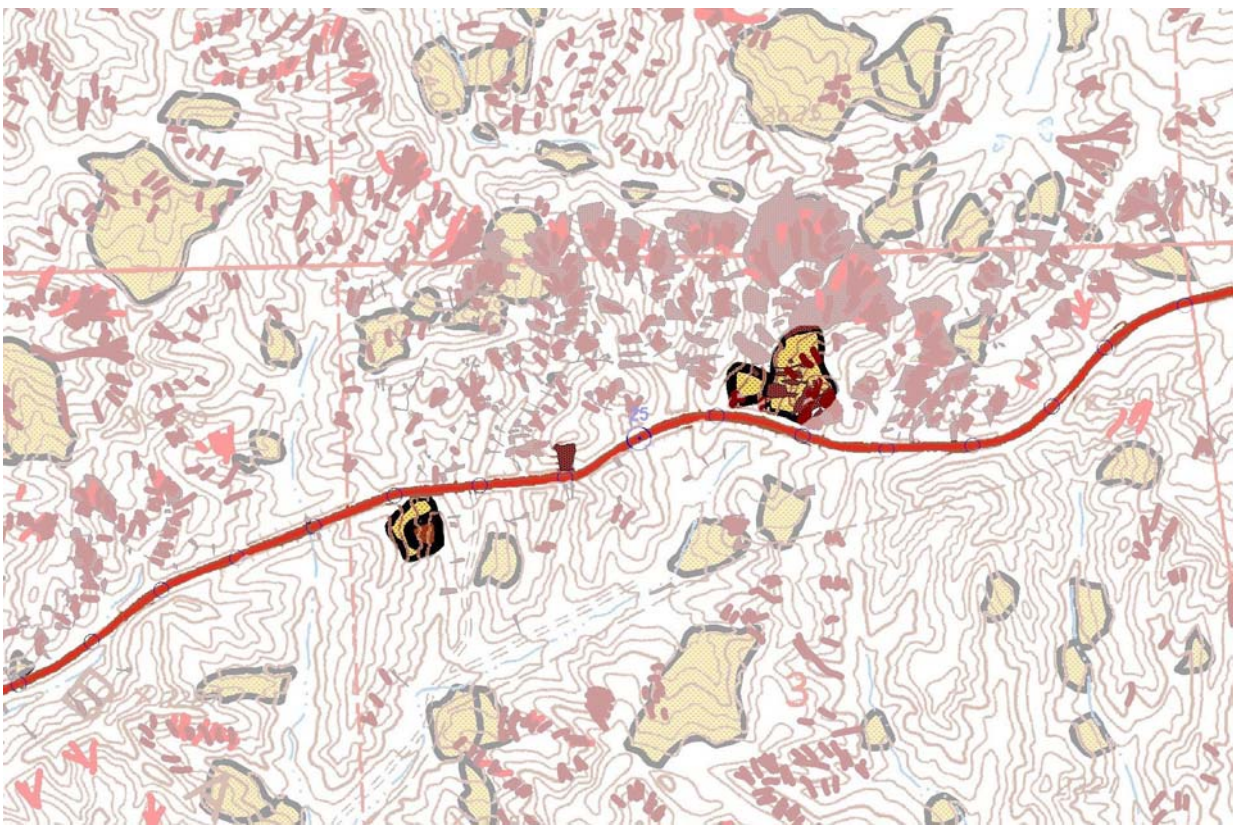


Figure 6. Landslides under or adjacent to Highway 60 include the definite historic slide at p.m. 24.7 and a probable dormant-mature slides at p.m. 25.2. The most intense area of debris flows in 1969 was north of the highway between p.m. 24.8 and 25.5.

The greatest concentration of debris flows near the highway in 1969 was between p.m. 24.8 and p.m. 25.5 in the steep canyons extending about 1200 feet north of the highway. In this area, debris flows removed nearly 30% of the surface soil layer. Other areas did not have comparable density of debris flows, but debris flows were also common between p.m. 23.8 and p.m. 24.4 and there was a smaller concentration of debris flows on the slopes above the road at p.m. 22.8 to p.m. 23.0.

Table 2: significant landslides along the Highway 60 alignment.

	NAME	TYPE	RECENCY OF MOVEMENT	SIZE	DEPTH	PROBABLE RATE OF MOVEMENT	POSSIBLE CONSEQUEN-CES	COMMENTS
1	p.m. 21.8	RS	o	13 ac	d	none	Road damage - cracks and grade offsets.	Questionable old slide area; no evidence of current movement.
2	p.m. 22.5	RS	m	1.8 ac	m	slow	Damage to fill up to edge of pavement.	No evidence of current movement.
3	p.m. 22.8-23.0	DF	h	>0.2 ac	s	rapid	Sediment filling basins, possibly clogging culverts.	
4	p.m. 22.8	RS	m	8 ac	d	slow	Damage to fill up to edge of pavement, Lane closure.	No evidence of current movement.
5	p.m. 23.8-24.4	DF	h	>0.2 ac	s	rapid	Sediment filling basins, possibly clogging culverts. Debris flow may impact roadway surface.	
6	p.m. 24.7	RS	m, h	2.5 ac	m	Slow-moderate	Damage to fill up to edge of pavement, Lane closure.	Historic movement of slide south of highway fill; older part of slide partially buried in highway fill.
7	p.m. 24.8-25.5	DF	h	>0.2 ac	s	rapid	Sediment filling basins, possibly clogging culverts. Debris flow most likely to impact roadway surface between p.m. 25.4 and 25.5.	
8	p.m. 25.2	RS	m	3.5 ac	m	slow	Damage to fill up to edge of pavement.	No evidence of current movement.

SUMMARY

Highway 60 is a main transportation corridor in southern California that traverses a landslide-prone area called the San Timoteo Badlands in Riverside County. Within this corridor, landslides have been an ongoing problem for decades. In order to evaluate the relative hazards of the landslides within the Highway 60 corridor through the San Timoteo Badlands, Caltrans contracted with the California Geological Survey to map the geology and landslides of the corridor. This mapping will help Caltrans plan landslide mitigation along the existing roadway and evaluate potential means of avoiding the most severe hazards.

Over 8500 landslides have been mapped within the corridor area between Gilman Springs Road and Jack Rabbit Trail. The type and activity of the slides, the level of confidence of our interpretation and several other factors are recorded for each slide. Of this large number of slides, only 281 are the relatively deep, slower-moving types of landslides that typically cause damage to roadways. In addition, the majority of the larger and deeper landslides that we mapped are dormant-mature based on the landslide features and level of erosion. A badlands topography is a very rapidly eroding landscape, so dormant-mature in this area may only mean a low level of activity over several decades. The small number of historic rock-slides that we were able to map does suggest, however, that the deeper and slower moving slides are not a very frequent occurrence in this highway corridor.

In contrast, small, shallow, rapidly-moving debris flows are very abundant in the San Timoteo Badlands. Thousands of individual flows were triggered by the storms of 1969, and hundreds of additional slides were triggered by the storms of 1998. Overall the debris flow process is probably the main erosional force on the slopes of the badlands. Hazards related to debris flows tend to be localized in the areas where a debris flow deposits its load. Plugging of culverts is a common consequence of debris flows, along with related flooding and erosion if a basin overflows. Potential damage to the roadway from debris flows is typically not great. Debris flow deposits on the roadway surface can typically be cleaned up by maintenance personnel. There is a hazard to the travelling public if debris flows reach the roadway surface while still travelling at high speeds. Because of the density of the sediment-laden fluid, vehicles can be easily transported across or off of the roadway if struck by a debris flow. These hazards are concentrated in the few areas where debris flows may impact the roadway surface, rather than flowing into a basin adjacent to the roadway, as listed above.

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