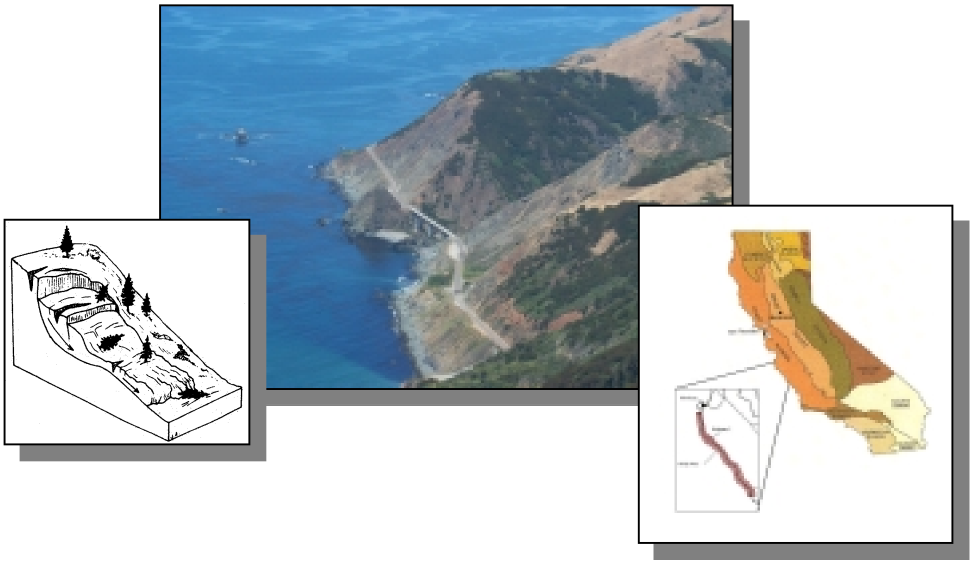
BIG SUR
Coast Highway Management Plan

LANDSLIDES IN THE HIGHWAY 1 CORRIDOR:

GEOLOGY AND SLOPE STABILITY ALONG THE BIG SUR COAST



Highway 1 along the Big Sur Coast
Between Point Lobos in Monterey County
and San Carpoforo Creek in San Luis Obispo County
SLO-1-71.4/74.3
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Prepared for: Caltrans District 5

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Division of Mines & Geology

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LANDSLIDES IN THE HIGHWAY 1 CORRIDOR: GEOLOGY AND SLOPE STABILITY ALONG THE BIG SUR COAST BETWEEN POINT LOBOS AND SAN CARPOFORO CREEK, MONTEREY AND SAN LUIS OBISPO COUNTIES, CALIFORNIA

Prepared for the
COAST HIGHWAY MANAGEMENT PLAN
In cooperation with
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EXECUTIVE SUMMARY

The Big Sur coast along Highway 1 between San Carpoforo Creek and Point Lobos has a richly varied geologic composition, which has lead to an abundance of a wide variety of landslides. Uplift of the Santa Lucia Mountains and continuing wave erosion at their base has formed precipitous slopes in many types of bedrock and overlying surficial deposits.

To provide background information for the Coast Highway Management Plan, and to assist Caltrans in planning for landslides, geologists with the California Department of Conservation, Division of Mines and Geology, have prepared maps of the geology and landslides of the area adjacent to Highway 1 on the Big Sur coast. The geologic map was prepared by compilation of existing mapping, interpretation of aerial photographs, and field mapping. Much of the bedrock geology is shown on previous maps of the area. Existing maps were digitized, conflicts among them resolved, and additional detail added. Few previous maps showed details of the surficial (Quaternary) geology or adequately characterized the extent of landslides. These aspects of the geologic map are mainly original interpretations for this study.

The landslide maps presented here are based on original mapping in the majority of the study area, and revisions to existing maps. The landslide map depicts the classification of each landslide by type, recency of activity, and our confidence of interpretation. Additional data on the material involved in the landslide and direction of movement is recorded for each landslide in a GIS (Geographic Information System) database.

Within this long and geologically complex part of the California coast, the potential for landsliding depends on the steepness of slopes, wave erosion, bedrock types and weathering characteristics, rainfall, geologic structure and faulting, and modification of slopes for roadway or other construction. For this report, we have divided the Big Sur coast into 12 segments based on similarities in the size, type, and activity of landslides. The potential for landslide damage to the highway ranges from low in the Pacific Valley area to very high in the Lopez Point-Lucia area. Landslides types range from small debris flows, common in the northern part of the study area, to very large rock slides in the Lucia area.

No part of the Big Sur coast is without some landslide potential, but the potential for damage to the highway is concentrated in areas where several aspects of the geology and geography converge to make landslide movement more likely. South of Hurricane Point, wave erosion of weak rocks along the southwest side of Sierra Hill undermines harder but faulted and fractured rocks on a steep slope. In Big Sur, deeply weathered metamorphic rocks of the Sur complex are particularly susceptible to debris flows when heavy rains follow a wildfire. The bedrock at Julia Pfeiffer Burns State Park is probably the most landslide-resistant along the entire coast, but the steep slopes failed in response to the extraordinary rainfall of 1983. At Lucia, the rocks are so weak that the constant wave erosion at the base of the slopes and typical rainfall patterns are sufficient to cause sliding, but ground movement accelerates in response to heavy rainfall and has also been triggered by an historic earthquake. South of Pacific Valley, numerous shear zones containing serpentinite cut the weak Franciscan Complex bedrock. These exceptionally weak seams within an already weak rock lead to a concentration of large, active landslides second only to the Lucia area.

INTRODUCTION

This report describes the geologic conditions and landslides mapped in the Highway 1 corridor along the Big Sur coast of Monterey and San Luis Obispo Counties, California. This study is the result of a pilot study to examine the utility of landslide maps for planning within highway corridors, and the needs of the Coast Highway Management Plan for up-to-date, detailed information. For this project, geologists with the California Department of Conservation, Division of Mines and Geology have prepared new geologic and landslide maps of the Big Sur coast from San Carpoforo Creek on the south to Point Lobos on the north. The limits of this study were chosen by Caltrans engineers and geologists to encompass the significant landslide hazards on the Big Sur coast. The area of this study therefore does not exactly coincide with the limits of the Coast Highway Management Plan.

Figure 1. View of Highway 1 at the mouth of Big Creek, where the road crosses several extensive landslide areas south of the bridge and a large area of rock fall and debris slides north of the bridge. View looking Northwest. Photo by C.J. Wills.

The maps presented here were prepared at a scale of 1:24,000 (1 inch = 2000 feet) by compilation of previous mapping, interpretation of aerial photographs and original field mapping. These maps were prepared using a computer geographic information system (GIS) on scanned images of USGS 7.5-minute topographic quadrangles. Portions of the quadrangles form the base map of Plates 1 and 2. The geologic and landslide maps were drawn in the computer GIS using the program Arcview v. 3.2. The computer files include database tables describing each mapped feature.

REGIONAL OVERVIEW

The study area traverses a long and geologically complex part of the Coast Ranges geomorphic province, which extends for about seven hundred miles within California from Santa Barbara County to the Oregon border. South of Cape Mendocino, the province is characterized by northwest-trending mountain ranges and valleys bounded by right-lateral, strike-slip faults.

The Big Sur coast is noted for its dramatically high, steep slopes, which rise from sea level to over 3000 feet within less than three miles. For this study we have attempted to map the geologic units and landslides that may affect the stability or operation of the highway. Typically, our maps cover the area between the coastline and the first major ridgeline to the east, resulting in a mapped strip that varies from 1 to 3 miles wide, wider in the area of the Big Sur River where the road is a few miles inland.

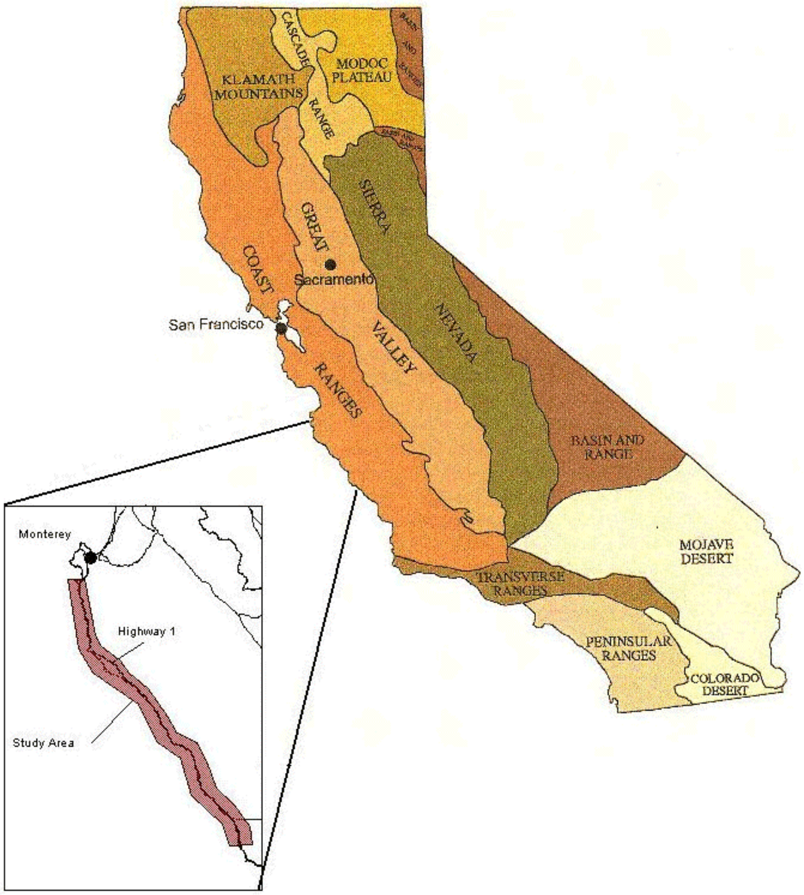


Figure 2 Geomorphic provinces of California showing the location of Highway 1 along the Big Sur coast and the study area.

Rocks of the Coast Ranges are highly varied and belong to all three major rock classes; igneous, metamorphic and sedimentary. Throughout much of the Coast Ranges, the most widespread unit is the Franciscan Complex, composed of variably metamorphosed fine to medium grained graywacke sandstone, and highly sheared shale. Several other rock types are minor components of the Franciscan Complex including serpentinite, greenstone (metamorphosed volcanic rocks), and chert.

Within the Coast Ranges extending southeast form Monterey and Salinas, a block of distinctive rocks is bounded by the San Andreas fault on the east and the Sur-Nacimiento faults on the west. This rock mass is known as the Salinian block. The geology of the Salinian block is quite different from the rest of the Coast Ranges. In contrast to the areas underlain by the Franciscan complex, where no crystalline basement rocks are exposed, large areas of the Salinian block are underlain by granitic and metamorphic rocks. One of the more extensive areas of granitic rocks is the northern Big Sur coast, from Rocky Creek north to Monterey. Metamorphic rocks of the Sur complex and overlying Cretaceous through Miocene sedimentary rocks underlie the remainder of the Salinian block from Rocky Creek south along the coast or just inland to south of Lopez Point.

In areas underlain by the Franciscan complex, all of the rock types tend to be weak, intensely sheared and slightly metamorphosed sedimentary rocks or overlying unconsolidated deposits. The tectonics of the region, driven by right-lateral motion on the San Andreas fault system, has lead to compression and uplift of these sedimentary rocks in recent geologic time. Uplift of such weak rocks has lead to high rates of erosion and abundant landslides.

The Salinian block bedrock is harder and in most places more resistant to landsliding than typical Franciscan bedrock, but the steep natural slopes lead to numerous landslides in most rock units. Deep weathering of many Salinian block rocks has broken down mineral grains within once-hard and landslide resistant rocks, leading to surficial layers in many areas of "decomposed" or weakened rocks that are relatively prone to landsliding. Landslides in Salinian block bedrock are both large intact blocks of bedrock that move as rock slides, and areas of deeply weathered coarse soils that mobilize as debris flows. Sedimentary rocks overlying the Salinian block basement are commonly weaker than the granitic and metamorphic rocks and more prone to sliding as intact masses on weak bedding planes.

Highway 1 was constructed through this geologically diverse landscape in the 1930's and opened in 1937. Parts of the Highway north of Big Sur follow the Old Coast Road, completed from Monterey to Big Sur by Monterey County in the 1880's. Construction of the highway involved extensive excavations that utilized steam shovels and blasting. Fill was placed in minor canyons and bridges constructed across major canyons. The highway has a long history of landslides which have both landed on the highway and undermined the road bed. Road closures have been common, with long term closure mainly due to large landslides in years of heavy rainfall.

GEOLOGIC MAPPING

The geologic map (Plate 1) was prepared from existing published geologic maps (Burch, 1971; Clark and others, 1997; Compton, 1960; Crippen, 1951; Dibblee, ;Hall, 1991; Norris, 1985; Oakeshott, 1951; Oshiro, 1981; Reiche, 1937; Ross, 1976; Seiders, 1989; Seiders and others, 1983; Talliaferro, 1957, Trask, 1926), with additional interpretation of aerial photographs and field mapping. Locations of faults on the geologic map are from the above geologic map sources with modifications based on the mapping of Manson (1985), Bryant (1985) and new observations for this study.

The available geologic maps had major differences in the identification and location of geologic units, and very few showed any detail in the Quaternary deposits or landslides, which are important for showing the materials on which the highway was constructed and its stability. To prepare a complete geologic map of the area, which includes both Quaternary and landslide deposits, we digitized many of the existing maps, spliced the digital files together, and added our own interpretations and observations to fill in those areas that lacked complete geologic maps or where existing maps differed. Differences in mapping and nomenclature were generally resolved by using the most detailed source of mapping. Field mapping was commonly needed to resolve the differences between the sources of mapping, add detail of Quaternary units, and improve the accuracy of the locations of contacts between rock units.

Geologic units

The geologic units mapped along Highway 1 are summarized below, and each unit is described in Table 1. The geology within this highway corridor is a complex cross section of the geology of the Coast Ranges of California. There are several major types of bedrock units, divided between two major structural blocks. The Salinian block, west of the San Andreas fault and east of the Sur-Nacimiento fault, is composed of granitic and metamorphic rocks and overlying Tertiary sedimentary rocks and Quaternary deposits. In the surrounding Coast Ranges, the main bedrock unit is the Franciscan Complex. The Franciscan rocks were intensively sheared and fractured, as the oceanic crust they were deposited on was subducted beneath the North American continental plate. The deformed sedimentary rocks, along with fragments of volcanic and metamorphic rocks from the crust and mantle of the oceanic plate, were attached to the North American Plate along a series of faults. The Sur thrust fault may represent one of these original boundary faults where the Franciscan Complex was attached to the North American Plate.

Sur complex metamorphic and igneous rocks

Bedrock within the Salinian block can be subdivided into three major types. The oldest of these is the Sur complex (Hall, 1991; originally the Sur Series of Trask, 1926) composed of metamorphic and igneous rocks. The Sur complex is distributed though the Santa Lucia Range east of the Sur-Nacimiento fault zone. Highway 1 crosses Sur complex rocks at Hurricane Point and from Castro Canyon (just north of Grimes Point) to McWay Canyon. Rocks of the Sur complex are reported to be dominantly gneiss, amphibolite and granofels, all metamorphic rock resulting from the recrystallization of original sedimentary and igneous rocks under very high temperature and pressure. A large mass of coarsely crystalline igneous rock and several smaller similar masses were intruded into the Sur complex at high temperatures and pressures and metamorphosed along with the surrounding rocks. These coarse grained igneous rocks of the Sur complex are mineralogically different from similar-appearing coarse-grained granitic rocks intruded into the Sur complex. They are called “Charnockitic tonalite” based on that mineralogy. As discussed below, details of that mineralogy appear to affect the size and distribution of landslides in those units. White, coarsely crystalline marble also is a very conspicuous component of the Sur complex. Most of the Sur complex rocks (except for the marble) tend to be very deeply weathered and prone to both large deep-seated rock slides and shallow debris flows and rock falls.

Cretaceous granitic rocks

The Sur complex metamorphic and igneous rocks are intruded by Cretaceous granitic rocks. These rocks are found along the northern Big Sur coast from Rocky Point to Monterey and inland through a large area of the northern Santa Lucia range. Ross (1976) divided the granitic rocks along the coast into three units based on their mineralogy. These are a quartz diorite in most of the area, a porphyritic granite at Point Lobos, and a transitional unit in between. Except for the prominent large pinkish crystals of feldspar in the porphyritic granite, these units are not easy to distinguish visually.

The quartz-diorite tends to be dark gray in color because it contains 20 to 25 percent mafic minerals (biotite and hornblende). Mafic minerals are distributed through the rock and concentrated along foliation planes. Because mafic minerals tend to break down (weather) to clay minerals rapidly (compared to quartz and feldspar), areas underlain by the granitic rocks tend to be deeply weathered on higher slopes and overlain by weak colluvium. Colluvium is typically formed of quartz and feldspar grains, and pieces of essentially unweathered quartz and aplite veins, in a weak matrix of red-brown silty clay formed from the weathering of the mafic minerals. The weak weathered rock and colluvium over much of the surface of the granitic rocks is prone to debris flows triggered by intense rainfall.

Franciscan Complex

West of the Sur-Nacimiento fault the sequence of rocks is completely different. The oldest rock in this area is the Franciscan Complex. The Franciscan is found in two areas, from north of the Little Sur River to Castro Canyon and south of McWay Canyon. The Franciscan is an extensive sequence of rocks, most of which began as sedimentary deposits in a deep ocean environment. The sedimentary rocks, along with fragments of volcanic and metamorphic rocks from the crust and mantle of the oceanic plate, are sheared and jumbled together into a unit referred to as melange. The Franciscan melange is the most widely distributed rock type along much of the Big Sur coast, and underlies much of Highway 1. Melange is composed of dark gray, highly sheared siltstone and shale, metamorphosed to argillite or phyllite. Outcrops commonly show highly contorted bedding or rock so sheared that bedding cannot be traced across the outcrop. Other areas may show consistent, parallel beds that extend for hundreds of feet across a sea cliff or cut slope, such as near Alder Creek at Post Mile (P.M.) 8.0. Gilbert (1973) describes the Franciscan Complex of the Big Sur coast as being composed of intersheared, well bedded units, such as those at Alder Creek, and pervasively sheared units. Our observations along the highway suggest that the pervasively sheared units predominate.

The melange can be considered essentially a large shear zone containing relatively few intact blocks. Within the melange unit, some blocks of different kinds of rocks are large enough to be mapped separately. These blocks may be graywacke, meta-volcanic rocks, or chert. Because the Franciscan melange is composed of highly sheared, weak rocks, it is highly prone to landslides. Much of the Franciscan bedrock, particularly in the Lopez Point area, is concealed beneath landslide deposits.

Serpentinite is found within the melange as irregular sheared masses along fault zones. Serpentinite is formed by the alteration of ultramafic rock (very high in iron and magnesium), usually representing fragments of the mantle from beneath the former oceanic plate. As the oceanic plate was subducted, fragments were incorporated into the overlying sedimentary material and the complex accreted to the North American Plate. The mineralogic alteration from peridotite or pyroxenite to serpentine and the intense shearing result in a weak rock that has numerous fractures and minor faults zones, all of which can be planes of weakness that contribute to the movement of landslides.

Cretaceous and Tertiary sedimentary rocks

Cretaceous and Tertiary sedimentary rocks overlie the Sur complex and granitic rocks in the Salinian Block and also overlie the Franciscan Complex to the west. Within the Salinian block, Cretaceous sedimentary rocks overlie the Sur complex outcrop along the road on the southwest flank of Sierra Hill, south of Hurricane Point. Another fault-bounded area of Cretaceous rocks extends to the southeast from Rocky Point. Several fault bounded areas of Cretaceous rocks are found in the Hot Springs Creek and Big Creek areas. The Cretaceous rocks are typically composed of sandstone and conglomerate and tend to be well-cemented, compact, hard rocks. Coarse, cobble-sized, rounded clasts are very common in the conglomerate units. In these units it is common for the sandstone matrix surrounding the cobbles to be harder than the cobbles, leading to fractures that cut through the cobbles, rather than go around them.

Younger rocks of the Paleocene Carmelo Formation and Miocene Monterey Formation overlie the granitic rocks near Point Lobos (Clifton, 1981; Clifton and Hill, 1987; Clark and others, 1997). The Carmelo Formation is a medium to coarse-grained yellowish-brown sandstone with conglomerate, noted by photographers for its weathering patterns and forms at Point Lobos. The Carmelo Formation crops out on relatively gentle slopes, and does not appear to be affected by landslides. The Monterey Formation is a weak, thin-bedded claystone with some sandstone and locally significant diatomite. In other areas it is subject to extensive landsliding, but along the Big Sur coast it crops out in small areas east of the highway near Point Lobos. Landslides mapped in this unit are not likely to affect the highway.

An entirely different sequence of Tertiary sedimentary rocks overlies the Franciscan Complex in the area between Big Sur and Sierra Hill. These rocks include several units of Miocene age, including shale and sandstone. The major rock unit, the Pismo Formation, has been correlated with similar rocks in the San Luis Obispo area, (Sutherland 1990; Hall, 1991) suggesting that there has been up to 100 km of right-lateral fault offset on the Sur-Nacimiento fault zone. The Pismo Formation, and the related Tertiary sedimentary rocks which overlie the Franciscan Complex, tend to be relatively weak compared to the nearby Cretaceous and Sur complex rocks, but have much more coherent bedding than the underlying Franciscan. Many of these units are nearly as prone to landsliding as the Franciscan melange.

Surficial deposits of Quaternary age

Overlying the bedrock units along the coast are surficial deposits of Quaternary age. These units have been deposited in low-lying areas along the coast and are composed of materials eroded from up-slope, either from adjacent slopes or transported by streams from within the mountains.

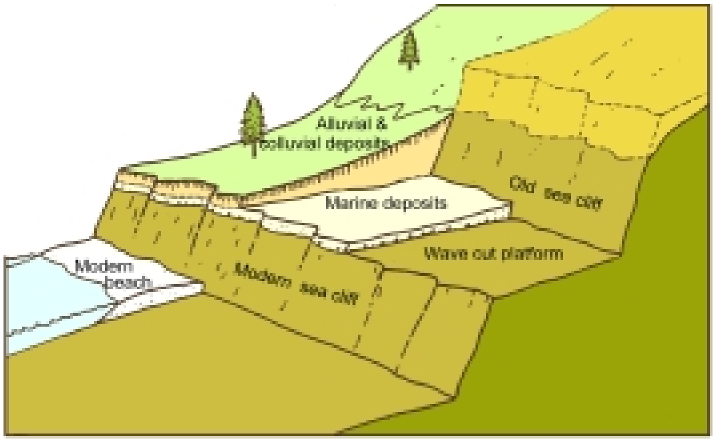


Figure 3. Typical landforms and deposits on a marine terrace. Along the Big Sur coast the alluvial and colluvial deposits overlying the marine deposits appear to be dominantly coarse colluvium, probably transported to the terrace by debris flows. We therefore refer to these as debris fans. Diagram after Weber (1979)

Along the coast a series of marine terraces have been eroded and uplifted over the past several hundred thousand years. Wave erosion at and below sea level planes off the bedrock to form a marine terrace platform. Sand and cobbles typically make up a marine terrace deposit on the platform. As the mountains have been uplifted, the terraces are raised above the elevation affected by wave erosion and are either eroded by rainfall and runoff, or are buried by material from the adjacent slopes (Figure 3). Along Highway 1, it is relatively rare to see the marine terrace platform or deposits. Most of the remaining terrace surfaces are buried by a thick sequence of crudely bedded silty sand with numerous angular cobbles and boulders. This material is apparently colluvium formed on the adjacent slopes and transported down onto the marine terrace platform by creep and debris flows. Some of these deposits contain areas of well sorted (poorly graded), moderately- to well-rounded sand and cobbles that indicate deposition by running water. Deposition by streams does not appear to be a major process in the deposition of these materials, so we refer to them as debris fans, to signify the coarse nature of the deposits and the probable role of debris flows in their deposition. We have distinguished three ages of debris fans based on relative uplift and erosion and on relative soil development.

Other significant Quaternary deposits along Highway 1 include alluvial (stream) deposits of three different ages; young alluvium near the current channels, older alluvium which forms raised stream terraces, and very old alluvium, mapped on the ridge west of the Big Sur River by Hall (1991). Beach and sand dune deposits were mapped locally on the coast and immediately inland. Dune sand deposits are divided into two units, modern dunes and older deposits. The dune deposits are composed of fine to medium grained sand, but the older deposits commonly are stabilized by vegetation and have a slightly cemented crust at the surface.

Landslide deposits shown on the geologic map are the larger and deeper slides from the landslide map. The headscarp areas of some large slides and the smaller and shallower slides are not shown on the geologic map for clarity. Headscarps of landslides can also locally have outcrops of fresh, intact rock, if the landslide deposit has completely moved off the scarp area. The materials in the landslide deposit are highly variable, depending on the source material, and range from nearly intact bedrock to completely disrupted clay soils.

Table 1: Geologic unit symbols, name, material types and related landslide and erosion hazards

Symbol	Name and materials	Erosion and slide hazards
Qal	**Alluvium** Unconsolidated sand and silty sand with lesser clay, cobbles and boulders. Deposited by streams.	Loose, erodible.
Qb	**Beach Sand** Unconsolidated, well-sorted medium to coarse sand.	Loose, erodible.
Qd	**Dune Sand** Unconsolidated, loose to medium dense, yellow brown, medium- to fine-grained sand subaerially deposited adjacent to coast. Material may have a scrubby vegetative cover, depending on distance from coastline.	Loose, highly erodible.
Qls	**Landslide Deposit** Highly variable composition depending on source materials and degree of disruption by landslide process.	Variable in consistency and erodibility.
Qdf	**Recent Debris Fan** Poorly bedded brown silty sand with angular rock fragments. Geomorphically distinct fan shapes are still observable. Includes vegetated talus-like slopes.	Unconsolidated deposits consisting mainly of silty sand with clay will stand in steep cut slopes but will erode over time into gullies.
Qydf	**Younger Debris Fan** Poorly bedded reddish brown silty sand with angular rock fragments. Occupies lower areas, broadly lobate fan shape somewhat disguised by subsequent erosion. Locally contains areas or layers of well bedded gravelly silty sand that represent stream-deposited alluvium.	Unconsolidated deposits consisting mainly of silty sand with clay will stand in steep cut slopes but will erode over time into gullies.
Qodf	**Older Debris Fan** Poorly bedded reddish brown silty sand with angular rock fragments. Overlies and in many cases comprises lower ridges. Typically deposited onto marine wave cut platforms or marine deposits. Fan shape often lost to erosion. Typically consists of angular rock fragments in sandy clay matrix deposited from numerous debris flow and debris slide events. Clast support observed, often at base of fan (i.e., stone line) in paleochannel or near source area of debris. Some outcrops have been cemented and oxidized to deep rusty color, with zones of apparent leaching adjacent to fractures within the unit. Unit can be 100 feet thick to thin layer over bedrock.	Unconsolidated deposits consisting mainly of silty sand with clay will stand in steep cut slopes but will erode over time into gullies.
Qoa	**Older Alluvium** Unconsolidated sand and silty sand with lesser clay, cobbles and boulders. Commonly forms terraces above recent stream channels. Deposits are out of the areas of current deposition and vegetation is usually well established.	Unconsolidated deposits consisting of sand and coarser materials tend to be highly erodible.

Table 1, continued: Geologic unit symbols, name, material types and related landslide and erosion hazards

Symbol	Name and materials	Erosion and slide hazards
Qom, **Qom2,** **Qom1**	**Marine Terrace Deposit** Clast-supported deposits of relatively uniform grain size overlying wave cut benches. Some deposits contain subrounded to rounded clasts ranging in size from pebbles to boulders 2-3 feet in diameter. May contain dune sand, and grade into dune deposits. Locally two ages of terrace deposits can be discerned, the older deposit is designated Qom1 and the younger Qom2.	Unconsolidated deposits consisting of sand and coarser materials tend to be highly erodible.
Qod	**Older Dune Sand** Unconsolidated, commonly with lightly cemented crust, medium dense to very dense, yellow to reddish brown, medium to fine-grained sand subaerially deposited adjacent to coast.	Unconsolidated deposits consisting of sand and coarser materials tend to be highly erodible.
Qfb	**Fault Breccia** Small areas of crushed or broken rock mapped by Hall (1991) along the Sur fault zone. Other areas of fault breccia along fault are too small to depict at this map scale.	Underlies limited areas along highway, not a significant source of landslides affecting highway corridor.
Qvoa	**Very old alluvium** Preserved as remnants of alluvial surfaces on ridge tops west of the Big Sur river	Underlies limited areas along highway, not a significant source of landslides affecting highway corridor.
Tmpe	**Pismo Formation, Edna member** Fine to medium-grained, thinly to thickly bedded sandstone, locally poorly cemented to friable, found north of the Little Sur River to Hurricane Point	Weakly to moderately cemented fine to medium-grained sandstone. Planes of weakness along shale bedding planes.
Tmpm	**Pismo Formation, Miguelito member** Well bedded, locally thin bedded siltstone and fine to rarely coarse-grained micaceous sandstone	Weak shaley claystone with numerous planes of weakness along bedding. Position at base of slope on Sierra Hill results in this unit, the weakest rock in the area, being eroded by wave attack and undermining stronger adjacent rocks.
Tm	**Monterey Formation** Thin bedded, white to light gray-brown siliceous shale	Underlies limited areas along highway, not a significant source of landslides affecting highway corridor.
Tmr	**Rincon Formation** Deeply weathered brown silty claystone contains sandy siltstone and gray to orange-colored calcareous beds or pods. Not exposed along Highway 1, but found south of the Little Sur River east of the highway.	Underlies limited areas in corridor, none along highway, not a significant source of landslides affecting highway corridor.
Tmv	**Vaqueros Formation** Small patches of this formation mapped by Hall east of Highway 1 and south of the Little Sur River are described as poorly stratified sedimentary breccia.	Underlies limited areas in corridor, none along highway, not a significant source of landslides affecting highway corridor.

Table 1, continued: Geologic unit symbols, name, material types and related landslide and erosion hazards

Symbol	Name and materials	Erosion and slide hazards
Tc	**Carmelo Formation** Conglomerate composed of pebbles and cobbles in a sandy matrix with interbeds of sandstone. Exposed at Point Lobos.	Underlies gently slopes and low hills in the Point Lobos area; not a significant source of landslides affecting highway.
Tv,Tvb	**Miocene Volcanics** Described by Clark and others (1974) as flows and flow-breccias of basalt and basaltic andesite. **Tvb** Basalt	Small areas mapped east of highway not located in areas where landslides are likely to affect the highway.
Tus	**Miocene Sandstone** Described by Clark and others (1974) as buff to light gray friable sandstone with minor conglomerate.	Small areas mapped east of highway not located in areas where landslides are likely to affect the highway.
Ks	**Cretaceous sandstone and shale** Medium to coarse-grained, brown-weathering, gray, well-bedded but sheared sandstone.	Moderately hard sandstone with common planes of weakness along shale beds and fractures.
Kush	**Cretaceous shale** Dark-colored silty claystone with interbedded sandstone and conglomerate	Limited exposures in the highway corridor. May be weak rock, but not a significant source of landslides.
Kuss	**Cretaceous sandstone** Medium to coarse-grained light brown sandstone with some conglomerate, commonly intensely fractured.	Moderately hard sandstone with planes of weakness along bedding and fractures.
Kucg	**Cretaceous conglomerate** Conglomerate composed of well rounded pebbles to cobbles of igneous and metamorphic rocks in matrix of reddish to yellowish brown sand to silty sand.	Hard, well-cemented silty sand with rounded cobbles. Susceptible to large slides on very steep slopes (possibly because of weaker adjacent rocks as at Sierra Hill).
KJf	**Franciscan Complex (melange)** A mixture of sheared and faulted medium-grained graywacke sandstone, siltstone, and shale with blocks of sandstone, siltstone, chert and metavolcanic rocks.	Weak, intensely sheared rock highly susceptible to large rock slides and earth flows.
KJfgw	**Franciscan Complex graywacke** A fine to medium-grained sandstone composed of quartz and feldspar grains and sand-sized rock fragments.	Relatively strong rock found as beds and blocks within matrix of sheared shale.
KJfsh	**Franciscan Complex micrograywacke** Very fine sandstone to shale composed of quartz, feldspar and rock fragments.	Typically found as blocks within melange. Blocks are not usually large enough to affect the stability of slopes
KJfc	**Franciscan Complex chert** Red, white and green thin bedded chert, typically contorted and sheared.	Typically found as blocks within melange. Blocks are not usually large enough to affect the stability of slopes.

Table 1, continued: Geologic unit symbols, name, material types and related landslide and erosion hazards

Symbol	Name and materials	Erosion and slide hazards
KJfgs	**Franciscan Complex greenschist** Hard, foliated, dark greenish gray schist found as blocks within melange. Large blocks as mapped by Hall (1991) shown on map.	Typically found as blocks within melange. Blocks are not usually large enough to affect the stability of slopes.
KJfb	**Franciscan Complex blueschist** Hard, foliated, dark bluish gray schist found as blocks within melange. Large blocks as mapped by Hall (1991) shown on map.	Typically found as blocks within melange. Blocks are not usually large enough to affect the stability of slopes.
KJfmg	**Franciscan Complex meta-gabbro** Medium to coarse grained, hard, greenish gray metamorphosed gabbro.	Found as a block within melange near Point Sur. Block is not large enough to affect the stability of slopes.
KJfmv	**Franciscan Complex metavolcanics** Fine grained hard, greenish gray metamorphosed volcanic rocks (typically basalt). Locally shows pillow structure from submarine eruption of basalt flows.	Typically found as blocks within melange. Blocks are not usually large enough to affect the stability of slopes.
s	**Franciscan Complex Serpentinite** Light gray green to green intensely sheared and foliated serpentinite. Contains relatively unaltered peridotite or pyroxenite blocks.	Intensely sheared, hard, dense rock, numerous planes of weakness lead to rock slides and rock falls.
Kpgd	**Cretaceous porphyritic granodiorite** Light to medium gray, medium to coarse-grained granodiorite with distinctive phenocrysts of pink potassium feldspar up to 10 cm long.	Weathers to moderate reddish brown grus. Subject to debris flows from colluvium and weathered rock.
Kgd	**Cretaceous granodiorite of Cachagua** Transition zone between porphyritic granodiorite to north and quartz diorite to south, properties change gradually across area.	Weathers to moderate reddish brown grus. Subject to debris flows from colluvium and weathered rock.
Kqd	**Cretaceous hornblende-biotite quartz diorite** Medium to dark gray medium to coarse-grained quartz diorite with abundant hornblende and biotite. Locally foliated with aligned diorite inclusions.	Weathers to moderate reddish brown grus. Subject to debris flows from colluvium and weathered rock.
KMct	**Charnockitic tonalite** Dark greenish gray, coarsely crystalline, slightly to highly foliated igneous rock composed predominantly of plagioclase, hornblende, actinolite and chlorite with lesser quartz and biotite.	Hard, resistant massive rock in sea cliff exposures. Occasional planes of weakness may lead to large slides of relatively intact rock. Deeply weathered on upper slopes.
KMt	**Tonalite probably correlative with charnockitic tonalite** Dark greenish gray, coarsely crystalline, slightly to highly foliated igneous rock composed predominantly of plagioclase, hornblende, actinolite and chlorite with lesser quartz and biotite.	Hard, resistant massive rock in sea cliff exposures. Occasional planes of weakness may lead to large slides of relatively intact rock. Deeply weathered on upper slopes.

Table 1, continued: Geologic unit symbols, name, material types and related landslide and erosion hazards

Symbol	Name and materials	Erosion and slide hazards
Ps, **Ps-q**	**Sur Complex undifferentiated metamorphic rocks** Highly variable metamorphic and igneous rocks including quartz-diorite, gneiss, and granofels. **Ps-q** Quartz dike	Commonly deeply weathered to deep red brown gravelly colluvium. Subject to large deep rock slides and debris flows from colluvium and weathered rock.
Pm	**Sur Complex marble** White coarsely crystalline marble	Resistant to weathering and erosion, tends to form resistant outcrops on slopes. Areas of marble are not usually large enough to affect the stability of entire slopes.

LANDSLIDES

More than 1500 landslides were mapped in the Highway 1 corridor area between San Carpoforo Creek and Point Lobos (Plate 2). The landslides shown on our map tend to be the larger, deep seated slides that affect large areas. Although we have attempted to show all landslides visible at the scale of 1:24,000, there are many small shallow slides that could not be shown individually. In addition, there are probably many small landslides that exist in the Franciscan melange matrix outside of mapped landslide boundaries but were not noticed during the project mapping.

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 (mainly Hall, 1991, and Weber,1979;few other geologic maps showed landslides) and in reports prepared by or 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 morphology. 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 (1996), but have attempted to simplify the designations by listing only the primary classification of a given landslide. For example, our 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 our 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, numerous weak, poorly consolidated formations are “rock”. Franciscan melange commonly is “earth” because its original sedimentary and tectonic fabric in many places has been destroyed by pervasive landsliding.

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

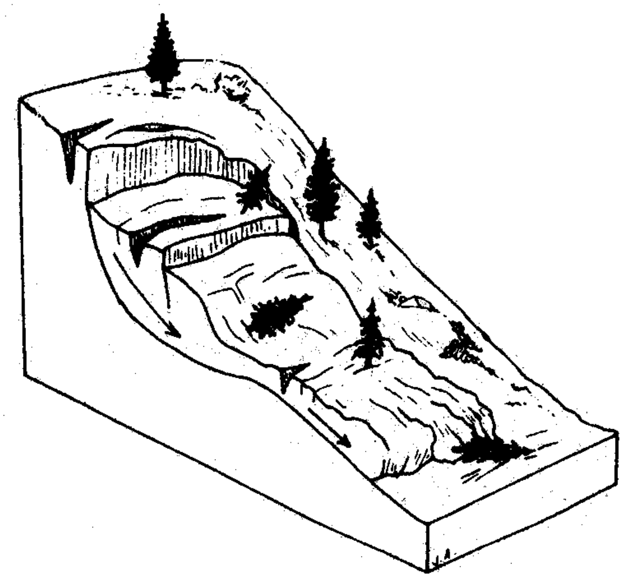


diagram by J. Appleby, R. Kilbourne, and T. Spittler after Varnes, 1978

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 35percent (%) 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. 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, however, 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 minutes.

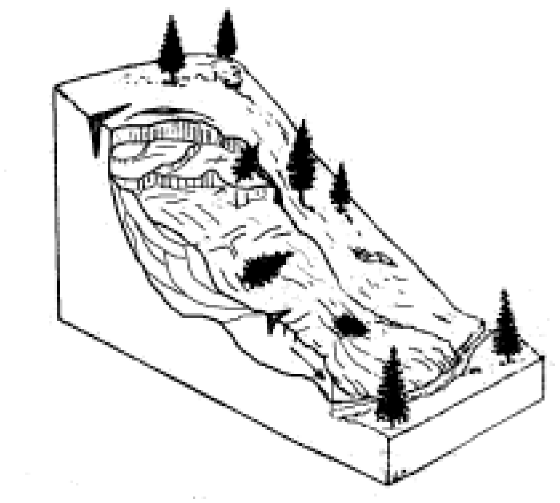


diagram by J. Appleby, R. Kilbourne, and C. Wills after Varnes, 1978

EARTH FLOW: A landslide composed of mixture of fine grained soil, consisting of surficial deposits and deeply weathered, disrupted bedrock. The material strength is low through much of the slide mass, and movement occurs on many discontinuous shear surfaces throughout the landslide mass. Although the landslide may have a main slide plane at the base, many internal slide planes disrupt the landslide mass leading to movement that resembles the flow of a viscous liquid.

Earth flows commonly occur on less steep slopes than rock slides, in weak, clay-rich soils or disrupted rock units. Slopes are commonly from 10% to as steep as 30%, although steeper slopes may be found in headscarp areas and where landslide toes are being eroded. Movement of a slide mass along numerous curved failure surfaces leads to an irregular steep headscarp at the upper boundary of the slide. Immediately below the headscarp is a series of blocks that are commonly rotated so they are less steep than the surrounding hill slopes. Below the bench, the slide mass is made up of many smaller masses which may move as intact masses for a time then break up into smaller masses and flow on a multitude of failure surfaces. The flowage of weak material with blocks of relatively intact material leads to a lumpy “hummocky” slope that is typical of large earth flow areas. The lower parts of the slopes usually bulge outward and are steeper than the surrounding slopes.

The rotation of the blocks that typically occurs in the upper part of an earthflow leads to a less steep slope which sometimes holds closed depressions. These areas 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. The water retention of these areas also decreases the overall stability of the slide mass by allowing more time for water to infiltrate the slide.

Earthflows are sensitive to conditions that affect the entire slope and to disturbances to any part of the slope. A rise in the water table that may occur in high rainfall years may decrease the overall stability. High water pore pressures, typically following a sustained period of heavy rains, may trigger earth flows, which then may continue to move for a period of days to weeks. Undercutting of the base of slope or addition of fill to the upper slope also tends to destabilize an existing slide. Because the slide mass is weak and contains slide planes throughout, cuts or fills on the slide mass may destabilize a part of the slide. Movement may occur for years as creep of the surficial soil as it shrinks in dry seasons and swells in wet seasons. Movement of the entire mass is more common in years of higher than normal rainfall. Movement is generally slow, in the millimeters or centimeters per day range, but can accelerate to as fast as meters per day in exceptional circumstances.

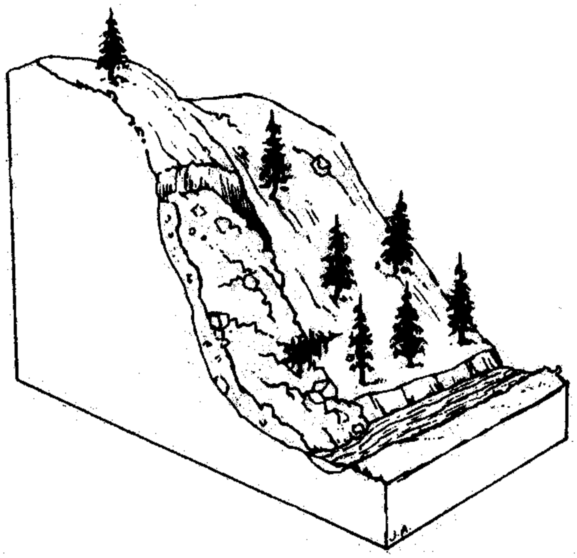


diagram by J. Appleby, and R. Kilbourne, after Varnes, 1978

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, commonly as steep as 60% to 70%, usually 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, commonly as a loose 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 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.

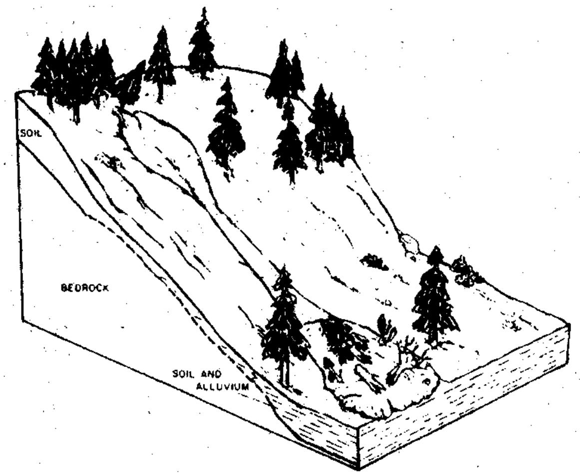


diagram by J. Appleby, and R. Kilbourne, CDMG

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. Roads, culverts or other works that tend to concentrate water on steep slopes have to be carefully designed to avoid increasing the potential for debris flows.

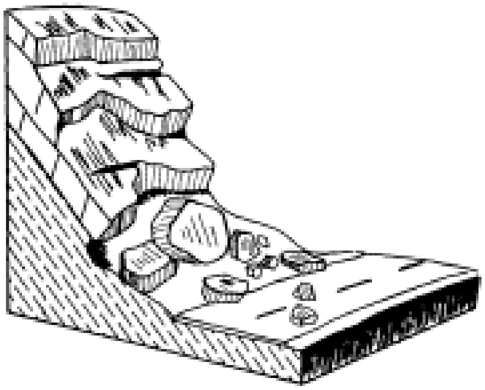


diagram after Colorado Geological Survey, 1989

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.

Rockfalls occur on steep slopes of hard, fractured rock. The scar left by a rockfall on the slope may be no more apparent than an area of rock that is less weathered than the surrounding rocks. Rockfall deposits are loose piles of rubble that may be easily removed by erosion. Because neither the scar nor the deposit are distinctive, and because rockfalls are typically small, individual rock falls are usually not shown on regional-scale (1:24,000 and smaller) landslide maps.

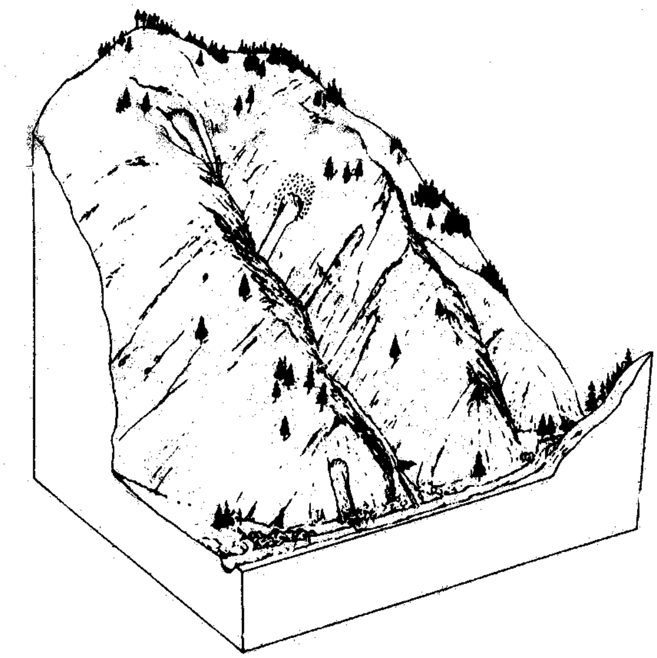


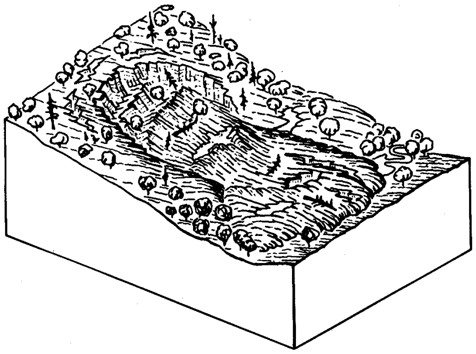
diagram by J. Appleby, and R. Kilbourne CDMG

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.

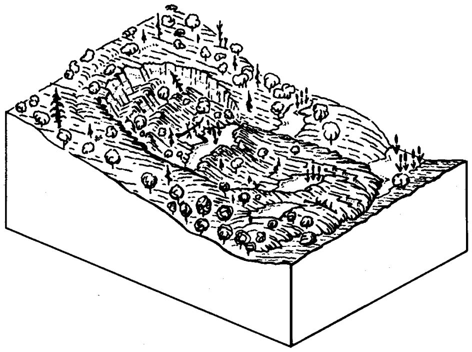
Debris slide slopes are typically very steep; 60% and steeper is common. Areas in which the dominant form of erosion is by debris slides and debris flows are characterized by uniformly very steep slopes, commonly with each small canyon having rounded amphitheater-shaped heads.

Activity of landslides

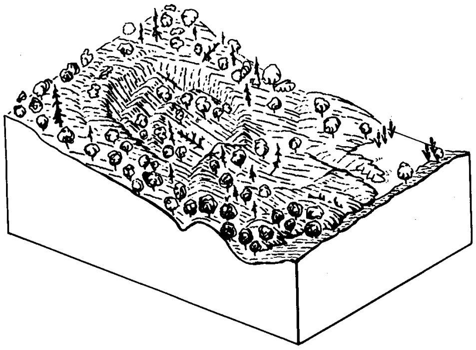
Each landslide is classified based on the recency of activity into one of four categories based on the system of Keaton and DeGraff (1996). The diagrams below illustrate levels of activity (diagrams from Wieczorek, 1984).



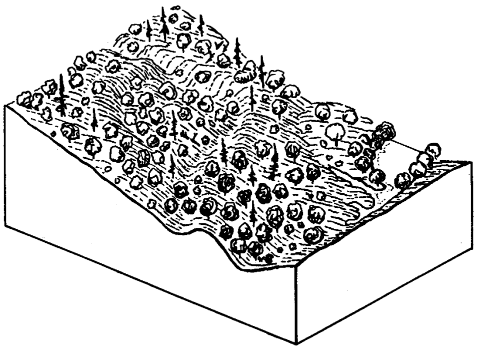
Active or Historic: The landslide appears to be currently moving or movements have been recorded in the past. Displaced or damaged man-made features, fresh cracks or disrupted vegetation indicate recent activity. Water may be ponded in depressions created by rotation of the slide mass or blockage of a 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 slightly 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 are 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. 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 vaguely to strongly imply the occurrence of mass movement.

Other factors

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

FIELD	VALUES	NOTES
Depth	s (shallow), m (medium) and d (deep)	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	
Primary geologic unit	Corresponding to geologic map symbols	The geologic unit from the geologic map
Primary lithology	ss, sh, ss-sh	Corresponding to the unit on the geologic map. For example, the lithologies are ss (sandstone), sh (shale) and ss-sh (sandstone with lesser shale).

Secondary geologic unit	Corresponding to geologic map symbols	If a landslide involves two bedrock geologic units
Secondary lithology	ss, sh, ss-sh	If a landslide involves two bedrock geologic units
Area	Value	Calculated by ArcView
Perimeter	Value	Calculated by ArcView

FACTORS INFLUENCING SLOPE STABILITY IN THE HIGHWAY CORRIDOR

The uplift of the Coast Ranges, the inclination of slopes, the underlying rock types and geologic structures, landforms, fire history, rainfall and waves related to winter storms all influence the slope stability along the Highway 1 corridor between San Carpoforo Creek and Point Lobos. In addition to the natural processes that have lead to numerous landslides along the coast, construction practices used in building the original highway and in maintaining it have locally affected the stability of slopes.

Slopes along the Highway 1 corridor range from moderate to extremely steep. The steepest slopes are along the sea cliffs. Some sea cliffs are as steep as 150% and as high as 400 feet. More typically sea cliffs are about 200 feet high and have about 100% slopes. Slopes that are this steep are characterized by bare rock outcrops and landslide scars. Most landslides on these very steep slopes involve shallow soil and loose rocks, moving as debris slides and rock falls. Slopes to the crest of the ridge above the highway are not so precipitous, but many slopes as steep as 50 to 60 % extend to the ridge crests at over 2000 feet.

These steep slopes are formed by the uplift of the mountains that has been ongoing for millions of years, combined with wave erosion along the coast. Uplift over the past 100,000 years has been estimated from the uplift of marine terraces in Santa Cruz to the north, and the San Simeon area to the south. McKittrick (1988) developed a preliminary uplift rate of about 1 mm/yr for the northern Big Sur coast (from Point Lobos to Garapata Creek). This rate of uplift is not exceptionally fast for California, but helps to maintain very steep slopes in the relatively hard rocks. Unfortunately, there apparently have been no studies of the terraces and uplift rates between the San Simeon fault at San Carpoforo Creek and the Sur-San Gregorio fault zone at Hurricane Point. The uplift rate for this part of the coast, the majority of the study area, is not known.

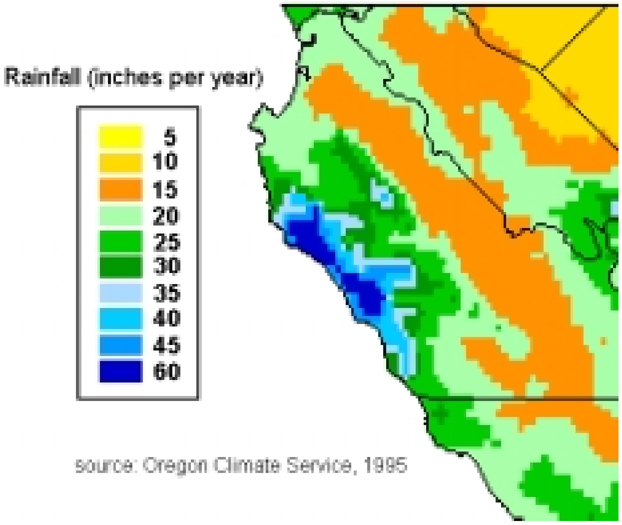
Wave erosion helps to maintain the steepest slopes in the sea cliffs by removing loose rock deposited at the base and undermining the base of slopes, triggering landslides. The effect of wave erosion is greatest where steep high slopes extend upwards from the beach, without intervening marine terraces, and where weak rocks are found at sea level. The weak rocks of the Pismo Formation, at sea level on the southwest side of Sierra Hill, are soft and erodible. Erosion of those rocks contributes to the instability of the harder rocks higher on the slopes. Similarly, loose fractured rocks at the toe of several landslides, such as the ”Duck Ponds" and "Gray Slip" slides, are at sea level. The landslide debris is eventually removed by the waves, decreasing the overall stability of the slide mass.

Bedrock geology also has a very strong influence on the types and activity of landslides. The rock units in this highway corridor range from massive, hard rocks with few fractures (notably the charnockitic tonalite and granitic rocks) to weak rock with pervasive shear surfaces and fractures (the Franciscan melange). The melange is much more prone to landsliding, and landslides in that unit tend to be made up of several blocks that may move different amounts at different times. The tonalite is less prone to large rotational landslides and forms very steep slopes along the coast. Those slides that have occurred historically, however, have been large and very damaging, notably the 1983 McWay (or J.P. Burns) slide. The granitic rocks on the northern part of the Big Sur coast, the quartz-diorite, granodiorite and granite, are similarly resistant to large landslides, though some slides are found in all units.

The weathering characteristics of the bedrock units are also important factors in controlling the size and density of landslides. Weathering is not as important in rocks that are weak and soil-like in their unweathered state, but in hard rocks the speed and depth of weathering influences the potential for landslides. The charnockitic tonalite, Sur complex gneiss and amphibolite, and the granitic rocks have significant surface weathered zones on some slopes. The depth of weathering is at least partly controlled by the original mineralogy of the rock units. We observed that the granitic rocks and gneiss, but not the charnockitic tonalite, typically have deep zones of decomposed rocks at the surface almost everywhere but on the sea cliffs and canyon bottoms. This thick zone of weathered rock implies relatively rapid weathering and leads to common shallow slides of the weathered layer. Because the layer of weathered rock is usually a few meters thick, it tends to fail in rapid debris slides or debris flows triggered by heavy rains. The slopes underlain by granitic rock in particular have many debris flow/slide scarps. The charnockitic tonalite, by contrast, usually has a very thin rubbly soil layer on the lower slopes. On some slopes above about 1500 feet elevation the tonalite does have a deep weathered layer. The deep weathering found only on higher slopes implies a very slow weathering rate.

The apparent contrast in weathering rates between the charnockitic tonalite and the granitic and gneissic rocks may be due to the original mineralogy of the rocks. Ross (1979) reports that the main mafic mineral in the granitic rocks and the gneiss is biotite, which makes up 12 - 13% of two samples of the quartz diorite and 8% of one sample of the gneiss. Biotite typically weathers very rapidly to clay minerals, expanding and breaking down the rock as it does so. The charnockitic tonalite in contrast has only 1 to 5% biotite (Ross, 1979). This basic difference in mineralogy may lead to the deeper weathering in the granitic rocks and gneiss and the greater number of debris flow scars that we observed in the areas underlain by those units.

Precipitation is a major factor influencing landslides. The Big Sur segment of Highway 1 receives up to 60 inches of rainfall annually, up to four times as much as the Salinas Valley on the landward side of the Santa Lucia Mountains (Oregon Climate Service, 1995)(Figure 3). This amount of rainfall adds to the level of saturation of the landslide masses on the coastal slopes, decreasing their stability. Long-term steady rain leads to deep saturation of landslide masses and tends to destabilize the larger, deeper types of landslides. Short-term, very intense rain tends to trigger the shallower types of landslides, such as debris slides and debris flows.



source: Oregon Climate Service, 1995

Figure 3. Average annual precipitation in Monterey County and surrounding area for the period 1961-1990.

Wildfires also contribute to the triggering of debris flows. The effect of fire on debris flow potential has been most clearly shown in the Big Sur River watershed, where a fire in 1971 was followed by debris flows in 1972 (Jackson, 1977). We have not found records of similar fires leading to debris flows in other areas, but the areas with deeply weathered bedrock and colluvium, mainly the granitic rocks and Sur complex metamorphic rocks, appear to be susceptible to the fire-flood-debris flow sequence.

The northwest trend of geologic structure, which is the similar orientation of bedding, shear zones and faults, controls the general 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 leads to relatively large landslides on slopes that face northeast and southwest.

The landforms created by landslides, in some cases, help to perpetuate the slides. Closed depressions, troughs and benches that commonly form near the headscarps of landslides allow increased percolation of water into the slide mass and along the slide plane, accumulate rainwater and destabilize the slide. Shallow debris slides may destabilize the adjacent upslope area when they move. This leads to a progressive upslope sequence of debris slides or debris flows.

The construction and maintenance of Highway 1 across many marginally stable and unstable slopes has also contributed to the triggering of new or renewed movement on landslides. In many cases, original construction of the highway left many steep cut slopes above the road. Blasting used during the original construction, left loose and fractured rocks on many steep cut slopes, which has contributed to rock falls and small debris slides.

Even when blasting was not used during construction, creating a cut slope in marginally stable material can trigger small slides. If an extensive area of weak rock or soil extends upward from the cut, small slides in the cut can reduce the stability of somewhat larger areas on the adjacent slopes. If the larger areas fail, that can reduce the stability of larger adjacent areas. This form of landslide, which develops from a small failure in a cut slope to a much larger failure in slopes that are largely natural, is called a retrogressive landslide failure. This type of sliding was probably extensive in the 10 to 20 years after construction of the highway. More recently, repairs and maintenance have led to similar failures. One example of a retrogressive failure related to highway maintenance may have occurred at “Pitkin’s Curve” (P.M. 21.5) where a landslide below the highway led Caltrans to move the highway to the southeast, off of the slide. A cut slope was required to move the highway inland. That cut slope in weak, loose debris and weathered rock rapidly failed, leading to retrogressive failure of the entire slope above the cut to the ridge crest (Figure 4)


6/26/2001

Figure 4, Debris slides above the highway at "Pitkin's Curve" may have formed due to retrogressive failure starting in a road cut.

Other construction practices that can contribute to landsliding are the placement of fill onto an existing slide mass, and the directing of runoff onto loose materials or unstable slopes. Placement of fill onto landslides may increase the “driving” forces causing the slide to move. This is clearly happening at the Willow Creek landslide (P.M. 11.8), where Caltrans has moved the highway to the east, so that most of the highway is off the landslide. The relatively flat area overlying the landslide has been used as a disposal site for debris from the Pitkin’s Curve area mentioned above. The placement of that debris as fill over the landslide has increased the driving forces on the landslide and probably increased its rate of movement. We observed ridges of pushed up material and open fractures at the toe of the landslide, as well as fractures and scarps at roadway level, indicating active movement of the slide since the fill was placed in the spring of 2001. Placement of fill may tend to stabilize a landslide, if it is emplaced at the toe to form a buttress, or have very little effect on the stability, but in some instances, such as at Willow Creek, fill placement clearly decreases the stability of the existing slide.

Direction of runoff onto loose material or existing landslides is common along roadways in mountainous areas and requires very careful construction and maintenance to avoid. We observed numerous culverts that were contributing to erosion and probably small landslides below the highway.

POTENTIAL FOR LANDSLIDES ALONG HIGHWAY 1

Landslides can and do cause damage and close roads, resulting in major repair and maintenance costs. Economic losses can be significant to an entire region of the state if a main route is closed for an extended 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 Big Sur coast where landslides are common, the highway will be exposed to the risk of slide damage.

The consequences of landslide movement are related to the size and location 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 the 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 traveling public. Large, deep landslides are less likely to move rapidly or have significant displacement in any one episode of movement, but the rare rapid, large displacement of large landslides can have particularly severe consequences. Significant displacements of large, deep landslides may result in the roadway being closed for repairor, in the worst case, closed for long periods for reconstruction or rerouting.

The following paragraphs discuss the Big Sur Coast area as 12 sections that are distinguished by differences in geology, geography and landslides. Discussion of some of the notable landslides and the potential for various types of landslides is included with each section. The description of each section of the highway corridor includes a general description of the potential for landslides. We have characterized the potential for landslides in each section as high, moderate or low, and describe the typical type and size of landslides. This description is an attempt to qualitatively summarize the characteristics of an area, and so does not reflect the hazard posed by any individual landslide in the corridor. The description is intended to reflect the overall numbers of landslides that we mapped in the area as well as records of historic slides and the characteristics of geologic units.

San Carpoforo Creek to Ragged Point Resort P.M. SLO 71.4 to 73.0

North from San Carpoforo Creek the highway climbs onto a marine terrace that is about 300 feet above sea level. In climbing the steep slopes onto the terrace the highway crosses a canyon that may be prone to rockfall and other small landslides. On the marine terrace the highway may be affected by landslides in a few places where it is close to the sea cliffs below the roadway, but generally there is only a moderate potential of the highway being affected by landslides.

Ragged Point Resort to Salmon Cone P.M. SLO 73.1 to MON 2.8

Immediately north of the end of the terrace at the Ragged Point Resort, the highway passes into an area of very steep slopes. Small landslides have been common, both above and below the highway, and some moderate-size slides have resulted in road closures (the Forest Boundary slide at P.M. 1.5, for example). Several very large pre-historic slides are evident from the geomorphology of this area. The steep slopes suggest this area is underlain by relatively competent rocks of the Franciscan melange, but overall this highway segment has a moderate to high potential for landslides due to the steep topography.

Salmon Cone to Willow Creek P.M. MON 2.8 to 12.1

The highway from Salmon Cone to Willow Creek is characterized by gentler slopes with prominent scarps and benches, indicating many large landslides. Large landslides known as "Gray Slip" at P.M. 6.7 and "Duck Ponds" at P.M. 8.2 have moved extensively in the past ten years and damaged the highway. A large landslide at Redwood Gulch (P.M. 5.9) reportedly failed rapidly in 1986 (Ron Richman, Caltrans p.c. 2001). Other large landslides north of Salmon Cone (P.M. 2.9) and at Spruce Creek (P.M. 9.6) may have also had historic movement, based on offsets in the highway. In addition to those that have had historic movement, several very large landslides have extremely fresh appearing geomorphology, including one large slide above and south of the Willow Springs Maintenance Station (P.M. 10.4) and the “Tree Bones” slide just north of Willow Springs (P.M. 11.0). Smaller historic slides have displaced parts of the larger, prehistoric slides, notably at Gorda in 1997 (P.M. 10.2).

The abundance of very large slides and active slides suggest that this part of the melange bedrock is notably weaker than the same unit immediately to the south. Overall this area has a high landslide potential, largely related to very large, slow moving slides, but also could be affected by parts of existing slides that move rapidly.

One element of the bedrock geology that is common in this area, but not to the north or south, is serpentinite. Bands of serpentinite along shear zones are prominent in this segment of the coast and rare to the north and south. This correspondence between the area of most abundant serpentinite and most abundant large landslides is probably not a coincidence. The serpentinite, with numerous planes of weakness, corresponds to large areas of melange bedrock that may slide along weaknesses in that run through the more competent rock.

Pacific Valley area P.M. MON 12.1 to 16.6

North of the Willow Creek landslide, the highway passes into an area of gently sloping marine terrace and debris fan deposits. Landslides are mapped on the slopes east of the road, but do not appear to be notably numerous or active. The uplifted terraces prevent wave erosion at the base of the steep slopes that adjoin the landward side of the terraces.

As a result, large active slides were not identified on these slopes. Overall the landslide potential of this segment is low, and the expected hazard is mainly small to moderate slides from the slopes above the highway.

Pacific Valley to Limekiln State Park P.M. MON16.6 to 21.0

Figure 5. Cut slopes south of Limekiln State Park were subject to small shallow landslides in 1998. These slides included debris slides from loose, slightly weathered rock, on the left, and debris flows from older, dark reddish brown colluvium, on the right. Photo by L. Highland, Caltrans.

The terrain between Pacific Valley and Limekiln State Park is similar to the terrain south of Salmon Cone, with very steep slopes rising almost directly from the beach, but relatively few large or active landslides. The one significant landslide that we found records for is the Wild Cattle Creek slide of 1997. Moderate-size landslides have clearly been repaired using extensive grading south of Limekiln State Park, but we were not able to find records of these slides or the repairs. The cut slopes adjacent to the landslide repairs were the source of small landslides in 1998 (Figure 5). This segment of the highway appears to have a moderate landslide hazard, mainly due to small to medium-size slides.

Rain Rocks to Cow Cliffs P.M. MON 21.0 to 28.5

The Lopez Point-Gamboa Point area shows great variation in the types of rocks and types of landslides. Bounding the area are two large blocks of greenstone within the Franciscan Complex. Both the southern block, known as Rain Rocks, and the northern one, known as Cow Cliffs, originally formed very steep sea cliffs that rose hundreds of feet above sea level. Construction of the highway across these cliffs resulted in hundreds of feet of very steep slopes above the highway. At Rain Rocks these slopes are nearly vertical and composed of hard rocks that are prone to rockfalls. At Cow Cliffs the rocks are more fractured and the slopes somewhat less steep, but rock falls and debris slides have been common.

Between these two blocks of very resistant rock, the Franciscan melange contains the greatest density of landslides on the Big Sur Coast. This segment definitely has the highest level of landslide activity in the highway corridor. The landslides are mainly very large and relatively slow-moving but with significant potential for debris slides and rock falls. Major slide blocks extend from sea level to over 2000 feet elevation and large parts of those slides have been active historically. Significant historic slides include those known as Big Slide (possibly also referred to as Blue Slip) at P.M. 22.0, Dani Creek at P.M. 22.8 and Granpa's Elbow at P.M. 23.2. Other slightly smaller, but still significant historic landslides have damaged the highway at Pitkin's Curve (P.M. 21.5), North Vicente Creek (P.M. 26.2) and south of Big Creek (P.M. 28.0). These slides are part of much larger slides that have moved less dramatically or not at all since the highway was built. The very large slide blocks north of Lopez Point appear to be somewhat older and more eroded in appearance than those to the east of Lopez Point. The current Dani Creek slide is part of a much larger mass that apparently moved in 1906 in response to the San Francisco earthquake (G. Harlan as reported by J. Norman in Zatkin, 2000). That slide reportedly extended upslope to about the 1000 feet elevation, where it diverted Dani Creek from its previous course. Surrounding this slide, a large area appears to be underlain by further landslide masses that are nearly as young, based on the fresh appearance of their landforms.

Cow Cliffs to McWay Canyon P.M. MON 28.5 to 35.7

The highway north of Cow Cliffs and south of McWay Canyon traverses an area that is somewhat steeper than the area immediately to the south, but apparently composed of more competent rocks. The bedrock in this area is composed of Franciscan melange and Cretaceous sandstone and conglomerate in long, narrow, fault-bounded blocks parallel to the coast. Remnants of marine terraces, with coverings of debris fans, are also common along this part of the coast, indicating a relatively slow rate of wave erosion and landslide movement. Based on the presence of marine terraces and the low numbers of large and active landslides, the Cretaceous sedimentary rocks appear to be relatively resistant to landsliding, compared to the Franciscan in the area immediately to the south.

Overall, the area appears to have a moderate potential for landslides, specifically small- to moderate-size slides. Two significant, moderate-sized slides in this segment are the Wing Gulch slide at P.M. 29.5, and the Rancho Barranca slide at P.M. 30.25.

The Wing Gulch area is reportedly a very early instance of human contribution to the instability of the Big Sur coast. According to J. Norman (in Zatkin, 2000), a "wing" fence built by a 19th century rancher diverted the rancher's cattle through a steep area, causing severe erosion. The resulting gully has been a source of shallow landsliding and damage to the road since the road was built. A moderate-sized graded area, the result of landslide repair efforts, is currently evident on the slopes above the highway. Adjacent cut slopes and steep natural slopes have also been sources of small, shallow landslides.

The Rancho Barranca slide is typical of slides that can be found on any of the steep sea cliffs along the Big Sur coast. Wave erosion at the base of the sea cliffs can destabilize a small bedrock slide, and adjacent areas of debris fan deposits and road fill. The damage to the road may only extend into the southbound lane initially, but further movement and enlarging of the slide is a natural consequence of further wave erosion.

McWay Canyon to Castro Canyon P.M. MON 35.7 to 43.0

A geologically distinct body of rock occupies a central part of the Big Sur coast, and gives that part of the coast a distinct geographic character. The geologic unit is the Charnockitic Tonalite, which is a very hard, massive, coarse-grained igneous rock with relatively few fractures. In contrast to the slopes to the north or south, which in many places alternate between steep slopes and benches, sea cliffs and terraces above the highway, this segment of the coast has almost uniformly steep slopes of 50 % to 65 % from sea level to elevations of 2000 feet or more. Although the slopes are very steep, they are apparently relatively stable; we mapped fewer landslides in this area than elsewhere.

Figure 6. Aerial view of the McWay slide of 1983. Photo by Lynn Harrison, Caltrans

Overall, this segment has a moderate potential for landslides, largely related to small rockfalls and debris slides, but there are zones of weakness in the tonalite, and major landslides have occurred in exceptional circumstances. The heavy rainfall in the winter of 1983 was one such circumstance, because it triggered not only the largest slide on this segment, the McWay (or J.P. Burns) slide at P.M. 36.25 (Works, 1984; Figure 6), but also a similar slide at Sycamore Draw.

Castro Canyon to Old Coast Road, P.M. MON 43.0 to 51.2

In the central part of the study area, near Big Sur, the Sur fault is on land, rather than offshore, and separates a block of land underlain by Franciscan bedrock, to the west, from a block underlain by Sur complex, to the east. In this area, the highway follows the relatively gentle topography along the fault, rather than following the coast. This segment has a moderate potential for landslides, specifically debris flows and debris slides, with some potential for movement of older, large landslides.

From Castro Canyon to Posts at P.M. 44.5, the highway crosses Graves and Mule

Canyons, both of which run directly southwest to the ocean. The steep sides of these canyons, in combination with the weak rocks along the fault zone lead to moderate-sized landslides. North of Posts, the highway follows Post Creek and the Big Sur River, both of which have eroded their canyons in the weaker rocks along the fault zone. Large landslides are shown by Hall (1991) and this study along the highway in most of this area, but most do not appear to have moved in historic time. Debris flows have been reported several times in this area, including several slides in 1908, 1909, 1910 and 1972, all following fires in the watersheds above the highway (Jackson, 1977; Cleveland, 1977a, 1977b), and at least one additional debris flow in 1986 (JRP Historical Consulting Services, 2001). These debris flows, or mudflows as they are commonly called, originate from shallow slides of loose weathered rock and soil high above the road. They flow down the canyons of the small creeks that drain into the Big Sur River, where they are deposited as a debris fan. The Pheneger, Juan Higuera and Pfeiffer-Redwood Creek drainages all have young debris fans at the point they enter the Big Sur River, and the highway crosses each of these fans. Another debris fan is located at P.M. 50.5 on an unnamed creek crossed by the highway. The culvert inlet was plugged by debris that was later removed by Caltrans maintenance workers. (We were not able to find records of this probable debris flow.) In each of these locations, the highway is subject to inundation by debris during heavy rain, especially in winters following wild fires in these watersheds.

Old Coast Road to Little Sur River P.M. MON 51.2 to 56.1

The highway crosses the landward side of a large marine terrace opposite Point Sur. This segment of the study area has a low to moderate potential for landslides compared to the rest of the highway corridor. Currently, there are no large landslides that affect the highway in this area, but the hills east of the highway are highly prone to landslides. The larger slides in the hills are the deeper, slower moving rock slides and earthflows, but there are also many small debris flow scars on the slopes. Debris flows have formed the debris fans that much of the highway is built on and several have the appearance of very young features. The highway crosses a short area of steep sea cliffs south of the Little Sur River from P.M. 54.9 to 55.4, which has been the location of erosion and small landslides below the highway. A sheet pile retaining structure, was constructed to prevent further erosion of the older dune sand, is located at P.M. 55.2.

Little Sur River to Rocky Creek: P.M. MON 56.1 to 60.0

The most rugged topography and greatest landslide potential in the northern part of the Big Sur coast is concentrated in this short area. Northward from the Little Sur River, the highway ramps upward across the steep southwest flank of Sierra Hill. This side of the hill is underlain by very weak rocks of the Tertiary Pismo Formation at the base, in fault contact with older Cretaceous rocks, which are in turn faulted against older Sur complex metamorphic rocks. Wave erosion of the weak rocks at the base tends to undermine the stronger rocks above. Shearing associated with the fault zones also weakens the rocks in this area. As a result, large landslides make up much of the southwest flank of Sierra Hill. We have not found records of historical movement of the larger slides, but slides known as "Straight Down" at P.M. 57, "South 40" (a culvert plugged by debris (p.c. Ron Richman, Caltrans, 2001) and "Hurricane Point" at P.M. 58 have disrupted the highway. In addition, debris flow scars are evident on the upper slopes of the hill, though we have no record of debris flows reaching the highway.

North of Hurricane Point the highway crosses an area underlain by marine terrace and debris fan deposits, then crosses Bixby Creek and goes around the seaward side of Division Knoll. The slopes of Division Knoll, both above and below the highway, are prone to rock falls and debris slides.

Rocky Creek to Point Lobos P.M. MON 60.0 to 70.4

The northern part of the Big Sur coast is underlain by granitic rocks that are not found to the south, and consequently has very different types of landslides. Within these bedrock units the potential for debris flows and debris slides is high, but the potential for these debris flows or slides reaching the highway appears to be low. The source areas for debris slide and flows are the steeper slopes that are relatively far away from the highway. We mapped very few large or deep slides, and found no records that any of those had moved historically. We did, however, find abundant evidence of small, shallow debris flows on the higher slopes east of the highway. Debris flows are largely responsible for depositing the debris fans that underlie the highway, but those fans do not appear to be recently active. A plausible scenario is that with continuing uplift of the coast, the marine terraces are first buried in debris, then streams incise canyons through the terrace/debris fan deposits. Subsequent debris flows are channeled down the major streams to the ocean. In modern times, some debris flows from adjacent slopes have been deposited on the older debris fans where they may reach the highway, but most would pass under highway bridges to the ocean. Severe storms and debris flows in 1998 appear to have followed this pattern. There are numerous fresh debris flow scars evident in aerial photos taken in 1998, and several debris flows did reach the highway. The majority of the debris flow scars, however, appear to be on upper slopes that drain into major channels, where the debris flows are incorporated in flood flows that reach the ocean after passing beneath one of the highway bridges.

CONCLUSION

Highway 1 traverses an area of diverse geologic materials between San Carpoforo Creek and Point Lobos. Rock units of the Salinian block and of the Franciscan Complex are juxtaposed along major faults and overlain by younger geologic units. Each rock unit has its characteristic weaknesses to weathering and erosion, ranging from chemical breakdown of some minerals in granitic rocks to weak shear zones that lead to instability of mountain-scale masses of rock. The types and abundance of landslides can be related to these characteristic weaknesses in the geologic units. A geologic map showing the distribution of the different materials is an important piece of data for any study relating to slope stability or erosion. We hope that the maps completed for this project will be used in continuing studies for the Coast Highway Management Plan and other studies related to the geology and landslide hazards of the Big Sur coast.

The geologic map presented with this report shows the distribution of bedrock geologic units as well as surficial units and landslides. We prepared this map by compilation of existing mapping, interpretation of aerial photographs, and field mapping. The bedrock geology shown is largely compiled from previous maps of the area. Existing maps were digitized, conflicts among them resolved and additional detail added. Surficial (Quaternary) geology and landslides are mainly original interpretations for this study. The landslide maps are based on original mapping in the majority of the study area, with revisions to existing mapping in the areas where previous mapping existed. The landslide map depicts the classification of each landslide by type, recency of activity, and our confidence of interpretation. Additional data on the material involved in the landslide and direction of movement is recorded for each landslide in a GIS database.

The potential for landslide damage to the Highway 1 along the Big Sur coast is concentrated in areas where several aspects of the geology and geography converge to make landslide movement more likely. South of Hurricane Point, wave erosion of weak rocks along the southwest side of Sierra Hill undermines harder but faulted and fractured rocks on a steep slope. In Big Sur, deeply weathered metamorphic rocks of the Sur complex are particularly susceptible to debris flows when heavy rains follow a wildfire. At Julia Pfeiffer Burns State Park, the charnockitic tonalite is probably the most landslide-resistant rock unit along the entire coast, but the steep slopes failed in response to the extraordinary rainfall of 1983. At Lucia, the rocks are so weak that the constant wave erosion at the base of the slopes and typical rainfall patterns are sufficient to cause sliding, but movement accelerates in response to heavy rainfall and has been triggered by an earthquake. South of Pacific Valley, numerous shear zones containing serpentinite cut the weak Franciscan melange. These exceptionally weak seams within an already weak rock lead to a concentration of large, active landslides second only to the Lucia area.

The 12 sections of the highway described in this report are based on similarities in the bedrock geology, slopes, and size, type, and activity of landslides, all of which relate to the overall potential for landsliding. The potential for landslide damage to the highway ranges from low in the Pacific Valley area to very high in the Lopez Point-Lucia area. Types and sizes of landslides range from small debris flows characteristic of the northern part of the area to the huge rock slides in the Lucia area. Although the complexity of the geology and the numbers of landslides within this corridor prevents us from providing any quantifiable estimate of the potential for movement of any particular landslide, this general description of the potential for landslides in the sections of the corridor may prove useful in deciding on areas that may warrant more detailed investigations.

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