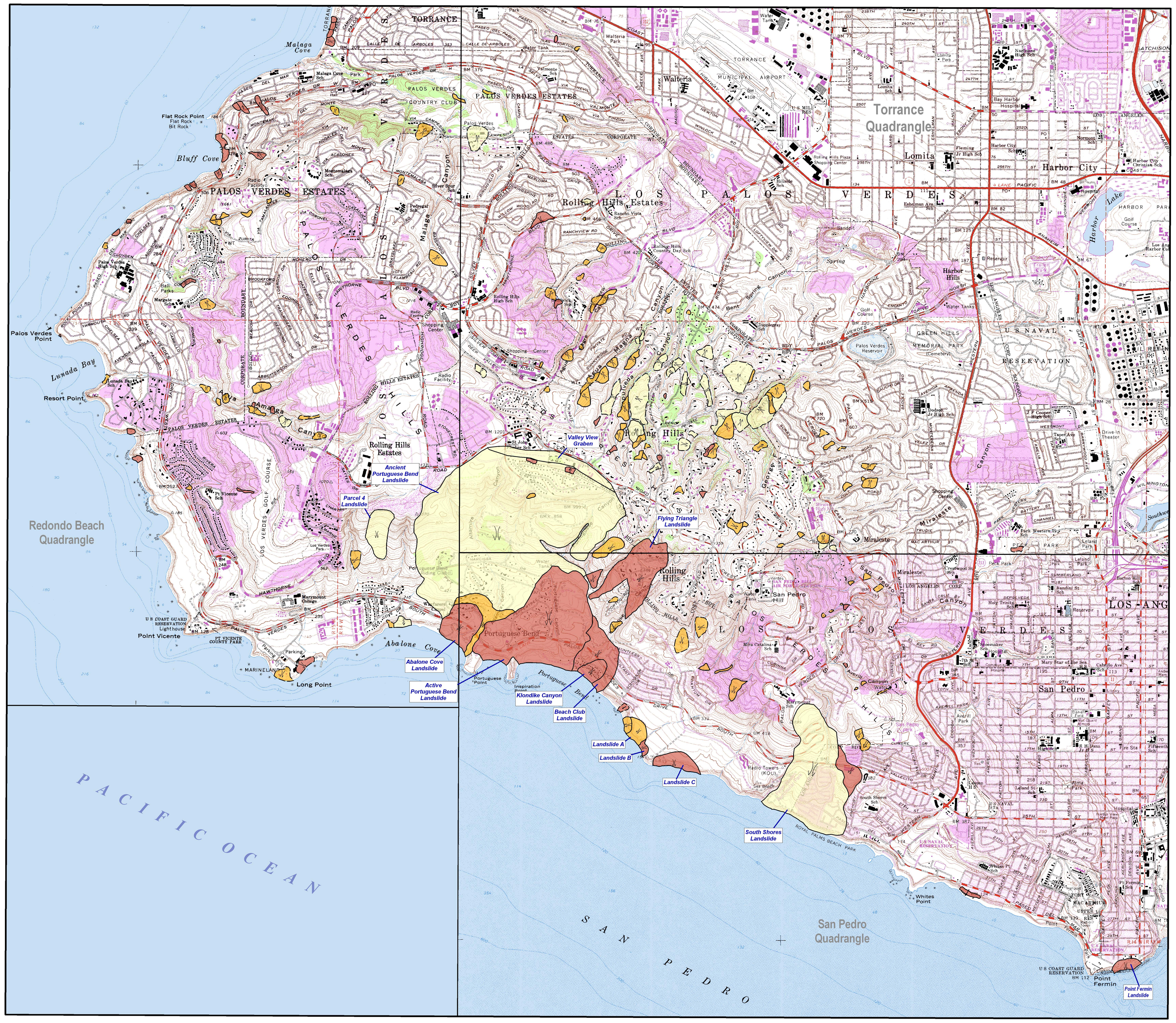
Landslide Inventory Map of the PALOS VERDES PENINSULA
Los Angeles County, California

Wayne D. Haydon



Digital representation by B. Wanish

NOTE: Basemap prepared by U.S. Geological Survey. Landslide boundaries may reflect updated digital topographic information that can differ significantly from the contours shown on this map. For basemap legend information see: http://permanent.access.gpo.gov/websites/ergusgsgov/erg.usgs.gov/isb/pubs/booklets/symbols/

Scale = 1:24,000

Miles: 0.0 0.5 1.0 1.5 2.0

Feet: 0.0 2000.0 4000.0 6000.0 8000.0

Kilometers: 0.0 0.4 0.8 1.2 1.6 2.0

Contour Interval = 20 feet

CALIFORNIA CONSERVATION

CGS CALIFORNIA GEOLOGICAL SURVEY

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California Geological Survey
Geologic Information and Publications
801 K Street, MS 14-34
Sacramento, CA 95814-3532
(916) 445-5716
www.conservation.ca.gov/cgs/geologic_hazards/landslides/

N E S W

Map Explanation

PURPOSE OF THIS MAP AND METHOD OF PREPARATION

This map presents an inventory of existing landslides of the Palos Verdes Peninsula. It was created by combining landslide inventories of the Redondo Beach, Torrance, and San Pedro quadrangles, which were prepared in 1997 as a part of the Seismic Hazard Zonation Program at the California Geological Survey (CGS; formerly the Division of Mines and Geology). The landslide inventory was one of the essential data layers used to delineate earthquake-induced landslide zones of required investigation in these three quadrangles (McMillan and Haydon, 1998a, b, and c). Because of its regulatory status, the Seismic Hazard Zone Map had a public review period and a date on which it became official. Unlike the zone map, this landslide inventory is not regulatory and revisions are allowed when new information regarding landslides is found. Therefore, it is possible that landslides shown on this map were not known when the zone map was prepared in 1998. In addition, new landslides identified after this map is published are likely to be included in later versions of this inventory. Ultimately, the landslides added to this and future inventory maps will be evaluated for inclusion in future revisions to the Seismic Hazard Zone Map.

The inventory map was prepared primarily by geomorphic analysis and interpretation of aerial photographs (the photographs used are listed in the References), and secondarily by field reconnaissance, interpretation of topographic map contours and review of previously published and unpublished geologic and landslide mapping. Landslides identified by these methods were digitally compiled at a scale of 1:24,000 on the U.S. Geological Survey topographic map and a number of characteristics (attributes) were recorded in an associated database. Several key characteristics have been extracted from the database and assigned symbology for visual representation on the map, as described below.

This landslide inventory map is intended to provide users with basic information regarding past occurrences of landslides within the Palos Verdes Peninsula. The geologic, terrain and climatic conditions that led to slope failures in the past may provide clues to the locations and conditions of future slope failures, and it is hoped that this map will provide useful information to guide site-specific investigations for future developments.

LANDSLIDE CLASSIFICATION

Each landslide shown on this map has been classified according to a number of specific characteristics identified at the time of its interpretation and recorded in a database. The classification scheme was developed by the CGS based on the terminology of Varnes (1978), Keaton and DeGraff (1996), Cruden and Varnes (1996), and Wieczorek (1984). Several significant landslide characteristics recorded in the database are portrayed with symbology on this map. The specific characteristics shown for each landslide are the activity or recency of landsliding, geologic material type that moved, type of landslide movement, direction of movement, and confidence of landslide interpretation. These landslide characteristics are determined primarily on the basis of geomorphic features, or landforms, observed for each landslide on stereo aerial photography, topographic maps and by field reconnaissance. The symbology used to display these characteristics is explained below.

LANDSLIDE ACTIVITY: Each landslide has been classified according to how recently the landslide last moved. The classification of landslide activity is primarily based on the system described by Keaton and DeGraff (1996). This map display uses color to show the activity.

ACTIVE or HISTORIC:
The landslide shows evidence of very recent movement (at the time the aerial photograph was taken or field observation occurred) or records show movement within historic time.

DORMANT:
The observed landforms related to the landslide are generally subdued by erosion and covered by vegetation, and there is no evidence of historic movement.

DORMANT - OLD:
The observed landforms related to the landslide have been greatly eroded, including significant gullies or canyons cut into the landslide mass and/or main scarp by small streams.

LANDSLIDE MATERIALS TYPES AND MOVEMENT: A two-part classification that records type of landslide material and type of landslide movement is displayed by arrow style. Material types recorded are either rock or soil, and soil is further subdivided into "earth" or "debris" on the basis of predominant particle grain size. There are five categories of landslide movement types: **slide, flow, fall, topple and spread**. These movement types are combined with material type to form the landslide classification. Not all combinations are common in nature, and only those that are recognized in the Palos Verdes Peninsula quadrangles are included here. Arrows are not displayed for landslides that encompass an area of less than 7000 square meters.

ROCK SLIDE
A landslide involving bedrock in which the rock that moves remains largely intact for at least a portion of the movement. Rock slides can range in size from small and thin to very large and thick, and are subject to a wide range of triggering mechanisms. The sliding occurs at the base of the rock mass along one to several relatively thin zones of weakness, which are variably referred to in engineering geology reports and literature as "slide planes," "shear surfaces," "slip surfaces," "rupture surfaces," or "failure surfaces." The sliding surface may be curved or planar in shape. Rock slides with curved sliding surfaces are commonly called "slumps" or "rotational slides," while those with planar failure surfaces are commonly called "translational slides," "block slides," or "block glides." Rock slides that occur on intersecting planar surfaces are commonly called "wedge failures."

ROCK FALL
A landslide where a mass of rock detaches from a steep slope by minor spreading or toppling and descends mainly through the air by falling, bouncing or rolling. Intense rain, earthquakes or freeze-thaw wedging may trigger this type of movement.

SOIL SLIDE
A landslide generally composed of combinations of soil, surficial deposits, rock fragments and vegetation, including both natural deposits and fills created by the activities of man. Soils slides are called **Earth Slides** if composed of predominantly fine-grained materials (silts and clays), or **Debris Slides** if composed of predominantly coarse-grained materials (fine sand to boulders). Sliding typically occurs along a basal low-strength zone at the soil-rock interface, at the base of a fill, in highly weathered rock, at the base of the vegetation root zone, or in some other weak zone in the soil mass. Soil slides typically move as shallow intact slabs of soil and vegetation, but may break up and flow after short distances.

EARTH FLOW
A specific type of **Soil Flow** landslide where the majority of the soil materials are fine-grained (silt and clay) and cohesive. Earth flows are typically initiated by periods of prolonged rainfall. They are characteristically slow moving and may continue to move for a period of days to weeks after initiating. Although an earth flow may have a main slide plane at its base, in larger landslides of this type sliding occurs on many discontinuous shear surfaces throughout the landslide mass, leading to a surface expression that resembles the flow of a viscous liquid.

CONFIDENCE OF INTERPRETATION: Each landslide is classified according to a "confidence" that the geologic interpreter assigns to it, and can be regarded as a measure of the likelihood that the landslide actually exists. Landslides are mapped on the basis of characteristic landforms, and the confidence of interpretation is based on the distinctness of those landforms. As a landslide ages after its last movement, erosional processes remove or cover the landforms that formed by landsliding. With time, these distinctive landforms become so subtle that they resemble landforms produced by geologic processes and conditions unrelated to landsliding. The visual display of this landslide characteristic is through the use of different line styles.

DEFINITE:
Landslide exhibits many of the diagnostic landforms, including, but not limited to, prominent scarps, open cracks, rounded toes, offset streams, well-defined mid-slope benches, closed depressions, springs, and irregular or hummocky topography; or has clear records of prehistoric, historic or ongoing activity from reports, aerial photography or instrumental monitoring.

PROBABLE:
Landslide exhibits several of the diagnostic landforms commonly associated with landslides. These landforms may be modified by erosion or obscured by vegetation such that other explanations are possible. However, the preponderance of evidence strongly suggests that a landslide does exist.

QUESTIONABLE:
Landslide exhibits only one or a few of the diagnostic landforms associated with landslides. The landforms may be heavily modified by erosion, altered by grading, obscured by dense vegetation, or formed by other geologic processes such as differential erosion of lithologic and structural features in the underlying bedrock.

BOUNDARY OF USGS QUADRANGLES

GEOLOGY AND LANDSLIDES OF THE PALOS VERDES PENINSULA

The Palos Verdes Hills form a northwest-southeast-trending dome-like ridge extending from the northwest to the southeast corner of the Palos Verdes Peninsula. Along the western and southwestern coast, the landscape is dominated by a series of stair step-like Pleistocene wave-cut marine terraces, which are dissected and deeply incised by streams. Along the coast, waves have eroded very steep to nearly vertical cliffs above narrow and discontinuous beaches.

The Palos Verdes Peninsula is underlain primarily by sedimentary and volcanic rocks of the middle to upper Miocene Monterey Formation, which is divided into two members - Altimira Shale and Valmonte Diatomite (Saucedo and others, 2003). The Altimira Shale member is divided into three lithofacies: tuffaceous, cherty, and phosphatic (Conrad and Ehlig, 1983). The tuffaceous lithofacies is the most areally extensive and the most important unit from a slope stability standpoint. The remainder of the uplands is underlain by the Mesozoic Catalina Schist, upper Miocene to lower Pliocene Malaga Mudstone, lower Pliocene to Pleistocene sedimentary rocks including the Repetto Formation, San Pedro Sand, Lomita Marl and Timms Point Silt, and marine and non-marine terrace deposits. Other Quaternary units include modern beach sand, landslide deposits, Holocene alluvial fan and dune deposits, and artificial fill.

Structurally, the Palos Verdes Peninsula is dominated by a large, broad northwest-southeast-trending doubly plunging anticlinorium and the Palos Verdes Fault. The Palos Verdes Fault is part of a system of right-lateral strike-slip faults that extends over 125 miles southeast from Palos Verdes. At San Pedro the fault bends left by nearly 30 degrees, leading to compression across the restraining bend in the fault system. The anticlinorium of the peninsula has been uplifted along a southwest dipping section of the Palos Verdes Fault within this restraining bend (Yeats, 2001). The axis of the anticlinorium forms a concave-to-the-southwest arc extending from the northwest to the southeast corner of the peninsula, roughly following the crest of the Palos Verdes Hills. Strata on the flanks of the anticlinorium generally dip less than 20 degrees. Additionally, there are a series of broad, northwest-southeast-trending anticlines and synclines in the southeastern half of the peninsula and a number of east-west, southwest, and northwest-trending synclines and anticlines in the western part of the peninsula. Bedding dips on the flanks of these structures range between 5 and 35, and locally up to 80 degrees. These folds are likely undulations in the general anticlinal structure of the Palos Verdes Peninsula.

Landslide occurrence is controlled by geologic structure and the areal distribution of susceptible geologic formations. The tuffaceous lithofacies of the Altimira Shale hosts the largest and highest density of mapped landslides on the peninsula. These include the large, destructive and well-known Portuguese Bend, Abalone Cove, Flying Triangle, Klondike Canyon, Beach Club, South Shores and Point Fermin landslides. These large landslides have been classified as historically active and dormant rock slides with complex movement modes, typically translational and rotational in different portions of the landslides, and the lower parts often fail as earth flows. They are situated on the southwestern and seaward-dipping flank of the doubly plunging anticlinorium, and are, therefore, dip-slope slides. The slide planes have been interpreted by many researchers as occurring on dipping tuff beds, which have been altered to low-strength and highly expansive montmorillonite-bentonite. The initiation of landslide movement is likely related to the tuffs acting as aquatards, allowing the accumulation of groundwater above the tuff, and the loss of support at the toe of the landslides caused by wave-induced coastal erosion (see Haydon, 2007 for a list of pertinent references).

Small- to moderate-size landslides are scattered across the Palos Verdes Peninsula, primarily occurring as rock slides and rock falls along steep-sided drainages and sea cliffs. Catalina Schist is locally susceptible to landslides, with moderate-size rock slides and an earth flow covering about half of its small outcrop area. Some of the rock slides failed along foliation planes. Small - to moderate-size rock slides and rock falls also occur in the tuffaceous and phosphatic lithofacies of the Altimira Shale. Most of the limited sea cliff outcrop area of the Malaga Mudstone in the northwest has failed as rock slides and rock falls. Only two small landslides are mapped on the terraces. However, a number of landslides are adjacent to the terraces and have likely disrupted them.

Very few, if any, landslides occur in the cherty lithofacies of the Altimira Shale, Valmonte Diatomite, Repetto Formation, Lomita Marl, San Pedro Sand, or Timms Point Silt. The lack of landslides is likely related to the relatively smaller outcrop area, general lack of tuff beds, and the exposures occurring on mostly gentle to moderately steep slopes.

LIMITATIONS

The landslides shown on this map were interpreted from smal l-to intermediate-scale aerial photography (1:40,000 to 1:24,000 scales) and were then located on a 1:24,000 scale topographical map. Identifying landslides smaller than about 60 meters (~200 feet) in maximum dimension is often difficult at these photo scales, and accurately locating them on the topographic base map can present additional challenges. Debris flows, in particular, often fall into this size category. As a result, landslides this size or smaller are not routinely included in the landslide inventories. CGS sometimes includes small landslides if they are provided by a local governmental agency, a site- or area-specific study report, or a local area landslide expert, and are found to be accurately located. However, it should be noted that when displayed at a scale of 1:24,000 such as on this map, small landslides are often indistinguishable from features on the base map.

It can be expected that the geological interpreter will not recognize some landslides as a result of air photo quality, scale, vintage, sun angle, vegetation, cloud cover, or other characteristics. The geologist's experience level and experience with landslides in the immediate area also play a role in the quality of the inventory map. CGS addresses these problems by having the geologist interpret multiple sets of aerial photographs, review previously prepared maps, visit areas of suspected landsliding, and by incorporating an internal peer review process.

Earthworks related to development on hillsides usually remove the geomorphic expressions of past landsliding, which can result in landslides being missed in the inventory. This limitation can sometimes be addressed by viewing aerial photographs that pre-date development. However, because CGS does not review or monitor grading practices to ensure that past slope failures have been adequately mitigated, slope failures identified on the pre-development photographs are included in the landslide inventory, whether or not surface expression currently exists.

One difference between the landslides shown on this map and those shown on a geologic map lies in the treatment of the main scarps or landslide source areas associated with slope failures. Geologic maps show landslide deposits; landslide scarps are not included with the landslide, but rather with the underlying geologic materials. This map, in contrast, includes the scarp areas associated with the landslide deposits because these areas are considered prone to future slope failures.

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