

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science Directorate
Geologic Resources Division



John Muir National Historic Site

GRI Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory (GRI) Digital Geologic Data for John Muir National Historic Site

jomu_geology.pdf

Version: 2/17/2022

Geologic Resources Inventory Map Document for John Muir National Historic Site

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Geologic Resources Inventory Map Document



John Muir National Historic Site, California

Document to Accompany Digital Geologic-GIS Data

[jomu_geology.pdf](#)

Version: 2/17/2022

This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for John Muir National Historic Site, California (JOMU).

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

This document contains the following information:

- 1) **About the NPS Geologic Resources Inventory Program** – A brief summary of the Geologic Resources Inventory (GRI) Program and its products. Included are web links to the GRI GIS data model, and to the GRI products page where digital geologic-GIS datasets, scoping reports and geology reports are available for download. In addition, web links to the NPS Data Store and GRI program home page, as well as contact information for the GRI coordinator, are also present.
- 2) **GRI Digital Maps and Source Citations** – A listing of the GRI digital geologic-GIS map and GRI digital geohazards-GIS map produced for this project along with sources used in their completion. In addition, a brief explanation of how each source map was used is provided.
- 3) **Digital Geologic-GIS Map of John Muir National Historic Site and Vicinity**
 - a) **Map Unit List** – A listing of all geologic map units present in the GRI digital geologic-GIS data.
 - b) **Map Unit Descriptions** – Descriptions for all geologic map units present in the GRI digital geologic-GIS data. Included with the unit descriptions is information pertaining to soils, as well as slope stability.
- 4) **Digital Geologic-GIS Map of John Muir National Historic Site and Vicinity**
 - a) **Slope-Failure Features** – Information pertaining to slope-failure features present in the GRI digital geologic-GIS data.
 - b) **Relative Landslide Susceptibility** – Information pertaining to landslide susceptibility features present in the GRI digital geohazards-GIS data.
 - c) **Relative Debris-Flow Susceptibility** – Information pertaining to debris-flow susceptibility features present in the GRI digital geohazards-GIS data.

- 5) **Ancillary Source Map Information** – Additional source map information presented by source map.
- 6) **GRI Digital Data Credits** – GRI digital geologic-GIS data and ancillary map information document production credits.

For information about using GRI digital geologic-GIS data contact:

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About the NPS Geologic Resources Inventory Program

Background

The Geologic Resources Inventory (GRI) provides geologic map data and pertinent geologic information to support resource management and science-informed decision making in more than 270 natural resource parks throughout the National Park System. Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The GRI is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The Geologic Resources Division of the NPS Natural Resource Stewardship and Science Directorate administers the GRI. The NPS Geologic Resources Division partners with the Colorado State University Department of Geosciences to produce GRI products. Many additional partners participate in the GRI process by contributing source maps or reviewing products.

The GRI team undertakes three tasks for each park in the Inventory and Monitoring program: (1) conduct a scoping meeting and provide a summary document, (2) provide digital geologic map data in a geographic information system (GIS) format, and (3) provide a GRI report. These products are designed and written for nongeoscientists.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: <https://www.nps.gov/articles/gri-geodatabase-model.htm>

Geologic Reports: GRI reports synthesize discussions from the original scoping meeting, follow up conference call(s), and subsequent research. Chapters of each report discuss the geologic setting of the park, distinctive geologic features and processes within the park, highlight geologic issues facing resource managers, and describe the geologic history leading to the present-day landscape. Each report also includes a poster illustrating these GRI digital geologic-GIS data.

For a complete listing of GRI products visit the GRI publications webpage: <https://go.nps.gov/gripubs>. GRI digital geologic-GIS data is also available online at the NPS Data Store: <https://irma.nps.gov/DataStore/Search/Quick>. To find GRI data for a specific park or parks select the appropriate park(s), enter "GRI" as a Search Text term, and then select the Search button.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: <https://>

www.nps.gov/subjects/geology/gri.htm. At the bottom of that webpage is a “Contact Us” link if you need additional information. You may also directly contact the program coordinator:

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The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) Division. Learn more about I&M and the 12 baseline inventories at the I&M webpage: <https://www.nps.gov/im/inventories.htm>.

GRI Digital Maps and Source Map Citations

The GRI digital geologic-GIS maps for John Muir National Historic Site, California (JOMU) are presented below.

Digital Geologic-GIS Map of John Muir National Historic Site and Vicinity, California (GRI MapCode JOMU)

The above geologic map was produced using the following source maps. The full extent of each source map was used, and all geologic features within these extents were captured.

Boucher, Kean, 1990, Status of the Oil and Gas Wells within the John Muir National Historic Site Expansion Area: Geologic Resources Division Reading File, National Park Service, scale 1:24,000 ([Status of the Oil and Gas Wells \(John Muir National Historic Site Expansion Area\)](#)). (GRI Source Map ID 75005).

Haydon, Wayne D., 1995, Geologic Map, Landslide Hazard Identification Map No.32: California Department of Conservation, Division of Mines and Geology, Open-File Report OFR 95-12, plate 32C, scale 1:24,000 ([Geologic Map \(Map No.32\)](#)). (GRI Source Map ID 46594).

Digital Geohazards-GIS Map of John Muir National Historic Site and Vicinity, California (GRI MapCode JOMU_geohazard)

The above geohazards map was produced using the following source maps. The full extent of each source map was used, and all geohazard features within these extents were captured.

Haydon, Wayne D., 1995, Relative Landslide Susceptibility Map, Landslide Hazard Identification Map No.32: California Department of Conservation, Division of Mines and Geology, Open-File Report OFR 95-12, plate 32A, scale 1:24,000 ([Relative Landslide Susceptibility Map \(Map No.32\)](#)). (GRI Source Map ID 46591).

Haydon, Wayne D., 1995, Landslide and Related Slope-Failure Features Map, Landslide Hazard Identification Map No.32: California Department of Conservation, Division of Mines and Geology, Open-File Report OFR 95-12, plate 32B, scale 1:24,000 ([Landslide and Related Slope-Failure Features Map \(Map No.32\)](#)). (GRI Source Map ID 46592).

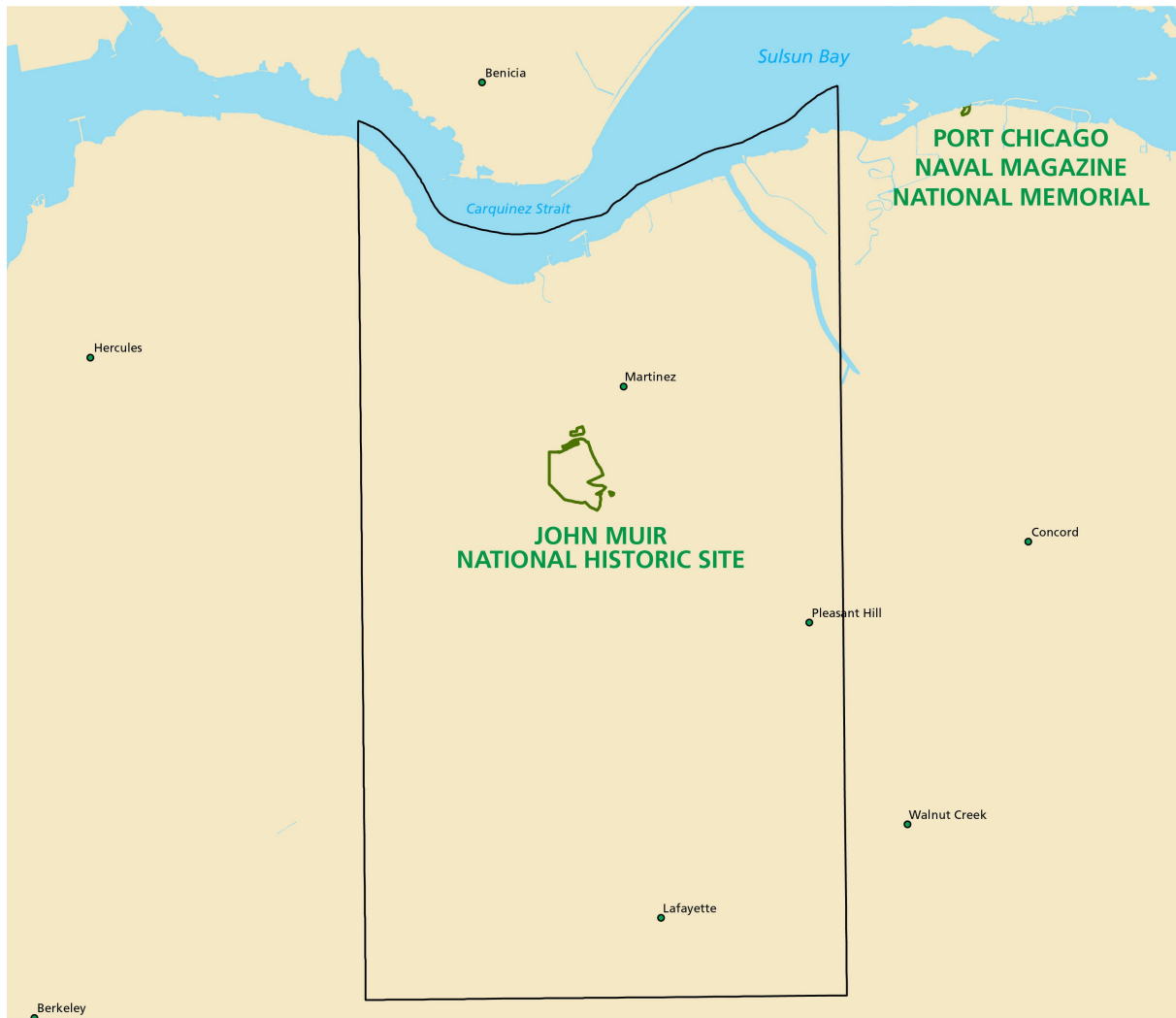
Haydon, Wayne D., 1995, Relative Debris-Flow Susceptibility Map, Landslide Hazard Identification Map No.32: California Department of Conservation, Division of Mines and Geology, Open-File Report OFR 95-12, plate 32D, scale 1:24,000 ([Relative Debris-Flow Susceptibility Map \(Map No.32\)](#)). (GRI Source Map ID 46593).

Information pertaining to landslide susceptibility, slope-failure features and debris-flow susceptibility, present in the GRI digital geohazards-GIS data, is presented in the [Relative Landslide Susceptibility](#), [Slope-Failure Features](#), and [Relative Debris-Flow Susceptibility](#) sections, respectively, of this document. Information related to geologic map units and slope stability is also presented in the [Map Unit Descriptions](#) section of this document.

Additional information pertaining to all source maps is presented in the GRI Source Map Information (JOMUMAP) table included with the GRI digital geologic-GIS and GRI digital geohazards-GIS data.

Index Map

The following index map displays the extent (outlined in black) of the GRI digital geologic-GIS maps produced for John Muir National Historic Site (JOMU). The boundary for John Muir National Historic Site (as of February, 2022) is outlined in green.



Index map by Stephanie O'Meara (Colorado State University).

Digital Geologic-GIS Map of John Muir National Historic Site and Vicinity

The following information, a map unit listing and map unit descriptions, relevant to the GRI Digital Geologic-GIS Map of John Muir National Historic Site and Vicinity, is presented below.

Map Unit List

The geologic units present in the digital geologic-GIS data produced for John Muir National Historic Site, California (JOMU) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., cf - Cut and fill). Units are listed from youngest to oldest. No description for water is provided. Information about each geologic unit is also presented in the GRI Geologic Unit Information (JOMUUNIT) table included with the GRI digital geologic-GIS data.

Cenozoic Era

Historic

[cf](#) - Cut and fill

[fm](#) - Filled marshlands

Quaternary Period

[Qbm](#) - Bay mud

[Qal](#) - Younger alluvium

[Qoal](#) - Older alluvium

[Qls](#) - Landslides

Tertiary Period

Mulholland Formation

[Tcmu](#) - Mulholland Formation, upper member

[Tcml](#) - Mulholland Formation, lower member

[Tco](#) - Orinda Formation

[Tpn](#) - Neroly Formation

Briones Sandstone

[Tpbu](#) - Briones Sandstone, upper member

[Tpbl](#) - Briones Sandstone, lower member

[Tmr](#) - Rodeo Shale

[Tmh](#) - Hambre Sandstone

[Tmt](#) - Tice Shale

[Tmo](#) - Oursan Sandstone

[Tms](#) - Sobrante Sandstone

[Tsr](#) - San Ramon Sandstone

[Tem](#) - Markley Formation

[Ten](#) - Nortonville Shale

[Ted](#) - Domengine Sandstone

[Tec](#) - Unnamed Claystone

Meganos Formation

[Tmgu](#) - Meganos Formation, upper member

[Tmgl](#) - Meganos Formation, lower member

Martinez Formation

[Tmz](#) - Martinez Formation, undifferentiated

[Tmzu](#) - Martinez Formation, upper member

[Tmzl](#) - Martinez Formation, lower member

Mesozoic Era

Cretaceous Period

[Ku](#) - Great Valley Sequence, undifferentiated

[Kcs](#) - Great Valley Sequence, sandstone

[Kus](#) - Great Valley Sequence, interbedded

[Kuh](#) - Great Valley Sequence, sandstone with minor clay shale

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below. All geologic unit descriptions were taken from source map [Geologic Map \(Map No.32\)](#). Included with the unit descriptions is information pertaining to soils, as well as slope stability. This information was also taken from source map [Geologic Map \(Map No.32\)](#).

cf - Cut and fill (Historic)

Lithology

Historic. In cuts, lithology should reflect unit descriptions. Fill is likely to be variable in composition and engineering characteristics.

Topography, Structure and Vegetation

Variable, see unit descriptions. Cut and fill areas are mapped where the natural ground surface has been greatly modified and the natural materials have been disturbed, rearranged, and/or removed by grading, filling, or quarrying so as to significantly alter the natural slopes. Generally indicated only in uplands or in flatlands where a specific development extends across flatlands from flanking upland areas. On the Geologic Map, only the large embankment dams are shown to avoid obscuring the predevelopment areal distribution of geologic units. The cut and fill areas depicted on the landslide inventory and susceptibility maps include large residential subdivisions and highway cuts and fills.

Soils

Variable. May include reworked native soils as in unit description or imported fill from various sources.

Slope Stability

Landslide Density, Type and Size

Variable, but generally rare. See unit descriptions. Landslides identified on predevelopment aerial photographs are shown in cut and fill areas.

Slope Aspect, Soil, Vegetation and Structural Relationship

Variable, see unit descriptions.

Landslide Susceptibility Rating

Slope stability not evaluated in these areas, however stability of natural materials can be inferred from information provided in the unit descriptions.

Debris Flows

Variable, see unit descriptions. Debris flows identified on predevelopment aerial photographs are shown in cut and fill areas.

fm - Filled Marshlands (Historic)

Lithology

Historic. Portions of San Francisco Bay filled since approximately 1850. Lithology, engineering and slope stability characteristics similar to bay mud.

Topography, Structure and Vegetation

Exists today primarily as marshlands. Filled marshlands subject to flooding at high tide. Slopes are less than or equal to 2 percent (1.5 degrees) and elevation generally ranges from 0 to 5 feet.

Soils

Variable, soils similar to bay mud.

Slope Stability

Landslide Density, Type and Size

No landslides identified.

Slope, Aspect, Soils, Vegetation and Structural Relationship

No landslides identified.

Landslide Susceptibility Rating

Slope stability not evaluated in these areas. Probably similar to bay mud.

Debris Flows

Debris flow susceptibility not evaluated in these areas. Probably similar to bay mud.

Qbm - Bay mud (Holocene)

Lithology

Holocene. Clay and silty clay with high organic-matter content. Contains fine sand and peat in lenses and pockets. Dark brown and black, dark grey, grey-brown, and black. Unconsolidated.

Topography, Structure and Vegetation

Forms flatlands in brackish and salt water marshes, and in the lower flood plains of Grayson, Pachaeo and Walnut creeks. Slopes are less than or equal to 2 percent (1.5 degrees) and elevation generally ranges from 0 to 5 feet.

Soils

Surficial soils are mapped as inorganic and organic clay, silty clay, silts and peat. The Unified Soil Classifications are CL, OH, MH, and PT. Clays are of medium to high plasticity and are highly expansive. Silts are of low to medium plasticity. Peats are nonplastic and shrink irreversibly when dried. All soils have low shear strength and low permeability. Soils are nonerosive in natural settings because of shallow slope, and moderately to highly erosive in cuts. Groundwater is generally at a depth of less than or equal to 5 feet. The bay mud generally lies within 100-year floodplain.

Slope Stability

Landslide Density, Type and Size

No landslides identified.

Slope, Aspect, Soil, Vegetation and Structural Relationship

No landslides identified.

Landslide Susceptibility Rating

Lack of landslides is presumably because outcrop area has very gentle slopes. However, bay mud is known to have very low strength and to be susceptible to flowage and lateral movement at slopes of less than or equal to 2 percent (1.5 degrees) and liquefaction. Slope stability of the bay mud is low, but this unit is in the Marginally Susceptible Area, Subarea 2.1. This rating is based more on the gentleness of the slope rather than the strength of the materials. Bay mud is subject to slope failure when undercut, excavated, or subjected to differential loading, especially at margins of tidal channels.

Debris Flows

Debris flow susceptibility is judged to be nil and this unit is in the Least Susceptible Area, based on the gentleness of the slopes. However, a risk from debris flow runout exist were unit is below steep, susceptible slopes.

Qal - Younger alluvium (Holocene and Pleistocene)

Lithology

Holocene-Late Pleistocene. Sand, silt, clayey silt, sandy or gravelly clay and clay with occasional sand and gravel in lenses, pockets and interbeds, gravel becoming more abundant toward fan heads and in narrow canyons. Dark gray, gray-brown, dark brown, black and occasionally brown or yellow-brown at depth. Well to poorly bedded and unconsolidated.

Topography, Structure and Vegetation

Forms level to gently sloping terrain on the active levees, alluvial fans and floodplains of Ygnacio, Alhambra and Martinez valleys, and along small creeks in upland valleys. Deposited by streams primarily during floods. Also includes some of the thicker colluvium and slopewash deposits in the uplands. Slopes are less than or equal to 5 percent (3 degrees) in the alluvial areas with limited local areas up to 20 percent (11 degrees) on the colluvium and slopewash.

The Martinez Valley from the filled marshlands south to approximately the intersection of Alhambra Avenue and Alhambra Valley Road lies within the "100-year" floodplain.

Soils

Surficial soils are mapped as clay, silt and silty clay. The Unified Soil Classifications are CL, ML, and CL-ML. Clays are of medium to high plasticity, and are moderately to highly expansive. Silt and silty clay are of low to medium plasticity and slightly to moderately expansive. Soils are of medium to low shear strength. Clay and silty clay have low to moderately low permeability, and silts are of moderate permeability. Soils are non to slightly erosive in natural settings because of gentle slope, and are moderately to highly erosive in cuts.

Slope Stability

Landslide Density, Type and Size

Landslides are rare.

Landslides are less than or equal to 1 acre soil slumps or slides.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides occur along stream banks and in the colluvium accumulated in first-order drainages with slopes of less than or equal to 15 percent (8.5 degrees). Few slumps and slides on adjacent rock slopes encroach on alluvium.

Landslide Susceptibility Rating

Lack of landslides presumably because outcrop area has gentle slopes. Younger alluvium is subject to slope failure when undercut, excavated, or subjected to differential loading, especially along stream channels. Slope stability of the younger alluvium is high in natural settings and is in the Least Susceptible Area. This rating is based more on the gentleness of the slopes rather than on the strength of the materials.

Debris Flows

Debris flow susceptibility is judged to be nil. This unit is in the Least Susceptible Area, based on the gentleness of the slopes. However, a debris-flow runout risk exists where unit is below steep, susceptible slope.

Qoal - Older alluvium (Holocene and late Pleistocene)

Lithology

Early Holocene-Pleistocene. Clay, sand, silt, sand and gravel. Dark grey, grey-brown, brown, red-brown and yellow brown. Weakly consolidated and irregularly bedded.

Topography, Structure and Vegetation

Forms level to rolling terrain on abandoned levees and floodplains of sedimentary terraces on the west side of Ygnacio Valley, on dissected older alluvial fans, dissected abandoned floodplains in small upland valleys and on abandoned upland sedimentary terraces. Deposited by streams primarily during floods. Slopes are primarily less than or equal to 15 percent (8.5 degrees) with limited areas up to 30 percent (17 degrees).

Soils

Surficial soils are mapped as clay and silty clay. The Unified Soil Classifications are CL and CL-ML. Clays are of low to high plasticity, and are slightly to highly expansive. Silty clays are of low to medium

plasticity and slightly to moderately expansive. Soils are of medium to low shear strength, with low to moderately low permeability. Non to slightly erosive on less than or equal to 10 percent (6 degrees) slopes, moderately on slopes of 10 to 15 percent (6 to 8.5 degrees), and highly erosive on slopes greater than or equal to 15 percent (8.5 degrees).

Slope Stability

Landslide Density, Type and Size

Landslides are rare.

Landslides are less than or equal to 1 to 2 acre soil slumps or slides.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides occur in heads of first-order drainages and along stream banks, in the limited areas with slopes of greater than or equal to 20 percent (11 degrees). Few slumps and slides on adjacent bedrock slopes encroach on older alluvium.

Landslide Susceptibility Rating

Unit is subject to slope failure when undercut, excavated, or subjected to differential loading, especially along stream channels. Slope stability is moderate in natural settings and the unit is in the Least Susceptible Area where on less than or equal to 15 percent (8.5 degrees) slopes. Unit is in the Marginally Susceptible Area with greater than or equal to 15 percent (8.5 degrees) slopes.

Debris Flows

Debris flow susceptibility is judged to be nil and this unit is in the Least Susceptible Area, based on the gentleness of the slopes. However, a risk from debris-flow runout exist were unit is below steep, susceptible slopes.

QIs - Landslides (Holocene and Pleistocene)

Lithology

Holocene-Pleistocene. Mixtures of rock fragments, soil and debris derived from adjacent and underlying geologic units. On Geologic Map only shown where underlying geologic relations are obscured. Landslide Inventory Map shows all identified landslides.

Topography, Structure and Vegetation

Variable, see unit descriptions.

Soils

Variable, see unit descriptions.

Slope Stability

Landslide Density, Type and Size

Variable, see unit descriptions

Slope, Aspect, Soil, Vegetation and Structural Relationship

Variable, see unit descriptions

Landslide Susceptibility Rating

Active landslides likely to continue movement, and inactive landslides can be reactivated if conditions are altered. Landslide crowns, flanks and deposits are generally less stable than surrounding materials of similar composition because of lack of lateral support and disrupted nature with accompanying cracks, fractures and voids. Small slumps and slides, and gullies have developed on some of the larger active and inactive slides. Slope stability of the landslides is poor and the unit is in the Generally to Most Susceptible Area. On the Landslide Susceptibility Map, landslides were not assigned a separate susceptibility rating from surrounding areas.

Debris Flows

Debris flow susceptibility is judged to be moderate to high and the landslides have been assigned to the Marginally and Most Susceptible Areas. The rating is based on the slope and general debris-flow susceptibility of the underlying formation. Susceptibility appears to be greatest on the oversteepened crowns and scarps.

Mulholland Formation

Tcmu - Mulholland Formation, upper member (upper Miocene)

Lithology

Upper Miocene, nonmarine-continental.

Sandstone: Light gray where fresh, weathers light yellow-gray. Sand fine to coarse grained, cross bedded, and feldspathic. Trace shell fragments locally. Intensely to moderately fractured, low to moderate hardness, strong to locally friable.

Conglomerate: Gray where fresh, weathers to red brown. Sand fine to coarse grained, gravel well rounded with fine to coarse grained sand matrix. Very thick bedded, very little fractured, gravel hard, matrix moderately hard, unit mostly strong, moderately weathered.

Andesite: Gray, hard, moderately strong.

Mudstone: Gray-green and blue-gray, massive, low hardness, weak.

Topography, Structure, and Vegetation

Forms smooth, rounded hills and drainages with slopes between 20 and 50 percent (11 and 27 degrees). Dips are about 40 degrees. Locally, slightly higher proportion of steeper slopes on anti-dip slopes.

Vegetation is primarily grass with local wooded areas.

Soils

Surficial soils are mapped as clay, but are somewhat sandy on the sandstones and gravelly on the conglomerates. The Unified Soil Classification is CL. Clays are highly plastic and expansive, have low to moderate shear strength, and are moderately to highly erosive.

Slope Stability

Landslide Density, Type and Size

Landslides are moderately common. Landslide type and size are:

*very small soil slumps in grassland are moderately common.

*5 to 7 acre soil and weathered rock slump/slides, which extend out of the study area are moderately common.

Slope, Aspect, Soils, Vegetation and Structural Relationship

Landslides of all sizes generally occur on grass-covered, north-facing slopes of greater than or equal to 30 percent (17 degrees), and occur equally on grassland and woodland. The very small landslides occur in the shallow surficial soil and the 5 to 7 acre landslides generally have slide planes that extend into the less weathered and fractured rock.

Dip-angles exceed slope angles. Bedrock landslides are more abundant on anti-dip slopes than dip-slopes.

Landslide Susceptibility Rating

Unit does not appear to be susceptible to dip-slope landslides, but is more prone to anti-dip slope failures. Rock slope stability appears to be related more to the attitude of fractures parallel to anti-dip slopes, rather than the bedding planes. Slope stability of the rock and surficial soil is moderate to poor and the unit is in the Generally to Most Susceptible Area.

Rockfall hazard is judged to be low because of the generally gentle slopes, and lack of outcrops.

Debris Flows

No debris flows identified. The lack of mapped debris-flows may be the result of the plastic and highly expansive, nonsusceptible soils, and slopes of <50 percent (27 degrees). Debris-flow susceptibility is judged to be moderate and the unit is in the Marginally Susceptible Area.

Tcml - Mulholland Formation, lower member (upper Miocene)

Lithology

Upper Miocene, nonmarine-continental.

Sandstone: Light gray where fresh, weathers light yellow-gray. Sand medium grained, and ripple marked. Intensely to moderately fractured, low to moderate hardness, strong to locally friable.

Claystone: Gray and blue-gray, thin bedded, low hardness, weak.

Topography, Structure, and Vegetation

Forms smooth rounded hills, strike ridges, and drainages with slopes between 20 and 50 percent (11 and 27 degrees). Dips

are about 40 degrees. Locally, slightly higher proportion of steeper slopes on anti-dip slopes. North-facing slopes are generally wooded or brushy, while south facing slopes are grassland.

Soils

Surficial soils are mapped as clay. The Unified Soil Classification is CL. In the western exposures, soils

are highly plastic and expansive, and moderately erosive. In the eastern exposures, soils are moderately plastic and expansive, and moderately to highly erosive. Soils are of low to moderate shear strength.

Slope Stability

Landslide Density, Type and Size

Landslides are moderately common.

Landslide type and size are:

- *less than or equal to 1 acre or very small soil slumps or slides are moderately common.

- *one, 8 acre soil and weathered rock slump/slide, coalescing on a drainage and adjacent planar slopes.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides generally occur on north-facing slopes of greater than or equal to 30 percent (17 degrees), and are more common on wooded or brushy slopes. The less than or equal to 1 acre landslides occur in the shallow surficial soil and the slide plane of the 8 acre landslide extends into the weathered rock.

Dip angles exceed slope angles. Bedrock landslides are most abundant on anti-dip slopes.

Landslide Susceptibility Rating

Unit does not appear to be susceptible to dip-slope landslides, but is more prone to anti-dip slope failures. Rock slope stability appears to be related more to the attitude of fractures parallel to anti-dip slopes, rather than the bedding planes. Slope stability of the rock and surficial soil is moderate to poor and the unit is the Marginally to Most Susceptible Area.

Rockfall hazard is judged to be low because of the generally gentle slopes, and lack of outcrops.

Debris Flows

No debris flows identified. The lack of mapped debris-flows may be the result of the plastic and highly expansive, nonsusceptible soils, and slopes of <50 percent (27 degrees). Debris-flow susceptibility is judged to be moderate and the unit is in the Marginally Susceptible Area.

Tco - Orinda Formation (upper Miocene)

Lithology

Upper Miocene, nonmarine.

Sandstone: Light gray where fresh, weathers light yellow-gray. Light and dark grains imparts "salt and pepper" appearance. Sand is fine with trace to little medium grained. Poorly cemented, intensely fractured, low hardness, friable.

Gravelly sandstone: Gray where fresh, weathers to red-brown. Sand is well rounded, fine to coarse grained with trace to little fine gravel, gravel clasts are sand matrix supported. Moderately hard, moderately strong to weak, moderately weathered.

Sandstone: Light gray where fresh, weathers red-brown. Sand is fine to medium grained with trace to little coarse sand in lenses, and fine to coarse sand. Trace shell fragments locally. Moderately to well cemented, moderately fractured, moderately hard, moderately strong to strong.

Conglomerate: Gray where fresh, weathers to red brown. Sand is fine to coarse grained. Gravel is well rounded. Matrix is fine to coarse sand, locally with trace to little shell fragments but in places between 30 and 50 percent shell fragments.

Very thick-bedded, very little fractured, gravel hard, moderately hard matrix, strong, moderate weathered. Some conglomerate has matrix of low hardness, weak and friable.

Andesite: Gray, hard, moderately strong. Exposed only in small area around Lafayette.

Clay Shale: Gray, thin bedded, low hardness, weak.

Topography, Structure, and Vegetation

Forms a large outcrop area of smooth and rounded strike and spur ridges, hills, and intervening drainages. Slopes range from 20 to 40 percent (11 to 22 degrees) with local areas up to 50 percent (27 degrees), and 75 percent (37 degrees) only on the flank of a strike ridge underlain by the Neroly Formation. Dips range from 35 to 85 degrees, with areas of 25 and 75 degrees.

North-facing slopes and many of the drainages are generally wooded or brush covered. South-facing slopes are generally grassland.

Soils

Surficial soils are mapped as clay, but are somewhat sandy on the sandstones and gravelly on the conglomerates. The Unified Soil Classification is CL. Soils are moderately to highly expansive and have low to moderate shear strength. Soils are generally moderately erosive, but are highly erosive on the steeper slopes.

Slope Stability

Landslide Density Type and Size

Landslides are common to very common. Landslide type and size are:

- *10 to 30 acre soil and weathered rock slides and slumps, which coalesce in several adjacent wooded, first-order drainages are common to very common. These landslides form on slopes of all aspects but are more extensive on the anti-dip slopes of the drainages.

- *less than or equal to 2 acre soil and shallow weathered rock slides and slumps. These landslides occur on all slope aspects, and are most common on grassy, first-order drainages with fewer on wooded slopes. Whereas these landslides are common to very common, they cover less area than other types.

- *5 acre and some up to 10 acre soil and weathered rock slides, slumps, and earthflows common on wooded, northwest, north, northeast or east-facing dip-slopes and slopes parallel to dip are common.

- *the least abundant landslides in number, but which cover a large portion of the outcrop area, are the less than or equal to 50 acre, rock/soil slumps and slides identified on wooded, north-facing, anti-dip slopes.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides of all types occur on slopes greater than or equal to 30 percent (17 degrees), but are most abundant on slopes greater than or equal to 40 percent (22 degrees). The widespread landslides less than or equal to 2 acres are primarily in the surficial soil, occurring throughout the unit on grass-covered and occasionally wooded slopes of all aspects and generally have slide planes that extend to only a very shallow depth into the weathered rock. The landslides >2 acres generally have slide planes that extend deeper into the less weathered rock.

Bedrock landslides tend to be least abundant on grass-covered, southwest-facing, dip-slopes with the largest and most abundant on the wooded, northeast-facing anti-dip slopes. Dip angles generally exceed slope angles.

Landslide Susceptibility Rating

Unit does not appear to be susceptible to dip-slope landslides, but is more prone to anti-dip slope failures. Rock slope stability appears to be related more to the attitude of fractures parallel to anti-dip slopes than by bedding itself. Slope stability of the rock and surficial soil is poor and the unit is in the Most Susceptible Area, Subarea 4.2.

Rockfall hazard is judged to be low because of the generally gentle slopes, and the lack of outcrops.

Debris Flows

Debris flows are uncommon. Only a few were identified on grassy slopes locally greater than or equal to 40 or 50 percent (22 or 27 degrees) and are about evenly distributed on soils mapped as moderately and highly expansive. Lack of debris-flows probably because of soils mapped as plastic and highly expansive, a soil type that has a low susceptibility to these slope failures, and slopes that are only locally >40 percent (22 degrees). Debris-flow susceptibility is judged to be moderate and the unit is in the Marginally Susceptible Area.

Tpn - Neroly Formation (upper and middle Miocene)

Lithology

Middle-Upper Miocene, marine.

Sandstone: Light blue-gray where fresh, locally retains this color when weathered, some beds weather to red-brown. Sand is rounded to well rounded, fine, fine to medium with trace coarse grained or fine to coarse grained. Sand has blue gray clay coating on grains. Unit contains fine gravel stringers. Dark grains are unevenly distributed throughout rock imparts "salt and pepper" appearance, but not as developed as in Briones Formation. Abundant fossil clam shells, molds and casts in fine to medium grained sandstone, in places almost a coquina. Differential weathering of shells and sandstone imparts a spheroidal weathering appearance. Surface or shallow outcrops are poorly cemented, thick bedded, closely to intensely fractured, low hardness, friable to weak, little to moderately weathered. Deep exposures in cuts or exposures on very steep slopes and local shallow outcrops, especially were exposed on ridges, are well cemented, very thick bedded, very little to occasionally fractured, hard, strong, little weathered to fresh.

Sandstone: Light brown, light gray or white where fresh, weathers to light red-brown with limonite staining on fractures. Sand is fine, fine to medium or fine to medium with little coarse grained and locally clayey or silty. Dark grains are unevenly distributed throughout rock with calcite cemented veins in some beds. Poorly to moderately cemented, thin bedded, closely to moderately fractured, low to moderate hardness, friable to weak, local spheroidal weathering. Light brown, light gray and white sandstones have been mapped as Cierbo Sandstone by some workers but are interbedded with the blue-gray sandstone throughout the study area and have been included with the Neroly Sandstone in this investigation.

Mudstone: Light brown-gray, gray, or light yellow-brown. Contains fine sand. Intensely fractured to crushed, low hardness, weak. Only minor surface outcrops observed, resembles Rodeo Shale.

Topography, Structure, and Vegetation

Forms sharp to smooth crested strike and spur ridges or hills. Slopes are between 15 and 40 percent (9 and 22 degrees) in the Miner Ranch and Pinole anticlines. Slopes are between 30 and 75 percent (17 and 37 degrees) with areas that exceed 100 percent (45 degrees) in the Briones and Happy Valley synclines. In much of the outcrop area, anti-dip slopes are generally steeper than dip-slopes.

Dips range from 20 to 50 degrees in most of the unit, but are as low as 10 degrees in the west end of the Briones Syncline and as high as 70 degrees in the Happy Valley Syncline and Pinole Anticline.

Vegetation is woodland or brushy on north-facing slopes and in drainages, and grassland on the south facing slopes.

Soils

Surficial soils are mapped as two types. Fine to medium-grained silty sand or silt, with areas lacking soil cover, are mapped on the western portion of the north limb of the Happy Valley Syncline, and southeast half of the central Briones Syncline. The Unified Soil Classifications are SM and ML. These soils are nonplastic and nonexpansive, have low to moderate shear strength, and are highly to very highly erosive.

Clay is mapped on the balance of the unit. The Unified Soil Classification is CL. These soils are moderately and locally highly expansive, have low to moderate shear strength, and are moderately to highly erosive.

Slope Stability

Landslide Density, Type and Size

Landslides are common to rare.

Landslide type and size are:

- *1 to 2 acre soil slumps or slides in the upper portions of first-order drainages are common.

- *2 to 7 acre soil/weathered rock slumps and slides involving entire first-order drainages are moderately common.

- *4 to 7 acre soil/weathered rock slides coalescing in up to several adjacent first-order drainages are rare.

- *1 to 4 acre soil slumps on planar slopes are rare.

- *One, 80 acre rock slump/disrupted translational slide along the axis of the central section of the Briones Syncline at the intersection of 3 faults.

Slope, Aspect, Soil, Vegetation and Structural Relationships

Landslides are most common on greater than or equal to 50 percent (27 degrees) slopes and are rare on slopes <40 percent (22 degrees). Landslides are more common in areas mapped as moderately or highly expansive soils, than in areas with granular, non-expansive soils with similar slope angle, and are about evenly distributed on wooded-, brush- or grass-covered slopes. There is generally a similar concentration of landslides on north-facing than on south-facing slopes. The most abundant landslides are the 2 to 4 acres in size, and generally occur in the surficial residual and colluvial soil, with slide planes that extend to only a shallow depth into the underlying weathered rock. The less abundant, less than or equal to 7 acre landslides have slides planes that are deeper in the less weathered rock.

There is generally a similar concentration of landslides on dip-slopes than on anti-dip slopes. Dip angles generally exceed slope angles, except on the western end of the Briones Syncline and no dip-slope landslides were identified there.

Landslide Susceptibility Rating

Unit does not appear to form dip-slope failures, instead landslides generally occur where colluvium is thickest and where the fracture density is greatest, which is generally in drainages. The rock slump/disrupted translational slide is considered to be an isolated case and is not representative of the average slope-stability characteristics of the unit. Failure has most likely occurred in the underlying upper Briones Sandstone and may be the result of failures in the rock weakened by the three mapped faults which intersect beneath the landslide. These faults can cause rock fracture density there to be greater than in non-faulted portions of the formation and, therefore, a locally greater landslide susceptibility. Slope stability is generally moderate in the rock and surficial soil, and the majority of the unit is in the Most Susceptible Area, Subarea 4.1. In the Miner Ranch Anticline, the unit is mostly in the Generally Susceptible Area. Small areas of the unit are in the Most Susceptible Area, Subarea 4.2. Outside the study area, in the Livermore Valley and in the Tassajara area, this unit has been judged to be weakly to moderately susceptible to landsliding and the Cierbo very susceptible, with some of the larger landslide and landslide complexes, but is judged generally not prone to landsliding in the Vacaville area.

Rockfall hazard is judged to be moderate where unit forms sharp crested strike ridges with very steep anti-dip or dip slopes with granular, noncohesive soils or lack soil cover. These areas include the west end and small portions of the central Briones Syncline, and the central and

Lafayette Ridge portion of the Happy Valley Syncline. Because the rockfall fragment size is controlled by the rock fracture density, block size will probably be in the coarse gravel to small boulder range.

Debris Flows

Debris flows are moderately common, and locally abundant in small clusters. Debris-flows were identified typically on south-facing, mostly grass- or brush-covered slopes, often near the transition to wooded areas, with slopes greater than or equal to 50 percent (27 degrees), mapped as non-cohesive soils. Debris-flow susceptibility is judged to be high and most of the unit is in the Most Susceptible Area. The southeast end of the Briones Syncline is in the Marginally Susceptible Area. Debris-flows and avalanches are major type of slope failure in the Diablo and Dublin 7.5 minute quadrangles.

Briones Sandstone

Tpbu - Briones Sandstone, upper member (upper and middle Miocene)

Lithology

Middle-upper Miocene, marine.

Sandstone: Light gray where fresh, weathers to yellow-brown and red-brown. Sand is fine and locally fine to medium grained, and unit is clayey or silty with the upper half of unit more clayey than the lower. Seldom fossiliferous, usually containing pectens. Moderately cemented, intensely fractured, low hardness, weak and weathers spheroidally. Locally, laterally discontinuous beds of white to light gray sandstone forms steep to vertical slopes. This sandstone is fine grained, moderately bedded, closely fractured, moderately hard, moderately strong and more resistant than clayey upper Briones. Identified on both limbs of the central portion of the Briones Syncline

Mudstone: Light gray, moderately consolidated, intensely fractured, low hardness, and weak.

Tuff: White, rhyolitic, and fine grained. Poorly to moderately consolidated, intensely fractured, low hardness, weak, and little weathered.

Topography, Structure, and Vegetation

Primarily underlies drainages and slopes on the flanks of ridges, and upland valleys below more resistant ridge-forming units. Occasionally forms sharp-crested to rounded strike and spur ridges, and rounded knolls and hills on low rolling uplands. On sharp-crested strike and spur ridges, slopes are 30 to 50 percent (17 to 27 degrees) and, locally, 20 to 75 percent (11 to 37 degrees). On slopes and drainages of ridge flanks, slopes are generally between 30 and 40 (17 and 22 degrees) percent and locally 20 to 50

percent (11 to 27 degrees). On the knolls, hills, and occasionally rounded strike ridges, slopes are between 10 and 30 percent (6 and 17 degrees).

Dips range from about 40 to 60 degrees in the Happy Valley, east half of the Briones, and Pacheco synclines. In the Miner Ranch Anticline and west half of the Briones Syncline, dips range from about 20 to 45 degrees. Dips in the Pinole anticline range from 20 to 65 degree.

Vegetation is wooded or brushy on most of the north-facing slopes and many of the drainages regardless of aspect, and grass-covered on south-facing slopes.

Soils

Surficial soils are mapped as two types. Fine- to medium-grained silt or silty sand is mapped on both limbs of the Briones Syncline in the southeast end of the central and the western portions. The Unified Soil Classifications are SM and ML. These soils are nonexpansive, have low to moderate shear strength, and are highly to very highly erosive.

Clay is mapped in the Miner Ranch Anticline, western and central portion of the Happy Valley Syncline, in the axis of the Pacheco Syncline, and on the balance of the Briones Syncline. The Unified Soil Classification is CL. These soils are generally moderately expansive and on the north limb of the Happy Valley Syncline south of Briones Valley, locally highly expansive, have low to moderate shear strength, and are moderately to highly erosive.

Slope Stability

Landslide Density, Type and Size

Landslides are very common to moderately common, with no landslides identified in areas. Generally, there is a higher concentration of landslides than in the adjacent lower Briones Sandstone or Neroly Formation, with similar structure and slopes.

Landslides size and type are:

- *2 to 5 acre soil/weathered rock slumps or earthflows in drainages are moderately to very common.

- *1 acre soil slides in the head of first-order drainages are moderately to very common.

- *5 acre and 10 to 15 acre soil/weathered rock slumps and slides on noses and planar slopes of spur ridges or coalescing in several adjacent first order drainages are moderately to very common. Many of the less than or equal to 10 acres slides have expanded upslope causing failures in the structurally or topographically overlying lower Briones Sandstone or Neroly Formation.

- *small soil slips are rare.

- *several 20 to 90 acre disrupted rock translational slides were identified on dip-slopes along the axis of the Briones Syncline. These landslides are the largest in the study area.

- *unit raveling in outcrop forming angular fine gravel-sized talus.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides of all sizes are rare on less than or equal to 30 percent (17 degrees) slopes, and most common on slopes greater than or equal to 40 percent.

(22 degrees), in areas with moderately or highly expansive soils, and are about evenly distributed on wooded, brush- or grass-covered slopes. Landslides less than or equal to 5 acres generally occur in drainages, with failures primarily in the surficial soil and have slide planes that extend only to a shallow depth into the underlying weathered rock. Landslides >5 acres generally have slide planes that are deeper in the less weathered rock. Generally, although unit forms more north-facing slopes than south-facing, landslides appear to be more common on south-facing slopes.

Although unit forms larger areas of anti-dip slopes, landslides less than or equal to 15 acres in size are about equally distributed on dip- and anti-dip slopes. Dip angles generally exceed slope angles, except in the west and central portion of the Briones Syncline where slope angles exceed dips.

Landslide Susceptibility Rating

The small number of landslides in the Miner Ranch Syncline and the lack of landslides identified in the Pacheco Syncline is most likely because slopes there are generally less than or equal to 30 or 40 percent (17 or 22 degrees), and 40 percent appears to be the slope threshold for failures. Unit does not appear to form less than or equal to 15 acre dip-slope failures, instead landslides of these sizes, and especially in the less than or equal to 5 acre size, generally occur where colluvium is thickest and/or where the fracture density is greatest, which is generally in drainages. The unit is subject to large, greater than or equal to 20 acre, dip-slope landslides where dip angles are less than the slope angles. Slope stability of rock is moderate to poor and poor in the surficial soil. Most of the unit is in the Most Susceptible Area, Subarea 4.2, such as the majority of the Briones Syncline, which underlies the largest portion of the outcrop area. The second largest portion of the outcrop area is in the Most Susceptibility Area, Subarea 4.1, such as the majority of the Happy Valley and portions of the Briones synclines. Small areas of the southeast end of the Briones Syncline are in the Generally Susceptible Area and the unit in the Pacheco Syncline is in the Marginally Susceptible Area, Subarea 2.1.

Rockfall hazard is judged to be moderate where unit forms sharp crested strike ridges with very steep anti-dip or dip-slopes without soil cover, and below the discontinuous resistant beds. These areas include the west end and small portions of the central Briones Syncline. However, as the fragment size will be controlled by the rock fracture density, fragment size will probably be smaller than coarse gravel size.

Debris Flows

Debris flows are moderately common, but locally abundant. Generally, there is a higher concentration of debris-flows than in the Neroly Formation or lower Briones Sandstone. Typically, debris flows were identified on south-facing, grass-covered slopes greater than or equal to 50 percent (27 degrees) with soils that are non-expansive, with some identified in areas mapped as moderately to highly expansive soil. That debris-flows occur on soils mapped as highly expansive, a soil type that has a low susceptibility to these slope failures, indicates that these areas contain hollows with unmapped noncohesive soils susceptible to debris-flows.

Debris-flow susceptibility is judged to be high and most of the unit is in the Most Susceptible Area. The balance of the unit is in the Marginally Susceptibility Area.

Extracted from Landslide Hazards in the Martinez-Orinda-Walnut Creek area, Contra Costa County, California, Landslide Hazard Identification Map No.32, Open-File Report OFR 95-12. ([OF95-12](#))

Tpbl - Briones Sandstone, lower member (upper and middle Miocene)

Lithology

Middle-upper Miocene, marine.

Sandstone: Light gray where fresh, weathers to red-brown and locally, to blue-gray. Sand is fine to medium and fine to coarse grained, dark clasts are evenly distributed throughout rock imparting a "salt and pepper" appearance. Fossiliferous throughout unit with clam and sand dollar shells. Moderately cemented, very thick bedded, moderately to closely fractured, moderately strong but locally weak. Locally well cemented, highly fossiliferous beds form resistant ridges and anti-dip slopes. Blue-gray lower Briones resembles Neroly, but Briones is less well cemented and weaker with evenly distributed dark grains.

Topography, Structure, and Vegetation

Primarily forms drainages and slopes on the flanks of ridges underlain by more resistant ridge-forming units. Also forms smooth to occasionally sharp- crested, spur and strike ridges, knolls and hills, especially in the larger outcrop areas. Slopes range from 10 to 30 percent (6 to 17 degrees) where unit primarily forms drainages and slopes with local areas up to 50 percent (27 degrees). On rounded knolls, hills, and strike and spur ridges slopes are between 30 and 40 percent (16 and 22 degrees) with areas up to 50 percent (27 degrees). Slopes are between 40 and 75 percent (22 and 37 degrees), with local areas of 10 to 30 percent (6 to 16 degrees), on sharp crested strike and spur ridges. Slope are usually steeper on anti-dip slopes.

Dips range from about 30 to 70 degrees throughout most of the unit and increase to 75 to 85 degrees in the nose of the Happy Valley Syncline.

Vegetation is wooded or brushy on most of the north-facing slopes and many of the drainages regardless of aspect and grass covered on south-facing slopes.

Soils

Surficial soils are mapped as two types. Fine- to medium-grained silt or silty sand is mapped on the west portion and northwest end of the southeastern portions of Briones Syncline. The Unified Soil Classifications SM and ML. These soils are nonexpansive, have low to moderate shear strength, and are highly to very highly erosive.

Clay is mapped on the balance of the unit. The Unified Soil Classification is CL. These soils are highly and locally moderately expansive, have low to moderate shear strength, and are moderately to highly erosive.

Slope Stability

Landslide Density, Type and Size

Landslides are very common to moderately common. Generally, there is a lower concentration of landslides than in adjacent upper Briones Sandstone with similar structure and slope.

Landslide type and size are:

*1 to 2 acre soil/rock slides on steep dip-slopes in the head of first order drainages are moderately to locally very common.

*2 to 5 acre soil/weathered rock slumps in drainages and planar slopes are moderately to locally common.

*5 to 10 acre rock slumps, slides and earthflows, some coalescing in several adjacent first-order drainages are locally common.

*the rare 10 to 30 acre rock block/disrupted translational slides identified on north-facing, anti-dip slopes, some resulting from slides expanded upslope or laterally from structurally or topographically overlying upper Briones Sandstone.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides are rare on <30 percent (17 degrees) slopes and most common on slopes greater than or equal to 40 percent (22 degrees). Most of the outcrop area forms south-facing and anti-dip slopes and most of the landslides occur on these slopes. Landslides occur in about equal proportions on the expansive and nonexpansive soils, with clusters in all soil types. Landslides of all sizes occur most often on grass-covered slopes and less so on brush-covered slopes. The greater than or equal to 10 acre landslides occur on wooded slopes. Landslides 5 acres and some of the 10 acre landslides generally occur in drainages, with failures primarily in the surficial soil and have slide planes that extend to only a shallow depth into the underlying weathered rock. Landslides >5 acres generally have slide planes that occur deeper in the less-weathered rock with a similar concentration on dip and anti-dip slopes.

Generally, dip angles exceed slope angles.

Landslide Susceptible Rating

Unit does not appear to be susceptible to dip-slope failures, instead landslides <5 and some <10 acre in size generally occur where colluvium is thickest and where the fracture density is greatest, which is generally in drainages. Slope stability of rock and surficial soil is moderate to poor on both in the rock and surficial soil. Most of the unit is in the Most Susceptible Area, Subarea 4.2. The second largest portion of the outcrop area is in the Most Susceptible Area, Subarea 4.2. The rest of the outcrop area are in the Marginally to Generally Susceptible Area.

Rockfall hazard is judged to be moderate where resistant beds forms steep anti-dip slopes on strike or spur ridges. This condition occurs primarily on the northern limb of the Happy Valley Syncline and locally throughout the outcrop area. However, as the fragment size will be controlled by the rock fracture density, fragment size will probably be coarse gravel to boulder size.

Debris Flows

Debris flows are generally not common, but locally abundant. Generally, there is a lower concentration of debris-flows than in upper Briones Sandstone. Typically debris flows occur mostly on south- and rarely north-facing, grass-covered and rarely brush-covered slopes, greater than or equal to 40 percent (22 degrees) with most on >50 percent (27 degrees) slopes. Debris-flows occur on slopes mapped as both noncohesive and cohesive soils, however, the majority occur on noncohesive soils. Susceptibility is judged to be moderate to high and most of the unit is in the Most Susceptible Area. The balance of the unit is in the Marginally Susceptibility Areas.

Tmr - Rodeo Shale (middle Miocene)

Lithology

Middle Miocene, marine.

Siliceous shale: Light yellow-brown. With fine sand. Anastomosing fracture pattern, joints coated with limonite and low strength.

Topography, Structure, and Vegetation

Primarily forms slopes and drainages on the flanks of strike ridges and saddles in spur ridges underlain by the more resistant ridge-forming Lower Briones and Hambre sandstones throughout most of the outcrop area. Forms limited areas of sharp crested strike and spur ridges and low rolling hills. Slopes typically range from 30 to 50 percent (17 to 26 degrees), with slopes up to 75 percent (37 degrees) on slopes oversteepened by overlying more resistant units, and as low as 20 percent (11 degrees).

Dips generally range from 30 to 60 degrees, with dips as high as 70 degree on the north limb of the Briones Syncline and from 75 to 88 degrees in the northern nose of the Happy Valley Syncline and southeast portion of the Briones Syncline.

Soils

Surficial soils are mapped as two types. Fine to medium grained silt or silty sand is mapped primarily in the west end of the north limb of the Briones Syncline, and partially on the south limb of the central portion of the Pinole Anticline. The Unified Soil Classifications are SM and ML. The soils are nonexpansive, have low to moderate shear strength and are highly to very highly erosive.

Clay is mapped throughout the rest of the outcrop area. The Unified Soil Classification is CL. These soils are generally highly expansive and locally moderately expansive on the north limb of the central portion of the Briones Syncline. These soils have low to moderate shear strength and are moderately to highly erosive.

Slope Stability

Landslide Density, Type and Size

Landslides are very common to uncommon. Generally, there is a similar concentration of landslides as in the adjacent lower Briones Sandstone and a lower concentration than in the adjacent Hambre Formation, with similar structure and slope.

Landslides type and size are:

*2 to 5 acre soil/rock slumps in drainages are locally very to moderately common.

*1 to 2 acre soil/rock slides in first-order drainages are moderately common.

*10 to 30 acre rock slumps and slides on oversteepened flanks of ridge held up by the overlying more resistant lower Briones Formation are rare.

*5 to 10 acre rock slumps and slides, some coalescing in several adjacent first order drainages and some resulting from landslides expanded upslope or laterally from the structurally or topographically overlying Hambre Formation are rare.

*unit ravel on cut slopes.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides occur mostly on greater than or equal to 40 percent (22 degrees) slopes with some occurring on >30 percent (17 degrees) slopes. There is a similar proportion of landslides on the steep terrain overlain with either nonexpansive, noncohesive soils as on cohesive, expansive soils, and landslides appear to be about evenly distributed on slopes of all aspects. The majority of the less than or equal to 5 acre landslides occur in the surficial soil in grass-covered drainages with slide planes that extend to only a shallow depth into the underlying weathered and fractured rock.

The rare >5 acre landslides occur on wooded, planar slopes, in the moderately weathered rock with failure planes probably along fractures parallel to the slope, at depths below the stabilizing effect of vegetation.

Landslides are about as common on steep dip-slopes as on steep anti-dip or parallel to dip slopes. Generally, dip angles exceed slope angles.

Landslide Susceptibility Rating

Unit is not susceptible to dip-slope failures, instead landslides <5 acre in size generally occur where colluvium is thickest and where the fracture density is greatest, which is generally in drainages. There is a similar susceptibility to landsliding on steep anti-dip or parallel to dip slopes. Slope stability of rock and surficial soil is moderate to low. Most of the unit is in the Most Susceptible Area, Subarea 4.2. A somewhat smaller portion of the outcrop area is in the Most Susceptible Area, Subarea 4.1.

Rockfall hazard is judged to be low from this unit because outcrops are rare and high rock fracture density causes raveled talus to be fine gravel or finer sized.

Debris Flows

Debris flows are uncommon, and were identified only in the western portion of the north limb of the Briones Syncline. Generally, there is a lower concentration of debris-flows than in the lower Briones or Hambre sandstones. Debris-flows typically occur on south and rarely north-facing, grass-covered and rarely on wooded slopes, greater than or equal to 40 percent (22 degrees) with most occurring on greater than or equal to 50 percent (27 degrees) slopes, and on both noncohesive, non-expansive and cohesive, expansive soils, with the majority occurring on noncohesive, nonexpansive or moderately expansive soils. Debris-flow susceptibility is judged to be high and most of the unit is in the Most Susceptible Area. The balance of the unit is in the Marginally Susceptible Area.

Tmh - Hambre Sandstone (middle Miocene)

Lithology

Middle-Miocene, marine.

Sandstone: Light gray where fresh, weathers to yellow-brown. Sand is fine grained, feldspathic, and unit is clayey. Very thick to thick bedded, closely to intensely fractured, low to moderate hardness, moderately strong to weak, occasionally friable, and weathers spheroidally. Interbedded locally with red massive claystone. Exposed in roadcuts only.

Topography, Structure and Vegetation

Primarily forms smooth, rounded and occasionally sharp crested hills, strike and spur ridges above the Rodeo Shale, and large, deep generally perpendicular, but occasionally parallel, to strike drainages. Slopes are 30 to 50 percent (17 to 27 degrees) with local areas of 75 and 100 percent (37 and 45

degrees).

Dips range from 30 to 55 degrees.

Soil

Surficial soils are mapped as two types. Most of the outcrop area is mapped as clay. This soil type overlies the central portion of the Briones and Bear Creek synclines, and Pinole Anticline. The Unified Soil Classification is CL. These soils are generally highly expansive, but are moderately expansive in the central portion of the north limb of the Briones Syncline. Soils have low to moderate shear strength and are moderately to highly erosive.

Fine to medium grained silt or silty sand is mapped on the western portion of the Briones Syncline and Pinole Anticline. The Unified Soil Classifications are SM and ML. These soils are nonexpansive, have low to moderate shear strength, and are highly to very highly erosive.

Slope Stability

Landslide Density, Type and Size

Landslides are very common to uncommon. Generally, there is a somewhat higher concentration of landslides than in the adjacent Rodeo Shale with similar structure and slope.

Landslides type and size are:

- *1 to 2 acre soil/rock slides in first-order drainages and on steep, planar slopes are very common to uncommon.
- *2 to 5 acre soil slumps in drainages, some coalescing in several adjacent first-order drainages are moderately common.
- *5 to 10 acre soil/rock slumps typically in drainages and occasionally on planar slopes are moderately common.
- *10 to 20 acre rock slumps and slides on slopes and ridge noses are scattered throughout unit but are uncommon.
- *5 to 10 acre soil/rock slumps and slides coalescing in several adjacent first-order drainages are scattered throughout unit but are uncommon.
- *10 to 20 acre disrupted translational rock slides are uncommon.
- *unit ravel in outcrop forming fine gravel talus.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides occur mostly on greater than or equal to 40 percent (22 degrees) slopes with some occurring on >30 percent (17 degrees) slopes. However, large areas of steep, greater than or equal to 50 percent (27 degrees) slopes, are free of landslides and appear relatively stable. Landslides less than or equal to 5 acres in size generally occur mostly on south-facing, grass-covered drainages and are about evenly distributed on dip, anti-dip slopes and generally parallel to dip slopes. These landslides generally occur in the surficial soil with slide planes that extend to only a shallow depth into the underlying weathered and fractured rock. Landslides >5 acres, and especially 10 acres in size, are less abundant, occurring on dip-slopes, slightly more often on south-facing slopes, and are about evenly distributed on grass-covered and wooded slopes. These landslides generally have slide planes that occur deeper in the shallow weathered and fractured rock. Landslides >10 acres generally have slide planes that occur in the deeper less

weathered and less fractured rock. Landslides density is similar in areas underlain by moderate or highly expansive soils. Locally, in areas where there is both highly and nonexpansive soils, landslides less than or equal to 5 acre size cluster in the nonexpansive soil areas.

Landslide Susceptibility Rating

Susceptibility to the less than or equal to 5 acre landslides is generally similar on dip, anti-dip slopes and generally parallel to dip slopes and generally occur where colluvium is thickest and where the fracture density is greatest, which is generally in drainages. Generally, dip angles exceed slope angles, but locally, the greater than or equal to 75 percent (37 degree) slopes are steeper than bedding, forming adverse, unstable, bedding configurations and these areas are susceptible to the >5 acre dip-slope landslides. The two large, 30 to 40 acre, rock slump/slides on anti-dip slopes on the south flank of Alhambra Valley involve the Martinez Formation, and are crossed by the Franklin Fault. It appears that these large landslides are the result of failures along parallel to slope fractures in the fault-weakened rock. Slope stability is moderate in the rock and surficial soil. Most of the unit is in the Most Susceptible Area, Subarea 4.2. A slightly smaller area is in Subarea 4.1. Small portions of the unit are in the Marginally Susceptible Area, Subarea 2.2.

Rockfall hazard is judged to be low because outcrops are rare and high rock fracture density causes raveled talus to be fine gravel.

Debris Flows

Debris flows are moderately common. Generally, there is a higher concentration of debris-flows than in the Rodeo Shale, but somewhat less than the concentration in the upper and lower Briones sandstones. Debris-flows were mapped mostly on south-and rarely north-facing, grass-covered, >40 percent (22 degrees) with most on greater than or equal to 50 percent (27 degrees) slopes and in areas mapped as both noncohesive, nonexpansive and the cohesive, expansive soils. However, the majority occur in areas mapped as moderately or highly expansive soils. That debris-flows occur mostly on soils mapped as highly expansive, a soil type that has a low susceptibility to these slope failures, indicates that in these areas there are hollows with unmapped noncohesive soils susceptible to debris flows. Debris-flow susceptibility is judged to be moderate to high and about half of the unit is in the Most Susceptible Area. The balance of the unit is in the Marginally Susceptible Area.

Tmt - Tice Shale (middle Miocene)

Lithology

Middle-Miocene, marine.

Siliceous shale: Olive-gray where fresh, weathers to yellow-gray to gray-orange. Unit has calcareous concretions, anastomosing fracture pattern, and the joints are often coated with yellow jarosite. Unit is laminated, crushed to intensely fractured, low hardness, weak, and weathers spheroidally.

Topography, Structure and Vegetation

Primarily forms rounded and smooth to sharp crested, strike and spur ridges and hills. Slopes are 30 to 50 percent (17 to 27 degrees) with areas of 20 and 75 percent (11 and 37 degrees). Dips are poorly defined, but appear to be 40 to 75 degrees. Generally, the formation outcrops as anti-dip and parallel to dip slopes, with small areas of dip-slopes.

Vegetation is mostly wooded with some grass covered slopes.

Soil

Surficial soils are mapped as two types. In the majority of the unit, as in the Sobrante Anticline and in part of the west portion of the Briones Syncline, surficial soils are primarily clay. The Unified Soil Classification is CL. These soils are highly expansive, have low to moderate shear strength, and are moderately to highly erosive.

In the extreme western portion of the Briones Syncline soils are mapped as fine to medium grained silt or silty sand. The Unified Soil Classifications are SM and ML. These soils are nonexpansive, have low to moderate shear strength and are highly to very highly erosive.

Slope Stability

Landslide Density Type and Size

Landslides are common to uncommon. Generally, the concentration of landslides is similar to the Hambre Sandstone.

Landslides size and type are:

*1 to 3 acre soil/rock slumps and slides in first-order drainages and some coalescing in several adjacent first-order drainages are common to uncommon.

*few 5 to 10 acre soil/rock slumps in large or multiple order drainages are uncommon to common.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides occur mostly on south-facing, grass-covered greater than or equal to 40 percent (22 degrees) slopes with some occurring on greater than or equal to 30 percent (17 degrees) slopes. All landslides occur in drainages and are about evenly distributed on anti-dip slopes and parallel to dip slopes, with no landslides identified on the small area of wooded and steep, dip-slopes. The few landslides between 5 and 10 acres in size occur near, but not overlying, the mapped trace of the Franklin Fault. In areas where there is both highly and nonexpansive soils, landslides density appears to be similar on both soil types, however, the majority of the outcrop area and landslides occur on the moderately to highly expansive soils. Landslides <3 acres generally occur in the surficial soil with slide planes that extend to only a shallow depth into the underlying weathered and fractured rock. Landslides between 5 and 10 acres are relatively rare and generally have slide planes that extend deeper into the less weathered and less fractured rock.

Landslide Susceptibility Rating

Unit does not appear susceptible to dip-slope failures and there is a similar susceptibility on anti-dip slopes and parallel to dip slopes. Landslides generally occur where colluvium is thickest and where the fracture density is greatest, which is generally in drainages. Slope stability of rock and surficial soil is moderate. The unit is entirely in the Most Susceptible Area, subareas 4.1 and 4.2.

Rockfall hazard is judged to be low because outcrops are rare and high rock-fracture density causes raveled talus to be fine gravel or finer.

Debris Flows

Debris flows are moderately common to common. Generally, there is a slightly greater concentration of debris-flows than in the Hambre Sandstone. Debris-flows often occur in clusters which extend into adjacent formations. Debris-flows were mapped on mostly on south- and rarely north-facing, grass-covered slopes, often just downhill of wooded areas, on greater than or equal to 50 percent (27 degrees) slopes with a few on >30 percent (17 degrees) slopes on both non-cohesive, nonexpansive and cohesive, expansive soils, however, the majority occur on nonexpansive soils. Debris-flow susceptibility is judged to be high and all of the unit is in the Most Susceptible Area.

Tmo - Oursan Sandstone (middle Miocene)

Lithology

Middle-Miocene, marine.

Sandstone: Light gray where fresh, weathers to yellow-brown. Sand is fine grained, feldspathic and unit is clayey. Very thick to thick bedded, closely to intensely fractured, low to moderate hardness, moderately strong to weak, occasionally friable and weathers spheroidally. Interbedded locally with red massive claystone. Resembles Hambre Sandstone. Exposed in roadcuts only.

Topography, Structure, and Vegetation

Primarily forms smooth, rounded hills, with slopes of 40 to 60 percent (22 to 31 degrees) with areas of 20 and 30 percent (11 and 17 degrees). Dips are poorly defined, but appears to range from 40 to 85 degrees.

Vegetation is about evenly distributed as woodland and grassland.

Soil

Throughout outcrop area surficial soils are mapped as fine to medium grained silty sand or silt. The

Unified Soil Classifications are SM and ML. These soils are nonexpansive, have low to moderate shear strength, and are highly to very highly erosive.

Slope Stability

Landslide Density Type and Size

Landslides are common. Generally, there is a similar concentration of landslides as in Tice Shale.

Landslide type and size are:

*3 to 5 acre, and one 10 acre, soil/rock slumps, each coalescing in two to several adjacent first-order drainages.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides are about evenly distributed throughout outcrop area and occur mostly on south-facing, grass-covered slopes and rarely north-facing or wooded slopes, on greater than or equal to 40 or 50 percent (22 to 27 degrees) slopes, with one occurring on >30 percent (17 degrees) slope. Landslides that are less than or equal to 5 acres generally occur in drainages, often with the crowns on anti-dip slopes and extending across the anticline axes so that the toes are on dip slopes, in the surficial soil with slide planes that extend to only a shallow depth into the underlying weathered and fractured rock. One of the landslides of this size is a soil/rock slump on a north-facing, anti-dip slope crossed by the Franklin Fault, which may have resulted from a failure in the fault-weakened rock. The 10 acre landslide occurs on a south-facing, grass-covered, 50 percent (27 degrees), dip-slope, with the slide plane occurring deeper in the less weathered and less fractured rock.

Dips are poorly defined, but appear to exceed slope angles. In the small areas of dip-slopes, the dip angles exceed slope angles. The local 75 percent slopes appear to be anti-dip slopes.

Landslide Susceptibility Rating

Unit does not appear to be susceptible to dip-slope failures, instead landslides generally occur where colluvium is thickest and where the fracture density is greatest, which is generally in drainages. Slope stability of rock and surficial soil is moderate. The unit is entirely in the Most Susceptible Area, Subarea 4.2 and Subarea 4.1.

Rockfall hazard is judged to be low because outcrops are rare and high rock fracture density causes raveled talus to be fine gravel or finer.

Debris Flows

Debris flows are common. Generally, there is a slightly greater concentration than in the Hambre Sandstone. Debris-flows were mapped mostly on south- and rarely north-facing, grass-covered greater than or equal to 50 percent (27 degrees) slopes with a few on >30 percent (17 degrees) slopes, often just downhill of wooded areas, in areas mapped as noncohesive, nonexpansive soils and often occurs in clusters which extend into adjacent formations. Debris-flow susceptibility is judged to be high and all of the unit is in the Most Susceptible Area.

Tms - Sobrante Sandstone (middle Miocene)

Lithology

Middle-Miocene, marine.

Sandstone: Light blue-gray where fresh, retains this color when weathered. Sand is fine to course grained, and rounded to well rounded with blue gray clay coating on the grains. Very thick bedded, moderately fractured, and moderately strong. Unit resembles the Neroly Formation.

Sandstone: Gray where fresh, weathers light brown. Sand is fine to course grained and feldspathic with rounded, fine gravel lens. Thin to thick bedded, moderately fractured, moderately hard, and moderately strong.

Sandstone: Gray where fresh, weathers to yellow-brown. Sand is fine grained, and unit is clayey. Thin bedded, crushed, and moderately strong to weak.

Topography Structure, and Vegetation

Primarily forms rolling hills and flanks of hills held up by San Ramon Formation. Slope are 10 to 20 percent (9 to 11 degrees) with areas of up to 40 percent (22 degrees). Dips range from 40 to 55 degrees.

Soils

Throughout the outcrop area surficial soils are mapped as clay. The Unified Soil Classification is CL. Soils are moderately to highly expansive, have low to moderate shear strength, and are moderately to highly erosive.

Slope Stability

Landslide Density, Type and Size

No landslides were identified.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Generally, dip angles exceed slope angles.

Landslide Susceptibility Rating

Lack of landslides may be due to the gentle slopes. Slope stability of rock and surficial is judged to be good. Outside of the cut and fill areas unit is in the Marginally Susceptible area, Subarea 2.1.

Rockfall hazard is judged to be low because of generally gentle slopes and lack of outcrops.

Debris Flows

No debris flows were identified. Lack of debris-flows probably because of soils mapped as plastic and highly expansive, a soil type that has a low susceptibility to these slope failures, and slopes that are only locally >20 percent (11 degrees). Debris-flows susceptibility is judged to be low because of the cohesive soils and slopes which are only locally >20 percent (11 degrees). The areas outside the cut and fill area is in the Least Susceptible Area.

Tsr - San Ramon Sandstone (lower Oligocene)

Lithology

Lower Oligocene, marine.

Sandstone: Gray where fresh or weathered. Sand is fine and fine to medium grained, feldspathic and unit is tuffaceous. Thick bedded, intensely to closely fractured, occasional red-brown iron-oxide cemented fractures, weak, many fractures friable and some beds weather spheroidally.

Topography, Structure and Vegetation

Forms narrow outcrops of grass covered slopes and low spur ridges on the flanks of the low, smooth rounded hills and strike ridges held up by the Markley Formation. Slopes are between 15 to 25 percent (8.5 to 14 degrees) with areas of 30 percent (17 degrees). Dips poorly defined, but appear to range from 40 to 55 degrees.

Forms a small area of a sharp crested to smooth rounded strike ridge, mostly grass covered but wooded on the highest ridge peak, above a small valley in the Markley Sandstone. Slopes range from 30 to 50 percent (17 to 26 degrees). Dips range from 30 to 50 degrees.

The formation crops out primarily as dip-slopes with much less area as anti-dip or parallel to dip slopes.

Soils

Throughout the outcrop area, surficial soils are mapped as clay. The Unified Soil Classification is CL. Soils are moderately expansive in the northern and central portions, and highly expansive in the southern portion of the Pacheco Syncline. In the Pinole Anticline, the soils are moderately expansive. Soils have low to moderate shear strength and are moderately to highly erosive.

Slope Stability

Landslide Density, Type and Size

Landslides are uncommon, although locally common on the small outcrop area within the Pinole Anticline. None were identified in the Pacheco Syncline.

Landslide type and size are:

*1 to 3 acre soil/rock slumps in shallow hollows on nearly planar slopes.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides occur mostly on west or northwest-facing, grass-covered, anti-dip or parallel to dip, greater than or equal to 40 percent (22 degrees) slopes. Landslides generally occur in the surficial soil with slide planes that extend to only a shallow depth into the underlying weathered and fractured rock. Generally, the dip angles exceed slope angles.

Landslide Susceptibility Rating

The lack of landslides may be due to the small area of steep slopes. Landslides generally occur where colluvium is thickest and where the fracture density is greatest, which is generally in hollows. Slope stability of rock and surficial soil is judged to be moderate. The small areas outside the cut and fill area in the Pacheco Syncline is in the Marginally Susceptibility Area, Subarea 2.1. In the Pinole Anticline, the unit is in the Most Susceptible Area, Subarea 4.2.

Rockfall hazard is judged to be low because of generally gentle slopes, and lack of outcrops.

Debris Flows

No debris flows were identified. Lack of debris-flows probably because of soils mapped as plastic and highly expansive, a soil type that has a low susceptibility to these slope failures, and slopes that are only locally >25 percent (14 degrees). Debris-flow susceptibility is low in the Pacheco Syncline and moderate in the Pinole Anticline. The small areas outside the cut and fill area in the Pacheco Syncline is in the Least Susceptible Area. In the Pinole Anticline, the unit is in the Marginally Susceptible Area.

Tem - Markley Formation (middle Eocene)

Lithology

Middle Eocene, marine.

Sandstone: Gray where fresh, weathers light brown. Sand is fine to coarse grained with rounded fine gravel lens, locally crossbedded, micaceous and feldspathic. Occasional red-brown, iron-oxide cemented nodules or fractures. Thin to thick bedded, moderately to occasionally fractured, many fractures calcite filled, moderately hard, and moderately strong. Sandy carbonaceous light gray shale interbeds.

Topography, Structure, and Vegetation

Forms low smooth rounded hills and strike ridges with slopes of 20 to 40 percent (11 to 22 degrees). Dips are poorly range from 40 to 55 degrees. In the small anticline to the east of the Calaveras Fault, in the extreme southeast corner of the study area, dips range from 50 to 70 degrees.

Soils

Surficial soils are mapped as clay. The Unified Soil Classification is CL. Soils are moderately expansive, have low to moderate shear strength and moderately to highly erosive.

Slope Stability

Landslide Density, Type and Size

No landslides were identified.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Generally, dip angles exceed slope angles.

Landslide Susceptibility Rating

The lack of landslides may be the result of the gentle slopes. Slope stability of rock and surficial soil in study area appears good. The small areas outside the cut and fill in the Pacheco Syncline have about equal areas assigned to the Marginally Susceptible Area, Subarea 2.1, and the Generally Susceptible Area. The unit is in the Generally Susceptible Area in the small anticline to the east of the Calaveras Fault. In the Vacaville and Cordelia-Vallejo areas, the sandstone rapidly disintegrates in water and therefore, is extremely susceptible to landsliding.

Rockfall hazard is judged to be low because of generally gentle slopes, and lack of outcrops.

Debris Flows

No debris flows were identified. Lack of debris-flows probably because of soils mapped as plastic and highly expansive, a soil type that has a low susceptibility to these slope failures, and slopes that generally are not >40 percent (22 degrees). Debris-flow susceptibility is judged to be low to moderate. The small areas outside the cut and fill in the Pacheco Syncline and throughout the Pinole Anticline in the Least Susceptible Area where slopes are <30 percent and the Marginally Susceptible Area where slopes are greater than or equal to 30 percent. In the Benicia-Vallejo area, sandy colluvial deposits have been mapped in some swales and may pose debris-flow hazard.

Ten - Nortonville Shale (middle Eocene)

Lithology

Middle Eocene, marine.

Clay Shale: Brown, with local argillaceous feldspathic sandstone interbed.

Topography, Structure, and Vegetation

Forms very limited exposures in drainages and a few low smooth rounded hills with slopes of 20 to 40 percent (11 to 22 degrees). Dips are poorly defined, but appears to range from 40 to 55 degrees.

Soils

Surficial soils consist of clay. The Unified Soil Classification is CL. Soils are moderately expansive in the north and central portions, and highly expansive in the southern portion of the Pacheco Syncline. Soils have low to moderate shear strength and are moderately to highly erosive.

Slope Stability

Landslide Density, Type and Size

No landslides were identified.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Generally, dip angles exceed slope angles.

Landslide Susceptibility Rating

The lack of landslides may be the result of the gentle slopes. Slope stability of rock and surficial soil appears good. The small areas outside the cut and fill have about equal areas in the

Marginally Susceptibility Area, Subarea 2.1, and the Generally Susceptible Area. In adjacent areas this unit has a high landslide susceptibility. Steep slopes have been mapped as subject to large rotational slides in the Benicia-Vallejo area. Shale and surficial soils have been judged to be extremely susceptible to landsliding in the Vacaville and Cordelia-Vallejo areas.

Rockfall hazard low because of generally low slopes, and lack of surficial outcrops.

Debris Flows

No debris flows were identified. Debris-flow susceptibility is judged to be low, because of the generally cohesive, plastic and expansive soils, and slopes which are <40 percent (22 degrees). The small areas outside the cut and fill area is in the Least Susceptible Area because slopes there rarely are >20 percent.

Ted - Domengine Sandstone (middle Eocene)

Lithology

Middle Eocene, marine.

Sandstone: Light gray where fresh, weathers to light brown or red-brown. Quartzose sandstone. Sand is fine to medium with trace coarse grained, and commonly crossbedded with occasional red-brown, iron-oxide cemented nodules or fractures. Occasionally to very slightly fractured, thin to thick bedded, low to moderate hardness, and moderately strong to weak.

Topography, Structure, and Vegetation

Forms smooth rounded strike and spur ridges and hills. Slopes are primarily 20 to 40 percent (11 to 22 degrees) and with limited local areas of 50 to 75 percent (27 to 37 degrees). Dip ranges from 40 to 75 degrees.

On the west flank of the Martinez Valley, forms low, rounded hills with slopes of 40 to 50 percent (22 to 27 degree). Dips are poorly defined, but appear to be vertical or overturned to about 80 degrees.

The 20 to 40 percent slopes are grass covered, while most of the 50 to 75 percent slopes areas are wooded.

Soil

Surficial soils are mapped as fine to medium grained, silty sand or silt. The Unified Soil Classifications are SM and ML. Soils are nonplastic and nonexpansive, have low to moderate shear strength, and are highly erosive.

Slope Stability

Landslide Density, Type and Size

Landslides are uncommon.

Landslide type and size:

*1 to 3 acre soil/rock slumps which are clustered into several groups of 2 or 3 landslides.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides occur mostly on wooded, southwest-facing drainages, on anti-dip slopes, in the limited areas with slopes of 40 to 50 percent (22 to 27 degrees), with very few occurring on northwest, southeast or northeast-facing, 20 to 30 percent slopes or along faults. Landslides generally occur in the surficial soil with slide planes that extend to only a shallow depth into the underlying weathered and fractured rock.

Generally, dip angles exceed slope angles.

Landslide Susceptibility Rating

Large areas are free of landslides and the clustering of landslides suggests that local and not areal geologic conditions control landslide susceptibility. Landslides generally occur where colluvium is thickest and/or where the fracture density is greatest, which is generally in drainages or along faults. The few landslides along faults are in grass-covered drainages and may be the result of failures in the fault-weakened rock. The lack of landslides may be due, in part, to the small areas of steep slopes. Slope stability of rock is good and of the surficial soil appears moderate to good. The areas outside the cut and fill are in the Marginally Susceptible Area, Subarea 2.1, with slightly greater area in the Generally Susceptible Area. The Domengine Sandstone in the nearby Tassajara area is considered to have a high landslide susceptibility. In Benicia-Vallejo area, the unit is locally highly sheared and subject to large rotational slides. While no landslides have been identified in the Domengine Sandstone in the Vacaville area, and only a few in the Cordelia-Vallejo area, the unit is considered to be generally susceptible to landsliding in those areas.

Rockfall hazard is judged to be low in areas of generally less than 50 percent (27 degrees) slopes, moderate in the areas of wooded, greater than 50 percent slopes, and moderate to high on the small areas of bare rock outcrop on greater than 75 percent (37 degrees) slopes. Rockfall block size will be controlled by the rock fracture density, therefore block size will probably be in the boulder size range.

Debris Flows

No debris flows were identified. While the nonplastic soils are generally susceptible to debris-flows, the lack of these failures is probably related to the relatively small area of steep slopes and that most of the steep slopes are wooded; grass covered slopes are generally more susceptible than wooded areas. Debris-flow susceptibility is judged to be low to high. In the areas outside the cut and fill, susceptibility is judged to be low on the slopes <30 percent and this area is in the Least Susceptible Area. Susceptibility is moderate on slopes of 30 to 50 percent and this area is in the Marginally Susceptible Area. On the limited local areas of greater than or equal to 50 percent slopes, susceptibility is high and is in the Most Susceptible Area.

Tec - Unnamed Claystone (lower Eocene)

Lithology

Lower Eocene, marine.

Claystone: Gray where fresh, weathers yellow-brown and red-brown. With fine grained sand. Thin bedded, intensely fractured, low to moderate hardness, and weak.

Sandstone: Gray where fresh, weathers red-brown, gray or yellow-brown. Sand is fine to medium grained. Sandstone forms very thin to thin interbeds near base of claystone. Intensely fractured, low to moderate hardness, and weak.

Topography, Structure, and Vegetation

Forms slopes, drainages, and saddles in spur ridges topographically below smooth rounded ridges and hills underlain by the more resistant Domengine Sandstone or Upper Meganos Formation. Slopes are between 20 and 50 percent (11 and 27 degrees), with the shallower slopes in the southern portion of the south limb of the Pacheco Syncline and are between 40 and 50 percent (22 and 27 degrees) in the hills on the west flank of the Martinez Valley. Slopes in the north limb of the anticline to the north of the Franklin Fault and in the narrow band of outcrops adjacent and east of the Franklin and west of the Calaveras faults are between 20 and 30 percent (11 and 17 degrees) with very limited areas of up to 40 percent (22 degrees) slopes in the first structure and as low as 10 percent (6 degrees) in the second. In general, slope angles are lower in the southern outcrops than the northern. Most outcrop area forms anti-dip slopes

Dips are generally poorly defined, but appear to range from about 40 to 80 degrees and about 80 degrees on overturned beds in the hills on the west flank of the Martinez Valley.

Soils

Surficial soils are mapped as clay. The Unified Soil Classification is CL. Soils are generally highly expansive but are moderately expansive on the north half of the exposure in the hills on the west flank of the Martinez Valley. Soils have low to moderate shear strength and are moderately to highly erosive.

Slope Stability

Landslide Density, Type and Size

Landslides are moderately common to uncommon. Generally, there is a higher concentration of landslides than in the adjacent Domengine Sandstone with similar structure and slope.

Landslides size and type are:

- *1 to 3 acre soil/rock slumps, about evenly distributed in drainages and planar or convex slopes are moderately common.

- *less than or equal to 1 acre soil slumps in drainages are uncommon.

- *one, 5 acre rock slump was identified in a drainage along an unnamed fault in the Pacheco Syncline, on an anti-dip slope.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides are about equally distributed on grass-covered, drainages and planar or convex slopes, greater than or equal to 40 or 50 percent (22 or 27 degrees) slopes in the northern exposures and greater than or equal to 20 percent (11 degrees) in the southern exposures, or in drainages along faults with slopes greater than or equal to 20 or 30 percent (11 to 17 degrees). No large, rock slumps or slides were identified. All landslides occur on highly expansive soils. Landslides generally occur in the surficial soil with slide planes that extend only to a shallow depth into the underlying weathered rock. The one five acre landslides, the largest identified in this unit, is in a drainage along a fault. The cause of this landslide is a likely from a failure in the fault-weakened rock.

Landslides occur mostly on anti-dip slopes as the unit crops out mostly as anti-dip slopes. However, landslides are locally very common on the limited area of steep, dip-slopes on the south limb of the Pacheco Syncline. Where measured, dip angles exceed slope angles, however, as dips are poorly defined, this may not occur everywhere.

Landslide Susceptibility Rating

The generally low density of landslides may be the result of limited areas of steep slopes,

although, a relatively large proportion of the steep slopes are free of landslides. Despite the fact that steeper slopes predominate in the northern exposures with gentler slopes in the southern exposures, landslide density is similar in both areas, indicating that landslide susceptibility in the southern exposures is greater than in the northern exposures. The cause of the one five acre landslide is likely from a failure in the fault-weakened rock. Unit appears to be susceptible to shallow dip-slope landslides. Slope stability of rock is judged to be good and of the surficial soil is moderate. The area outside the cut and fill is in the Most Susceptibility Area, Subarea 4.2. A much smaller portion is in the Marginally and Generally Susceptible Area.

Rockfall hazard is judged low because of lack of outcrops and generally gentle slopes. High rock fracture density will cause raveled talus to be fine gravel or finer.

Debris Flows

Debris flows are generally uncommon. Only three were identified in the northern half of the outcrop area on southwest, north and east-facing, grass-covered slopes of >40 percent (22 degrees) with soils mapped as plastic and highly expansive. Generally low debris-flow density and absence in the southern outcrop area is most likely because of the combination of generally plastic and expansive soils, and large areas of slopes which do not exceed 40 percent (22 degrees). Debris-flow susceptibility is judged to be low to moderate. In the areas outside the cut and fill, susceptibility is judged to be low on the slopes <40 percent (22 degrees) and this area is in the Least Susceptible Area. Susceptibility is moderate on slopes greater than or equal to 40 percent (22 degrees) and this area is in the Marginally Susceptible Area.

Meganos Formation

Tmgu - Meganos Formation, upper member (lower Eocene)

Lithology

Lower Eocene, marine.

Claystone: Gray where fresh, weathers yellow-brown and red-brown. Thin bedded, intensely fractured, low to moderate hardness, and weak.

Topography, Structure and Vegetation

Forms slopes and drainages in the Pacheco Syncline, topographically below ridges and hills underlain on the south limb by the unnamed Eocene Claystone, and on the north limb below the more resistant Domingine Sandstone. Slopes on the south limb are about 40 to 50 percent (22 to 27 degrees) with areas of 30 percent (17 degrees). Dips are poorly defined but where measured are 46 degrees. On the north limb slopes are between 20 and 30 percent (11 and 17 degrees), with dips between 58 and 70 degrees. In the hills on the west flank of the Martinez Valley, dips are poorly defined but where measured are about 80 degrees on overturned beds.

In the north limb of the unnamed anticline on the north side of the Franklin Fault, forms smooth, rounded, spur and strike ridges. Slopes are between 20 and 30 percent (11 and 17 degrees) with very limited areas of up to 50 percent (27 degrees). Dips are poorly defined, but where measured are between 60 and 80 degrees.

Practically all slopes are grass covered.

Soils

Surficial soils are mapped as consisting of clay. The Unified Soil Classification is CL. Soils are highly plastic and expansive, have low to moderate shear strength and are moderately to highly erosive.

Slope Stability

Landslide Density Type and Size

Landslides are common to very common. Generally, there is a much higher concentration of landslides than in adjacent Domengine Sandstone with similar structure and slope.

Landslides type and size are:

*1 to 3 acre soil/rock slumps about equally distributed in drainages, planar or convex slopes are common to very common.

*one, 5 acre soil/rock slump slide was identified in a drainage.

*one, 30 acre rock slump was identified on a planar anti-dip slope.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides in the 1 to 3 acre size range occur on anti-dip slopes of greater than or equal to 40 to 50 percent, where as they occur on dip slopes of greater than or equal to 25 percent slopes. The 5 acre landslide is on a dip-slope of 30 percent. Landslides <5 acres in size generally occur in the surficial soil with slide planes that extend to a shallow depth into the underlying weathered rock. The 30 acre landslide slide plane occurs deeper in the less weathered and less fractured rock.

Where measured, dip angles exceed slope angles, however dips are poorly defined and this may not occur everywhere. Landslides density is similar on anti-dip and dip slopes.

Landslide Susceptibility Rating

While landslides density is similar on anti-dip and dip slopes, the lower slope failure threshold on dip-slopes and that slope angles may exceed dip angles where dips are poorly defined suggest that the unit is susceptible to dip-slope landslides. Slope stability of rock is judged to be moderate to poor and surficial soil is poor. Outside the cut and fill areas, the unit is in the Most Susceptibility Area, Subarea 4.2, with a much smaller portion in the Marginally Susceptible Area. Small outcrops of this unit are exposed in the Tassajara area, but are not much affected by landslides.

Rockfall hazard is judged low because of lack of outcrops and generally gentle slopes. High rock fracture density will cause raveled talus to be fine gravel or finer.

Debris Flows

Debris flows are rare. Only three were identified on south or southwest facing, grass-covered slopes of greater than or equal to 40 to 50 percent (22 degrees to 27 degrees) mapped as plastic and expansive soils. Debris-flows are rare probably because of the generally nonsusceptible soils, and slopes which are generally <40 percent (22 degrees). Debris-flow susceptibility is judged to be low to moderate. Outside of cut and fill areas, susceptibility has been judged to be low on the <30 percent slopes and this area is in the Least Susceptible Area. Susceptibility is moderate on slopes of 30 to 50 percent and this area is in the Marginally Susceptible Area.

Tmgl - Meganos Formation, lower member (lower Eocene)

Lithology

Lower Eocene, marine.

Sandstone: Gray where fresh, weathers red-brown, gray or yellow-brown. Sand is fine to medium grained. Intensely fractured, low to moderate hardness, and weak.

Topography, Structure, and Vegetation

Forms primarily gently sloping to rolling slopes topographically below strike ridges underlain by the more resistant Martinez Formation. Slopes are less than 30 percent (17 degrees). Dips poorly defined, but where measured range from 55 to 75 degrees.

Soils

Surficial soils are mapped as fine to medium grained silty sand or silt. The Unified Soil Classifications are SM and ML. Soils are nonexpansive, have low to moderate shear strength and are highly to very highly erosive.

Slope Stability

Landslide Density, Type and Size

No landslides were identified.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Generally, dip angles greatly exceed slope angles.

Landslide Susceptibility Rating

Slope stability of rock and surficial soil in study area appears good. Outside of cut and fill areas, equal portions of the unit is in the Marginally Susceptibility Area, Subarea 2.2, and the Generally Susceptible Area. Small outcrops have been mapped in the Tassajara area, but are not much affected by landslides.

Rockfall hazard is judged to be low because of the lack of outcrops and gentle slopes.

Debris Flows

No debris flows were identified. The nonplastic and nonexpansive soils are generally susceptible to debris-flows, however, slopes on this soil type are generally <30 percent (17 degrees). Debris-flows susceptibility is judged to be low to moderate. Outside the cut and fill areas, susceptibility is judged to be low on the <30 percent slopes and this area is in the Least Susceptible Area. Susceptibility is moderate on slopes of 30 to 50 percent and this area is in the Marginally Susceptible Area.

Tmz - Martinez Formation, undifferentiated (upper Paleocene)

Lithology

Upper Paleocene, marine.

Mapped as undifferentiated on the north limb of the Pacheco Syncline.

Sandstone: Light brown, red-brown, or light gray weathered. Sand is fine grained. Unit locally tuffaceous. Moderately consolidated, intensely fractured, low hardness, weak to friable, and locally spheroidally weathered.

Claystone: Gray or green-gray. Moderately consolidated, platy to flaggy, crushed to intensely fractured, laminated to thin-bedded and occasionally thick-bedded, low to moderately hard, and weak.

Sandstone: Light red-brown weathered. Sand is fine to medium with little coarse grained. Moderately consolidated, thin-bedded, occasionally fractured, moderately hard, and moderately strong.

Topography, Structure, and Vegetation

Forms grass-covered, rounded strike slopes. Slopes are between 30 and 50 percent (17 and 27 degrees). Dips are 55 to 75 degrees.

Soils

Surficial soils are mapped as fine to medium grained silty sand or silt. The Unified Soil Classifications are SM and ML. Soils are nonexpansive, have low to moderate shear strength and are highly to very highly erosive.

Slope Stability

Landslide Density, Type and Size

Landslides are rare.

Only one smaller than 1 acre soil/rock slump was identified.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Generally, dip angles greatly exceed slope angles.

Landslide Susceptibility Rating

Slope stability of rock and surficial soil appears good. Outside the cut and fill areas, about equal portions of the unit is in the Marginally Susceptibility Area, Subarea 2.2, and in the Generally Susceptible Area.

Rockfall hazard is judged to be low because of the lack of outcrops and gentle slopes.

Debris Flows

No debris flows were identified. The nonplastic and nonexpansive soils are generally susceptible to debris-flows, however, slopes on this soil type are generally <50 percent (27 degrees). Debris-flow susceptibility is judged to be low to moderate. Outside the cut and fill areas, susceptibility is judged to be low on the <30 percent slopes and this area is in the Least Susceptible Area. Susceptibility is moderate on slopes of 30 to 50 percent and this area is in the Marginally Susceptible Area.

Martinez Formation

Tmzu - Martinez Formation, upper member (upper Paleocene)

Lithology

Upper Paleocene, marine.

Sandstone: Light brown, red-brown, or light gray weathered. Sand is fine grained. Unit is locally tuffaceous. Moderately consolidated, intensely fractured, low hardness, weak to friable, and locally

spheroidally weathered.

Claystone: Gray or green-gray. Moderately consolidated, platy to flaggy, crushed to intensely fractured, laminated to thin-bedded and occasionally thick-bedded, low to moderately hard, and weak.

Topography, Structure, and Vegetation

North of the Southampton Fault, along the Carquinez Straits, forms wooded slopes and drainages on the lower flanks of a larger strike ridge. Slopes are between 50 and 75 percent (27 and 37 degrees) with small areas of 30 percent (17 degrees). Dips are vertical to 80 degrees on overturned beds.

In the anticline just north of the Franklin Fault and east of the Southampton Fault, forms about evenly distributed wooded and grass-covered slopes. Slopes are between 20 and 40 percent (11 and 22 degrees), with areas of 50 percent (27 degrees) slopes. Dips are poorly defined on the south limb, but where measured range from 40 to 75 degrees. On the north limb, no dips were measured and dips are undefined.

Soils

Surficial soils are mapped as consisting of clay. The Unified Soil Classification is CL. Soils are highly expansive, have low to moderate shear strength and are moderately to highly erosive.

Slope Stability

Landslide Density, Type and Size

Landslides are uncommon to very common. Generally, there is a higher concentration of landslides than in lower Martinez Formation and Great Valley Sequence.

Landslides type and size are;

- *5 acre soil/rock slumps occurring mostly in drainages and rarely on planar slopes are common to very common.

- *5 to 10 acre rock slumps and slides occur on planar slopes are common.

- *less than or equal to 1 acre soil slumps occur in drainages are rare.

- *one, 40 acre disrupted translational rock slide was identified on an anti-dip slope, in the east half of the west central outcrop area and these landslides are rare.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides occur mostly in grass-covered drainages on dip-slopes, or along faults and usually where slopes are greater than or equal to 30 percent (17 degrees). Landslides are uncommon on the northeast-facing slopes and drainages with vertical dips, common on the north-facing, anti-dip slopes, and very common on the mostly north-facing dip-slopes. Landslides >5 acres are relatively large and deep, with slide planes occurring in the less weathered rock. The 40 acre translational landslide also involves the Hambro Formation and is located along the Franklin Fault.

Where measured, dip angles appear to greatly exceed slope angles, however, slope angles may exceed dip angles where dips are poorly defined.

Landslide Susceptibility Rating

It appears that failure planes of the >5 acre landslides are deeper than the stabilizing affect of

the roots of woodland vegetation as these landslides occur only in grasslands. Unit appears to be susceptible to anti-dip-slope landslides, and very susceptible to dip-slope landslides. Slope stability of rock and soil is judged to be moderate to low. That portion of the unit along the Carquinez Straits is in the Most Susceptible Area, Subarea 4.1. In the anticline, the unit is in the Most Susceptible Area, Subarea 4.2.

Rockfall hazard is judged to be low because of the generally gentle slopes, and lack of outcrops.

Debris Flows

Debris flows are rare. One was identified on a north-facing, 50 percent (27 degrees) slope. Lack of debris-flows is most likely because of the generally nonsusceptible soils and woodland vegetation. However, debris-flow susceptibility is judged to range from low to high because of the steep slopes and that the presence of debris-flows which may indicates local pockets of susceptible soil. On <30 percent slopes debris-flow susceptibility is judged to be low and the unit is in the Least Susceptible Area. Susceptibility is judged to be moderate on 30 to 50 percent slopes and this area is in the Marginally Susceptible Area. Susceptibility is judged to be high on slopes >50 percent and this area is in the Most Susceptible Area.

Tmzl - Martinez Formation, lower member (Paleocene)

Lithology

Upper Paleocene, marine.

Sandstone: Light red-brown weathered. Sand is fine to medium with little coarse grained. Moderately consolidated, thin-bedded, occasionally fractured, moderately hard, and moderately strong.

Topography, Structure, and Vegetation

Forms wooded slopes and drainages on the middle flanks of the larger strike ridge held up by the Great Valley Sequence, north of the Southampton Fault, along the Carquinez Straits. Slopes are between 50 and 75 percent (27 and 37 degrees) with small areas of 30 percent (17 degrees). Dips are vertical to 80 degrees on overturned beds.

In the anticline just north of the Franklin Fault and mostly east of the Southampton Fault, in the northwest-southeast trending anticline just south of Martinez and in the unnamed syncline south of Franklin Canyon and west of the Southampton fault, forms about evenly distributed wooded and grass covered, dip slopes. Slopes are between 20 and 40 percent (11 and 22 degrees), with small areas of 50 percent (27 degrees) slopes in the first structure with dips that are poorly defined, but appear to range from 20 to 75 degrees. In the second and third structures, slopes are between 30 and 50 percent (17 and 27 degrees). Dips in the second structure are poorly defined, but where measured range from 80 to 88 degrees and 88 degrees on overturned beds and dips in the third structure are undefined but the outcrop pattern suggests steep dips.

Soils

Surficial soils are mapped as consisting of clay. The Unified Soil Classification is CL. The soils are moderately to highly expansive, have low to moderate shear strength and are moderately to highly erosive.

Slope Stability

Landslide Density, Type and Size

Landslides are moderately common to common. Generally, there is a lower concentration of landslides than in adjacent upper Martinez Formation.

Landslides type and size are:

*1 to 5 acre soil/rock slumps mostly in drainages with less on planar slopes are moderately common to common.

*5 to 10 acre rock slumps and slides on planar slopes are moderately common.

*one, 30 and part of a 40 acre disrupted translational rock slide.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides generally occur on grass-covered and rarely on wooded slopes of greater than or equal to 40 to 50 percent (22 to 27 degrees), with some on >30 percent (17 degrees) slopes of all aspects and do not cluster along faults. Landslides are generally more common on the highly expansive soils than the moderately expansive soils. The <10 acre landslides are generally more common on dip-slopes. The toe of the 30 acre translational landslide occurs on a dip-slope while the toe of the 40 acre translational landslide occurs on an anti-dip slope. Both landslides continue upslope, suggesting that the failure may have been initiated in the lower Martinez Formation with progressive failure upslope into the overlying formations. Landslides in the 1 to 3 acre size generally occur in the surficial soil with slide planes that extend to only a shallow depth into the underlying weathered rock. The landslides between 3 and 10 acres in size and especially the 30 and 40 acre landslide, are relatively large and deep, with slide planes occurring in the less weathered rock.

Where measured, dip angles appear to equal or exceed slope angles, however, slope angles may exceed dip angles where dips are poorly defined.

Landslide Susceptibility Rating

It appears that failure planes are deeper than the stabilizing affect of the roots of woodland vegetation as the landslide are more common on grasslands. Unit appears to be susceptible to dip-slope landslides or the dip-slope failure planes may occur along fractures that are subparallel to bedding planes, but with a lower dip. Slope stability of rock and surficial soil is judged to be moderate to low. Most of the unit is in the Most Susceptible Area, Subarea 4.1. A small portion of the unit south of Martinez is in the Most Susceptible Area, Subarea 4.2.

Rockfall hazard is judged to be low because of lack of outcrops and slopes which are not generally >40 percent (22 degrees).

Debris Flows

Debris flows are moderately common to common. They were mapped on south-facing, woodland and grassland slopes of greater than or equal to 50 percent (27 degrees) with moderately to highly expansive, cohesive soils. The widespread distribution of debris-flows in an area mapped as generally nonsusceptible soils, probably indicates that hollows with unmapped susceptible soils may also be widespread throughout the unit. Therefore, debris-flow susceptibility is judged to be moderate to high. On <50 percent (27 degrees) slopes, susceptibility is moderate and this area is in the Marginally Susceptible Area. Susceptibility is high on slopes >50 percent (27 degrees) and this area is in the Most Susceptible Area.

Ku - Great Valley Sequence, undifferentiated (Cretaceous)Lithology

Cretaceous, marine.

Sandstone: Gray to dark-gray where fresh, light brown where weathered. Sandstones are lithic feldspathic wackes. Sand is fine to medium grained. Moderately to well cemented, very-thin bedded, closely to intensely and conchoidally fractured, moderately hard to hard, moderately strong to strong, and moderately weathered.

Sandstone: White with 3-5% dark grains. Sand is fine grained. Poorly cemented, shaley to flaggy, intensely fractured to crushed, low hardness, weak, and moderately weathered. Thin beds gives banded chert appearance.

Siltstone: Dark gray. Well cemented, slabby, closely fractured, hard, and strong.

Clay Shale: Gray. Moderately cemented, laminated to thin-bedded, low hardness, and weak.

Conglomerate: Gray. Fine to medium grained gravel in matrix of fine to medium with trace coarse grained sand, polymict. Well cemented, hard, and strong.

Beds of differing lithology too thin to depict separately at this scale. Ku lithology and topography changes along strike; sandstone and shale, and drainages and hills or knolls align along strike. In general, shale appear to underlie drainages and sandstones underlie ridges. Unit poorly exposed with outcrops usually only in road and railroad cuts, streams and with small resistant sandstone outcrops occurring sporadically on ridges or on steep slopes without soil cover. Lithologic variability along strike may be result of offset along unmapped small faults.

Topography, Structure, and Vegetation

Forms smooth rounded, flat topped, and occasionally sharp crested strike and spur ridges, hills and intervening drainages. Slopes primarily of 30 to 50 percent (17 to 27 degrees) with areas of 75 percent (37 degrees).

Vegetation is generally wooded on north-facing drainages and grassland in the south-facing slopes and on the hills and ridges.

Soils

Surficial soils are mapped as two types. On most of the outcrop area, surficial soils are mapped primarily as clay. The Unified Soil Classification is CL. Soils are highly expansive on hills and ridge tops and moderately expansive in the drainages and slopes. Soils have low to moderate shear strength and are moderately to highly erosive.

In the extreme southern portion of the outcrop area, surficial soils are mapped as fine to medium grained silty sand or silt. The Unified Soil Classifications are SM and ML. Soils are nonplastic, nonexpansive, have low to moderate shear strength and are highly to very highly erosive.

Slope Stability

Landslide Density, Type And Size

Landslides are common to very common. Generally, there is a higher concentration of landslides than in the adjacent Kcs member with similar structure and slope.

Landslides type and size are:

*2 to 5 acre and occasionally 10 acre soil/rock slumps and slides in first order drainages or planar slopes, or coalescing in several adjacent first order drainages are very common.

*less than or equal to 2 acre soil slumps in first order drainages or planar slope are common.

*5 to 10 acre rock slumps and occasionally translational slides on steep planar and convex slopes, and occasionally earthflows in first order drainages are moderately common.

*areas of ravelling and rilling along steep slopes without soil cover along road and railroad cuts and isolated natural outcrops along the Carquinez Straits.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides occur mostly on greater than or equal to 50 percent (27 degrees) slopes, but some occur on >30 percent (17 degrees) slopes. The 2 to 5 acre and 5 to 10 acre slump/slide landslides occur mostly on planar slopes with highly expansive soils and appear to have slide planes in the less weathered rock. They are about evenly distributed on wooded or grass-covered slopes.

The less than or equal to 2 acre soil slumps were identified about equally on all soil types and these landslides occur as shallow earth-flows in colluvium accumulated in first-order drainages, with most of these drainages involved in sliding and many of the earthflows extend from the head to the toe of a drainage. This indicates that the landslides have slide planes in the colluvium or shallow weathered rock and occur shallower than the stabilizing effect of woodland vegetation. The less than or equal to 2 acre soil slumps and 2 to 5 acre coalescing landslides are about evenly distributed on dip and anti-dip slopes and occur mostly in grass-covered drainages. The areas of ravelling are more common on dip slopes than on anti-dip slopes. The unit is crossed by several faults, however, no clustering of landslides occurs along faults.

Dip angles are about equal to, or do not greatly exceed slope angles.

Landslide Susceptibility Rating

The translational and slump slides occur mostly on dip-slopes, and dip angles are about equal to, or do not greatly exceed slope angles. Therefore, the unit appears to be susceptible to dip-slope landslides. Susceptibility to these types of landslides appears to be greatest in the southern area because unit forms a higher proportion of dip-slopes there, while northern area has more anti-dip slopes. Landslides on the wooded areas probably have slide planes below the stabilizing effect of the woodland vegetation. Susceptibility to the less than or equal to 2 acre soil slumps and 2 to 5 acre coalescing landslides does not appear to be related to formation structure, but landslides occur where the fracture density is greatest which is generally in drainages rather than in the surrounding rock which forms planar or convex slopes. Slope stability of the rock is judged to be moderate while the surficial soil is judged to be poor. The southern and northwestern outcrop areas are in the Most Susceptible Area, Subarea 4.2. The northeastern areas are in the Most Susceptible Area, Subarea 4.1. The unit has been mapped as being highly to moderately prone to landsliding in the Tassajara area. The fissile nature of the lower shale member contributes a moderate susceptibility to slope failures in Vacaville area. In the Cordelia-Vallejo area, the mudstones slake in water and are extremely susceptible to landsliding.

There is a moderate rockfall hazard below steep anti-dip slopes and cuts. Road and railroad cuts and isolated natural outcrops on steep slopes without soil cover generally fail by small rock falls and ravelling. The degree of rock fracturing and lithification control the size of the rockfall fragments. Shale and highly fractured or softer sandstone rockfall fragments are generally angular, fine gravel size or finer, which break down rapidly and are not transported far from the slope base. The rockfall fragments from the hard or less fractured sandstone are generally boulder size or finer, which accumulates locally in small amounts in upland stream and drainage channels, and less often at base of steep slopes. Small fragment amount and local accumulations indicates material is not transported far from area of deposition.

Debris Flows

Debris flows are common and locally very common, occurring both singularly and in clusters. Debris-flows were mapped on grass-covered, planar slopes and less often in drainages in areas mapped as plastic and expansive soils with >40 percent (22 degrees) slopes of all aspects, but

most common on south-facing slopes. The widespread distribution of debris-flows in areas mapped as generally nonsusceptible soils, probably indicates that hollows with unmapped susceptible soils may also be widespread throughout the unit. Many debris-flows are continuing to fail and are enlarging by sliding or raveling of the head and lateral flank scarps and therefore are mapped in larger landslides. Debris-flow susceptibility is judged to be high and the entire unit is in the Most Susceptible Area.

Kcs - Great Valley Sequence, sandstone (Cretaceous)

Lithology

Cretaceous, marine.

Sandstone: Red-brown weathered. Sandstone is a quartz arenite. Sand is fine to medium with trace coarse grained. Moderately to well cemented, thick-bedded to massive, moderately to occasionally fractured, moderately hard, moderately strong, and moderately weathered.

Sandstone: Light brown. Sand is very fine or fine to medium grained, light-green fine to coarse grained sand in glauconitic beds. Minor interbedded light-brown siltstone. All units poorly cemented, crushed, with fractures contorted with red-brown weathering extending approximately 0.25 inch from fractures.

Topography, Structure, and Vegetation

Outcrops as a few narrow band across slopes on spur ridges and drainages. Slopes are 40 to 75 percent (22 to 37 degrees). Forms wooded slopes with dips from 55 to 67 on overturned beds along the Carquinez Straits. Dips in the anticline which is south of Martinez and east of the Southampton Fault and extends to the east of Alhambra Valley, are between 75 to 88 degrees on overturned beds of the north limb, and between 30 and 70 degrees on the upright south limb. Dips in the unnamed syncline south of Franklin Canyon and west of the Southampton fault are undetermined.

On the north limb of the Pacheco Syncline forms narrow, low strike ridges. Slopes are <40 percent (22 degrees). Dips are between 50 and 75 degrees.

Vegetation is generally woodland, with much smaller areas of mixed woodland and grassland.

Soils

Surficial soils are mapped as two types. Throughout most of the outcrop area surficial soils are mapped as clay. The Unified Soil Classification is CL. Most of these soils are moderately expansive, as along the Carquinez Straits, in the anticline and the west half of the south limb of the syncline, and a smaller area are highly expansive, as in the rest of the syncline, have low to moderate shear strength and are moderately to highly erosive.

In the Pacheco Syncline, near the north end of the north limb, surficial soils are mapped as fine to medium grained silt. The Unified Soil Classification is ML. These soils have a low expansion potential, low to moderate shear strength and are highly erosive.

Slope Stability

Landslides Density, Type and Size

Landslides are uncommon. None were identified in much of the outcrop area, although small areas where landslides are moderately common exist in the eastern part of the anticline. The Kcs member has a much lower landslide density than any similar sized outcrop area in the Ku member with similar structure and slope.

Landslides size and type are:

- *less than or equal to 2 acre soil/rock slumps in drainages.

- *rockfalls and ravelling occur along road and railroad cuts and isolated natural outcrops on steep slopes without soil cover.

Slope Aspect, Soil, Vegetation and Structural Relationship

Landslides occur on greater than or equal to 40 percent (22 degrees) slopes, however, this is about the minimum slope for this unit, except in the Pacheco Syncline. No large bedrock landslides which originate in this unit were identified. Landslides are small and shallow and occur in the colluvium and surficial soils that accumulate in drainages. Landslides occur on the moderately or highly expansive soils and on slopes of all aspects, with slide planes that extend to only a shallow depth in to the underlying weathered, fractured rock. Most landslides occur on dip-slopes, but most of the outcrop area forms dip-slopes. Landslide concentration is similar throughout most of the unit.

In the anticline, where dips were measured on dip-slopes, generally, dip angles exceed slope angles. Landslides also cluster along the north-south trending fault at the west end of the syncline and to a lesser degree in the eastern part of the anticline.

The one, 30 acre translational landslide that originated in the lower Martinez Formation and encroaches onto Kcs is relatively large and deep, with the slide plane occurring in weathered rock. The toe of this landslide occurs on a dip-slope in the lower Martinez Formation and extends upslope into the Kcs member. This suggests that the failure may have been initiated in the lower Martinez with progressive failure upslope into the overlying formations.

Landslide Susceptibility Ratings

As dip angles generally exceed slope angles, that landslides cluster along faults and the small and shallow nature of the landslides, indicates that the unit does not generally form dip-slope

failures, instead landslides occur where colluvium is thickest and where the fracture density is greatest, which is generally in drainages and along faults. Lack of landslides in Pacheco Syncline may be because slopes there are less than or equal to 40 percent. Slope stability of the rock is judged to be generally good while the surficial soil is judged to be moderate. Most of the outcrop area is in the Most Susceptible Area, Subarea 4.1. The west end of the syncline near the fault is in the Most Susceptible Area, Subarea 4.2.

Rockfall hazard is judged to be high in the quartz arenite sandstone below steep dip- or anti-dip slopes and cuts. Rock fracture density and lithification will control the size of rockfall fragments, which will most likely be in the cobble to boulder size. Rockfall hazard is judged to be low in the glauconitic sandstone because of the high fracture density and poor cementation of that material, despite the steep slopes. High fracture density and poor cementation indicate that the glauconitic sandstone is more likely to fail by raveling than rockfall. Rock fracture density and lithification will control the size of ravelled material which will probably be gravel size and would likely disintegrate during downslope movement.

Debris flows

No debris flows were identified. Lack of debris-flows is most likely because of the generally nonsusceptible soils and woodland vegetation. However, debris-flow susceptibility is judged to be high throughout the unit because of the steep slopes and that many of the adjacent formations appear to have local or widespread distribution of hollows with susceptible soil which do not appear on the topographic or soil maps. Debris-flow susceptibility is judged to be high, and the entire unit is in the Most Susceptible Area.

Kus - Great Valley Sequence, interbedded (Cretaceous)

Lithology

Cretaceous, marine.

Sandstone: Gray to dark-gray where fresh, light brown where weathered. Sandstone is a lithic feldspathic wackes. Sand is fine to medium grained. Moderately to well cemented, very-thin bedded, closely to intensely and conchoidally fractured, moderately hard to hard, moderately strong to strong, and moderately weathered.

Sandstone: White with 3-5% dark grains. Sand is fine grained. Poorly cemented, shaley to flaggy, intensely fractured to crushed, low hardness, weak, and moderately weathered. Thin beds gives banded chert appearance.

Siltstone: Dark gray. Well cemented, slabby, closely fractured, hard, and strong.

Clay Shale: Gray. Moderately cemented, laminated to thin-bedded, low hardness, and weak.

Topography, Structure, and Vegetation

Forms flat crested, rounded, and sharp crested strike and spur ridges with well developed ribs, flutes and drainages. Slopes are 40 to 75 percent (22 to 37 degrees), with areas on slopes and particularly on ridge crests of <30 percent (17 degrees). Dips are between 30 and 48 degrees and between 55 and 65 degrees on overturned beds. Dips west of the Southampton Fault on the anticline and syncline are undefined, but outcrop pattern indicate high angles. Vegetation is mostly woodland with some grassland in the drainages and on the slopes and grassland on the ridge crests.

On the north limb of the Pacheco Syncline forms small area of grass covered rounded to sharp crested strike ridge. Slopes are 10 to 30 percent (6 to 17 degrees) with limited areas of 40 percent (22 degrees) slopes. Dips are between 24 and 64 degrees.

Soils

Surficial soils are mapped as clay. The Unified Soil Classification is CL. These soils are moderately expansive in the west end of the exposures along the Carquinez Straits, and just west of the Alhambra Valley in the anticline, and highly expansive in the rest of the outcrop area. These soils have low to moderate shear strength and are moderately to highly erosive.

Slope Stability

Landslide Density, Type and Size

Landslides are moderately common. The Kus member has a lower landslide density than the Ku member with similar structure and slope.

Landslides type and size are:

- *greater than or equal to 2 acre soil slump in drainages are moderately common.

- *2 to 5 acre soil/rock slump/slides in drainages and occasionally translational landslides on planar slopes or coalescing in up to several first order drainages are moderately common.

- *5 to 10 acre rock complex translational slides and slump or earthflows are rare.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides generally occur on slopes of greater than or equal to 40 percent (22 degrees), and locally on 30 percent (17 degrees) slopes with a similar concentration throughout the western exposures. No landslides were identified in the Pacheco Syncline. Landslides generally occur on the grass-covered slopes and drainages of all aspects while the adjacent wooded areas of similar slope and structure are free of landslides. Landslides are about evenly distributed on the moderately and highly expansive soils, although most earthflows occur in the highly expansive soils. Landslides cluster along the north-south trending fault at the west end of the syncline and to a lesser degree in the eastern part of the anticline. The 2 acre and 2 to 5 acre landslides occur primarily in the colluvium accumulated in drainages with slide planes that extend to only a shallow depth into the underlying weathered and fractured rock with a similar landslide concentration throughout most of the unit and on dip and anti-dip slopes. The 5 to 10 acre translational slides involve other units and occur along faults.

Where measured dip angles generally exceed slope angles and where dips are undefined, dip angle appear to be high, greater than slope angles.

Landslide Susceptibility Rating

No landslides were identified in the Pacheco Syncline probably because slopes are only locally >30 percent (17 degrees), and 40 percent (22 degrees) seems to be the lower slope threshold for failure. It does not appear that the unit forms dip-slope failures, instead landslides occur where colluvium is thickest and where the rock fracture density is greatest, which is generally in drainages and along faults. Slope stability of the rock is judged to be generally good while the surficial soil is judged to be moderate. Most of the unit is in the Most Susceptible Area, Subarea 4.1. The west end of the syncline near the fault is in the Most Susceptible Area, Subarea 4.2.

Rockfall hazard is judged to be low to moderate, despite the steep slopes. High fracture density and thin bedding indicate that unit is more likely to fail by raveling than rockfall. Rock fracture density and lithification will control the size of ravelled clasts which will probably be gravel size and would likely disintegrate during downslope movement.

Debris Flows

Debris flows are moderately common. Debris-flows occur on south-facing, grass-covered drainages in areas mapped as primarily plastic and moderately to highly expansive soils with slopes of greater than or equal to 50 percent (27 degrees) with some on greater than or equal to 40 percent (22 degrees) slopes. That the identified flows are widespread, occurring primarily in areas mapped as generally nonsusceptible material probably indicates that hollows with unmapped susceptible soil are also widespread throughout the unit, but do not appear on the topographic or soil maps. Therefore the distribution of debris-flows reflects the general debris flow potential of the unit better than the mapped soil type. Debris-flow susceptibility has been judged to be high throughout the unit and the entire unit has been assigned to the Most Susceptible Area.

Kuh - Great Valley Sequence, sandstone with minor clay shale (Cretaceous)

Lithology

Cretaceous, marine.

Sandstone with minor clay shale.

Sandstone: Red-brown weathered. Sand is fine to medium with trace coarse grained. Moderately cemented, thick-bedded to massive, moderately to closely fractured, some beds intensely fractured with spheroidal fracturing, moderately hard, moderately strong, and moderately weathered.

Clay Shale: Brown-gray. Conchoidally fractured, hard, and moderately strong. Resembles chert with white calcareous coating.

Clay Shale: Gray. Well cemented, slabby, closely fractured but some beds crushed, low hardness, weak to friable.

Topography, Structure, and Vegetation

Outcrops across spur ridges and intervening drainages and on slopes of larger strike ridges, and in the syncline south of Franklin Canyon and west of the Southampton Fault. Slopes are 30 to 50 percent (17 to 27 degrees) with areas of 75 percent (37 degrees). Forms mostly woodland vegetation on the west half of the south limb and grassland on the rest of the unit. Dips in the syncline are undefined, but the unit outcrop pattern suggests steep dips.

Forms grass covered, smooth rounded strike ridges and hills on the north limb of the Pacheco Syncline. Slopes are 10 and 30 percent (6 and 17 degrees) with limited areas of 40 percent (22 degrees) slopes. Dips are between 24 and 64 degrees.

Soils

Surficial soils are mapped as clay. The Unified Soil Classification is CL. Soils are highly expansive, have low to moderate shear strength and are moderately to highly erosive.

Slope Stability

Landslide Density, Type and Size

Landslides are moderately common to uncommon. Landslide density is about the same as in the Kcs member.

Landslides are <2 acre soil/rock slumps in drainages.

Slope, Aspect, Soil, Vegetation and Structural Relationship

Landslides occur mostly on south-facing slopes and are about evenly distributed on wooded and grass-covered slopes of greater than or equal to 30 or greater than or equal to 40 percent (17 to 22 degrees), although much of the outcrop area have slopes of 50 to 75 percent (27 to 37 degrees) without landslides. No landslides were identified in the Pacheco Syncline. Landslides are moderately common on the north limb of the syncline and are uncommon on the south limb. No large bedrock landslides were identified, however, a 30 acre translational landslide originates in the lower Martinez Formation and encroaches onto Kuh. Landslides, including the large translational landslide occur mostly on dip-slopes, however, unit mostly outcrops as dip-slopes and much of these slopes are free of landslides. The <2 acre landslides are shallow and occur in the colluvium and surficial soils that accumulate in drainages with slide planes that extend to only a shallow depth in to the underlying weathered and fractured rock. The 30 acre landslide is relatively large and deep, with the slide plane occurring deeper in the less weathered rock. The toe of this landslide occurs on an dip-slope in the lower Martinez Formation and extends upslope into the Kuh member. This indicates that the failure may have been initiated in the lower Martinez Formation with progressive failure upslope into the overlying formations. Landslides cluster somewhat along the north-south trending fault at the west end of the syncline.

Generally, dip angles exceed slope angles in the Pacheco Syncline. Dips are undefined in the unnamed syncline, but outcrop pattern indicates dips are steep and probably exceed the slope angle.

Landslide Susceptibility Rating

No landslides were identified in the Pacheco Syncline probably because slopes there are not >30 percent and 30 to 40 percent seems to be the lower slope threshold for failure. In general, unit does not form dip-slope failures, and instead landslides occur where the colluvium is thickest and where the fracture density is greatest, which is generally in drainages and along faults. The one larger landslides appear to be related more to the slope stability properties of the lower Martinez Formation than the Kuh member. Slope stability of the rock is judged to be generally good while the surficial soil is judged to be moderate. Most of the outcrop in the unnamed syncline area is assigned to the Most Susceptible Area, Subarea 4.1. Along the fault, at the west end of the syncline and at the encroaching large translational landslide, the unit is

assigned to the Most Susceptible Area, Subarea 4.2. In the Pacheco Syncline, the unit is assigned to the Marginally or Generally Susceptible Area.

Rockfall hazard is judged to be low on slopes less than 50 percent (27 degrees) and moderate on slopes exceeding 50 percent, because of the moderate to high fracture density, moderate cementation, woodland vegetation on the 75 percent (37 degrees) slopes and lack of outcrops. Degree of rock fracturing and lithification will control the rare rockfall fragment size which will probably be gravel to boulder size.

Debris flows

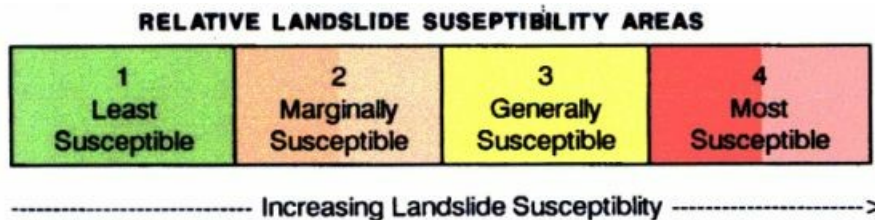
No debris flows were identified. The lack of mapped debris-flows may be the result of the plastic and highly expansive soils and slopes which are only locally greater than or equal to 50 percent (27 degrees). However, most of the adjacent formations appear to have local or widespread distribution of hollows with susceptible soil which do not appear on the topographic or soil maps. Therefore, the debris-flow susceptibility is judged to be high in the unnamed syncline and this area is in the Most Susceptible Area. In the Pacheco Syncline, the unit is judged to have a low debris-flow potential and is assigned to the Least Susceptible Area.

Digital Geohazards-GIS Map of John Muir National Historic Site and Vicinity

The following information, information pertaining to relative landslide susceptibility, slope-failure features and relative debris-flow susceptibility, relevant to the GRI Digital Geohazards-GIS Map of John Muir National Historic Site and Vicinity, is presented below.

Relative Landslide Susceptibility

Information related to relative landslide susceptibility features in the GRI digital geohazards-GIS data.



AREA 1 Least Susceptible Area.

This area is characterized by topographically low-lying valley bottoms and alluviated floodplains. Slopes are generally less than 5 percent (3 degrees), although slopes up to 20 percent (11 degrees) occur locally. Landslides and other features related to slope instability are extremely scarce, but can occur where slopes exceed 15 percent (9 degrees), such as along steep banks of streams and gullies or in artificial cuts. Most of the area is underlain by unconsolidated sediments that lack the strength to support steep slopes but occupy a relatively stable position due to the flatness of the slope which limits potential energy. Land within Area 1 will probably remain relatively stable unless the topography is radically altered by excavation or grading. Area 1 may also contain landslide deposits that have moved to relatively stable positions at or beyond the bases of the bedrock slopes from which they are derived.

Recommended Application: Engineering geologic investigations addressing slope stability are generally not necessary for proposed development except where mass grading is likely to create deep cuts, encroach upon local slopes or drainage-channel banks or cut into the toes of landslides which have moved onto the area from the adjacent slopes.

AREA 2 Marginally Susceptible Area.

This category contains two subareas:

Subarea 2.1: The land underlain by the bay mud and filled marshlands constitutes subarea 2.1. These materials are susceptible to flowage and lateral movement on nearly flat-lying slopes (less than 2 percent or 1 degree) and liquefaction during earthquakes. The weak materials in subarea 2.1 are vulnerable to slope failure when undercut, excavated, or subjected to differential loading, especially along margins of tidal channels.

Subarea 2.2: This area is characterized by gentle to moderately steep terrain with slopes that are generally less than 30 percent (17 degrees). Also includes broad ridgetops and spur crests, commonly flanked by steep, potentially or identifiably unstable slopes. Landslides and other features related to slope instability are uncommon. The materials underlying the slopes are not considered likely to mobilize under natural conditions. In general, slope stability is due more to the gentleness of the slopes rather than the strength of the geologic material. The stability of slopes within Area 2.2 may change substantially in response to excavation or mass grading.

Recommended Application: Engineering geologic investigations are advisable for proposed

development that specifically address slope stability because of the weakness of the bay mud and potential effects that modifications of the land can have on slope stability.

AREA 3 Generally Susceptible Area.

This area is characterized by steep terrain with slopes of 30 to 50 percent (17 to 27 degrees). Although landslides are uncommon, slopes are likely to be near their stability limits because of the strength of the rocks and steepness of the slopes. Thus, the material underlying this area can be expected to fail, locally, when natural processes or man-caused alterations adversely modify the terrain and steepen, load, or remove natural supporting buttresses from slopes.

Recommended Application: Detailed engineering geologic investigations for proposed development, which address slope stability, should be required and completed prior to development, because of the potential for slope failure that can result from land modification.

AREA 4 Most Susceptible Area.

This area is characterized by rugged, very steep terrain with slopes that are generally greater than 50 percent (26 degrees) and locally 75 percent (37 degrees) or steeper. Most of the identified landslides are within Area 4. This category contains two subareas:

Subarea 4.1: Within area 4, the steepest, most rugged terrain with the highest relief is primarily located within this subarea. Typically, within subarea 4.1, landslides, which range from moderately common to common, are often widely spaced. Landslides are generally of the smaller and shallower type, usually less than 5 acres in size, that incorporate colluvium or shallow, fractured bedrock. Some larger, deeper landslides occur in this subarea, but they are not common. There is a moderate rockfall hazard where bare or sparsely vegetated slopes of 75 percent (37 degrees) or greater occur. The combination of the steep, rugged and high-relief terrain, low landslide density, generally small landslide size, and the performance of the geologic formations exposed in Subarea 4.1 indicate that these rock units are among the harder, stronger, more resistant and more stable rocks found in the study area. Although slopes in Subarea 4.1 are generally more stable than those in Subarea 4.2, they are interpreted to be at or close to their stability limits because of the steepness of the slopes. The materials underlying this area can therefore be expected to fail, locally, when adversely affected by natural processes or man-caused modifications that steepen slopes, increase loads, or remove natural buttresses from the bases of the slopes. Slope instability is probably more the result of the steepness of the slopes than the weakness of the rocks.

Subarea 4.2 The subarea consists primarily of the gentler and lower relief terrain within Area 4, in contrast to the steep terrain within Subarea 4.1. The subarea also includes places surrounded by Subarea 4.1, where the presence of faults appears to have adversely affected the slope stability. Landslide density is greater than elsewhere in the study area with landslides being common to very common, as well as being closely spaced. Landslides in Subarea 4.2, range from small and shallow (less than 5 acre) to very large (30 to 40 acres), deep bedrock translational slides. The larger, deeper landslides are widespread and, locally, very abundant. The combination of predominantly gentler and lower relief terrain, abundance of landslides, large landslide size, and the performance of the geologic formations exposed in Subarea 4.2 indicate that these rock units are generally softer, weaker, less resistant and less stable than the rocks exposed in Subarea 4.1 and are invariably less stable than those in the balance of the Study Area. Slopes in Subarea 4.2 are considered to be naturally unstable and subject to failure even in the absence of the activities of man. Slope instability results primarily from the weakness of the rocks in what is only moderately steep terrain.

Recommended Application: Detailed, comprehensive engineering geological investigations addressing slope stability should be required for any proposed development.

IMPORTANT: PLEASE NOTE

Note 1. Information shown on this map is based upon the best data currently available. The boundaries of the areas were determined by combining observations (objective data), which are shown on Plate 328 and Plate 32C, with judgments and interpretations (subjective data) drawn from the

experience of the author with the field area at the time the map was made.

Note 2. This map is based upon judgments that are interpretative and that apply generally to large areas. Therefore, within each area conditions may range, locally, through all levels of susceptibility. Small unmapped slope failures may exist within Area 1 and there may be relatively stable sites within Area 4.

Note 3. Landscape modifications by man may significantly alter slope stability in specific areas. Thus, the relative landslide susceptibility of these areas may change accordingly.

Note 4. The delineation of the various areas of susceptibility is limited by the scale or the map.

Note 5. No attempt was made to assess the susceptibility of slopes to seismically induced landslides.

GENERAL INFORMATION

This map has been prepared to aid in general land-use planning. It is neither intended nor suitable for detailed evaluation of individual sites. Such evaluations require engineering geologic studies and soils engineering investigations for proper planning of specific construction projects.

The susceptibility map is a derivative map based upon the following information gathered for this 1) the occurrence and distribution of landslides, other types of slope failure, and features indicative of slope instability (see Plate 328 - Landslides and Related Features Map); 2) the geology of the area, including bedrock types and distribution of the various units, lithologic properties relative to slope stability, and the structural framework - the folding and faulting of strata (see Plate 32C - Geologic Map); and 3) the relative behavior of slopes within the study area as interpreted from analysis of aerial photographs and field observations.

Although stability studies for proposed grading projects commonly require development of quantitative data through laboratory testing of samples taken in the field, such testing was not done for this regional evaluation. In producing this map, it was assumed that actively sliding material has the lowest relative strength, and thus, the highest relative susceptibility to landsliding, of all the geological materials underlying the slopes. Conversely, apparently stable alluvial and bedrock areas of low relief were assumed to be least susceptible to landsliding due to the lack of slope failure feature. The relative stability between these extremes was evaluated subjectively based on field observations. The principal factors considered in making the interpretations shown on this map are the following:

- Steepness of slopes, whether or not landsliding is apparent upon them.
- The apparent stability characteristics of geological materials underlying the slopes and adjacent lower-lying areas, as expressed in their natural exposures and their observed responses to alteration by the activities of man. For example, slopes that exhibit abundant evidence of landsliding or downslope creep of the soil are considered oversteepened relative to the strength of the materials that underlie them.
- The presence of active or intermittent natural influences that tend to cause slope failure. These include gravity, active faulting, fluvial processes, and the tendency of certain expansive soils (which are high in smectite-group clays) to shrink and swell under changing moisture conditions

These criteria are combined to yield the 4-value scale used on the map to indicate the comparative capacity of slopes to resist failure.

cf Areas not classified. These areas have been significantly modified by grading for development, road construction, filling of marshlands or mining.

Program Authority Statement - The map has been prepared in accordance with the LANDSLIDE HAZARD IDENTIFICATION ACT (Chapter 7.7, Division 2 of the California Public Resources Code).

Text and graphic from source map: [Relative Landslide Susceptibility Map \(Map No.32\)](#).

Slope-Failure Features

Information related to landslide and other hazard features in the GRI digital geohazards-GIS data.

LANDSLIDE DEPOSITS

A landslide is a mass of rock, soil and debris that has been displaced downslope by sliding, flowing, or falling. Landslides include cohesive block glides and disrupted slumps that have formed by translation or rotation of the slope materials along one or more planar or curvilinear slip surfaces. Most of the landslides whose boundaries are delineated on the map are greater than 10 feet thick. Also shown are selected surficial features that typically involve only soil, colluvium, or other superficial debris that covers bedrock. The rates of movement of slope failures range from almost imperceptibly slow (as in earthflows) to extremely, even dangerously, rapid (as in debris flows).

SLOPE MOVEMENT SYMBOLS

DEFINITE OR PROBABLE LANDSLIDE: Exhibits all or many of the diagnostic features, including but not limited to headwall scarps, cracks, rounded toes, well-defined benches, closed depressions, springs, and irregular or hummocky topography, that are common to landslides and indicative of downslope movement. Continuous, single-barbed arrows indicate general direction of movement. Scarp (headwall of slump or block glide) is indicated by hachures where mapped.

QUESTIONABLE LANDSLIDE: Exhibits one or a few, generally very subdued, diagnostic features that commonly are associated with landslides. Typically lacks distinct landslide morphology but may exhibit disrupted terrain or other abnormal features that strongly to vaguely imply the occurrence or downslope movement. Possible scarp (headwall of slump or block glide) is indicated by hachures where mapped. Question mark signifies the uncertainty in the existence of the landslide.

SMALL LANDSLIDE: Filled arrowhead indicates a landslide too small to delineate at the scale of the map. Center of arrowhead corresponds to the location of the landslide; arrowhead points in the direction of movement (downhill). Question mark used where existence of the landslide is uncertain.

EARTHFLOW: A relatively shallow deposit of soil or other colluvial material that has oozed downslope, commonly at a rate too slow to observe except over long duration. Head scarp is shown by hachures where mapped. The area immediately upslope of failure typically unravels due to successive small slumps that occur in the oversteepened banks left by movement of the main body away from the source area. Arrow shows general direction of movement.

DEBRIS FLOW: A short-lived phenomenon resulting from the rapid failure of surficial slope materials. Also called mudflow, soil slip, or debris avalanche. Typically leaves a train of debris in a scoured channel following runout of the flow. Curved line delineates channel. Scarp depicted by triangle.

GULLY: Upland drainage channel where colluvium and alluvium underlying channel floor has been incised. Indicated by elongated outlined areas, where channel sides are slumping or sliding. Slumps and slides on channel sides retain vegetation and are generally steeper than upslope areas above the gully, without slumps or slides. Where indicated by single track, channel sides have few, if any, slides or slumps, they are nearly vertical and largely lack vegetation.

cf: Areas not classified. These areas have been significantly modified by grading for development, road construction, filling of marshlands or mining.

NOTE. This map records observations and interpretations that were used, along with other data, in the preparation of the accompanying Relative Landslide Susceptibility and Relative Debris-Flow

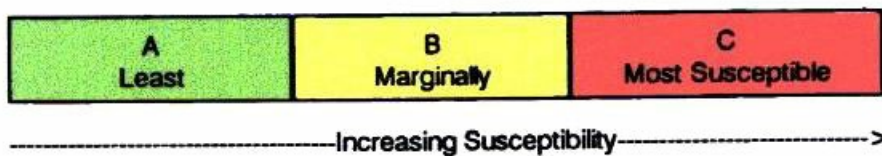
Susceptibility Maps (Plates 32A and 32D). Landslides shown on this map have been divided into groups on the basis of the clarity of their morphology and type of movement. The landslides are classified according to the certainty of their existence as determined by direct observation in the field, by analysis of aerial photographs, or by a combination of both methods. The various designations are not intended to imply, nor should they be interpreted to imply, the relative stability of the slopes involved. Accordingly, this map should not be used as a substitute for site-specific engineering geologic and soils engineering investigations.

Text and graphic from source map: [Landslide and Related Slope-Failure Features Map \(Map No.32\)](#)

Relative Debris-Flow Susceptibility

Information related to relative debris-flow susceptibility features in the GRI digital geohazards-GIS data.

EXPLANATION



Area A - Evidence of debris-flow activity was not observed in this area, which includes most areas of nearly level and gently sloping terrain, such as ridge tops and flood plains.

Area B - Evidence of debris flows is uncommon but occurs locally. Relatively few source hollows were noted on slopes within this area

Area C - Evidence of debris flows is relatively common on the slopes or on aerial photographs of terrain within this area. The necessary combination of source hollows, swales, or slopes, and appropriate source materials is relatively widespread.

cf - Areas not classified. These areas have been significantly modified by grading for development, road construction, filling of marshland or mining.

This Relative Debris-Flow Susceptibility Map has been prepared to aid in general land-use planning. It is neither intended nor suitable for detailed evaluation of individual sites. Such evaluations require engineering geologic studies and soils engineering investigations for proper planning of specific construction projects.

This map is a derivative map based upon the following information gathered for this study: 1) the occurrence and distribution of debris avalanches and debris flows (see Plate 328 - Landslides and Related Features Map); 2) the geology of the area, including the bedrock types and distribution of the various units, lithologic properties related to slope stability, and the structural framework - the folding and faulting of strata (see Plate 32C - Geologic Map); and 3) the relative behavior of slopes within the study area as interpreted from analysis of aerial photographs and field observations.

Debris flows and related phenomena differ significantly from the more commonly recognized rotational and translational landslides. Because the hazards posed by debris flows differ substantially from those posed by landslides, especially in size of surface area affected and speed of movement, this susceptibility map has been prepared. Although the three-fold system of classification used on this

map resembles that used on the Relative Landslide Susceptibility Map (Plate 32A), the two maps have important differences. Some sites that are least susceptible to landslide failure may be most susceptible to inundation by debris flows, whereas debris flows may be uncommon in areas most susceptible to other kinds of landslides.

Debris flows that originate as landslides and achieve velocities in excess of 10 feet per second (about 7 miles per hour) are termed “debris avalanches”. A typical debris avalanche begins as a shallow landslide that leaves a distinct, commonly spoon-shaped scar at its source. Triggered by intense local rainfall, the landslide material may mobilize as a slurry, or it may be quickly transformed from a relatively coherent mass into a slurry. If it becomes a slurry, it is indistinguishable from other types of debris flows. Once mobilized, the debris flow moves rapidly downslope, frequently gathering speed and, in some cases, more debris. This debris is deposited when the avalanche slows, commonly when gentler slopes are reached. These areas of deposition are sometimes far from the point of origin.

The hazard posed by a single debris flow or debris avalanche is dependent on several factors, including the volume of the flow, the velocity the flow achieves, and the slope and shape of the flow channel or runout area. Debris flows range in size from very small to very large. Very small flows (two cubic yards or less) may cause only slight damage. Large flows can seriously damage structures, sometimes demolishing them completely, and can bury people, causing death or serious injury. Velocities of large flows commonly reach 30 feet per second (20 miles per hour) or more. Because of the damage resulting from such flows, the National Flood Insurance Program was amended in the mid-1970's to cover inundation by “mudslides” (a term commonly applied to debris flows and debris avalanches in news reports). Other terms frequently used to describe such phenomena include soil slip-debris flow and debris side-debris flow.

Note 1. Information shown on this map is based upon the best data currently available. The boundaries of the debris flow susceptibility areas were determined by combining observations (objective data shown on Plate 32B and Plate 32C), with judgments and interpretations (subjective data) drawn from the experience of the author with the field area at the time the map was made.

Note 2. This map is based upon judgments that are interpretative and that apply generally to large areas. Therefore, within each area conditions may range, locally, through all levels of susceptibility. Small, unmapped debris flows may exist within Area A and there may be relatively stable sites within Area C.

Note 3. Modifications of the terrain by man may significantly alter slope stability in specific areas. Thus, the relative debris-flow susceptibility of these areas may change accordingly.

Note 4. The delineation of the various areas of susceptibility is limited by the scale of the map.

Note 5. No attempt was made to assess the susceptibility of slopes to seismically-induced slope failures.

Text and graphic from source map: [Relative Debris-Flow Susceptibility Map \(Map No.32\)](#)

Ancillary Source Map Information

The following sections present ancillary source map information associated with sources used for this project.

Open File Report OFR 95-12

Additional text and graphics associated with source map plates from the larger work, Landslide Hazards in the Martinez-Orinda-Walnut Creek Areas (Open-File Report OFR 95-12). The report, references and study area index map are relevant to both GRI digital geologic-GIS maps.

The larger work citation.

Haydon, Wayne D., 1995, Landslide Hazards in the Martinez-Orinda-Walnut Creek Areas, Contra Costa County, California; Landslide Hazard Identification Map No. 32: California Department of Conservation, Division of Mines and Geology, Open-File Report OFR 95-12, plates 32A, 32B, 32C and 32D, scale 1:24,000

Citations for plates 32A, 32B, 32C and 32D.

Haydon, Wayne D., 1995, Relative Landslide Susceptibility Map, Landslide Hazard Identification Map No.32: California Department of Conservation, Division of Mines and Geology, Open-File Report OFR 95-12, plate 32A, scale 1:24,000. (*GRI Source Map ID 46591*).

Haydon, Wayne D., 1995, Landslide and Related Slope-Failure Features Map, Landslide Hazard Identification Map No.32: California Department of Conservation, Division of Mines and Geology, Open-File Report OFR 95-12, plate 32B, scale 1:24,000. (*GRI Source Map ID 46592*).

Haydon, Wayne D., 1995, Geologic Map, Landslide Hazard Identification Map No.32: California Department of Conservation, Division of Mines and Geology, Open-File Report OFR 95-12, plate 32C, scale 1:24,000. (*GRI Source Map ID 46594*).

Haydon, Wayne D., 1995, Relative Debris-Flow Susceptibility Map, Landslide Hazard Identification Map No.32: California Department of Conservation, Division of Mines and Geology, Open-File Report OFR 95-12, plate 32D, scale 1:24,000. (*GRI Source Map ID 46593*).

Text and graphics from the larger work and its map plates.

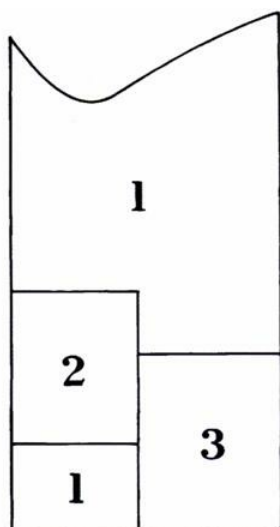
Geologic Map Symbols

SYMBOLS

	CONTACTS: Solid where well located; dashed where approximately located; dotted where concealed.
	STRIKE AND DIP OF BEDDING
	STRIKE AND DIP OF OVERTURNED BEDDING
	STRIKE OF VERTICAL BEDDING
	AXIS OF ANTICLINAL FOLD: Solid where well located; dashed where approximately located; dotted where concealed.
	AXIS OF SYNCLINAL FOLD: Solid where well located; dashed where approximately located; dotted where concealed.
	AXIS OF OVERTURNED SYNCLINAL FOLD: Solid where well located; dashed where approximately located; dotted where concealed.
	FAULT: Solid where well located; dashed where approximately located; dotted where concealed. Arrows show apparent relative movement. U-upthrown side, D-downthrown side.

Graphic from source map: [Geologic Map \(Map No.32\)](#)

Index to Geologic Source Data



INDEX TO GEOLOGIC SOURCE DATA *

Geology compiled and revised
from source data by Wayne D. Haydon.

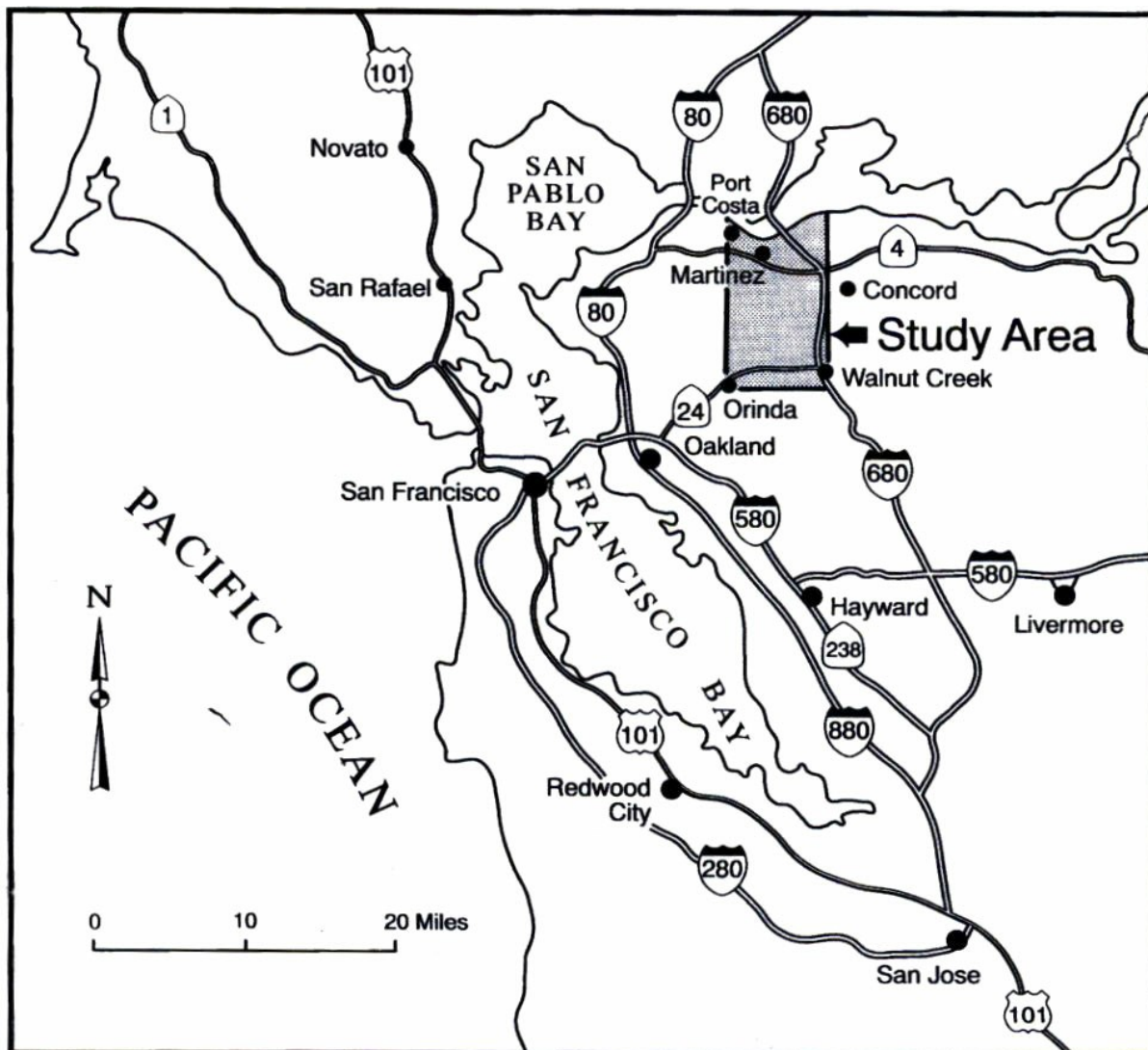
1. Jones, D., and Graymer, R. (1990-1992)
2. Pease, M. H. (1954)
3. Saul, R. B. (1973)

* see accompanying text for
complete list of references

Program Authority Statement. This map has been prepared in
accordance with the LANDSLIDE HAZARD IDENTIFICATION ACT
(Chapter 7.7 Division 2 of the California Public Resources Code).

Graphic from source map: [Geologic Map \(Map No.32\)](#)

Study Area Index Map



INDEX MAP

Graphic from source map: [Landslide Hazards in the Martinez-Orinda-Walnut Creek Areas](#)

Report

LANDSLIDE HAZARDS IN THE MARTINEZ-ORINDA-WALNUT CREEK AREA CONTRA COSTA COUNTY, CALIFORNIA

by

Wayne D. Haydon, Geologist
California Department of Conservation
Division of Mines and Geology

INTRODUCTION

This report depicts the results of a study of the landslide hazards in the Martinez-Orinda-Walnut Creek study area (study area), Contra Costa County, California. This study was conducted within the Landslide Hazard Identification Project of the Geohazard Assessment Program of the Division of Mines and Geology.

LOCATION

The study area is centered about 22 miles northeast of San Francisco in the East Bay Hills. It consists of about 76 square miles of grassy, brushy to wooded, rolling hills, low rugged mountains, and small to large alluviated valleys and terraces. The town of Orinda lies at the southwest corner, the City of Walnut Creek lies at the southeast corner, Port Costa lies at the northwest corner and the City of Martinez lies about 4 miles southwest of the northeast corner of the study area. This area comprises portions of four U. S. Geological Survey topographic quadrangles: the east half of the Briones Valley; the west half of the Walnut Creek; and the southeast quarter of the Benicia, and southwest quarter of the Vine Hill quadrangles, south of the Carquinez Straits (see index map on Plates).

ACCESS

California State Highway 24 crosses the southern portion of the study area and Highway 4 crosses the northern portion. Interstate Highway 680 runs along a part of the eastern edge and through the northeast corner of the study area. County roads cross the unincorporated portions of the study area.

LAND USE

Much of the flatland and the low rolling hills in the uplands of the northeast corner and along the eastern and southern edges of the study area have been developed as high-density, single-family residential neighborhoods with associated businesses. These developments in the uplands are depicted as cut and fill areas on the maps. Low- to moderate-density residential developments are spreading to the west of existing developments into the narrow canyons and valleys and into the moderately sloped uplands. Most of the balance of the study area is large cattle ranches and parkland.

PURPOSE

The primary purpose of the study was to identify and inventory existing landslides, evaluate slope stability, and prepare relative landslide susceptibility maps of the study area. The maps are primarily intended to provide information about slope stability for use by local officials in land-use planning and evaluation of building permits. Additionally, the maps and text have other uses, such as providing background data for engineering geologists conducting slope stability investigation in the study areas. This study was conducted as Landslide Hazard Identification Map No. 32, in accordance with the Landslide Hazard Identification Act, Chapter 7.7, Division 2, of the California Public Resource Code.

SCOPE OF INVESTIGATION

The investigation consisted of: compilation of a geologic map; collection of data on soils; interpretation of geologic and slope stability features on aerial photographs; field mapping; and evaluation of relative

landslide and debris-flow susceptibility of the study area. The geologic map was compiled and locally modified primarily from Jones and Graymer (1992), Pease (1954) and Saul (1973). The soil data were taken from Welch (1977).

Aerial photographs were used to identify landslides and other slope stability features. Two sets of stereo photographs dated 1950 and 1988, were used. The 1950 photographs provided pre-development coverage of the upland areas while the 1988 photographs provided a modern representation of the extent of land development and landslides.

Field mapping was conducted during the summer of 1992 and early 1993 to check the geology, soils, and landslide distribution. The geologic map and landslide inventory map were prepared by a combination of compilation from referenced sources and modification from field mapping.

GEOLOGY AND SLOPE STABILITY

The study area lies within the Northern Coast Range Geomorphic Province of California. Geologic formations (Plate 32C) consist of two man-made units, four surficial units of Holocene to Pleistocene age, three upper Miocene nonmarine units, and 22 marine units of middle-upper Miocene to Cretaceous age. Except for the man-made and surficial units, the formations have been folded into a series of northwest-southeast-trending anticlines and synclines. These structures are cut by several north-south, northeast-southwest, and one northwest-southeast-trending faults, including the Holocene active Concord Fault (California Division of Mines and Geology, 1993a and b).

Slope failures were mapped from aerial photographs and field mapping. Debris flows were taken from Ellen and Wieczorek (1988) and generally represent those failures that occurred in the study area during the January 3-5, 1982 storm. Recent debris flows were practically nonexistent in the study area, most likely because this investigation was conducted near the end of the 1986 to 1992 drought, when debris flow-causing storms were rare, and because these features are usually small and disappear quickly. Only selected large landslides are shown on the Geologic Map, but all identified landslides and debris flows are presented on the Landslide and Related Slope Failure Features Map, Plate 32B. Descriptions of the lithology, topographic expression, structure, soils, and the evaluation of the slope stability characteristics of each map unit are presented in the Explanation of Geologic Units.

In the younger and older alluvium, landslides are rare and generally less than or equal to 1 and some up to 2 acre soil slumps or slides along stream banks and in the colluvium in first-order drainages on slopes of 15 to 20 percent (8.5 to 11 degrees). No landslides were identified in the filled marshlands and bay mud.

In the bedrock formations of the west half and southeast quarter of the study area, landslide and debris flow are locally uncommon to very common; in general, slope instability features are common. Landslides range from very small soil slips to up to 90-acre translational rock slides. Landslides less than or equal to 5 acre in size are the most common type identified in the upper and lower Mulholland Formation, Neroly Formation, Rodeo Shale, Oursan Sandstone, San Ramon Sandstone, Domengine Sandstone, Unnamed Claystone, upper Meganos Formation, and the Kcs, Kus and Kuh members of the Great Valley Sequence. In most of these units, landslides are typically slumps, slides and earthflows in the colluvium accumulated in drainages. In the upper and lower Mulholland, landslides occur as shallow slumps and slides on planar anti-dip slopes, and in the Unnamed Claystone and upper Meganos Formation landslides are typically shallow slumps about equally distributed on planar or convex slopes and drainages on dip-slopes.

Landslides up to 10 acres in size are common in the Orinda Formation, upper and lower Briones Sandstone, Hambre Sandstone, Tice Shale, upper and lower Martinez Formation, and the Ku member of the Great Valley Sequence. In the upper and lower Briones Sandstone, Hambre Sandstone and Tice Shale, landslides occur as slumps, slides or earthflows in the colluvium accumulated in drainages or on planar slopes. In the Orinda Formation, landslides less than or equal to 10 acres occur as slumps, slides and earthflows on dip or parallel to dip slopes, with large slumps and translational slides on dip-slopes occurring in the upper and lower Martinez Formation and Ku member of the Great Valley Sequence.

In the Orinda Formation, landslides greater than or equal to 10 acres in size are common to very common and occur as slumps and slides on anti-dip slopes. Landslides greater than or equal to 10 acres occur, but are uncommon to rare in the lower Briones Sandstone, Rodeo Shale and Hambre Sandstone, where they are typically slumps and translational slides.

Landslides were either not identified or were rare in the Sobrante Sandstone, Markley Formation, Nortonville Formation, lower Meganos Formation and the undifferentiated Martinez Formation. Lack of landslides is most likely because of the predominantly gentle slopes on these units.

Rockfalls are rare to nonexistent in the study area and the potential for these failures is judged to be generally low, but locally there are areas of moderate to high potential in the harder, stronger, and more resistant ridge forming units. Rockfall potential is judged to be moderate in the Neroly Formation, upper and lower Briones Sandstone, and the Ku member of the Great Valley Sequence. This rating is based on the fact that while these units are susceptible to rockfalls, slopes are only locally greater than or equal to 50 percent (27 degrees) and high rock-fracture density and/or low rock strength will limit rockfall fragment size to boulder or smaller and fragments are likely to breakup during runout. Rockfall potential is judged to be low to moderate in the Kus and Kuh member of the Great Valley Sequence and low to high in the Domengine Sandstone, and the Kcs member. Susceptibility is judged to be low where slopes are commonly less than or equal to 50 percent (27 degrees), moderate where slopes are greater than or equal to 50 percent, and high where slopes are greater than or equal to 50 percent and locally up to greater than or equal to 75 percent (37 degrees). High rock-fracture density and low rock strength will, however, limit fragment size generally to less than boulder size with a limited runout. In the rest of the units, rockfall potential is judged to be low because of the gentle slopes and lack of outcrops.

In most of the formations, debris flows were generally identified on greater than or equal to 50 percent slopes, with some on slopes of 30 to 50 percent, and usually, in areas mapped as nonplastic, nonexpansive and, therefore, susceptible soil. However, debris flows were moderately common to locally very common in the Briones and Hambre sandstones, lower Martinez Formation and the Ku and Kus members of the Great Valley Sequence, on soils mapped as plastic and expansive. The presence of debris flows in areas mapped as generally nonsusceptible soils indicates that on these formations there are areas of nonplastic, nonexpansive, susceptible soils which are unmapped and local to widespread.

Landslides and debris flows are generally rare in the northeastern quarter of the study area, in the Pacheco Syncline, most of which was mapped as cut and fill. The lack of these slope instability features is probably because slopes in this area are generally greater than or equal to 30 to 40 percent (17 to 22 degrees) and the slope threshold for slope failures is generally 30 to 40 percent. That this area exists mostly as cut and fill reflects the practice of locating high density developments in areas of greater than or equal to 30 percent (17 degrees) slopes.

Evaluation of the slope stability characteristics of each of the formations was conducted by comparing landslide and debris-flow distribution and density with the: 1) lithology of the units, 2) soil type, 3) slope steepness and aspect, 4) the structure and faulting of the formation, and 5) the slope stability of the formation as evaluated from other investigations. The filled marshlands, and the cut and fill areas were not evaluated because the required small scale and detailed studies of cut slopes or fills were beyond the scope of this investigation. The evaluation of the slope stability in the study area, and the detailed descriptions of the susceptibility ratings used in this study, is presented on the Relative Landslide Susceptibility Map, Plate 32A, and the Relative Debris-Flow Susceptibility Map, Plate 32D.

Text from source map: [Landslide Hazards in the Martinez-Orinda-Walnut Creek Areas](#)

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