EXPLANATION

LANDSLIDE CLASSIFICATION

STATE OF ACTIVITY	CERTAINTY OF LANDSLIDE IDENTIFICATION	DOMINANT TYPE OF SLOPE MOVEMENT (FROM VARNES, 1978)
A - ACTIVE OR RECENTLY ACTIVE	D - DEFINITE	SF - COMPLEX SLUMP EARTHFLOW
D - DORMANT	P - PROBABLE	DS - DEBRIS SLIDE
	Q - QUESTIONABLE	DF - DEBRIS FLOW
		EF - EARTHFLOW
		S - SLUMP

D Q E F
30 1941

MAXIMUM DEPTH OF LANDSLIDE (FEET)

DATE OF MOVEMENT

BOUNDARY OF LANDSLIDE DEPOSIT - DASHED WHERE APPROXIMATELY LOCATED; QUERIED WHERE UNCERTAIN

GENERAL DIRECTION OF MOVEMENT

LANDSLIDE SCARP - DASHED WHERE APPROXIMATELY LOCATED

DRILL HOLE LOCATION (FOR LOG - WIECZOREK, 1978)

SAG - TOPOGRAPHIC DEPRESSION OR SAG POND

PATH OF EXTENSIVE GULLYING

Base made for the R. W. Driscoll property by Murray-McCormick, Inc., 1975.
Property boundary shown hereon is approximate, having been developed from record information supplied by the title company, and does not represent a field survey.

SCALE 1:4800
CONTOUR INTERVAL 10 FEET

AREA OF MAP

Mapped from aerial photographs; field checked in 1975-81.

MAP SHOWING RECENTLY ACTIVE AND DORMANT LANDSLIDES NEAR LA HONDA, CENTRAL SANTA CRUZ MOUNTAINS, CALIFORNIA

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INTRODUCTION

Although landslides cover much of the central Santa Cruz Mountains of California (Brabb and Pampeyan, 1972) most of them have not been classified with respect to type of slope movement and activity. The accompanying map shows more than 230 dormant and recently active landslides in a 5-mi^2 area northeast of La Honda, Calif. (fig. 1). Several sets of vertical aerial photographs taken between 1931 and 1975 (table 1) were used to identify landslides. Active landslides were identified during field reconnaissance from 1975 through 1981. The map scale of 1:4800 was chosen so that the details of individual landslides could be shown and so that smaller recently active landslides could be plotted accurately.

The geologic map of the La Honda quadrangle by Brabb (1980) was used in conjunction with laboratory tests of engineering properties of soils and weathered rock in the area (Wieczorek, 1978) to examine the relation between material properties of the geologic units and landsliding. Ground-water levels and precipitation were monitored between 1975 and 1981 (Wieczorek, 1981) to study the relation between ground-water levels and the triggering of landslides.

LANDSLIDE INVENTORY

The inventory of landslides shown on this map was prepared from interpretation of black-and-white, high- and low-altitude vertical aerial photographs. Low-sun-angle photography was used because it accentuated much of the landslide topography. Landslides originally identified and classified in this way were field checked between 1975 and 1981.

For each landslide, the map designates (1) state of activity, (2) certainty of identification, (3) dominant type of slope movement, (4) primary direction of movement, (5) estimated depth of material involved in landsliding and (6) date(s) of known activity. The state of activity of a landslide was characterized as either dormant or recently active on the basis of aerial photographic interpretation and field observation. Landslides that showed evidence of movement since 1931 (the date of the earliest aerial photography available in this area) were classified as recently active. Other features indicative of recent movement include exposures of fresh soil and bedrock in main or minor scarps, open distinct crown, transverse or radial cracks, and disruption of original vegetation indicating the principal direction of movement (for landslide terminology used, see Varnes, 1978, fig. 2.1t). Landslides that may be slowly creeping were classified as dormant because such slow, long-term movement commonly does not produce obvious surficial effects.

Certainty of identification depends on the extent to which the landslide features have been modified by erosion and revegetation. Certainty of identification is qualified as definite, probable, or questionable according to judgment based on previous experience, field checking, and drilling several of the landslides. The location and logs of the drill holes were given in Wieczorek (1978). Eyewitnesses supplied dates of movement for several landslides.

Different types of slope movement were classified on the basis of the type of material before movement and the dominant type of movement (Varnes, 1978). Landslide depth was estimated from the physical dimensions of the landslide and from drilling several landslides.

A detailed landslide inventory of this type is useful for statistical analyses of the roles of various factors that cause landsliding, such as the effects of slope and lithology on the type of landsliding (see table 2). More than 50 percent of the recently active landslides in this area are reactivated parts of dormant landslides. This high percentage has important implications for elected officials, planners, and others concerned with the mitigation of landslide hazards and planning for future land use, particularly with respect to proposed development on dormant landslides. Examples of the high cost and potentially disastrous effects of reactivated landslides can be seen at the San Jose Highlands in San Jose, Calif. (Nilsen and Brabb, 1972) and at Bluebird Canyon in Laguna Beach, Calif. (Leighton and Associates, 1978).

GEOLOGY

The geologic units in the La Honda area (fig. 2) consist of from oldest to youngest, (1) undivided San Lorenzo Formation and Lambert Shale (Eocene, Oligocene, and Miocene), (2) Mindego Basalt and related volcanic rocks (Oligocene and (or) Miocene), (3) Tahana Member of the Purisima Formation (Miocene and Pliocene), and (4) alluvial fan deposits (Holocene). The Lambert Shale and San Lorenzo Formation contain primarily mudstone, siltstone, and shale. The Mindego Basalt consists mainly of basaltic volcanic rocks (submarine flow breccia, pillow lava, and lithic tuff). The Tahana Member of the Purisima Formation is composed principally of medium-grained to very fine-grained sandstone and siltstone. Landslides were identified in all of the above units with the exception of the alluvial fan deposits.

Weathering of bedrock influences the type and depth of landsliding in the La Honda area. The degree of weathering was characterized according to the system adopted by the Geological Society Engineering Group Working Party (1972). According to this system, weathered rock is classified as fresh, slightly weathered, moderately weathered, highly weathered, completely weathered, or residual soil.

The Tahana Member and the Lambert Shale and San Lorenzo Formation weather deeply and extensively. Samples were moderately weathered as deep as 30 feet in 9 of 12 drill holes (Wieczorek, 1978, p. 195-208). These moderately weathered samples contained discolored corestones that were noticeably weaker than the fresh rock; closely spaced, open discontinuities in the samples were lined with moist, highly plastic clay. Even this small number of samples indicates that in the area underlain by these two geologic units the rock is moderately weathered to substantial depths. The weakness of these weathered rocks accounts for the widespread development of slumps and earthflows in these two units. Table 2 shows the high relative percentage of slumps and earthflows within these two units. The slip surfaces of these landslides are restricted to the zone of residual soil and highly or moderately weathered rock. Due to the greater strength of the underlying fresh rock, deeper landslides are less common in these units. Thus the weathering characteristics of the rock strongly control both the type and the depth of landsliding.

In contrast, weathering within the Mindego Basalt and related volcanic rocks is generally limited to within several feet of the surface. As observed in outcrops, several shallow, hand-augered holes, and one drill hole (Wieczorek, 1978, p. 206), slightly weathered or fresh rock is found within 5 to 15 ft of the surface. The slide plane of several very shallow debris slides and debris flows occurred at the contact between moderately weathered and slightly weathered to fresh rock. Owing to the relatively high strength of the fresh basalt, deeper types of landslides were uncommon, and very shallow debris slides and debris flows were most common (see table 2) and restricted to the shallow weathered zone.

Material properties of the residual soils derived from these three geologic units, summarized in table 3, indicate that these materials are very susceptible to landsliding. Grain-size analyses and Atterberg-limit determinations show the soils to be chiefly inorganic silty clay and clayey silt of medium to high plasticity. Highly plastic soils are capable of absorbing great quantities of water, and when they do, they lose considerable strength. X-ray diffraction analyses of these soils showed montmorillonite to be the major clay constituent of all three units, together with minor amounts of illite, kaolinite, and chlorite. Montmorillonite, a member of the smectite group of expansive clay minerals, is frequently associated with slope-stability problems (Borchardt, 1977; Underwood, 1967).

GROUND-WATER LEVELS AND PRECIPITATION

Ground-water levels and precipitation were regularly monitored in this area from October 1975 to June 1981. Landslides active since 1975 correlate with measured ground-water-level increases. Landslides were triggered by high-intensity, short-duration storms that caused rapid saturation near the ground surface and by series of major storms that caused a more gradual buildup of deeper ground-water levels. The rate and magnitude of changes in ground-water level in response to precipitation was found to depend on previous cumulative seasonal rainfall, storm duration and magnitude, and local topography (Wieczorek, 1978, 1981). Although qualitative observations such as this have been made, a more quantified relation between landsliding, ground-water-level response, and precipitation has yet to be developed.

The role of rainfall in triggering landslides was observed in this area between 1975 and 1981. The majority of active landslides (table 4) developed during the 1977-78 and 1979-80 seasons. Rainfall in these seasons exceeded the mean seasonal rainfall of 30 in./yr for the La Honda area (Rantz, 1971). Landslides occurred during four of the six seasons after cumulative seasonal rainfall had exceeded 20 in. This total may represent a threshold for landsliding similar to the threshold identified by Nilsen and Turner (1975) for the initiation of landsliding in Contra Costa County, California.

The greatest number of landslides in a single series of storms occurred between December 12, 1977, and January 20, 1978, when 17 in. of rain fell. During this time, the ground surface became saturated, and deep ground-water levels rose more than 20 ft over a period of several months following this series of storms (Wieczorek, 1978; 1981). Landslides started at various times, ranging from days to weeks, after the storms, and continued to move slowly for several months.

Debris slides and debris flows usually occurred during short-duration, high-intensity storms, whereas slumps and earthflows began several days to several weeks after a series of major storms, presumably as a result of gradual increase in ground-water levels. Ground-water-level measurements and observations of recently active landslides were useful not only as qualitative indicators of how much an increase in ground-water level is required to trigger landslides, but as indicators of the relation between particular patterns and distributions of rainfall and the type of landslides triggered.

SUMMARY

More than 230 dormant and recently active landslides were identified in a 5-mi^2 area near La Honda, Calif. The material properties of soils and weathered rock derived from geologic units of the area indicate a high potential for slope stability problems. Weathering profiles had significant influence on the depth of landsliding and the type of slope movements observed within each geologic unit.

During recent years, increases in the ground-water level played a role in triggering landslides after both intense, heavy storms and during prolonged periods of gradual increase after a series of major storms. This relation is significant because it distinguishes the effects of rainfall distribution on types of landsliding, thus providing a preliminary tool for predicting landslide hazard from rainfall forecasts. The fact that more than 50 percent of the landslides active between 1975 and 1981 occurred within larger dormant landslides is also significant in its implications for mitigation of landslide hazards. Because many of the remaining developable sites in the Santa Cruz Mountains are situated on large dormant landslides, these sites should be examined in light of their tendency to reactivate smaller, but potentially disasterous landslides.

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Table 1. Aerial photographs used to map landslides

Year	Scale	Flight series-photo nos.	Source of negatives
1931	1:18,000	C-1471: 111; 116-118	Teledyne Geotronics
1941	1:25,000	6660 150-152, 459-461	Teledyne Geotronics
1956	1:20,000	DDB - 3R 18, 19	U.S. Department of Agriculture
1960	1:30,000	GS-VACY 126-129	U.S. Geological Survey
1963	1:20,000	DDB-3DD-31, 32, 33	U.S. Department of Agriculture
1968	1:30,000	GS-VBZK 1-68, 69, 70	U.S. Geological Survey
1973	1:14,500	3567-4-094-099	Cartwright Aerial Surveys
1975	1:6,000	5883-1-P 1-36 5883-2-P 1-36 5883-3-P 1-36	Murray-McCormick, Inc.

Table 2. - Relationship between geology and depth of weathering, type of landslide, and estimated depth of landsliding.

Geologic Unit	Depth of Weathering (feet)	Type of Landslide: earthflow	debris slide	debris flow	slump	complex slump flow
Tahana Member of Purisima Formation	Moderately weathered from 15 to 50	6/7 [1]	1/10	1/3	16/35	0/15
		14% [2]	12%	4%	54%	16%
		8/14 [3]	25/28	5/41	18/51	--/50
Lambert Shale and San Lorenzo Formation	Moderately weathered from 15 to 45	10/12 [1]	8/11	1/3	11/6	0/4
		33% [2]	29%	6%	26%	6%
		10/13 [3]	10/27	2/20	11/77	--/44
Mindego Basalt and related Volcanic rocks	Slightly weathered from 5 to 15	5/7 [1]	4/23	3/16	2/7	1/2
		17% [2]	39%	27%	13%	4%
		10/12 [3]	8/31	5/25	8/67	5/38

(1) number of particular type of landslide within each geologic unit (active / dormant)

(2) percentage of particular type of landslide with respect to total number of landslides within each geologic unit

(3) average estimated maximum depth (feet) of landslide (active / dormant)

* Weathering characterized according to system adopted by the Geological Society Engineering Group Working Party (1972).

Table 3. - Average material properties of soils derived from geologic units of the La Honda area

	Tahana Member of Purisima Formatation	Mindego Basalt	Lambert Shale and San Lorenzo Formation, undivided
Grain size (percent)			
Gravel	1	8	1
Sand	20	11	10
Silt	50	53	60
Clay (<2μ)	30	28	29
Plasticity			
Liquid limit	51	50	55
Plasticity index	24	20	22
Clay mineralogy (percent)			
Montmorillonite	90	67	65
Illite	4	28	30
Kaolinite	6	2	2
Chlorite	0	3	3

Table 4. - Correlation of active landslides with seasonal precipitation in the La Honda area between 1975 and 1981

Season	Number of active landslides	Season precipitation (in.)
1975-76	0	13.37
1976-77	0	14.12
1977-78	20	38.99
1978-79	1	26.07
1979-80	14	31.81
1980-81	2	22.50

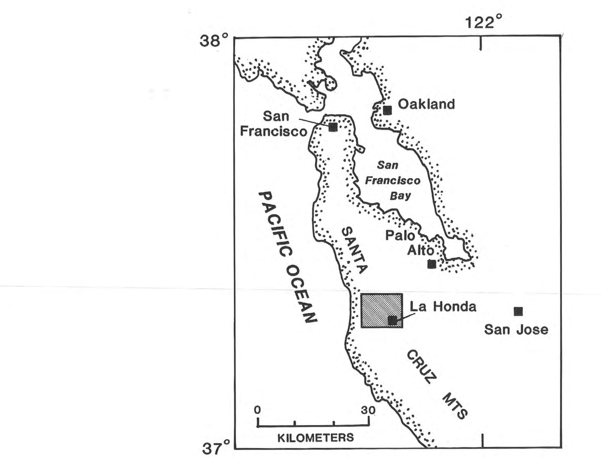
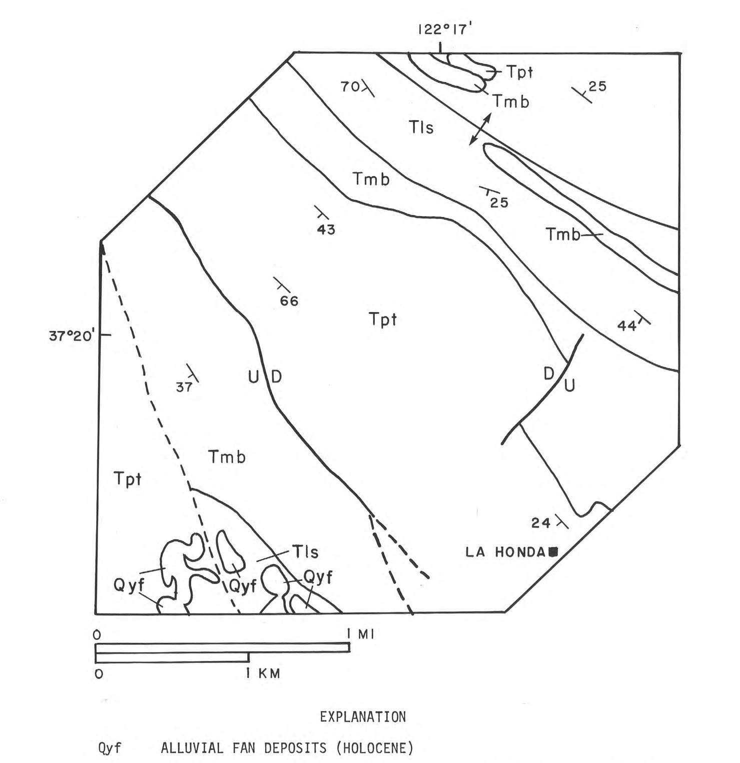


Figure 1 - Location of study area near La Honda, in central Santa Cruz Mountains, Calif.



EXPLANATION

Qyf	ALLUVIAL FAN DEPOSITS (HOLOCENE)
Tpt	TAHANA MEMBER OF THE PURISIMA FORMATION (PLIOCENE AND MIOCENE)
Tmb	MINDEGO BASALT AND RELATED VOLCANIC ROCKS (MIOCENE AND (OR) OLIGOCENE)
Tls	LAMBERT SHALE AND SAN LORENZO FORMATION, UNDIVIDED (MIOCENE, OLIGOCENE, AND EOCENE)

CONTACT - Dashed where approximately located

FAULT - Dashed where approximately located. U, upthrown side; D, downthrown side

ANTICLINE

47 STRIKE AND DIP OF BEDS

Figure 2 - Generalized geology of the La Honda area (from Brabb, 1980).

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