DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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SHEET 1 of 2

Map of Debris-Flow Features Evident After the Storms of December 1955 and January 1982 in the Montara Mountain Area, California

by
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INTRODUCTION

The disastrous rainstorm of January 3-5, 1982, reemphasized the importance of debris flows in the San Francisco Bay region as a geologic hazard to man and his structures (Smith and Hart, 1982). Many thousands of debris flows were triggered by the severe rainfall of that storm. Most of these simply moved patches of soil downslope in avalanche fashion as part of the natural long-term erosion of the landscape, leaving scattered scars on the hillsides and thin deposits of new sediment in the stream bottoms. Where structures lay in their paths, however, the debris flows caused great damage.

The Montara Mountain area experienced many hundreds of debris flows in the 1982 storm. North of Montara Mountain in Pacifica, where residential development filled the floor of San Pedro Valley and some of its tributaries, debris flows damaged or destroyed tens of houses, caused 3 deaths, and imposed nearly $6 million in property damage. The much more numerous debris flows that occurred on the southwest flank of the mountain illustrate the vulnerability of this largely undeveloped area to debris flows. Twenty-seven years earlier, the similar storm of December, 1955 also produced hundreds of debris flows southwest of Montara Mountain, although the San Pedro Valley area, then relatively undeveloped, was largely spared.

This map inventory shows soil-slip debris flows produced during the 1955 and 1982 storms and in the remainder of each rainy season, together with those debris-flow features formed in the years prior to each storm that were still evident in the landscape. The inventory serves two main purposes. It stands as a record of the occurrence of debris flows in the map area, particularly during those two triggering storms. This will aid evaluation of future hazard from debris flows in the map area. It also provides data on debris flow occurrence and behavior for use in the continuing effort to better understand debris flows and the evaluation of debris flow hazard. The hillsides southwest of the mountain crest represent the most geologically homogeneous area in the region: steep, brush-covered slopes mantled with coarse granular soil derived from the underlying fractured granitic rock. Mapping was done principally by interpretation of aerial photographs, supported by limited field study to aid photo identification of soil-slip and debris-flow features.

SOIL SLIP-DEBRIS FLOWS

Debris flows are fluid mixtures of sediment and water that flow downslope and downstream at speeds as great as 15-50 km/hr (10-30 mi/hr). Most of the debris flows in the map area must have formed nearly instantaneously during heavy rainfall, typically on steep upland slopes (slope inclinations greater than 20-25°). The heavy rainfall, falling on already wet ground, saturated the weathered sand and clay that forms the layer of surficial mantle a meter or so thick that overlies bedrock. This saturation triggered failure of slabs of the surficial mantle (the soil slips). Water in and around the soil slips enabled them to liquify and flow. Once such masses of fluid are created on steep slopes, they move rapidly as debris flows in avalanche fashion directly downslope to the first stream course and thence on downstream, tearing away trees and other vegetation in their path and rising up like a bobsled on the outsides of bends in the canyons.

The soil slips tend to form close to ridge crests near the uppermost limits of the stream system (heads of first-order streams) or on the steep planar slopes that border the stream system. Other failures of surficial mantle, including some relatively large ones, form at the toes of steep slopes. The resultant debris flows range from small flows that travel only a few tens of meters to large flows capable of traversing long canyon systems. Regardless of size, the flows tend to spread out and stop where they emerge from narrow canyons or steep slopes onto gently sloping alluvial surfaces.

Interpretation of aerial photographs indicates that the soil-slip scars in the map area typically range from 1- 2 m to 10 m in width, from a few meters to at least 50 m in length, and from 1 to rarely 3 m in depth. Most are flat bottomed, although the deeper ones seem more irregular. Corresponding initial volumes of the debris flows thus range from a few cubic meters to as much as 1000 m^3, although most are probably between 10 and 100 m^3. Many of the debris flows reached no farther than the base of the slope on which they formed or to the end of the first-order stream. Others, in contrast, traveled 600 to more than 1000 m farther down the stream systems where steep valley walls contained the flow.

GULLEYS

Although most debris flows probably started as shallow soil slips in surficial mantle on steep slopes, a few seem to have emerged from large gulleys in colluvial swales with moderately inclined axes. The clearest example is a gulley, prominent in the aerial photographs, that is located 2 1/2 km east of Pt. Montara near Grant Avenue. This gulley formed during the January, 1982, storm in a colluvial swale that showed no evidence of erosion in photos taken the previous summer. The swale, which was underlain by slightly cohesive, granite-derived sand and had an axial slope of about 14°, failed catastrophically. The resultant flow overrode the downstream flanks and lip of the failure carrying sand and fragments of dark-colored A horizon and proceeded 800 m downstream depositing a train of sand and soil balls. Field relations suggest initial failure of an upper soil layer 1-2 m thick followed by concentrated erosion of the underlying sand, probably by pore water flowing out of the colluvial layer. The resultant gulley is 150 m long, about 3 m deep, and carved internally into miniature badland topography. There are many other similar-looking gulleys in the map area, some of which produced new downstream deposits in the two storms.

MAPPING

The debris flows -- soil-slip scars, debris-flow tracks, and new deposits -- were mapped by steroscopic study of aerial photographs. The photo observations were calibrated and locally supplemented by field study in the map area and elsewhere in the region after the January storm in 1982. Plotting on the base map was done visually, using symbols that, because of the scale, necessarily exaggerate the size of most of the features (except track length).

Debris flows were identified by a characteristic signature, which in its fresh, complete form consists of (1) a bare, sharply bounded scar on a steep slope that marks the site of initial failure of a slab of surficial mantle as a soil slip, (2) a narrow downslope track, light colored and generally bare of vegetation, which marks the path of the liquified mass of surficial mantle where it flowed straight downhill from the scar and then on down subsequent stream courses, and finally (3) a thin, light-colored sheet of sediment newly deposited where the flow debouched onto a gently sloping alluvial surface. In many cases only part of this complete debris flow was evident. Recognizable old soil-slip scars and debris-flow tracks were mapped as well. Most tracks in this area become revegetated and unrecognizable within several years, but many old scars, even where revegetated, are still recognizable by the relief of the scar depression and local contrast in vegetation. Gulleys are mapped only where there is evidence of new downstream deposition.

Although the debris-flow features are readily evident in aerial view over most of the map area, they are easily concealed by trees and shadows. Shadows were a serious problem only in the January, 1982, photos, in which they obsured about 30 percent of the new soil-slip debris flows. These were mapped from photos taken the following summer. Some of the largest debris flows that formed in the region during the January, 1982 storm occurred in forested terrain. Despite their large size, many of these cleared too narrow a path through the trees to make a recognizable break in the forest canopy. Most of the map area is covered with brush, however tree cover is sufficient in the southeast part of the map area to conceal most evidence of any debris flows. Elsewhere, trees and local shadows may have obscured tracks along many canyon bottoms. The maps are thus minimum statements, particularly concerning track length and, in the forested areas, even the occurrence of debris flows.

The 1982 debris flows were mapped from black and white photos taken two days after the storm (USGS, JSS, 1-7-82, 1:20,000) and color infrared transparencies taken late in the following summer (NASA Ames, September 1982, 1:26,000). In the winter pictures, the sun was not high enough to illuminate steep, north-facing slopes and deep canyon bottoms. The summer photos postdated the entire 1981-82 rainy season, were difficult to work with, especially at high magnification, and produced only a very subdued vertical relief in the stereoscopic model.

Comparison of aerial photos taken of the map area at various times and field study after the 1982 storm indicated that, particularly near the coast, some old soil-slip scars and debris-flow tracks have persisted as distinct features in the landscape for many years. To assure distinction of features formed in the January storm from older features, the 1982 photos were compared, scar by scar, with black and white photos taken early the previous summer (California Department of Water Resources, CDF-ALL-SF, 6-5-81, 1:24,000). Similarly, the summer, 1982, photos were compared with the January ones to identify those few debris flows that formed after the January storm. Where shadows in the January photos prevented this comparison, post-1981 debris flows in the summer pictures were assumed to have formed in the January storm. Some new debris flows could have formed prior to the January storm in the fall of 1981.

The 1955 map was prepared from black and white photos taken in the late spring of 1956 (DDB-IR, 5-27-56, 1:20,000). Like the 1982 photos, these show abundant fresh-looking debris flows, whereas most other available photos of the area do not. All debris-flow features evident on the 1956 photos are shown, without distinction of age. Most of them probably formed in the storm of December, 1955, storm, which was the severe local storm that winter. Recognition from the 1956 photos that scars and tracks are new is complicated by rapid recovery of vegetation in many places, although mappable new deposits are probably a good indicator. Inspection of the 1982 map suggests that most scars with downslope tracks should be new, whereas many soil-slip scars without tracks are probably old.

Topography and Geology

The bedrock and surficial mantle in the map area are quite varied. They range, respectively, from granitic rock to shale and from coarse sand to clay. Despite this variation, the steep-walled valleys that disect most of the terrain and nearby ubiquitous surficial mantle provide a favorable setting for debris flows nearly everywhere. The 500-580 m (1700-1900 ft) high crestal ridge of Montara Mountain divides the area into two fundamentally different parts: southwest of it the steep slopes are everywhere underlain by relatively uniform granitic rock, whereas to the northeast they are developed on several quite different rock types. The 1982 map distinguishes these principal types of bedrock and one prominent area of marine terrace deposits (map generalized from Pampeyan, 1981; character of rock and surficial mantle from Wentworth and others, 1985).

The granitic rock (Montara Quartz Diorite) is medium to coarse grained, pervasively fractured, and weathers to a loose granular mantle. The area of steep-sided valleys underlain by this rock southwest of the ridge crest should have a relatively uniform susceptibility to the formation of debris flows. As a result, it is a good place to study possible areal variation in triggering rainfall, the topographic habitats of debris flows, and the behavior of individual places in the terrain through time.

Northeast of the ridge crest the geology is more complicated. The northeast side of the ridge is underlain by Tertiary sedimentary rocks that consist primarily of rhythmically interbedded shale and fine- to medium-grained sandstone. This rock weathers to a clayey sand mantle. Rocks of the Franciscan assemblage farther northeast are grossly interleaved in northwest-trending lenses and are everywhere pervasively fractured and extensively faulted and sheared. The sandstone and locally interbedded shale weather to a clayey sand mantle. The sheared rock (melange) consists of severely sheared shale containing blocks and larger masses of sandstone; it weathers to a sandy clay or clayey sand mantle that may be expansive. The greenstone consists of altered basaltic lava as flows, pillowed masses and tuff and weathers to a somewhat expansive clay mantle. The serpentinite, which yields a rocky soil, is typically bounded by narrow zones of severely sheared rock and gouge containing highly expansive clay. In this area, the occurrence of debris flows should be influenced by variations in soil texture and in structural control of shallow ground water. Areal variation in storm rainfall, however, tends to obscure these influences.

Damage

Debris flows can cause serious damage to structures in their paths and can produce damaging secondary effects as well. In the residential development composing the City of Pacifica, the January, 1982, storm caused property damage that amounted to nearly $6 million (Smith and Hart, 1982). "Slope failures resulting from the storm caused three deaths, total destruction to four houses, damage to tens of others and perceived life threatening situations for at least 500 families living at the foot of steep hillsides" (Howard-Donley Associates, 1982, p. 1). The absence of dense residential development in the steep-walled valleys southwest of Montara Mountain spared that hard-struck area similar damage. Coast highway 1 was cut in two places between Montara and Devils Slide where flood waters rose and eroded completely through the road embankment after debris flows clogged the culverts (oral commun., T. C. Smith, 1982 and 1984).

Damage can be imposed in several ways by debris flows. The most spectacular is the direct impact of fast moving flows against structures, which can shatter buildings and carry away the debris. Less dynamic but important is innudation of structures, streets and other features and clogging of drainage ways and culverts by debris flows. Direct damage can be done by the weight of sediment and water. Streets can be blocked and emergency access denied. Clogging of drainages can cause or exacerbate flooding and thereby threaten road embankments, bridges, and other structures.

CONTINUED ON SHEET 2

EXPLANATION

SOIL-SLIP DEBRIS FLOWS

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Soil-Slip Scar

Surface scar or upstream end of debris-flow track that marks soil slip or debris-flow source; shown by horseshoe symbol, curved end upslope, queried where identification uncertain; large or irregular symbols show actual size; horseshoe is filled for scars formed during the January 1982, storm, is open for pre-existing scars, and contains a dot for post-storm scars

Debris-Flow Track

Flow track more than 20 m long, marked by cleared vegetation and-or new coating of sediment, queried where identification uncertain; query along track up or down channel where probable track concealed by trees or shadow; track dotted on steep slopes where intact vegetation overridden with little deposition (identification depends on lighting) or on gentle slopes where track is narrow

Tracks of Large Flows

Double line where track is wide and expands downslope and soil slip scar is typically deep or large; dotted adjacent to track line where flow rose well above channel on outside of bends in bobsled fashion

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New Deposit

Deposit on gentle slope, typically at downstream end of debris flow track; boundary approximate, queried where identification uncertain

Gulley

Large gulley with downstream evidence of fresh deposition of sediment; open dots mark pre-existing gulley, closed dots mark new gulley, border dotted where gulley overtopped by flow

OTHER SYMBOLS

Landslide with deposit remaining in scar

Perimeter of area of heavy tree or brush cover where evidence of debris flows typically is obscured

Approximate boundary of summit area of Montara Mountain, essentially free of debris flows, in which the topography is relatively subdued and smooth, the valleys are round-bottomed, and side slopes lack sharply defined drainage

Selected geologic boundary (contact or fault) generalized from Pampeyan (1981)

GEOLOGIC UNITS

Principal bedrock units and selected terrace deposits (generalized from Pampeyan, 1981) are shown except in the wooded southeast part of the map area; alluvium, slope deposits, and most terrace deposits are not distinguished

Qt

Quaternary terrace deposits in the Princeton-Moss Beach area

Ts

Tertiary sedimentary rocks

Km

Montara Quartz Diorite

sp

Serpentinite

fs

Franciscan sandstone

fsr

Franciscan sheared rock (melange)

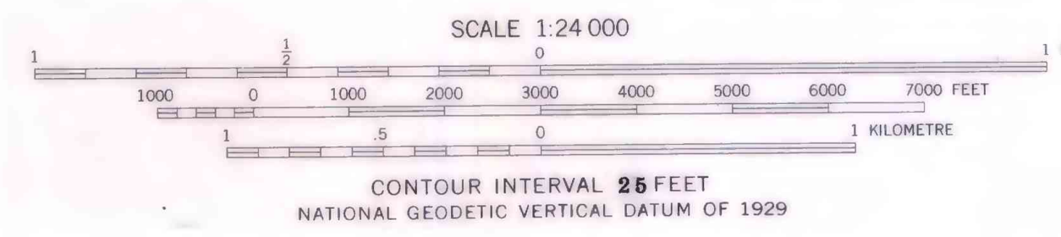
fg

Franciscan greenstone

DEBRIS-FLOW FEATURES EVIDENT AFTER THE STORM OF JANUARY, 1982

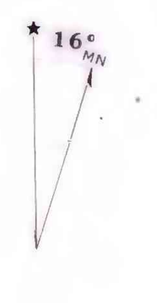
Base from U.S. Geological Survey
Montara Mountian Quadrange 1956, 1:24,000

Landslides mapped as of September, 1982



CONTOUR INTERVAL 25 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

MONTARA MOUNTAIN 7.5 MINUTE QUADRANGLE



This map is preliminary and has
not been reviewed for conformity
with U.S. Geological Survey editorial
standards and stratigraphic nomenclature.

MAPS OF DEBRIS FLOW FEATURES EVIDENT AFTER THE STORMS OF DECEMBER 1955 AND JANUARY 1982, MONTARA MOUNTAIN AREA, CALIFORNIA

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1986