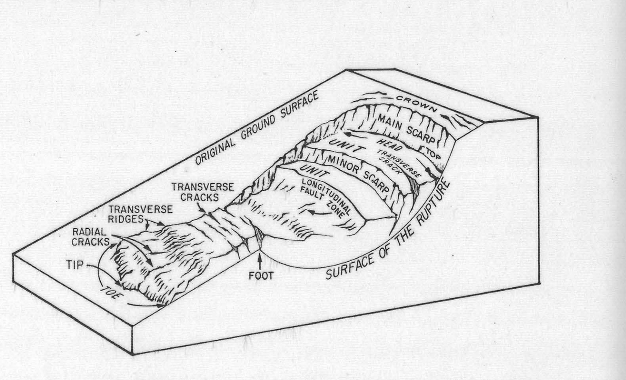
DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

MISCELLANEOUS FIELD STUDIES
MAP MF- 594

INTRODUCTION

The San Francisco Bay region lies within a geologically active portion of central California. Fault movements, earthquakes, land subsidence, landslides, coastal and stream erosion, flooding, and sedimentation are some of the physical processes occuring in the Bay region that, from time to time, may cause problems for man. This map, a photo-reconnaisance map of landslide deposits for the northernmost portion of Sonoma County, was prepared to supply information about one aspect of the environment that may be potentially hazardous to man. When combined with other types of information on the physical environment, such as bedrock geology, slope steepness, and hydrology, the information presented herein on the distribution of landslide deposits should make it easier to arrive at decisions regarding physical aspects of land use.



Nomenclature of parts of a landslide (from Eckel, 1958)

LANDSLIDE DEPOSITS

Landslide deposits are composed of fresh and weathered bedrock fragments, locally derived sediment, soil. and combinations of these materials that have been transported downslope by falling, sliding, rotational slumping, or flowing. Two types of landslide deposits were differentiated during the preparation of this map (Eckel, 1958, dicusses different types of landslides). The most common type is the complex landslide deposit, which results from combinations of different types of downslope movement. This type of deposit is formed by various kinds of sliding, falling, slumping, or flowing of incoherent or broken masses of rock and other surficial debris. The other type contains deposits produced predominantly by a slumping process in which intact masses of material move downslope by rotational slip on surfaces that underlie as well as penetrate the deposit.

Landslide deposits vary in appearance from clearly discernible, largely uneroded topographic features (such as shown in figure to left) to indistinct, highly eroded and modified features recognizable only by topographic configurations that are not normally developed on outcrops of stable bedrock. The thickness of landslide deposits may vary from a few feet to several hundred feet with the larger deposits generally being the thickest. Small slides typically are thin and often involve only the surficial materials.

Information on the activity of the landslide deposits is not generally available. Some landslides appear to have been recently active, whereas others may not have moved for thousands of years. In general, landslide susceptibility is highest in places within or adjacent to areas that have a history of landsliding. Even old and apparently inactive landslide deposits may be reactivated by either natural or artificial means because the materials that form them are commonly so broken up an disturbed that landslide activity is easily renewed. On the other hand, some areas within landslide deposits may be relatively stable.

FACTORS THAT EFFECT LANDSLIDES

Many of the natural factors that promote the landslide process are present in the mapped area. These include, among others, 1) areas of relatively weak bedrock, 2) steep slopes, 3) seasonally high rainfall, and 4) periodic seismic shaking. In a report on landslide susceptibility in San Mateo County, Brabb and others (1972) stated that, of these factors, degree of slope and nature of bedrock seemed to be the principal factors controlling the distribution of landslides.

Recent work by Tor H. Nilsen and others (Tor H. Nilsen, U.S. Geological Survey, oral commun., 1973) indicates that 85 percent of bay area landslides occur on slopes greater than 15 percent. In this map area over 92 percent of the slopes exceed 15 percent slope; and about one-third of this "steeper" area is mapped as landslide deposits. Only two percent of the area of less than 15 percent slope is underlain by landslide deposits, and approximately half of these low slope areas are contained within very large slides.

In a discussion of landslides in a region about 60 miles north of this study area, Dwyer (1972) correlated different amounts and sliding styles with two different lithologic units within the Fransiscan assemblage. One of the units, a pervasively sheared tectonic mixture of shale and sandstone (mélange), exhibits more extensive landslide development than does the intact, relatively unsheared, Franciscan sandstone and shale unit. About eighty percent of the map area is underlain by rocks of the Franciscan assemblage (Blake, and others, 1971), with thirty-eight percent of the former area underlain by the sheared (mélange) unit. Forty-eight percent of the mélange unit is mapped as landslide deposits. The more intact sandstone and shale unit underlies 26 percent of the study area and is here mapped as about 30 percent landslide deposits. Greenstone, an altered volcanic rock unit of the Franciscan assemblage, inderlies about 14 percent of this study area and is about 45 percent covered with landslide deposits.

In contrast to the relatively large number of landslides found within the units in the Franciscan assemblage, another bedrock unit, a part of the Great Valley sequence, is only about fourteen percent covered with landslide deposits. This intact, generally unsheared sandstone, shale, and conglomerate unit is limited to about seven percent of the study area and is restricted to the area southwest of Cloverdale (Blake and others, 1971). Although landslide deposits are found throughout the mapped area depending on the type of local bedrock, the bedrock near The Geysers Steam Field has been so highly altered that, regardless of its original physical properties, it is now relatively weak.

High seasonal precipitation in the mapped area saturates the ground during winter months and promotes landsliding. The high water content of the ground at that time makes it easier for the pull of gravity to overcome internal resistance to shear and frictional resistance to downslope movement. The rainfall is orographically controlled, with mean annual precipitation ranging from 36 inches along the lowlands of the Russian River valley to more than 70 inches in the southeastern corner of the mapped area and to 56 inches in the western portion.

Earthquakes, a common phenomon in the San Francisco Bay region, may trigger landslides. Morton (1971) documented the influence of the 1971 San Fernando earthquake on landslides and reported that the gross distribution of slides activated by that earthquake was controlled primarily by the intensity of ground shaking. He also showed that the number of landslides in the region was influenced by local bedrock conditions.

Man may also affect the potential for landsliding. In some cases he decreases it by leveling slopes, building retaining walls at the base of slopes, by planting trees or other vegetation, and by practicing soil conservation. Other activities, such as, 1) exceeding natural slope angles in road or building sites, 2) adding water to marginally stable slopes from irrigation of lawns or crops, from improperly concentrated rain-water runoff, and from septic tank drain fields, 3) adding weight in the form or structures of fill to marginally stable slopes, and 4) removing natural vegetation, may increase the potential for slope failures.

MAP PREPARATION

This map was prepared exclusively by viewing overlapping vertical aerial photographs with a stereoscope. This method allows the geologists to see a three-dimensional model of the terrain to be analyzed and thereby permits him to estimate the distribution and nature of landforms interpreted to be landslide deposits. No field time was spent checking the relations between mapped landslide deposits and landslide deposits actually observed in the field. Photographs used to prepare the map include black and white aerial photographs taken for Sonoma County in 1961 (Series CSH 3BB to 7BB, scale approximately 1:20,000). These photographs were supplemented by some black and white photographs taken for the U.S. Geological Survey in 1970 (Series GS-VCMI, scale approximately 1:80,000), and some color photographs (scale approximately 1:12,000) flown in 1971 for Occidental Petroleum Company for areas near The Geysers Steam Field.

Landslide deposits were recognized on aerial photographs by a combination of such distinctive features as 1) small isolated ponds, lakes, and other closed depressions; 2) abundant natural springs; 3) abrupt and irregular changes in slope and drainage pattern; 4) irregular or hummocky surfaces; 5) steep arcuate scarps at the upper edge of the deposit; 6) irregular soil and vegetation patterns; 7) tilted trees and other signs of disturbed vegetation; and 8) level areas within steep slopes.

FACTORS AFFECTING MAP RELIABILITY

PROBLEMS in INTERPRETATION: Mapping of landslide deposits by photointerpretation alone presents a number of difficult problems, some of which can be resolved only through field checking. Problems that are especially difficult include: 1) distinguishing between irregular or hummocky topography caused by variation in the erosional resistance of the bedrock or by the erosion due to the landslide process, 2) recognizing stable masses of bedrock surrounded by landslide deposits, especially where the bedrock may appear only as an isolated ridge or mound within the surrounding landslide deposit, 3) recognizing landslide deposit boundaries - whereas the upslope boundary is sometimes defined by an easily recognized scarp, the toe or downslope boundary is seldom well defined and is difficult to locate exactly. Recognizing bedrock cropping out beneath other surficial deposits may be difficult, especially where a creek or stream has cut through the overlying surficial deposits to expose bedrock along the streambed.

DATE of PHOTOGRAPHY: Most of the depictions of landslide deposits shown on this map were derived from interpretations of 1961 photography. Thus modifications or further development of landslide deposits after 1961 are not shown. As noted above, however, some 1971 color photography was used in some areas in the vicinity of The Geysers Steam Field.

SIZE of LANDSLIDE DEPOSITS: Landslide deposits less than about 100 feet in longest dimension are not shown because they are too small to be identified consistently on the photographs or to be clearly portrayed on the topographic base.

QUALITY of PHOTOGRAPHY: The accuracy of the map varies directly with the clarity and contrast of the aerial photographs used. Accordingly, haze, cloud cover, poor sun angle, or problems in development of photographs make photointerpretation more difficult; also, the steepness of the topography and the location and extent of shaded areas affect the usefulness of individual photographs.

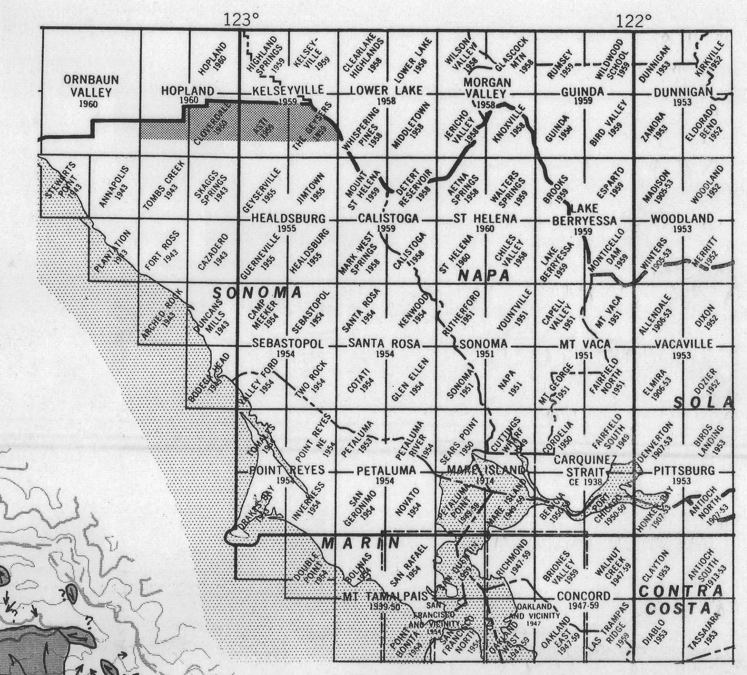
VEGETATION COVER: Landslide deposits are most easily recognized in open grassy areas. Conversely, they are most difficult to recognize in forested areas where many landslides may have been overlooked. Figure 1 shows areas in the map area covered by a) trees, b) brush, and 3) grass.

A REMINDER FOR MAP USERS

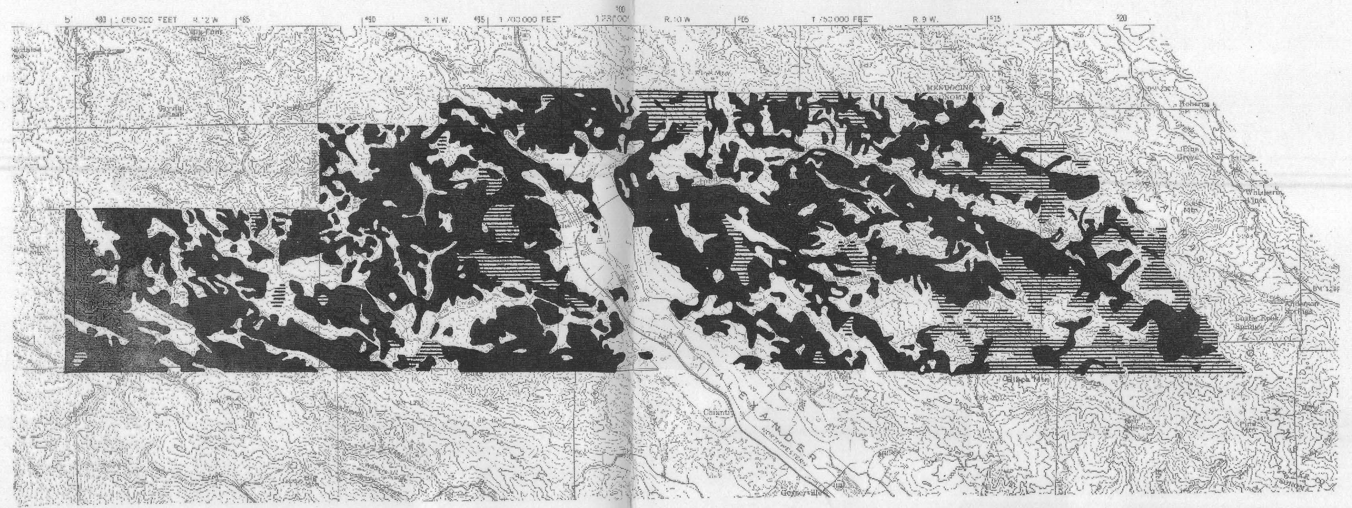
Map users are reminded that this map was produced solely by photointerpretation methods and is therefore not a substitute for on-site investigations. However, since the density of landslide deposits is a crude measure of the importance of slope failure as an erosional process and, therefore, a measure of the overall slope stability of an area, this map identifies areas susceptible to landslide activity that should be carefully studied before any site development.

ACKNOWLEDGEMENTS

Carl M. Wentworth provided the opportunity for me to acquire a background for this work, primarily in terms of methodology in identifying landslide deposits. Valuable discussions with Robert J. McLaughlin lead to modification of the map in the vicinity of The Geysers Steam Field. The explanation benefited from those previously prepared by Tor H. Nilsen and Earl E. Brabb. Sandi Hayden and Trudy Edmonston helped prepare materials for the map, and Libby L. Jones supplied technical support.



INDEX TO TOPOGRAPHIC MAPS

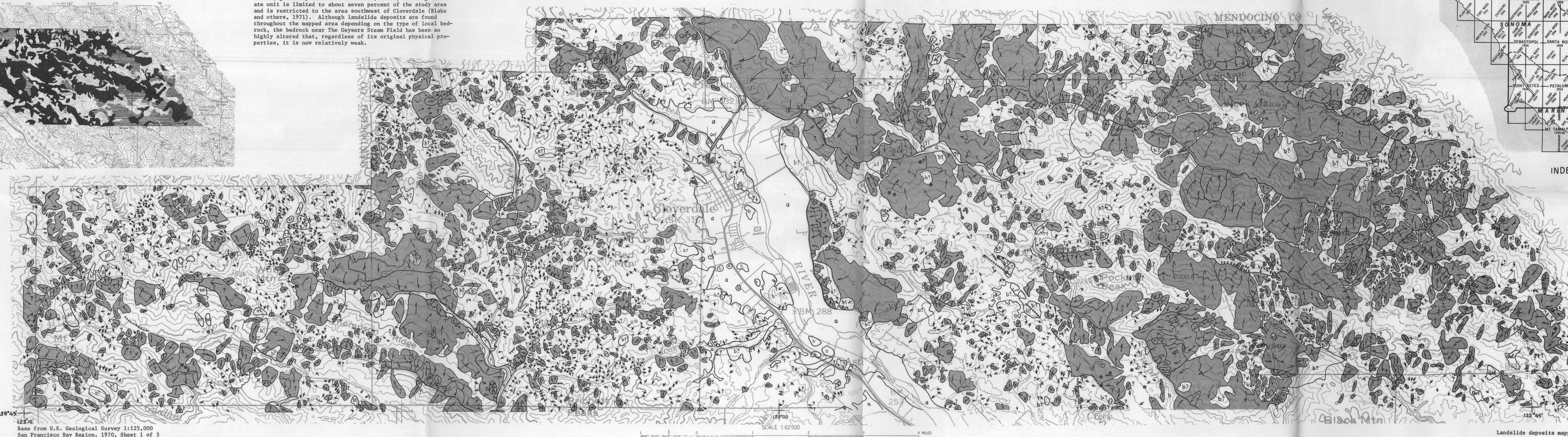


EXPLANATION OF MAP SHOWING RELATIVE VISIBILITY OF GROUND SURFACE

Ground surface least visible, with the ground surface and outline of the ground surface usually obscured by trees or combinations of trees and brush. Landslides most easily overlooked. Contains some areas of brush or grass too small to be shown

Ground surface usually obscured by brush, but outline of ground surface is observable. Locally this unit designates logged areas. Also locally contains areas of trees or grass too small to be shown

Surface of the ground covered by grass and is easily visible. Includes some areas of trees or brush too small to be shown. Landslides most obvious



Base from U.S. Geological Survey 1:125,000
San Francisco Bay Region, 1970, Sheet 1 of 3

SCALE 1:62500

1 2 3 4 MILES

9000 12000 15000 18000 21000 FEET

2 3 4 5 KILOMETERS

This scale now at 1:62 500

Landslide deposits mapped in 1972 and 1973

EXPLANATION OF MAP SYMBOLS

Landslide deposits

Identification confident to probable; queried where uncertain. Inferred movement style variable, including uncertain to indeterminate. Arrows indicate direction of inferred downslope movement. Deposits generally larger than 500 feet in maximum dimension

Block slide deposits

Identification confident to probable; queried where uncertain. Consists of landslides or parts of larger landslides inferred to have moved downslope as relatively intact blocks. Arrows indicate direction of inferred downslope movement. Deposits generally larger than 500 feet in maximum dimension

Small landslide deposits

Identification confident to probable; queried where uncertain. Inferred movement style variable, including uncertain to indeterminate. Arrows indicate direction of inferred downslope movement and are centered over location of deposits. Deposits generally larger than 100 feet but smaller than 500 feet in maximum dimension. If included in larger queried deposit or other unit, denotes small slide therein

b?

Bedrock with erosional topography

Queried bedrock represents anomalous topography with a very low probability of being a landslide. Areas not otherwise designated should be considered bedrock

a a?

Young sedimentary deposits with constructional topography

Queried where uncertain. Includes alluvium, colluvium, alluvial fan and terrace deposits

T T?

Terrace deposits that underlie flat surfaces adjacent to but above the present steambed on valley floors

Queried where uncertain. Some units so designated may represent erosional surfaces cut into bedrock. Not differentiated adjacent to Russian River flood plain

Qaf

Artificial fills composed of rock and (or) surficial deposits derived from nearby cut or quarries

Only large fill areas are shown. In some upland areas symbol represents artificial cut

Anomalous swale, trench, or small valley

Possibly landslide related, some possibly fault related

Anomalous scarp-like feature; possibly landslide related

Closed depression

"x" at bottom. May be landslide related, some possibly fault related

SELECTED REFERENCES

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Blake, M. C., Jr., Smith, J. T., Wentworth, C. M., and Wright, R. H., 1971, Preliminary geologic map of western Sonoma County and northernmost Marin County, California: U.S. Geol. Survey open-file map, 5 sheets, scale 1:24,000.

McNitt, J. R., 1968, Geological map and section of Kelseyville quadrangle, Mendocino, Lake, and Sonoma Counties, California: California Div. Mines and Geology Map Sheet 9, scale 1:62,500.

SOURCE MATERIALS

The following photographs were used in the preparation of this map: U.S. Dept. of Agriculture (ASCS) Series CSH taken in 1961 including photographs numbered 3BB-28 to 35, 3BB-40 to 47, 3BB-100 to 107, 3BB-112 to 118, 3BB-172 to 179, 3BB-181 to 188, 4BB-27 to 33, 4BB-35 to 42, 4BB-98 to 103, 5BB-135 to 140, 6BB-77 to 83, 6BB-122 to 124, 6BB-128 to 135, 7BB-7 to 12, and 7BB-71 to 76.

In addition, vertical aerial photographs taken for the U.S. Geological Survey in 1970, scale approximately 1:80,000, were used supplementally. These photographs are from series GS-VCMI, and include numbers 3-20 to 22, 3-42 to 44, 3-55 to 57, 3-83 and 84, and 3-111 to 113.