DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

U.S. GEOLOGICAL SURVEY
OPEN FILE MAP

76 - 74 (SHEET 1 OF 25)

Introduction

The nine San Francisco Bay region counties lie within a geologically active, young, and dynamic part of the central and northern Coast Ranges of California. Significant movements of the earth's crust are occurring here at the present time, posing numerous problems to urbanization, including some of special concern. Geological processes such as fault movements, earthquakes, land subsidence, landsliding, slow downslope movement of bedrock and surficial materials, coastal and stream erosion, flooding, and sedimentation are all potentially hazardous. Because of these factors, an understanding of the operation of physical processes in the bay region is desirable for harmonious, efficient, and safe land-use planning, particularly now, with greatly expanded pressures for urban growth.

This map presents preliminary information about one aspect of the physical environment necessary to sound land-use planning--the nature and distribution of landslides. Because landslides are common in much of the bay region, it is useful to know how and why they are formed, as well as what properties they possess. When maps like this are used in combination with other types of environmental information, such as data on soils, bedrock geology, slopes, vegetation, climatic variation, seismic response, and hydrology, it should be easier to arrive at sound decisions regarding the physical aspects of land use.

These maps were prepared by Cooper-Clark and Associates at the request of the U.S. Geological Survey. The maps are similar to those produced as part of the Survey's San Francisco Bay Region Study in cooperation with the Department of Housing and Urban Development.

Landslide deposits:

Landslides occur when the pull of gravity on earth materials overcomes their frictional resistance to downslope movement. Slope stability is affected by (1) type of earth materials--unconsolidated, soft sediments or surficial deposits will move downslope easier than consolidated, hard bedrock; (2) structural properties of earth materials--the orientation of the layering of some rocks and sediments relative to slope directions, as well as the extent and type of fracturing and crushing of the materials, will affect landslide potential; (3) steepness of slopes--landslides occur more readily on steeper slopes; (4) water--landsliding is generally more frequent in areas of seasonally high rainfall, because the addition of water to earth materials commonly decreases their resistance to sliding; water decreases internal friction between particles, decreases cohesive forces that bind clay minerals together, lubricates surfaces along which slippage may occur, adds weight to surficial deposits and bedrock, reacts with some clay minerals, causing volume changes in the material, and mixes with fine-grained unconsolidated materials to produce wet, unstable slurries; (5) ground shaking--strong shaking during earthquakes can jar and loosen bedrock and surficial materials, thus making them less stable; (6) type of vegetation--trees with deep penetrating roots tend to hold bedrock and surficial deposits together, thereby increasing ground stability; (7) proximity to areas undergoing active erosion--rapid undercutting and downcutting along stream courses and shorelines makes slopes in these areas particularly susceptible to landsliding.

All the natural factors that promote landsliding are present in the bay region. In addition, man has at times decreased the potential for slope failures by leveling slopes, building retaining walls at the base of slopes, planting trees or seeding forests, as well as practicing soil conservation. However, other of his activities have increased the potential for slope failures, including increasing slope angles for road or building construction; adding water to marginally stable slopes by watering lawns, improperly handling rain-water runoff and choosing poor sites for septic tank drainfields; adding to the weight of marginally stable slopes by building structures as well as by adding fill for foundations; and removing natural vegetation. Thus, slope failure, a natural phenomenon that has occurred throughout the bay region in the past, may be aggravated by improper land use.

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.

Problems in interpretation:

Mapping of surficial 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 terrace-shaped slump-type landslide deposits from alluvial terrace deposits where both are located adjacent to stream courses; (2) recognizing bedrock cropping out beneath surficial deposits, especially where a creek or stream has cut down through the overlying surficial deposits to expose bedrock along the streambed; (3) determining boundaries between adjacent surficial deposits that laterally grade into or interfinger with one another without leaving any easily discernible topographic boundaries, e.g., the downstream gradation of alluvial terrace deposits into alluvial deposits; (4) recognizing landslide deposit boundaries--whereas the upslope boundary is commonly defined by an easily recognized scarp, the toe or downslope boundary is seldom well defined and is difficult to locate exactly; (5) recognizing stable masses of bedrock within landslide deposits, especially where the bedrock may appear only as a large block within the surrounding landslide deposit; and (6) distinguishing between irregular or hummocky topography caused either by variations in the erosional resistance or bedrock or by the erosion of landslide deposits.

Comparison of this map with 1:62,500 scale photointerpretation landslide mapping done by Sims and Frizzell (1976) in the Mt. Vaca 15-minute quadrangle will reveal some differences in landslide interpretation. Such differences are not uncommon on regional reconnaissance geologic maps, especially those prepared solely on the basis of aerial photographic interpretations. The difference may arise from a variety of reasons, including scale, date and quality of photography employed, local conditions such as soil moisture and density of vegetative cover, techniques of photographic interpretation, and the experience of the interpreting geologists.

Landslide maps of the same area that have been prepared by different interpreters may therefore show variability in the location of landslide boundaries, variability in how individual landslides are classified, or some landslides appearing on one interpreter's map may be omitted on another. These differences emphasize the fact that variation in interpretation can occur between geologists using the same data base and underscores the need to recognize both the use and limitations of such maps. In the case of the Mt. Vaca 15-minute quadrangle, it is suggested that the map user refer to both landslide maps prepared for the area. The user will thus have the benefit of two interpretations rather than one. In this manner, comparisons between the two maps can be made which will reduce the likelihood of specific landslides which have not been delineated on one of the maps going undetected by the user. Comparison of this type will also provide the user with an estimate of the certainty both interpreters had in the identification and classification of specific landslides.

Date of photography:

Modifications of the landscape that have occurred since 1957, 1958, 1959, 1961, 1964 and 1970, when the aerial photographs were taken, are not shown on this map.

Scale of maps and photography:

Landslide deposits less than about 200 feet long are not shown because they are too small to be clearly identified on the photographs or clearly portrayed on the topographic base map.

Quality of photography:

The accuracy of the map varies directly with the clarity and contrast of the aerial photographs used. Accordingly, haze, cloud cover, or poor sun angles make photointerpretation more difficult; also, the steepness of the topography and the location and extent of shaded areas effect the usefulness of individual photographs. In general, however, the photographs used to prepare this map are of excellent quality.

Forest cover:

Surficial deposits may be difficult to recognize in forested areas, so that such areas may be mapped less accurately than grass-covered areas. Many landslide deposits may be impossible to recognize on slopes covered with dense stands of tall trees.

Urbanization and farming:

Surficial geologic features can be obscured in urbanized areas by (1) modification of the natural landscape by grading (leveling, cutting, filling, or terracing), and (2) man-made structures that cover the natural land surface.

SELECTED REFERENCES ON LANDSLIDES

Eckel, E. B., ed., 1958, Landslides and engineering practice: Highway Research Board Spec. Rept. 29, NAS-NRC 544, Washington, D.C., 232 p.

Leighton, F. B., 1966, Landslides and hillside development, in Engineering geology in southern California: Assoc. Engr. Geologists, Los Angeles Sec., Spec. Pub., p. 149-193.

Sharpe, C. F. S., 1960, Landslides and related phenomena: Paterson, N. J., Pageant Books, 137 p.

Terzaghi, Karl, 1950, Mechanism of landslides, in Paige, S. M., Chm., Application of geology to engineering practice (Berkey volume): New York, Geol. Soc. America, p. 83-123.

Varnes, D. J., 1958, Landslide types and process, in Eckel, E. B., ed., Landslides and engineering practice: Highway Research Board Spec. Rept. 29, NAS-NRC 544, Washington, D.C., p. 20-47.

Zaruba, Quido, and Mencl, Vojtech, 1969, Landslides and their control: Amsterdam, Elsevier Pub. Co., 205 p.

REGIONAL GEOLOGY

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.

Fox, K. F., Jr., Sims, J. D., Bartow, J. A., and Helley, E. J., 1973, Preliminary geologic map of eastern Sonoma County and western Napa County, California: U.S. Geol. Survey Misc. Field Studies Map MF-483.

McLaughlin, R. J., 1974, Preliminary geologic map of the Geysers steam field and vicinity, Sonoma County, California: U.S. Geol. Survey Misc. Field Studies Map MF-238.

Sims, J. D., Fox, K. F., Jr., Bartow, J. A., and Helley, E. J., 1973, Preliminary geologic map of Solano County and parts of Napa, Contra Costa, Marin and Yolo Counties, California: U.S. Geol. Survey Misc. Field Studies Map MF-484.

REFERENCES ON SAN FRANCISCO BAY REGION LANDSLIDES

Brabb, E. E., Pampeyan, E. H., and Bonilla, M. G., 1972, Landslide susceptibility in San Mateo County, California: U.S. Geol. Survey Misc. Field Studies Map MF-360.

Dwyer, M. J., 1972, Landslide and related processes in the Round Valley-Little Lake Valley and Fort Bragg region, Mendocino County, California, in Moores, E. M., and Matthews, R. A. eds., Geologic Guide to the Northern Coast Ranges, Lake, Mendocino, and Sonoma Counties, California: Annual field trip guidebook of the Geological Society of Sacramento, p. 33-49.

Frizzell, V. A., Jr., 1974, Reconnaissance photointerpretation map of landslides in parts of the Hopland, Kelseyville, and Lower Lake 15-minute Quadrangles, Sonoma County, California: U.S. Geol. Survey Misc. Field Studies Map MF-594.

Frizzell, V. A., Jr., Sims, J. D., Nilsen, T. H., and Bartow, J. A., 1974, Preliminary photointerpretation map of landslide and other surficial deposits of the Mare Island and Carquinez Strait 15-minute Quadrangles, Contra Costa, Marin, Napa, Solano, and Sonoma Counties, California: U.S. Geol. Survey Misc. Field Studies Map MF-595.

Nilsen, Tor H., 1975, Preliminary photointerpretation maps of landslide and other surficial deposits of 56 7 1/2-minute quadrangles, Alameda, Contra Costa and Santa Clara Counties, California (with parts of adjoining counties on several maps by John A. Barow, Virgil A. Frizzell, Jr. and John D. Sims): U.S. Geol. Survey Open File Map 75-277.

Sims, J. D., and Frizzell, V. A., Jr., 1976, Preliminary photointerpretation map of landslides and other surficial deposits of Mt. Vaca, Vacaville, and parts of Courtland, Davis, Lake Berryessa, and Woodland 15-minute quadrangles, Napa and Solano Counties, California: U.S. Geol. Survey Misc. Field Studies Map MF-719.

Wentworth, C. M., and Frizzell, V. A., Jr., 1975, Reconnaissance landslide map of parts of Marin and Sonoma Counties, California: U.S. Geol. Survey Open File Map 75-281.

MAP EXPLANATION

SYMBOLS USED

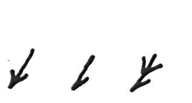
LARGE LANDSLIDE DEPOSITS

Landslide which is 50 feet or more in maximum dimension. Arrows indicate general direction of downslope movement (omitted for lack of space on some landslides and on all questionable landslides). Double barbed arrows indicate primarily slump or block slump landslide movement. Single barbed arrows indicate primarily flow movement; while a combination of double and single barbed arrows indicate a complex movement, slump or block slump with earthflow extending downslope from foot (see FIGURE 1). Smaller arrows within a large landslide indicate smaller and more recent landslides occurring on a large landslide mass (see SMALL LANDSLIDE DEPOSITS). Capital letters shown on each landslide have the following designations: D, DEFINITE landslide deposits; P, PROBABLE landslide deposits; Q, QUESTIONABLE landslide deposits; R, landslide features on photographs strongly suggest a RAPID rate of slide movement; A, landslide features on photographs strongly suggest recent ACTIVITY. Hachured lines show the approximate position of inferred landslide scarps.

Recognition of some or all of the following landslide-formed features, if well defined and readily observable in aerial photographs, lead to an interpretation of definite landslide (D on map): (1) broken ground, including scarps and fissures; (2) primary and secondary slump blocks; (3) sag ponds; (4) slide toes; (5) hummocky topography; (6) springs and seeps often with water-loving vegetation; (7) abrupt and irregular changes in slope and drainage pattern and stream gradient.

Topographic features recognized with the following landforms are interpreted as being very probably of landslide origin (P on maps): (1) continuous, relatively sharp breaks on slope interpreted as being poorly preserved and/or poorly developed slide scarps; (2) topographic flats, or benches interpreted as being poorly preserved and/or poorly developed slump blocks; (3) small, presently free-draining areas, of gentle relief interpreted as old sag ponds which have become infilled by sediment.

Topographic features whose outlines are subdued by weathering and/or largely obscured by vegetation but whose overall form is suggestive of landslide origin are called questionable landslides (? on map).



SMALL LANDSLIDE DEPOSITS

100 to 500 feet in maximum dimension. Arrows indicate general direction of downslope movement and are centered over the location of deposits. Meaning of symbols: arrows, D, P, ?, R, and A are the same as for LARGE LANDSLIDE DEPOSITS (see above).

SOIL CREEP

Area of suspected soil creep; the shallow and gradual downhill movement of soil and loose rock material. Undulating arrows indicate general direction of creep and are centered over the location of creep area. Areas with a maximum dimension of less than 500 feet are shown only by undulating arrows.

LANDSLIDE ZONE

Slide area consisting of numerous coalesced and superposed landslides of various sizes, types of movement, and degrees of activity. Because of spatial complexity, it is generally not feasible to delineate individual slides composing these zones. Meaning of symbols: D, P, and A are the same as of LARGE LANDSLIDE DEPOSITS (see above). The following symbols are used only for the LANDSLIDE ZONES: D-DA, landslide zone consists of primarily DEFINITE TO DEFINITE and ACTIVE landslide deposits; P-?, landslide zone consists of primarily PROBABLE to QUESTIONABLE landslide deposits; S, STABLE appearing areas within a landslide zone.

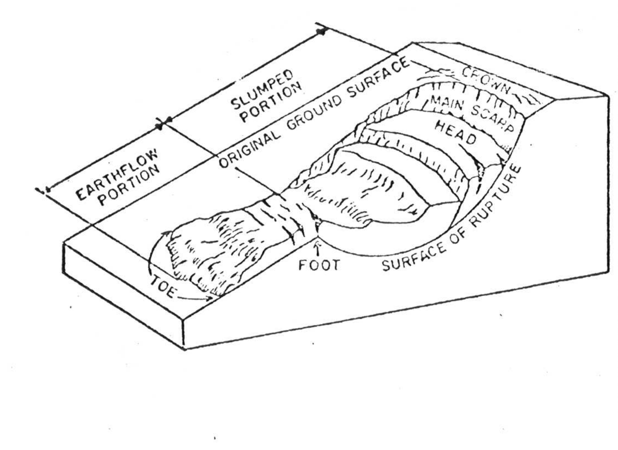


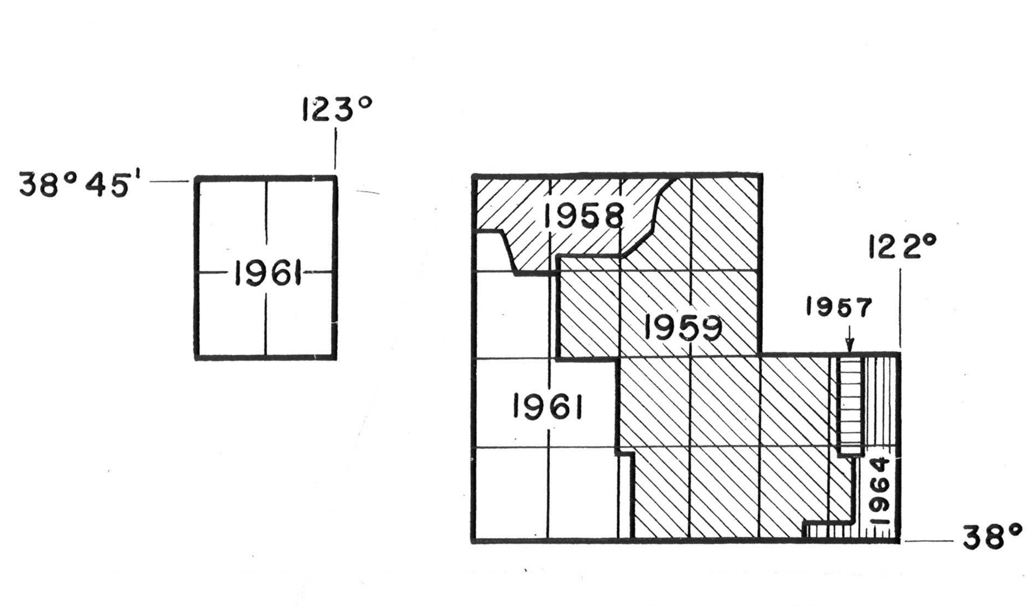
FIGURE 1*

TYPE OF MOVEMENT		TYPE OF MATERIAL			
		BEDROCK		SOILS	
FALLS		ROCKFALL		SOILFALL	
SLIDES	FEW UNITS	ROTATIONAL SLUMP	PLANAR BLOCK GLIDE	PLANAR BLOCK GLIDE	ROTATIONAL BLOCK SLUMP
	MANY UNITS		ROCKSLIDE	DEBRIS SLIDE	FAILURE BY LATERAL SPREADING
		ALL UNCONSOLIDATED			
		ROCK FRAGMENTS	SAND OR SILT	MIXED	MOSTLY PLASTIC
FLOWS	DRY	ROCK FRAGMENT FLOW	SAND RUN	LOESS FLOW	
			RAPID EARTHFLOW	DEBRIS AVALANCHE	SLOW EARTHFLOW
	WET		SAND OR SILT FLOW	DEBRIS FLOW	MUDFLOW
COMPLEX		COMBINATIONS OF MATERIALS OR TYPE OF MOVEMENT			

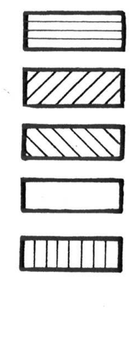
FIGURE 2*

GENERAL MORPHOLOGY OF RECENTLY ACTIVE LANDSLIDES
AND CLASSIFICATION OF LANDSLIDES

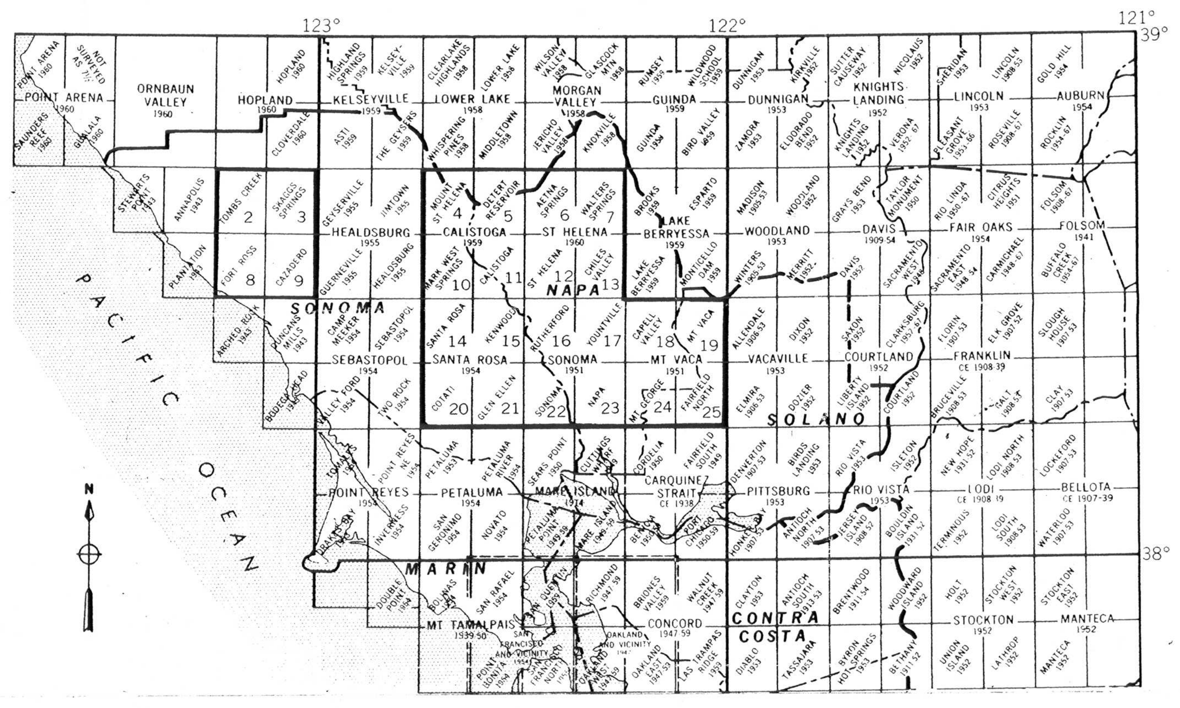
REF: Varnes, D. J., 1958, Landslide types and process, in Eckel, E. B., ed., Landslides and engineering practice: Highway Research Board Spec. Rep. 29, NAS - NRC 544, Washington, D.C., p. 20-47.



INDEX TO PHOTOGRAPH COVERAGE

	Flight Date	Agency	Scale	Series
	8/23/57	U.S.A.S.C.S.[1]	1:20,000	ABH 59T
	11/28/58	U.S.A.S.C.S.[1]	1:20,000	CVM 7V-13V
	4/15/59	U.S.A.S.C.S.[1]	1:20,000	CSI 1V-7V
	5/12/61	U.S.S.C.S.[2]	1:20,000	CSH 1BB-7BB
	5/9/64	U.S.A.S.C.S.[1]	1:20,000	ABO 2EE-3EE
	4/19/70 5/1/70	U.S.G.S.[3]	1:80,000	GS-VCMI

1) U. S. Agricultural Stabilization and Conservation Service
2) U. S. Soil Conservation Service
3) U. S. Geological Survey (Covers entire study area.)



INDEX TO TOPOGRAPHIC MAPS

RECONNAISSANCE PHOTOINTERPRETATION MAP OF LANDSLIDES IN 24 SELECTED 7.5 - MINUTE QUADRANGLES IN LAKE, NAPA, SOLANO, AND SONOMA COUNTIES, CALIFORNIA

1976

BY

M. J. DWYER, N. NOGUCHI AND J. O'ROURKE

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