DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

MISCELLANEOUS FIELD STUDIES
MAP MF-719

INTRODUCTION

This map presents preliminary information about the distribution and general character of landslides and other surficial deposits. When used in combination with other types of information, such as data on soils, bedrock geology, slopes, seismic response, hydrology, vegetation and climatic variation, it should be easier to arrive at sound decisions regarding the physical aspects of land use. The U.S. Geological Survey is studying many of these factors as part of its San Francisco Bay Regional Environment and Resources Planning Study in cooperation with the Department of Housing and Urban Development.

The representation of surficial deposits on this map reflects the way in which a geologist, working exclusively with aerial photographs, interpreted the origin of various elements of the present landscape. The deposits shown here have not been examined in the field. However, by viewing overlapping vertical aerial photographs through a stereoscope, the geologist sees a three-dimensional relief model of the ground surface and can study and interpret the origins of landforms with considerable ease. In fact, for mapping surficial deposits, particularly in reconnaissance-type studies, photointerpretation has advantages over both ground observations and laboratory studies of surficial materials. Of course, better information can be provided when all aspects of the study are integrated.

The surficial deposits represented on this map are formed largely from the effects of natural physical and chemical processes on soil and rock. However, man's activities can alter these natural processes in many ways. Simple acts such as overwatering a lawn or placing a septic tank drainfield in ground that is marginally stable may weaken the bedrock and surficial materials enough to induce landsliding. Relatively stable areas may be made unstable as the result of construction activities that involve cutting or oversteepening of natural slopes. The potential effects of all types of development must be evaluated carefully by planners, engineers, builders, conservationtists, and others involved with land use decisions in order to avoid or minimize loss of life and destruction of property and the natural landscape.

This map, then, shows the cumulative effects of various processes that have yielded surficial deposits up to the time the photographs used for photointerpretation were taken. It does not indicate directly areas where processes will be most active, nor does it show the rate at which they will operate. However, knowledge of the history of geologic events is a key to understanding and predicting the evolution of an area, even where man's activities significantly change the character of the land. Almost all new landslides, for example, occur in areas with a history of landslide activity.

CHARACTERISTICS OF SURFICIAL DEPOSITS RELEVANT TO LAND-USE PLANNING

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.

The landslide deposits shown on the map may or may not be continuously or intermittently moving at the present time. The potential for continued movement varies greatly and depends on many factors, including the age of the deposits and their previous histories of activity. Some deposits may pose no problems for many types of development, while development on others may offer serious problems. Most landsliding takes place in areas where landsliding has occurred before, and old landslide deposits are commonly reactivated by either natural or artificial means. The materials that form landslide deposits may be so broken up and disturbed that landsliding may easily recur, especially if slope angles or moisture contents are changed. Landslide deposits are characterized by (1) small isolated ponds, lakes, and other closed depressions; (2) abundant natural springs; (3) abrupt and irregular changes in slope and drainage pattern; (4) hummocky irregular surfaces; (5) smaller landslide deposits that are commonly younger and form within older and larger landslide deposits; (6) steep, arcuate scarps at the upper edge of the deposit; (7) irregular soil and vegetation patterns; (8) disturbed vegetation; and (9) abundant flat areas that might appear suitable as construction sites. In general, fewer of these characteristics will be noted in the smaller deposits. Detailed ground studies, of course, are required for predicting the future behavior of landslide deposits under changing conditions.

Alluvial deposits:
The surfaces of these deposits generally are relatively flat or gently sloping, with finer grained sediments deposited on flood plains surrounding the active stream channels. Excellent soils suitable for diverse agricultural activities are found on many older flood plains. These deposits may be water bearing, are commonly porous and permeable, and may compact slightly upon loading. In larger drainage basins, they may be excellent shallow sources of water and of construction aggregate. They are probably easy to excavate, with pebble- and cobble-rich layers locally abundant. The surface may be subject to flooding seasonally or less frequently; the active stream channel may alter its course gradually over a long period of time or rapidly during flooding. Migration of the channel can result in erosion, undercutting, and failure of stream banks if the bank edges slump or fall off into the stream channel.

Alluvial terrace deposits:
These deposits have many of the characteristics of alluvial deposits. However, because they are older and lie well above present stream level, they probably contain less water than alluvial deposits and may be more consolidated. The terrace deposits may be subject to slope failures, particularly where adjacent streams undercut the edges of the deposit. The lowest terrace deposit may still be subject to periodic flooding and sediment deposition by the adjacent stream, inasmuch as complete abandonment by the stream cannot be determined by photointerpretation.

Colluvial deposits and alluvial fan deposits:
Colluvial deposits generally are easily eroded and excavated; they will probably compact under loading and may continue to move slowly downslope, particularly the steeper parts. They may be water-bearing, with small springs associated with some. Grading (road construction, etc.), particularly when it results in steeper slopes, may accelerate the rate of downslope movement and produce landslide deposits.

Alluvial fan deposits range in character from very thick, extensive, stream-deposited sands and gravels to thin, small deposits from single mudflows. Some fans include abundant colluvial material, while others contain only alluvial sediments. As a result, porous and permeable gravel-rich layers may alternate with impermeable clay-rich layers; if the gravels are areally extensive, the deposits may be a good shallow source of water. Fan deposits are generally easy to excavate and not very resistant to erosion. Flooding and considerable erosion of the fans can be expected during periods of heavy rainfall. Natural slopes are normally stable, although stream undercutting can produce streambank failure, and some compaction or local subsidence of the fan surface may take place.

Slough deposits:

Soft, unconsolidated mud in abandoned stream channels along the margins of San Francisco Bay have some unique characteristics that pose serious problems to development and construction.

FACTORS AFFECTING MAP ACCURACY

Date of photography:
Modifications of the landscape that have occurred since 1973 when the most recent aerial photographs were taken are not shown on this map.

Scale of maps and photography: Landslide and other surficial 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. In addition, no attempt has been made to show the numerous small areas covered by artificial fill along highways, railroads and airstrips, in cementeries, in populated and farming areas, or near quarries and mines, even though some are more than 200 feet in longest dimension.

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 difficult. Also, the steepness of the topography and the location and extent of shaded areas affect the usefulness of individual photographs. In general, however, the photographs used to prepare this map are of excellent quality.

Forest cover: Surficial deposits commonly are 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. About 25 percent of the area included in this map is densely forested.

Urbanization: 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. Less than 5 percent of the area included in this map has been extensively urbanized.

SUGGESTIONS FOR MAP USERS

Planning departments and developers:
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. However, this map cannot be used to determine the probability of future landsliding, primarily because geologic and climatic changes during the past few hundred thousand years have altered slope stability and because the map does not provide detailed information regarding the composition and type of movement of individual landslide deposits. Therefore, the map should not be used as a substitute for detailed site investigations by engineering geologists and soils engineers; areas susceptible to landslide activity should be carefully studied before any development.

Geologists and engineers:
This map has been prepared to provide a regional context for interpreting detailed site investigations and should be used in conjunction with slope maps, bedrock geology maps, soils maps, and other available information. It is not intended as a substitute for site investigations, and its limitations should be clear. Comments regarding its usefulness and accuracy would be appreciated.

Home buyers:
Areas with relatively low densities of landslide deposits probably have good slope stability compared with areas with high densities of landslide deposits. However, landslide deposits less than 200 feet long have not been mapped, and the scale of this map is such that individual buildings cannot be precisely located. In fact, areas mapped as landslide deposits are not necessarily less stable than adjacent areas. The map, therefore, should not be used as a substitute for a report by an engineering geologist or soils engineer, because detailed site investigations are necessary for judgments about the slope stability of individual areas. In addition, other types of surficial deposits may pose construction problems and require investigation.

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 of bedrock or by the erosion of landslide deposits.

Comparison of this map with 1:24,000-scale photointerpretation landslide mapping done by Dwyer and others (1976) in the Mt. Vaca 15-minute quadrangle will reveal some differences in landslide interpretation. Such differences are common on regional reconnaissance geologic maps, especially those prepared solely on the basis of aerial photographic interpretations. The differences 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.

On landslide maps of the same area that have been prepared by different interpreters, the location of landslide boundaries may differ, the classification of individual landslides may differ, and some landslides shown on one map may be omitted on the other. Geologists using the same data base may differ in their interpretations, and these differences emphasize the need to recognize the use and limitations of these maps. The map user should refer to both landslide maps of the Mt. Vaca 15-minute quadrangle, to benefit from two interpretations rather than one. Comparison of the two maps will reduce the likelihood that specific landslides not shown on one of the maps will go undetected by the map user. Such a comparison will also provide a means of estimating the certainty with which both interpreters identified and classified specific landslides.

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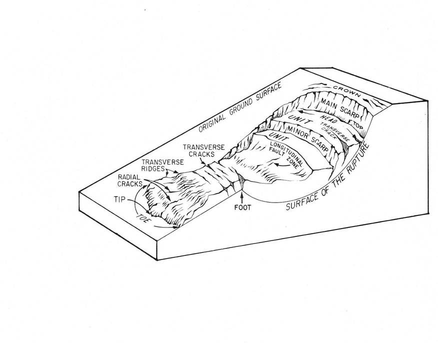
SOURCE MATERIALS

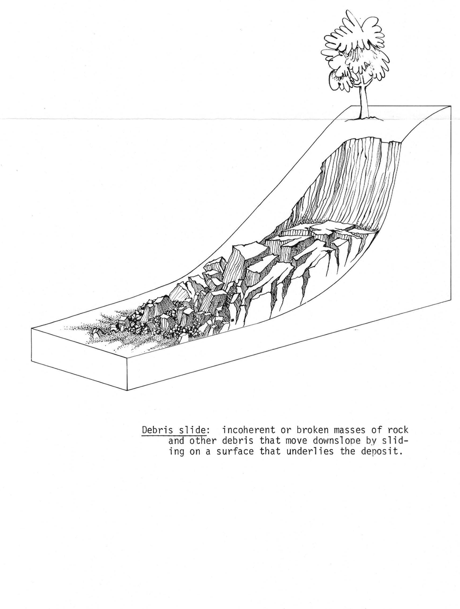
Sims used four series of vertical aerial photographs, scale 1:20,000, for his work on this map: (1) series ABO, taken in May 1964, including photograph numbers 1EE-14 to -25, 1EE-42 to -46, 1EE-79 to -87, 1EE-120 to -136, 1EE-145 to -162, 1EE-191 to -207, 1EE-216 to -232, 2EE-30 to -46, 2EE-55 to -62, 2EE-97 to -115, 2EE-133 to -141, 2EE-156 to -164, 2EE-171 to -178, 3EE-15 to -31, 3EE-46 to -54, 3EE-38 to -45, 3EE-105 to -111, 3EE -143 to -148, 3EE-151 to -157; (2) series CSI, taken in April 1959, including photograph numbers 1V-48 to -64, 1V-94 to -106, 5V-66 to -79, 6V-28 to -30, 6V-9 to -22, 6V-37 to -40; (3) series CSI, taken in March 1959, including photograph numbers 5V-23 to -26, 5V-5 to -11; (4) series CSI, taken in September 1958, including photographs 1V-77 to -93, 1V-25 to -41.

Frizzell used two series of vertical aerial photographs, scale approximately 1:14,000, for his work on this map: series 3575 taken in June 1973, including 4-56 to -103, 4-127 to -150, 4-153 to -177, 5-4 to -46, 5-58 to -94, 5-98 to -166, 5-177 to -180, and 5-188 to -195; and series 3594 taken in July 1973, including 1-147 to -163, 1-207 to -212, 1-216 to -220, 2-18 to -25, 2-28 to -39, 2-44 to -55, 2-71 to -75, 2-119 to -162, 2-183 to -202, 2-216 to -220, 2-238 to -248, 3-210 to -218, 3-222 to -229, 3-248 to -259, 4-145 to -157, and 5-157 to -159.

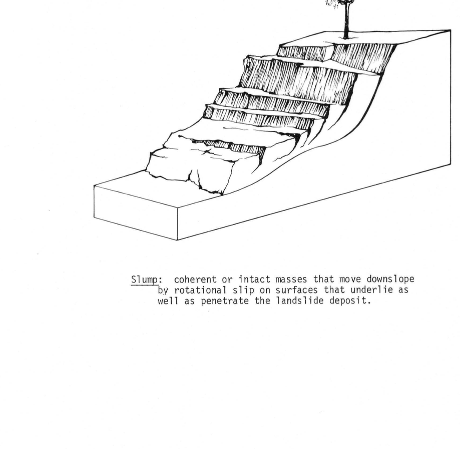
In addition, vertical aerial photographs, taken in May 1970, scale 1:80,000, were used to supplement the larger scale photographs; these photographs are series GS-VCMI and include photograph numbers 3-73 to -74, 1-122 to -126, 1-174 to -180, 2-98 to -104, 2-127 to -133, 3-121 to -129.

THESE ILLUSTRATIONS SHOW, RESPECTIVELY, THE NOMENCLATURE USED TO DESCRIBE LANDSLIDE DEPOSITS, AND FOUR COMMON TYPES OF LAND SLIDE DEPOSITS FOUND IN THE SAN FRANCISCO BAY REGION:

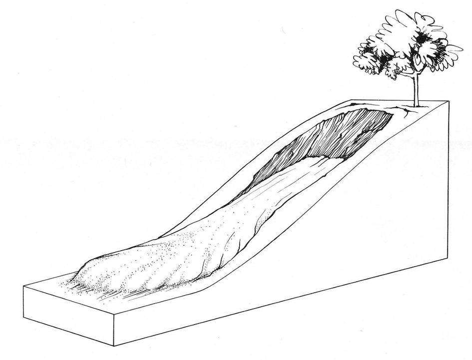




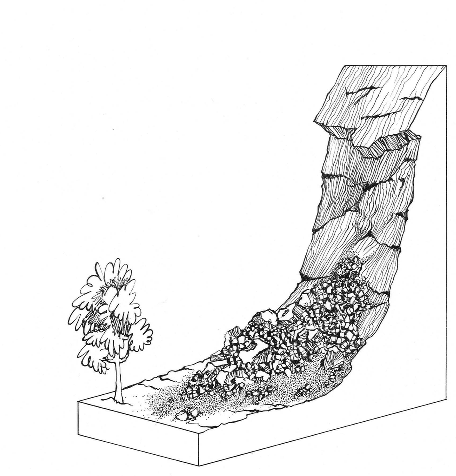
Debris slide: incoherent or broken masses of rock and other debris that move downslope by sliding on a surface that underlies the deposit.



Slump: coherent or intact masses that move downslope by rotational slip on surfaces that underlie as well as penetrate the landslide deposit.



Earthflow: colluvial materials that move downslope in a manner similar to a viscous fluid.



Rockfall: rock masses that move primarily by falling through the air.

EXPLANATION

Landslide deposit approximately 200-500 feet in longest dimension. Queried where identification uncertain. Arrow indicates general direction of downslope movement and is positioned over location of deposit

Landslide deposit larger than approximately 500 feet in longest dimension. Queried where identification uncertain. Arrows indicate general direction of downslope movement

Debris composed of fresh and weathered rock fragments, sediment, colluvial material, and artificial fill, or any combinations thereof, that has been transported downslope by falling, sliding, rotational slumping, or flowing. Landslide deposits smaller than approximately 200 feet in longest dimension are not shown on the map. Complex landslide deposits, which result from combinations of different types of downslope movement, are perhaps the most common type of landslide deposit in the bay region. In particular, materials near the head of landslide deposits typically move in a different manner than materials at the toe. The landslide deposits shown on this map have not been classified according to either type of movement or type of material of which the deposit is composed. The deposits vary in appearance from clearly discernible, largely unweathered and uneroded topographic features to indistinct, highly weathered and eroded features recognisable only by their characteristic topographic configurations. The time of formation of the mapped landslide deposits ranges from possibly a few hundred thousand years ago to 1966. No landslide deposits that formed since 1966 are shown. The thickness of the landslide deposits may vary from about 10 feet to several hundred feet. The larger deposits are generally thickest; many small deposits may be very thin and may involve only surficial materials

Qal

Alluvial deposits

Irregularly stratified, poorly consolidated mud, silt, sand, and gravel in stream and river beds and on adjoining flood plains. Alluvial deposits less than about 200 feet wide, common along smaller streams, generally have not been mapped; where colluvial deposits are adjacent to such narrow strips, the alluvial deposits have been included within them. Includes alluvial fan deposits that form broad, extensive, gently sloping surfaces composed of coalesced large alluvial fans that border upland areas. Deposition is continuing on the younger parts of these fan complexes as well as in the major alluvial channels that cut across the fan surfaces. Also includes deltaic deposits of the San Joaquin-Sacramento River delta area, which are included with alluvial deposits because they are difficult to distinguish from alluvial deposits by photointerpretation techniques

Alluvial terrace deposits
(boundaries dashed and queried where uncertain)

Irregularly stratified alluvial deposits of mud, silt, sand, and gravel that underlie horizontal to gently inclined flat surfaces that are adjacent to but above the present streambeds or valley floors. These deposits are generally not present sites of sedimentation, but represent older levels of stream deposition and erosion that have been abandoned as the stream continued to erode downward. Some areas may consist only of flat stream-cut surfaces eroded into bedrock without alluvial deposits on them; these areas cannot be easily distinguished from true terrace deposits by photointerpretation

Colluvial deposits and alluvial fan deposits

Colluvial deposits: unstratified or poorly stratified, unconsolidated to poorly consolidated deposits composed of fresh and weathered rock fragments, organic material, sediments, or irregular mixtures of these materials that accumulate by the slow downslope movement or surficial material predominantly by the action of gravity, but assisted by running water that is not concentrated into channels. Colluvial deposits have been mapped only where they form a distinct apron near the base of slopes or where they fill and flatten canyon, ravine, and valley bottoms. Colluvial deposits are probably forming on almost every slope in the bay region, but only the thicker and more extensive accumulations that are recognizable on aerial photographs have been mapped. In some narrow stream valleys, colluvial deposits include alluvial deposits. Colluvial deposits may move downslope along the axes of ravines and may form fan-shaped deposits where they emerge onto more gently sloping valley floors

Alluvial fan deposits: irregularly stratified, unconsolidated to poorly consolidated, fan-shaped accumulations of water-laid sediment formed where narrow canyons emerge onto more gently sloping valley floors. The fan sediments are composed of mud, silt, clay, and gravel deposited by streams and thin water-rich mudflows. These deposits commonly grade upslope into colluvial deposits and may be interbedded with them

Note: Because of the difficulties in distinguishing alluvial fan deposits from fan-shaped colluvial deposits on aerial photographs, the two units have not been distinguished on this map

Qsl

Slough deposits

Stratified carbonaceous fine-grained sediments in the San Joaquin-Sacramento River delta area. Primarily soft mud and silt, with some shell, peat, sand, and gravel layers. Generally form marshy or swampy areas at or near sea level; commonly inundated during high tides or floods. Extensive areas cultivated and filled where protected by artificial levees. Grade laterally shoreward into alluvial deposits; grade eastward into deltaic deposits of the San Joaquin-Sacramento River delta area, which are mapped herein as alluvial deposits. Old slough deposits can be easily recognized and mapped from aerial photographs by their characteristic meandering shape and by the different vegetation growing on them

QUATERNARY

b

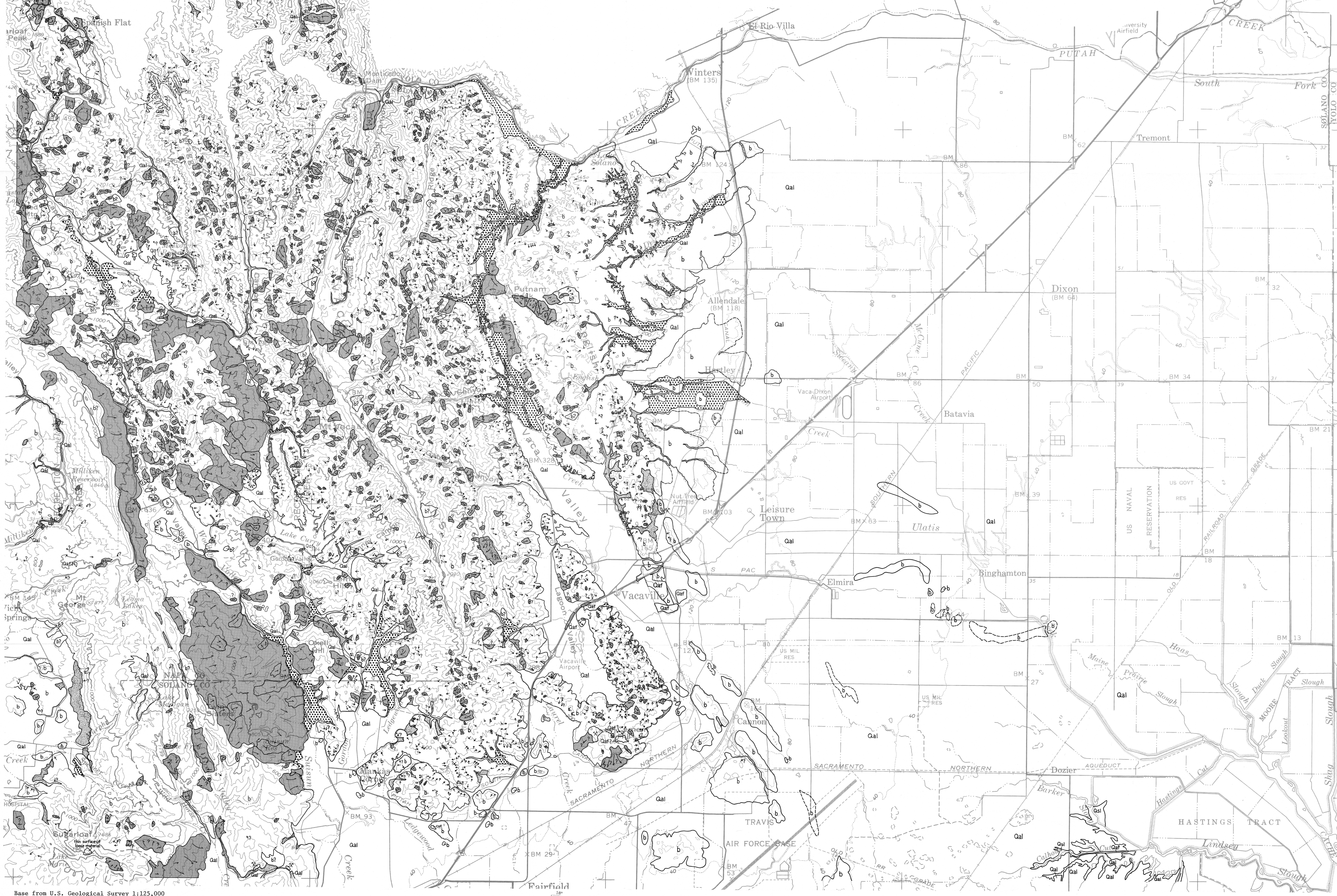
Bedrock

Igneous, metamorphic, and sedimentary rocks of pre-Quaternary age with various physical properties and engineering characteristics. Areas not shown on the map as covered with surficial deposits probably contain bedrock either exposed at the surface or mantled by a thin veneer of surficial deposits, most commonly colluvial material. The bedrock is commonly weathered to a considerable depth, so that there is a gradual change downward from highly weathered organic-rich soil to fresh bedrock. Thus, many of the small landslide deposits and some of the large landslide deposits that are shown on the map to lie within bedrock areas probably involve only material derived from weathered bedrock and other colluvial material.

Queried bedrock represents anomalous topography which has a low possibility of being a landslide deposit

Qaf

Highway, railroad and canal fills composed of rock and surficial deposits derived from nearby cuts or quarries; only large fill areas are shown on the map

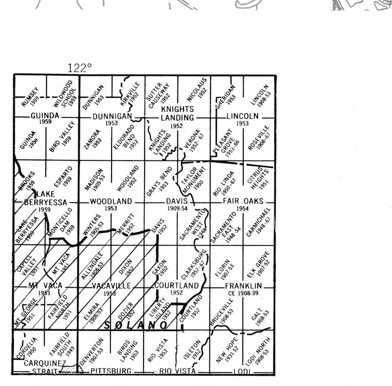


Base from U.S. Geological Survey 1:125,000
San Francisco Bay Region sheet 2 of 3, 1970

SCALE 1:62 500

3 MILES

3 KILOMETERS



Both Sims and Frizzell mapped the entire area. Sims mapped in 1971 and 1972 and Frizzell in 1973 and 1974.

For sale by U. S. Geological Survey, price $.50

PRELIMINARY PHOTOINTERPRETATION MAP OF LANDSLIDE AND OTHER SURFICIAL DEPOSITS OF THE MOUNT VACA, VACAVILLE, AND PARTS OF COURTLAND, DAVIS, LAKE BERRYESSA, AND WOODLAND 15-MINUTE QUADRANGLES, NAPA AND SOLANO COUNTIES, CALIFORNIA

by

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1976