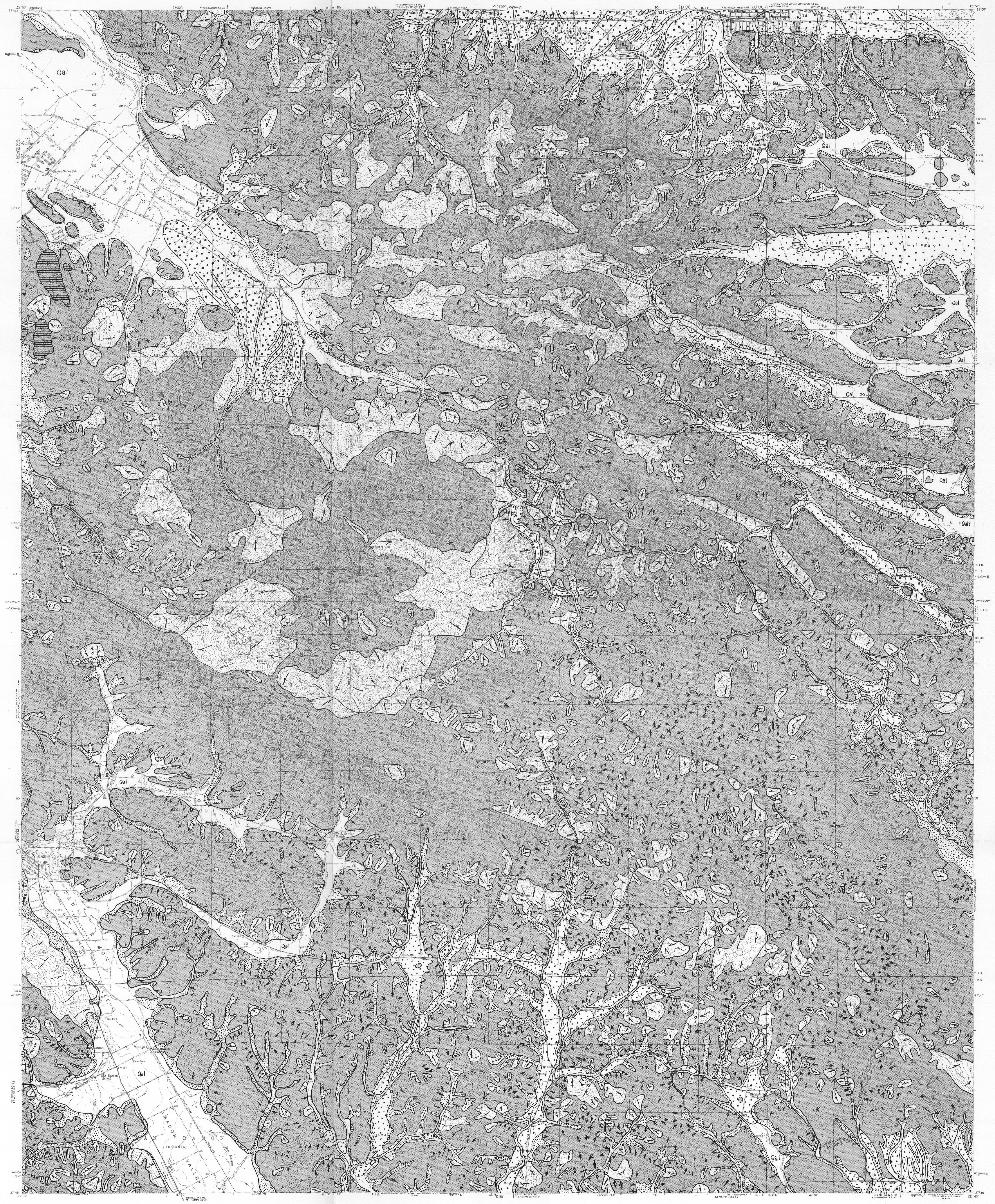
PREPARED IN COOPERATION WITH THE
DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT



Base from U. S. Geological Survey 7½-minute quadrangles: Clayton, Antioch South, Diablo, and Tassajara, 1953; all with 1968 photo revisions.

SCALE 1:62 500

PRELIMINARY PHOTOINTERPRETATION MAP OF LANDSLIDE AND OTHER SURFICIAL DEPOSITS OF THE MOUNT DIABLO AREA, CONTRA COSTA AND ALAMEDA COUNTIES, CALIFORNIA

by
Tor H. Nilsen
1971

The nine San Francisco Bay region counties lie within a geologically very active and dynamic part of the central and northern Coast Ranges of California. These rugged mountain ranges, with intervening fertile valleys, are geologically very young. Significant movements of the earth's crust are continuing to occur here at the present time, and this crustal activity poses numerous problems to human settlement of the area, including some problems that are unique and 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 to human activities. Because of these factors, an understanding of the nature and distribution of physical processes active in the Bay region is desirable for harmonious, efficient, and safe land-use planning, particularly at the present time because of the 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 surficial deposits. Because surficial deposits are common and well-developed in much of the Bay region, it is useful to know how and why they have formed, as well as what properties they possess. When this or other maps of surficial deposits 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, then planners and others may be in a better position to make sound judgments regarding the physical aspects of land use. The U.S. Geological Survey is presently studying many of these factors in the Bay region, and hopes to provide the community with much of the required information as part of its San Francisco Bay Region Study in cooperation with the Department of Housing and Urban Development.

INTRODUCTION

The map shows the distribution of landslide and other surficial deposits by presenting the writer's best judgments regarding the origins of the various parts of the present landscape. It is based completely on the interpretation of aerial photographs--no field examinations of the mapped deposits have been made. However, the viewing of overlapping vertical aerial photographs through a stereoscope, which permits a three-dimensional relief model of the ground surface to be seen, enables the geologist to study and interpret the origins of landforms with considerable ease. In fact, photointerpretation provides many advantages over both ground observations and laboratory studies of surficial materials in the mapping of surficial deposits, particularly for reconnaissance-type studies. Of course, better information can be provided when all aspects of the study are integrated. These preliminary photointerpretation maps are the initial stage of a continuing, more detailed study of surficial deposits in the Bay region, but they will hopefully provide map users with immediately useful information about the regional distribution of landslide and other surficial deposits.

This map indicates the dominant surficial processes that have probably been operative over the map area by showing the distribution of different types of surficial deposits. Natural processes such as weathering, erosion, sedimentation, and the slow as well as rapid downslope movement of earth materials, have been constantly shaping and reshaping the land surface in the past. These processes will continue to do so in the future, although their locations and rates of activity may change through time. The processes are not completely independent of one another, but are interrelated to varying degrees. For example, crustal uplift of the Coast Ranges will lead to increased erosion and downcutting by streams, which in turn generally results in increased deposition of sediments in river valleys, lakes, and shoreline areas. Older flood plains and river deposits may be cut into, leaving elevated terrace deposits. In addition, downcutting by the streams may cause the adjacent slopes to become unstable, thereby increasing the possibility of slope failures.

The actions of man can upset and alter the natural physical processes that form surficial deposits in many ways, often with disregard for and unawareness of the forces of nature. For example, the simple act of excessively watering a lawn or placing a septic tank drainfield in ground that is marginally stable may provide enough fluid to weaken the bedrock and surficial materials enough to induce landsliding. More common, perhaps, is the conversion of relatively stable areas into unstable ones by cutting into and oversteepening slopes by construction activities related to road building and urban development. Thus, the necessity of accurately mapping and making an inventory of the nature and distribution of surficial deposits should be recognized and the maps utilized to the fullest extent possible.

This map, then, shows the cumulative effects of various geologic processes that have yielded surficial deposits up to the time the photographs used for the photointerpretation were taken (1949). Thus, the map does not directly indicate future sites or rates of surficial processes. For example, the landslide deposits shown on the map record past slope failures, not areas of present or future slope instability. However, knowledge of the past history of geologic events is the most important key to understanding and predicting the future behavior of a particular land area, even where man's activities significantly change the character of the land. The overwhelming majority of new landslides, for example, occur in areas with a past history of landslide activity. As such, this map can be used to evaluate the regional importance of different surficial deposits in land-use planning.

EXPLANATION

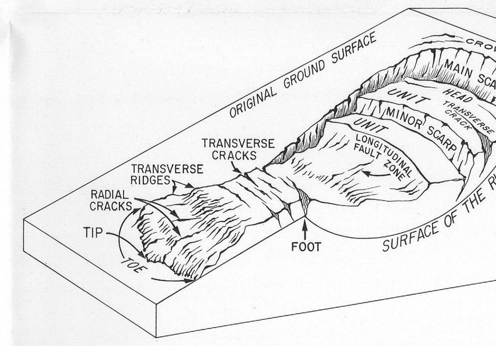
Landslide deposits:
Debris composed of fresh and weathered rock fragments, sediment, soil, and artificial fill, or any combinations thereof, that has been transported downslope by falling, sliding, rotational slumping, or flowing. Landslide deposits smaller than approximately 200 feet in longest dimension are not shown on the map.

Landslide deposit larger than approximately 500 feet in longest dimension; arrows indicate general direction of downslope movement; queried where identification is uncertain.

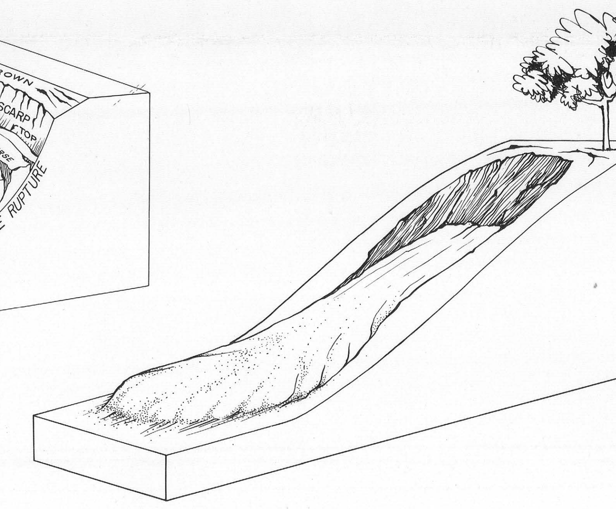
Landslide deposit between approximately 200 feet and 500 feet in longest dimension; arrow indicates general direction of downslope movement, and is positioned over location of deposit; queried where identification uncertain.

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 that the deposit is composed of. The deposits vary in appearance from clearly discernible, largely unweathered and uneroded topographic features to indistinct, highly weathered and eroded features recognizable 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 1949, with no landslide deposits formed since 1949 shown. The thickness of the landslide deposits probably varies from about 10 feet to perhaps several hundred feet, in general being greater in the larger deposits; many of the small landslide deposits may be very thin and involve only soil materials.

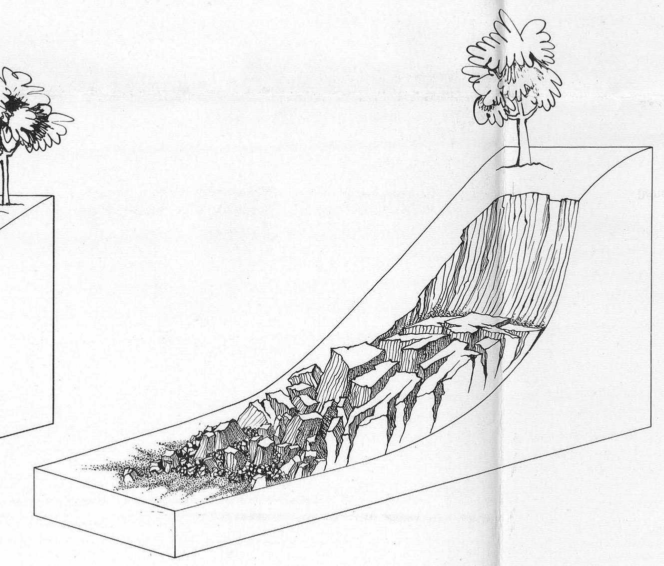
These illustrations show, respectively, the nomenclature used to describe landslide deposits, and four common types of landslide deposits found in the San Francisco Bay region:



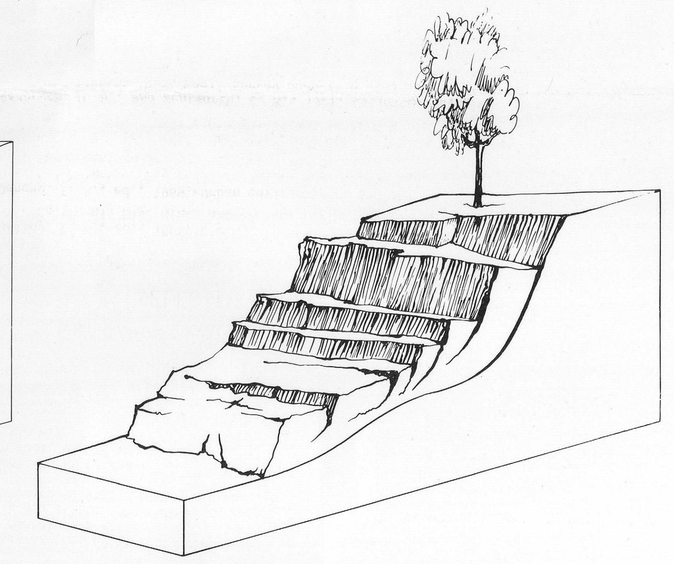
Nomenclature of parts of a landslide (from Eckel, 1958).



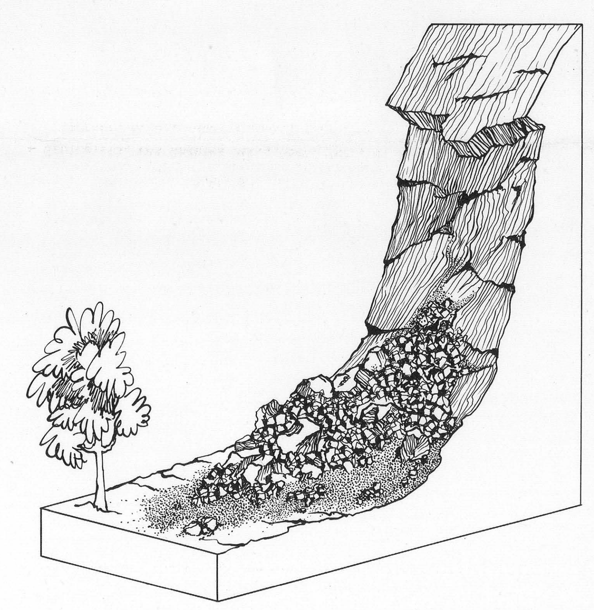
Earthflow: soil and other colluvial materials that have moved downslope in a manner similar to that of a viscous fluid.



Debris slide: incoherent or broken masses of rock and other debris that have moved 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 deposit.



Rockfall: rock that has moved primarily by falling through the air.

Colluvial deposits and alluvial fan deposits

Colluvial deposits: unstratified or poorly stratified, unconsolidated to poorly consolidated deposits composed of fresh and weathered rock fragments, soil, sediment, or irregular mixtures of these materials, that accumulate near the foot of a slope or cliff by slow downslope movement of 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 fill and flatten canyon, ravine, and valley bottoms. Colluvial deposits are probably forming on almost every slope in the Bay region--however, 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 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.

Qal — Alluvial deposits

Irregularly stratified, poorly consolidated deposits of mud, silt, sand, and gravel deposited in stream and river beds and on adjoining flood plains. Alluvial deposits less than about 200 feet in width, common along smaller streams, have not generally been mapped; where colluvial deposits are adjacent to such narrow strips, the alluvial deposits have been included within them.

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 stream beds or valley floors. These elevated terrace deposits are generally not sites of current sedimentation, but represent older levels of stream deposition and erosion that have subsequently been abandoned as the stream continued to erode downward. Some areas mapped as alluvial terrace deposits may consist only of flat stream-cut surfaces eroded into bedrock without alluvial deposits upon them; these cannot be easily distinguished from true terrace deposits by photointerpretation.

Windblown sand deposits

Irregularly stratified deposits of loose, generally fine-grained sand, locally consolidated or cemented, and typically deposited as dunes of various shapes. Common along ocean coasts, but also present elsewhere. Active sedimentation is not currently taking place on the sand deposits shown on this map.

Bedrock and associated soil (queried where identification uncertain)

Igneous, metamorphic, and sedimentary rocks of various ages, 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 soils or other colluvial material. The bedrock is commonly weathered to a considerable depth, so that there is a gradual change downward from soils to fresh bedrock. Because of this, many of the small landslide deposits and some of the large landslide deposits that are shown on the map to be within bedrock areas probably involve only soils, weathered bedrock fragments, and other colluvial material.

CHARACTERISTICS OF SURFICIAL DEPOSITS RELEVANT TO LAND-USE PLANNING

General background:
The physical properties and engineering characteristics of the mapped surficial deposits can be inferred from geologic knowledge of the processes responsible for their formation. Thus, at least preliminary judgments regarding the significance of the materials and processes for land-use decisions can be made from the distribution of surficial deposits shown on this map.

Landslide deposits:
Landsliding takes place when the downward pull of gravity on earth materials overcomes the frictional resistance of the materials to downslope movement. Some of the important factors that affect slope stability are: (1) type of the earth materials--unconsolidated, soft sediments or surficial deposits will move downslope easier than consolidated, hard bedrock; (2) structural properties of the 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--landsliding will generally take place more easily on steeper slopes; (4) water--landsliding will generally occur more frequently in areas of seasonally intense rainfall, because the addition of water to earth materials will usually decrease their resistance to sliding by (a) decreasing the internal friction between particles, (b) decreasing the cohesive forces that bind clay minerals together, (c) lubricating surfaces along which slippage may occur, (d) adding weight to surficial deposits and bedrock, (e) reacting with some clay minerals, causing volume changes in the material, and (f) mixing 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 more unstable; (6) type of vegetation--trees with deep penetrating roots tend to hold bedrock and surficial deposits together, thus increasing ground stability; (7) proximity to areas undergoing active erosion, i.e., rapid undercutting and downcutting along stream courses and shorelines causes slopes in these areas to be particularly susceptible to landslide activity.

All of the natural factors that promote landslide activity are present in the Bay region. In addition to these factors, man's activities have had varying effects upon the potential for slope failures, often decreasing it by the leveling of slopes, building of retaining walls at the base of slopes, planting of trees or seeding of forests, as well as through soil conservation practices. However, other activities of man may increase the potential for slope failures, including the increasing of slope angles for road or building construction; adding water to marginally stable slopes by watering of lawns, improper handling of rain-water runoff and use of septic tank drainfields; adding to the weight of marginally stable slopes by building structures as well as adding fill for foundations; and removing natural vegetation. Thus, slope failure, a natural phenomenon that has occurred many times in the past throughout most parts of the Bay region, may be encouraged and promoted through improper use of the land.

The landslide deposits shown on the map may or may not be continuously or intermittently moving at the present time. Moreover, the potential for continued movement varies greatly, depending upon many factors, including the age of the deposit and its previous history of activity. Some deposits may pose no problems for many types of development, while development on others may pose severe problems. However, most landslide activity takes place within areas that have a previous history of landsliding, and old landslide deposits are commonly reactivated either by natural or artificial means. The materials comprising landslide deposits may be so broken up and disturbed that renewed landslide activity will easily form within the older deposits, 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 for building upon. 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 are generally relatively flat, 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 the deposits may be excellent shallow sources of water and 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; in fact, the active stream channel may alter its course gradually over a long period of time or rapidly during flooding. This migration of the stream channel can result in erosion, undercutting, and failure of the stream banks by slumping and falling off of bank edges 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 are generally easily eroded and easily excavated; they will probably compact under loading, and may continue to move slowly downslope, particularly in the steeper parts of the deposits. They may be water-bearing, with small springs associated with some deposits. Grading activities, particularly those resulting in steeper slopes, may accelerate the rate of downslope movement, producing 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 former are extensive areally, 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 yield streambank failure, and some compaction or local subsidence of the fan surface may take place.

Windblown sand deposits:
These deposits are typically quite porous and permeable, very susceptible to erosion, easy to excavate, and they may be water bearing. However, where consolidated or well cemented, they may be difficult to excavate and be resistant to erosion. Ancient sand deposits are stable and may have fertile soils developed on them; those undergoing active deposition, however, may consist of rapidly migrating and shifting sand dunes forming unstable slopes.

PROPER USE OF THIS MAP

Planning departments and developers:
The density of landslide deposits is a crude measure of the importance of slope failure as an erosional process, and is therefore a crude measure of the overall slope stability of a particular area. However, quantitative determinations of the probability of future landsliding based on information available from this map are not possible, primarily because geologic and climatic changes have occurred during the past few hundred thousand years that have altered slope stability, and because detailed information regarding the composition and style of movement of individual landslide deposits is not available from the map. Therefore, this map must not be used as a substitute for detailed site investigations by engineering geologists and soils engineers; the areas of relatively high susceptibility to landslide activity, in fact, are those areas that should be very carefully studied prior to any development.

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

Home-buyers:
Areas of the map with relatively low densities of landslide deposits probably have good slope stability compared to areas with high densities of landslide deposits. However, it must be remembered that landslide deposits less than 200 feet in longest dimension have not been mapped, and that the scale of this map is such that individual buildings cannot be precisely located on the map. In fact, areas shown on the map as landslide deposits are not necessarily less stable than adjacent areas not mapped as landslide deposits. The map, therefore, should not be used as a substitute for a report by a competent soils engineer, because detailed site investigations are necessary for judgments about the slope stability of individual areas. In addition to landslide deposits, other surficial deposits may pose problems to building and should be carefully investigated.

FACTORS AFFECTING MAP ACCURACY

Date of Photography: Modifications of the landscape that have occurred since the time the aerial photographs were taken in 1949 have not been incorporated into this map. Thus, landslide deposits and large artificial fill deposits that have been formed since 1949 are not delineated on the map, although the topographic base maps were photorevised in 1968 and do show the extent of urbanization to that date.

Scale of maps and photography: Landslide and other surficial deposits less than approximately 200 feet in longest dimension are not shown on this map because they are too small to be clearly identified on the photographs used 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 cemeteries, in populated and farming areas, or near quarries and mines, even though some are greater 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, the presence of haze or cloud cover, or poor sun angles, will make photointerpretation more 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: The recognition of surficial deposits in forested areas may be difficult, resulting in decreased map accuracy in these areas as opposed to grass-covered areas. Many landslide deposits, in fact, may be impossible to recognize on slopes covered with dense stands of tall trees. About fifteen percent of the area is covered by such dense tree cover.

Urbanization: Surficial geologic features can be obscured in urbanized areas by (1) modification of the natural landscape by grading (leveling, cutting, filling, terracing, etc.), and (2) covering the natural land surface with man-made structures. Less than 10 percent of the area has been extensively urbanized.

Problems of interpretation: Mapping of surficial deposits by photointerpretation alone presents a number of difficult problems, some of which can only be resolved through field checking. Situations and problems that are especially difficult and which affect the accuracy of the map include: (1) the distinction of terrace-shaped slump-type landslide deposits from alluvial terrace deposits where both are located adjacent to stream courses; (2) the recognition of bedrock cropping out beneath surficial deposits, especially where a creek or stream has cut down through the overlying surficial deposit to expose bedrock along the streambed; (3) the location of 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) the recognition of landslide deposit boundaries--whereas the upslope boundary is commonly defined by an easily recognized scarp, the toe or downslope boundary is often not well-defined and difficult to locate exactly; (5) the recognition of stable masses of bedrock within landslide deposits, especially where the bedrock may appear to be just a large block within the surrounding landslide deposit; and (6) the distinction between irregular or hummocky topography caused by variations in the erosional resistance of bedrock and that produced by the erosion of landslide deposits.

SOURCE MATERIALS

Vertical aerial photographs taken for the U.S. Geological Survey in November 1949, scale 1:23,600, were principally used in the preparation of this map. All of these photographs are from the series GS-JL, with the following photograph numbers covering the map area: 1-1 to 1-56, 1-66 to 1-77, 1-103 to 1-115, 1-123 to 1-130, 2-107 to 2-115, 2-122 to 2-130, and 3-58 to 3-67. In addition, vertical aerial photographs taken in April 1970, scale 1:80,000, were used as a supplement to the larger-scale photographs; these photographs are from the series GS-VCMI, and include photograph numbers 1-185 to 1-189 and 2-89 to 2-93.

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