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PRELIMINARY REPORT ON LANDSLIDES IN A PART OF THE ORINDA FORMATION, CONTRA COSTA COUNTY, CALIFORNIA

By

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This report is preliminary
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PRELIMINARY REPORT ON LANDSLIDES IN A PART OF THE ORINDA FORMATION, CONTRA COSTA COUNTY, CALIFORNIA

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INTRODUCTION

Purpose of report

This preliminary report presents the results of a study of landsliding in the Orinda Formation. The report is based largely on data collected from 195 landslides within an area of approximately 6 square miles underlain by the Orinda Formation east of San Francisco Bay, in Contra Costa County, Calif. (See fig. 1 for general location of area studied.) Although landslides can be found in almost every geologic formation in the San Francisco Bay region, they are nowhere more abundant for an area of given extent than in the Orinda Formation. The purpose of this study was to obtain an indication of the general factors involved in the landsliding in the Orinda Formation, including the geologic controls involved in the landsliding.

Rapid urbanization of the San Francisco Bay area requires the development of much land formerly used for farms and ranches. Landslides in the hills underlain by the Orinda Formation were no obstacle to rural use of the land, but they may present obstacles to urban utilization. The present study is designed to provide background information to aid in solving engineering problems which may arise in the course of urban development.

The area studied for this report is a small segment of the region underlain by the Orinda Formation, and only part of the slides within the area shown on plate 1 were examined. Only general preliminary indications of the factors involved in landsliding in the Orinda Formation were obtained from this study.

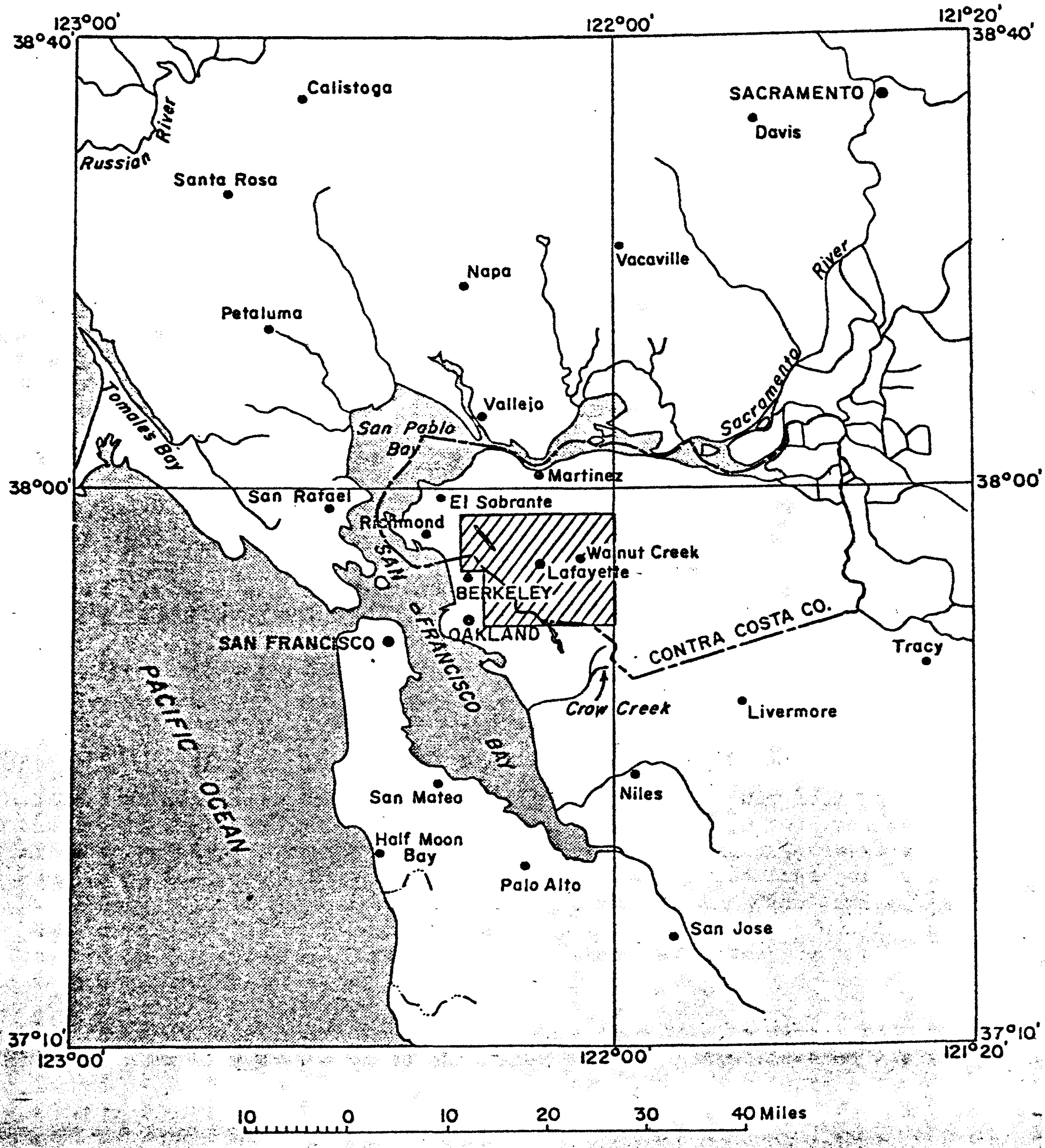


Figure 1.-Index map of part of California showing area covered by Plate 1.

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

Acknowledgments

Personnel of the soils laboratory of Abbot A. Hanks, Inc., ran tests and provided data on plasticity index and maximum density of samples. Logs of borings and much general information were supplied by Woodward, Clyde, Sherard, and Associates; many of their clients, too numerous to mention, gave permission to use data obtained in investigations on their property. Triaxial tests were run by T. C. Nichols and R. A. Speirer, of the U.S. Geological Survey. Many individuals in the Contra Costa County Department of Public Works provided data on landslides in the county. Donald L. Rheem, Utah Construction Company, and the East Bay Municipal Utilities District gave permission for entrance on their lands in the area of study, and many local residents gave information and permission to examine landslides on their property. The courtesy and assistance of all these firms, agencies, and individuals are gratefully acknowledged.

Method of collecting and compiling data

Landslides were examined within the area shown on plate 1. No augering or other subsurface exploration was undertaken. An attempt was made to include all types of landslides and landslides formed in various settings, such as slides on both natural and artificial slopes; in both built-up and undisturbed areas; in both natural material and fill; in bedrock and surface soil; on steep and gentle slopes; with various exposures and a variety of vegetative cover. Slide-free slopes were also studied to obtain an indication of geologic conditions in non-slide areas.

Landslides listed in table 1 (in back) and most of those shown on plate 1 were examined in the field during May and June of 1961, or January through April 1962; a few were examined in October 1962 to January 1963. Some of these may since have been enlarged by further movement or removed or otherwise modified by construction activities. Many landslides recorded by the Contra Costa County Department of Public Works were visited. However, many of those which took place during the heavy rains of 1958 had been repaired when the present study was made, and the evidence for sliding obliterated; such landslides are not included in this report.

All available data were tabulated on a form (see appendix) for each landslide as it was studied in the field, and the slide location was plotted on 1:12,000-scale aerial photographs. These data were entered on table 1.

The length and width of the landslides were estimated in the field where possible, generally by pacing, but some were estimated from the aerial photographs. Where possible, the length was measured from crown to foot of landslide (fig. 2) excluding any debris that may have flowed over the foot, as this length was thought to be a truer dimension of the landslide than the debris length. If debris length was measured, it is designated in the table by a "d" following the length figure. No attempt was made to determine specific areas that might become unstable in the future.

Presentation of data

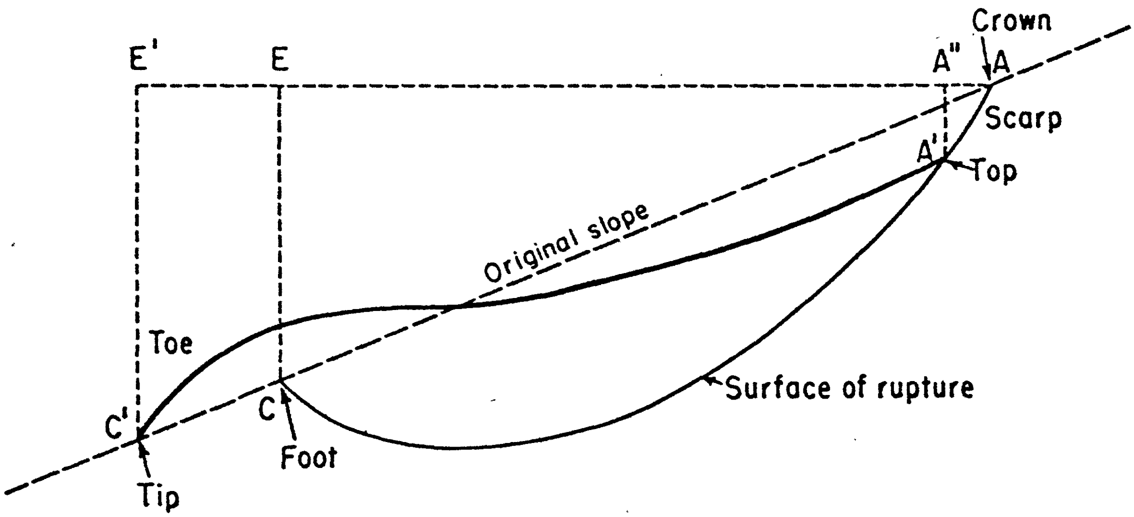
The location of 229 landslides in the area studied were plotted on a 1:24,000-scale topographic map consisting of parts of the Richmond, Oakland East, Las Trampas Ridge, Briones Valley, and Walnut Creek 7½-minute quadrangles. Landslides examined in the field are shown by solid dots and are numbered on the map and in the table; landslides seen only from a distance or on aerial photographs are shown on the map by unnumbered circles, and are not listed in the table. Multiple slides (see p. 13 for definition) are shown by one dot (or circle). For reference purposes a grid was drawn on the map; individual landslides within a given grid square are numbered consecutively.

Every landslide shown on the accompanying map was well defined and easily observable at the time of the study; however, not every landslide in the area is shown on the map. Therefore, although a landslide exists (unless it has since been removed by construction activity) at every point where one is shown on the map, it does not follow that there are no landslides elsewhere on the map.

Each landslide numbered on the map is shown by its identifying grid number in table 1. Blanks in the table indicate incomplete data.

Form of landslide refers to the physical shape and complexity of the landslide (single, multiple, or coalescent, p. 13). (See figure 4.) A multiple landslide is assigned a single number and the individual parts making up the larger multiple landslide use the same number and a letter. The relative ages of the parts were determined if possible, and the oldest one designated "a", the next younger one "b", and so on, but the letters should not be regarded as absolute indicators of the ages of individual parts making up a multiple landslide. Type of landslide on table 1 refers to the type of landslide described on plate 1 of an article by Varnes (1958) in Highway Research Board Special Report 29.

Type of material refers to the material in the landslide, which was generally determined by examination of the scarp. Where only soil could be seen in the scarp, the sliding material was listed as soil. However, most large slides probably involved bedrock, although subsequent slumping of the scarp may have obscured the rock.



AE -- length

AC -- slope length

A"E' -- debris length (measured from top to tip)

EC -- height

E'C' -- height if debris length is used

Width is measured at widest part, normal to length, as seen in plan view

Figure 2. Idealized longitudinal cross section showing parts of a landslide.

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Geologic setting indicates the relationship of the slide to the orientation of the bedding and jointing. Attitudes of bedding and (or) jointing recorded at the slide are given in table 1; where no attitude was recorded at the slide, orientation of beds was assumed to be that of the nearest recorded attitude. For a definition of the terms used in this column see page 18 and figure 5. Geologic setting was not given for landslides in fill. Exposure refers to the approximate compass direction the slope is facing.

The vegetation recorded gives only a general idea of the type of vegetation in the immediate vicinity of the landslide. The term "grass" includes many herbaceous plants such as thistles, yarrow, tarweed, aster, and dock. "Brush" consists primarily of coyote brush and poison oak; trees are mainly live oak, laurel, and buckeye.

The "damage" column is left blank if the landslide was in an open field and caused no damage to man-made structures.

GEOGRAPHY

Topography

Long steep-sided northwest-trending ridges and valleys are the most prominent features of the topography of the area underlain by the Orinda Formation. Perennial and intermittment streams flow generally parallel to the ridges but in places have cut ravines across the ridges to form a trellis drainage pattern typical of folded rocks. The hillsides are furrowed by numerous gullies, and are characteristically pock-marked with the scars of landslides. The heads of the gullies commonly are cirque-like basins, which are formed by continuous creep and sliding of the soil and rock. Many of the hillsides have a "ribbed" appearance, where prominent beds of resistant sandstone alternating with shale extend in parallel bands across the hillside.

The highest point in the map area underlain by the Orinda Formation is a peak southeast of Saint Mary's College (pl. 1), with an elevation of 1,296 feet. Local relief is greatest west of San Pablo Reservoir, where the highest point on San Pablo Ridge is about 900 feet above the reservoir.

Climate and vegetation

The climate, although relatively mild, is characterized by high temperatures and little or no rainfall during the summer months, and by moderately cool temperatures and rainfall during the winter months. Mean annual precipitation at Saint Mary's College, for a period of record 1943 through 1952, was 26.86 inches (U.S. Weather Bureau, 1931-52), with

84 percent falling from November through March, and a maximum annual total of 41.82 recorded in 1950. During the same period temperatures above 100° were recorded at Saint Mary's College during June through September, the highest being 107° in September; temperatures below freezing were recorded during October through May, the lowest being 19° in December and January.

Native vegetation consists primarily of live oak, buckeye, laurel, coyote brush, and poison oak in ravines and on many northerly facing slopes, and grasses, various herbaceous plants, sparse poison oak and coyote brush in most other areas. Plants characteristic of disturbed ground, such as thistles, are numerous on many landslides, cuts, and fills.

Culture

The Rancho Acalanes and Laguna de Los Palos Colorados land grants included much of the area shown on plate 1. Rancho Acalanes was granted to Candelario Valencia in 1834 (Bowen, 1951, p. 348); the town of Moraga preserves the name of Joaquin Moraga who in 1835 was co-grantee of the Laguna de Los Palos Colorados grant (Gudde, 1960, p. 200). Until recently the area was occupied primarily by small communities and ranches; since World War II it has been increasingly utilized for suburban housing, and is now populated by many people who work in San Francisco, Oakland, and other cities to the west. Large ranches have been sold to be used for suburban development. A freeway (California State Highway 24) now extends northeastward through the town of Orinda, and intensive development of transportation, commercial, and housing facilities is planned for most of the area.

GEOLOGY OF THE ORINDA FORMATION

Definition and boundaries

The Orinda Formation was described by Lawson (1914) as fresh-water conglomerate, sandstone, clay shale, and limestone, with some thin seams of lignite and some thin layers of tuff, of Pliocene age. It was shown on the maps of the San Francisco folio (Lawson, 1914) as a broad band extending from the upper part of Crow Creek northwestward to El Sobrante. An arm of the formation extends into the Berkeley Hills, southwest of the Moraga Formation, from near Valle Vista to Strawberry Creek above the University of California. The formation is shown by Hall (1958) to extend southeastward to the Livermore Valley.

In 1951 Savage, Ogle, and Creely, in a published abstract of a paper presented at a meeting of the Geological Society of America, Cordilleran Section, in Los Angeles, proposed that upper Tertiary nonmarine and volcanic rocks of west-central Contra Costa County be defined as a group which would include, in ascending order, the Orinda Formation of Miocene to very early Pliocene age, the Moraga and Siesta Formations of early Pliocene age, the Bald Peak Formation of early to middle(?) Pliocene age, and a new unnamed formation of middle Pliocene age. The ages were based on vertebrate fossil evidence. They restricted the name Orinda to the rocks which lie in the Berkeley Hills proper; the unnamed formation included rocks similar in lithology but younger in age, which lie northeast of the Moraga Formation, and which were included in the unrestricted Orinda by Lawson. The proposed new terminology would eliminate having deposits both older and younger than the Moraga, Siesta, and Bald Peak Formations designated as the Orinda Formation. However, as was pointed out by Ham (1952, p. 15), differentiation of the Orinda Formation and the Mulholland Formation (the new formation of Savage, Ogle, and Creeley, 1951) is difficult in places where rocks of the Mulholland Formation directly overlie those of the Orinda Formation. Ham (1952) described the Orinda and Mulholland rocks separately, but did not differentiate them on his map.

Part of the main band of the Orinda Formation as mapped by Lawson (1914) is shown on the accompanying map, excluding the arm of the formation that extends up into the Berkeley Hills proper, but including the unnamed formation proposed by Savage, Ogle, and Creely (1951). Recent mapping in the area indicates that some changes should be made in the boundaries and structure shown by Lawson, but because the work is incomplete, the boundaries were not revised for this report.

Lithology

The Orinda Formation consists of discontinuous, lenticular beds of fresh-water conglomerate, sandstone, and shale, with minor amounts of limestone, lignite, and tuff. Many of the beds are gradational normal to the bedding, and those which change rather sharply, such as shale to conglomerate, commonly have irregular bedding surfaces between them.

The proportions of conglomerate, sandstone, and shale vary from place to place. Some exposures several hundred feet long are almost entirely hard, firm sandstone and conglomerate, others are almost entirely shale, but commonly the formation consists of interbedded conglomerate, sandstone, and shale; the beds range in thickness from less than an inch to 80 feet. Most of the rocks, including the sandstone and conglomerate, contain some clay. Many thick beds of shale consist of fine crossbedded laminae, some less than a hundredth of an inch in thickness, which vary from slightly silty clay to slightly clayey fine sandstone.

The following small partial section containing rocks typical of the Orinda Formation was measured along a cut southeast of the Rheem Shopping Center, where the beds strike N. 62° W. and dip 50° SW. (Section measured to the nearest 0.5 foot.)

	Feet
Conglomerate at top	
Yellowish-gray water-laid crystal tuff, partly altered to clay; contains numerous euhedral feldspar crystals	9.0
Dark greenish-gray silty clay shale and clayey fine-grained sandstone	22.5
Conglomerate with lenses of coarse, pebbly sandstone a few inches to 2 ft. thick; conglomerate contains pebbles of sandstone, limestone, quartz, chert, rhyolite, diabase, glaucophane schist and other metamorphic rocks; pebbles as much as 4 in. in diameter, average about 1 in., in a clayey sandstone matrix	22.0
Medium greenish-gray soft clayey fine- to medium-grained sandstone	4.0
Light-gray hard dense limestone with sand grains and shell fragments	0.5
Medium greenish-gray sandy silty clay shale	4.0
Conglomerate with sandstone lenses a few inches thick; similar to conglomerate described above	67.0
Medium dark-gray, dark greenish-gray, and reddish-brown silty clay shale; breaks into fragments less than 1 in. in diameter	25.5
Light olive-gray clayey soft fine-grained sandstone, with some lenticular beds of medium- to fine-grained clayey sandstone, silty clay shale, and conglomerate a few inches thick	12.0
Conglomerate with some sandstone lenses a few inches thick; similar to conglomerate described above; cut by small fault, strikes N. 35° to 44° E., dips about vertical; displacement on fault could not be determined; fault contains very wet clay gouge approximately 1 in. thick; at base, conglomerate fills shallow channels cut in underlying sandstone	36.0

	Feet
Light olive-gray clayey soft fine- to medium-grained sandstone, with some lenticular beds and pockets of medium- to coarse-grained clayey sandstone, silty clay shale, and conglomerate a few inches thick; sandstone is jointed in three directions: N. 18° E., dips 24° SE.; N. 70° W., dips 23° NE.; and N. 18° E., dips 37° NW.; joints are spaced ½ in. to 2 in. apart; sandstone breaks into fragments generally ½ in. to 1 in. in diameter; within a few inches of the surface the fragments spall and weather concentrically	21.5
Conglomerate at base.	
Total	224.0

Results of a size analysis of sandy, silty shale from a cut between Saint Mary's College and Burton School is shown on the accompanying graph (fig. 3). An X-ray diffraction test of the shale showed that approximately 10 percent of the sample is montmorillonite clay.

Kachadoorian (1956) reports that microscopic analysis of a clay from the Orinda Formation near Orinda, stained by malachite green and safranine-Y, indicates that it contains 25 to 90 percent montmorillonite, and averages from 45 to 50 percent. Montmorillonite clay expands when saturated; free-swelling tests by Kachadoorian (1956) show that montmorillonite clays taken from the Orinda Formation near Orinda expand from 20 to 100 percent when saturated. Locally beds of clay shale show numerous minute slickensides which may be caused by swelling of the clay during wet seasons.

Although the rocks of the Orinda Formation are the bedrock of the area, they generally can be moved with standard earth-moving equipment without blasting. They may be considered soil or earth in the sense used by engineers and builders, but they are considered rock by geologists.

The bedrock is commonly weathered to a depth of several inches to several feet. Weathered sandstone and conglomerate are soft and friable; the weathered shale generally consists of sandy silty clay with no visible bedding or joint structure. The plasticity index for a sample of weathered clay shale from a cut between Saint Mary's College and Burton School was measured to be 22.

The soil developed on the bedrock generally consists of dark-colored sandy, silty clay with organic material, most of which is classified by the Department of Agriculture as adobe clay (Carpenter and Cosby, 1939). In general it is sandier and lighter in color where it is derived from sandstone, and in places it contains pebbles from the conglomerate. The plasticity index for one sample of soil from a cut between Saint Mary's College and Burton School was measured to be 31. Thickness of

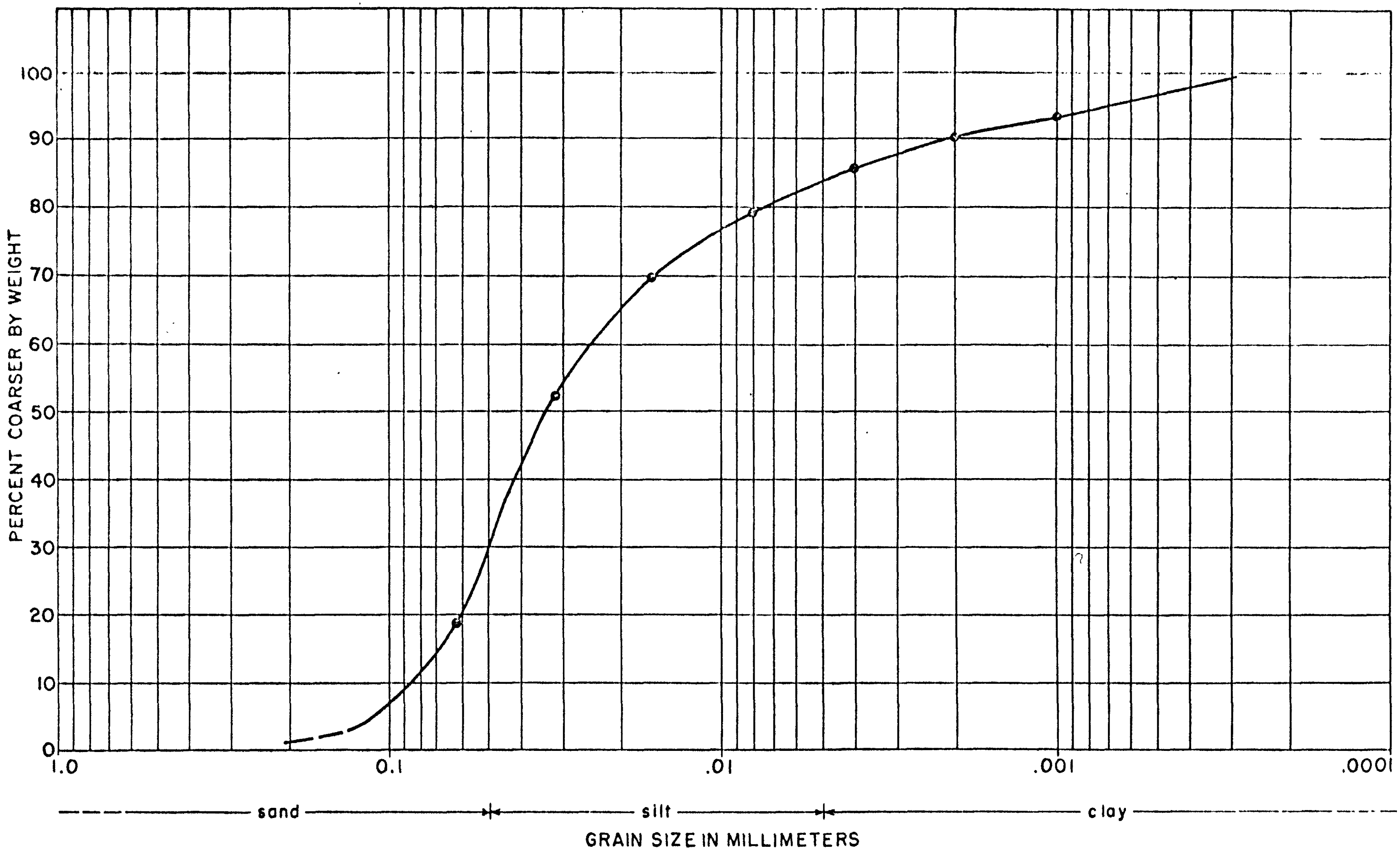

Figure 3. Size analysis graph of a sandy silty shale from the Orinda Formation. Grain-size divisions are according to the Am. Soc. Testing Materials, Mechanical analysis of soils, D422-39, 1939.

This illustration is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards

the soil depends largely on the type of underlying rocks and the topography and drainage. Soil may be lacking on hard sandstone layers, which rise as bare ridges from the hillsides. In general, thicker soils form on shales than on coarse-grained rocks, and the thickest soils, 10 feet or more in thickness, are in ravines and small gullies, where they consist of both residual and transported material. There does not seem to be any appreciable difference in thickness between soils on north-facing slopes and those on south-facing slopes.

Structure and age

The area studied lies in the Coast Ranges of California, which have a conspicuous northwest-trending structure. The rocks of the Orinda Formation have been compressed into northwest-trending folds, some of which are shown on the accompanying map (pl. 1). Detailed geologic mapping in this area has not yet been completed, and therefore only incomplete structural data can be shown on the map.

The northwest-trending folds are cut by numerous faults with differing orientations. In addition to those shown on the map, several bedding faults and numerous small cross faults, with displacements of a few inches to a few feet, were observed in fresh cuts; several faults that cut diagonally across the dipping beds were exposed during excavation for the Briones Dam, which will be on Bear Creek northwest of Sleepy Hollow School (pl. 1).

Faults in the Orinda Formation cannot be mapped easily except in fresh cuts. Unless the rocks are freshly exposed, it is not generally possible to tell whether a difference in lithology and attitude of beds from one place to another is due to the lenticular nature of the beds or to minor faulting.

Most of the rocks are jointed, the joints ranging from fractures a quarter of an inch wide spaced a foot or more apart, to hairline cracks a fraction of an inch apart. Many joint surfaces are stained with yellowish-brown iron oxide. The relationships of jointing to bedding are discussed in detail on pages 18-20.

A few fresh-water mollusks which were found in the course of the present study were not diagnostic, so that no new information on the geologic age of the formation was obtained. The age is generally accepted as Miocene and Pliocene, on the basis of work by Lawson (1914) and Savage, Ogle, and Creely (1951).

LANDSLIDES

Description

Landslides described in this report are classified in part by a system proposed by Varnes (1958). He classified landslides according to type of movement--falls, slides (slump and block glide, etc.), flows, or complex--and type of material. Landslides are further classified in this report as single, multiple, or coalescent, according to their physical shape and complexity. (See fig. 4.) Single landslides are isolated and well defined, generally with one pronounced scarp. Multiple landslides consist of two or more well-defined landslides in the same slide area, generally overlapping, which have formed at different times. Coalescent landslides consist of many overlapping and merging landslides; both the scarps and the debris have coalesced. Most coalescent landslides are amoeboid in shape, and the individual landslides making up the larger one are poorly defined. Generally only one or two distinct scarps can be seen within the entire coalescent landslide.

Most landslides in the Orinda Formation closely resemble the one illustrated in plate 1-h of Varnes (1958) which is a slump in the upper part and an earthflow in the lower part, in soil. Many slump and earthflow landslides in the Orinda Formation involve bedrock, which in general is loosely consolidated and in physical characteristics resembles a soil, in the sense used by engineers, rather than a hard, dense rock such as granite. Although slumping is definitely involved in the movement, slump blocks may not be well defined, and the extent and nature of the internal slip surfaces cannot be determined easily. Many other landslides are slow earthflows, illustrated in plate 1-p of Varnes (1958); some of these also involve loosely consolidated bedrock. Some landslides involving only soil are rapid earthflows or mudflows. Only two rockfalls were examined.

Coalescent slides are typical of the Orinda Formation. Although they may be on relatively smooth hillsides, coalescent landslides are characteristic of the many basin-shaped ravines. In such ravines, many landslides, generally involving largely soil but in some places bedrock as well, have formed at the head and along the sides of the ravine, and both the scarps and the debris have coalesced. The ravines are enlarged by continuous creeping and sliding of their sides, so that the larger ravines eventually have a rounded, cirque-like basin at the top, and a rather wide, hummocky floor of slide debris which continues to creep slowly downslope. The term "coalescent" is also used to describe a group of merging slides in cuts or fills.

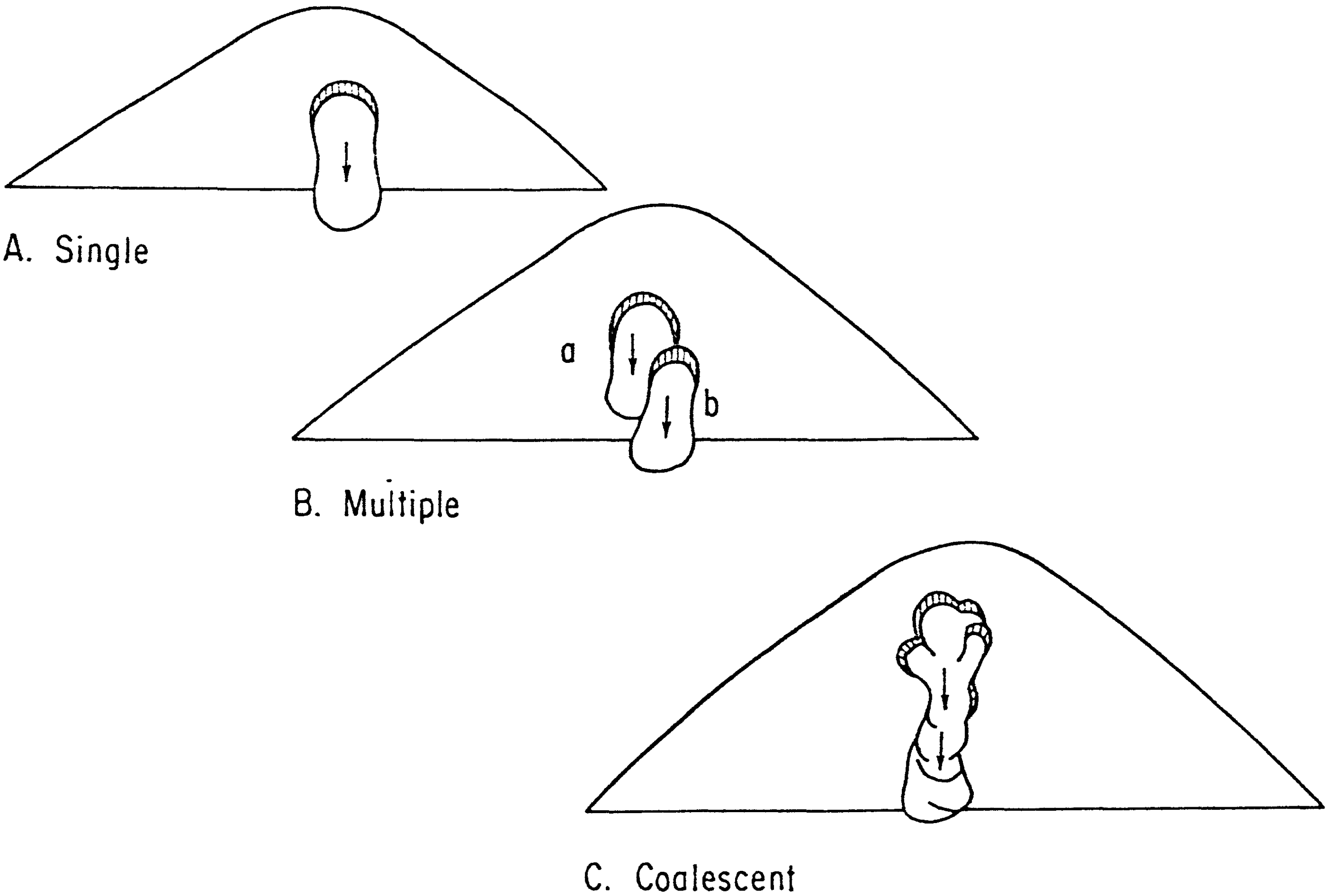

Figure 4. Generalized sketches showing classification of landslides according to physical shape and complexity. *A*, single landslide; *B*, multiple landslide (slide a older than slide b); *C*, coalescent landslide.

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Some landslides in the Orinda Formation develop in one short period of time, come to rest, and do not move again, but historical records and personal observation show that many of them move in small increments over many years. Large movements of a slide may take place during an unusually wet winter season, or if the equilibrium of a slope is disturbed relatively rapidly by erosion (such as a stream cutting the toe) or by man.

Many soil slides move on the upper, weathered surface of clayey bedrock. Most of the landslides involving bedrock have a surface of rupture in shale. Less commonly, the slippage surface is in soft slightly clayey sandstone or conglomerate. Many landslides start in clay shale, and move out over sandstone and conglomerate layers; if a landslide continues to enlarge from year to year, sandstone and conglomerate both above and below the original landslide may move.

The depth of most of the landslides examined could not be estimated from surface observations. The few whose rupture surfaces were completely exposed were 10 feet or less in depth. Most of the landslides show evidence of both slump and earthflow movement, and the methods described by Philbrick and Cleaves (1958) for estimating the depth of slump slides cannot be accurately applied to them. Their depth can be established only by subsurface or geophysical exploration. Engineering firms who have investigated landslides in the Orinda Formation report that those investigated range from 10 feet to more than 100 feet in depth (Soil Mechanics and Foundation Engineers, Inc., 1960).

Causes of landsliding

The cause of a landslide is generally an increase in weight and (or) a decrease in shearing strength (Krynine and Judd, 1957, p. 641). The causes of landslides can also be described as external, which produce an increase of shearing stresses at unaltered shearing resistance of the material adjoining the slope, and internal, which reduce the shearing resistance of the slope material at unaltered shearing stresses (Terzaghi, 1950). Events or conditions that promote the cause of a landslide are defined by Krynine and Judd as contributing factors. Water is a major contributing factor for most landslides, because it both increases weight and decreases shearing resistance. Climate, topography, geology, vegetation, and activities of man and animals are also contributing factors. Most of these factors are interrelated, and it is difficult to evaluate their individual contributions to landsliding. In general a particular combination of factors rather than one specific factor contributes to landsliding.

Climate and geology are probably the basic contributing factors. The climate determines the amount and distribution of precipitation, which is generally the ultimate source of both surface and ground water, and the geology and climate together influence topography, vegetation, and the density of human and animal population. The topography in turn may determine the microclimates of small areas. The composition and structure of the rocks are major factors contributing to landsliding. For example, soft, well-bedded alternating sands and clays that have been fractured and sheared by faulting will easily absorb water, causing reduced shearing resistance, and often slippage along fractures and bedding planes.

Rainfall is the primary source of water contributing to landsliding in the San Francisco Bay region. Landslides are especially numerous during and after winter rains, particularly in years of above-average rainfall. For example, an unusually large number of landslides formed in the spring of 1958, during a season in which the total precipitation recorded at Saint Mary's College was 46.78 inches (U.S. Weather Bureau, 1958). Weather records show that there are striking climatic differences in various parts of the San Francisco Bay region. For example, in the rainfall season of 1957-1958, precipitation at Lafayette was 41.22 inches; Oakland 31.37; Palo Alto 24.41; San Francisco 39.51; San Rafael 62.43; and Walnut Creek 30.20. However, amount of landsliding cannot be directly correlated to amount of rainfall alone; although rainfall was greater at San Rafael than any other place listed above, the amount of sliding in an area of comparable size there was less than in the area studied. Within the area of the Orinda Formation, however, it appears that less sliding has taken place near Lafayette than near Saint Mary's College, where annual rainfall is consistently higher than at Lafayette. It is not possible to tell from the available data whether the difference in amount of sliding is due to small differences in climate, small differences in the lithology of the formation, or a combination of these and other factors.

The annual distribution of rainfall influences the type of slide that forms in the Orinda Formation. Most of the slides that formed in February of 1962, when 11.32 inches of rainfall was recorded at Saint Mary's College during 15 days from February 6 through 20, were of the slump-earthflow type. The rain fell on ground already damp from previous winter rains. The sliding material, consisting of soil, or soil and bedrock, generally moved as a single mass, with some slumping at the top of the slide, and earthflow at the toe. In October 1962, 13.82 inches of rainfall was recorded at Saint Mary's College during 4 days from October 10 through 14, with 8.40 inches recorded during the 24 hours ending at 5:00 p.m. on October 13 (State Climatologist, U.S. Weather Bureau, oral communication January 2, 1963). The rain was the first of the winter rainy season, and fell on ground that had dried during the summer. Most of the landslides that formed during the above 4 days of rain were mudflows, consisting of saturated soil that moved on the underlying bedrock surface. The soil did not move as a single mass, but flowed out of small pockets in a semi-liquid state, leaving a train of debris extending down the hillside for as much as several hundred feet. The debris consisted of thin mud containing pieces of turf and subangular to rounded pieces of soil. These landslides are the type described by Kesseli (1943) as "disintegrating soil slips." Landslide no. I7-23 (table 1) is typical of such a mudflow.

Geologic factors that make it easy for rainwater to enter the ground contribute to landsliding. One of these factors is the montmorillonite clay in the rocks of the Orinda Formation and its overlying soil. During wet seasons the clay absorbs much water, which increases the weight of the rock and soil and decreases its shearing resistance. During dry seasons the clay loses water and shrinks, causing the formation of cracks several inches wide and several feet deep, which provide easy access for rainwater during the next wet season. Other geologic factors affecting the penetration of water into the ground are the stratigraphy of the Orinda Formation, which consists primarily of alternating layers of sandstone or conglomerate and shale; the deformation of the strata into folds, so that they commonly dip steeply; and the numerous joints, faults, and other fractures cutting the rocks.

Rainwater can find easy access to the formation through exposures of the tilted sandstone and conglomerate beds, many of which are relatively soft and porous. The joints allow some passage of water into the shale, as well as into the sandstone and conglomerate. The water can move downward and laterally through the sandstone and conglomerate beds and along the interfaces between the sandstone or conglomerate and the shale, and some is absorbed by the shale. Pore water pressures may build up in sandstone layers which are confined by less pervious shale beds. These pressures contribute to landsliding (Krynine and Judd, 1957, p. 648). Water within the formation decreases its shearing resistance, especially along the joint planes, and to a lesser extent along the bedding planes, which in many places are poorly defined.

Most faults that cut the Orinda Formation contain impervious clay gouge ranging from a fraction of an inch to as much as 18 inches in thickness; in many places the gouge acts as a barrier to ground water. Water moving in sandstone beds dams up against the fault, so that pore water pressure in the sandstone is increased. The increase in pore pressure makes rocks more susceptible to sliding. Faults do not appear to be a major geologic factor contributing to landsliding in the Orinda Formation, although slickensided or clay-coated fault surfaces may infrequently be slide surfaces, as in slide no. G4-2 (table 1).

A geologic factor which is indirectly related to landsliding is the effect of the geology on the topography. It is obvious that landsliding will not take place on a perfectly flat surface. If rocks are uplifted, erosion begins immediately. Where stream erosion takes place rapidly, valley sides will be generally steep. The rocks of the Orinda Formation have been uplifted during geologically recent times, and they are still being actively eroded. Therefore the hill slopes are relatively steep, and if the weight of the rocks and (or) soil underlying these slopes is increased, and (or) their shearing resistance decreased, they will tend to move down the slopes into more stable positions. As rapid erosion continues, the equilibrium of the slopes will be constantly disturbed, and landsliding and other forms of mass movement will continue until all slopes are reduced to a very gentle gradient.

Another geologic factor which influences landsliding is the relationship of the bedding and jointing to the land surface.

The tilted beds of the Orinda Formation strike generally northwest, and most major ridges and valleys are roughly parallel to the strike. Synclinal troughs roughly coincide with the crests of some of the ridges; on each flank of these ridges the beds dip in a direction opposite to the ground slope. On strike ridges with no synclinal troughs at their crests, the beds dip in a direction opposite to the slope on one side, and in the same direction (but not necessarily at the same angle) as the hill slope on the other side of the ridge.

In some places ridges and valleys cross the strike of the dipping beds. In most of these places hillsides cut across the strike of the beds at nearly right angles. Relatively few hillsides cut diagonally across the strike of the beds.

The above general relationships between the attitude of the beds of the Orinda Formation and the slope of the hills can be described in terms of the following six general categories: (1) beds dip in a direction opposite to the slope of the hill; (2) beds dip in the general direction of hill slope but more steeply; (3) beds dip in the general direction of hill slope but less steeply; (4) strike of dipping beds is approximately normal to direction of hill slope; (5) strike of dipping beds intersects hill slope at approximately 45°, beds dip in a direction opposite to the hill slope; and (6) strike of dipping beds intersects hill slope at approximately 45°, beds dip in the general direction of hill slope. In classifications (1) to (3), the strike of the beds is approximately parallel to the slope contours. Some of these relationships are illustrated on figure 5. The above six categories are used in the tables and in the following text to describe the relationship of the bedding to the land surface.

No general categories similar to those listed above can be used to describe the relationship of the jointing to the bedding or the land surface. The general trend of the beds can be traced for hundreds of feet both in the field and on aerial photographs, even though the beds are lenticular, bedding planes are poorly defined in many places, and the beds are offset by minor faults. In most places the attitude of bedding recorded nearest any given slide can be assumed to represent the approximate attitude of bedding at the slide. In contrast, the general trend of a particular joint set cannot be traced as can the bedding. A joint surface recorded at an individual exposure may not

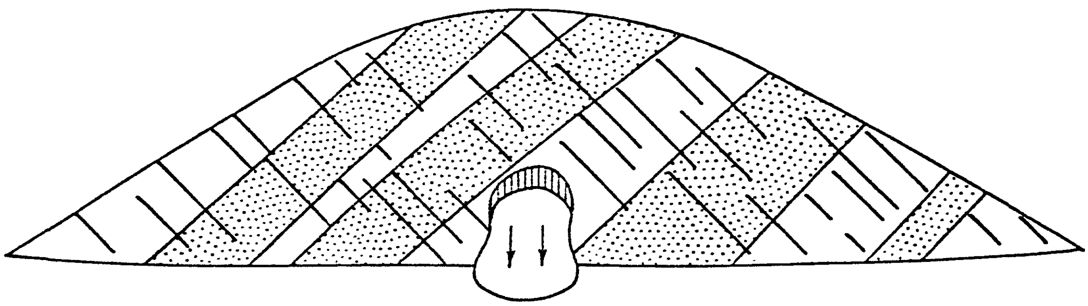

Figure 5. Sketch showing certain idealized relationships of bedding and jointing to land surface. Face of cut perpendicular to northwest-trending ridge looking northwest. In this sketch the cut trends at right angles to the strike of the beds (strike of beds is the direction of a line formed by the intersection of a bedding plane with a horizontal plane). Beds of sandstone (stippled) and shale dip in a direction opposite to the hill slope on the northeast side of the ridge, and in the general direction of the hill slope but more steeply on the southwest side of the ridge. Joints (dashes) dip in a direction opposite to the hill slope on the southwest side of the ridge, and in the general direction of the hill slope but more steeply on the northeast side of the ridge. Landslide in shale moved parallel to the strike of the beds. Slide moved out of face of cut toward observer.

represent the most prominent joint set in the area, and it may not extend for any great distance. Only joint measurements taken at the slide itself are applicable to any individual slide. For this reason no generalizations are made in the text or the table regarding the attitude of joints with respect to the bedding and hill or cut slope; specific attitudes are given in the table where measurements were taken at a particular slide.

Most attitudes of joints were recorded at cut slopes, as joints could in general be more clearly observed in cuts. Only eight sets of data including attitudes of beds, joints, and slopes were obtained for landslides on natural slopes. Seven of these sets included a joint plane having a strike subparallel to the slope contours, and dipping in the same general direction as the slope, but more steeply.

In order to determine whether certain joint sets were more prominent than others in the Orinda Formation, and their relationship to the bedding, 36 sets of data consisting of attitudes of associated joint planes and bedding planes were plotted on a stereographic net (Higgs and Tunell, 1959). Figure 6 is a simplified stereographic diagram showing the poles of the joint and bedding planes. In addition the angles between strike of beds and joints were tabulated, and the downward-opening dihedral angles between joint and bedding planes were determined by use of a stereographic net. These studies show that out of 76 joint planes measured, 30 have strikes intersecting the strike of the bedding at 0° to 30°; 22 intersect the strike of the beds at 31° to 60°; and 24 intersect at 61° to 90°. The downward-opening dihedral angle between joint and bedding planes lies between 80° and 100° for 37 out of 76 angles determined; the largest recorded angle was 125°, and the smallest 28°; 67 are between 50° and 105°.

These data indicate that joints strike in almost any direction in relation to the bedding, with a slight preference for a strike subparallel to the beds, and approximately half form downward-opening dihedral angles with the bedding of between 80° and 100°. These general relationships are also indicated in the stereographic diagram.

Exposure must also be considered in evaluating the effect of the relationship of bedding and jointing to the land surface. Slopes with a general northerly exposure do not dry out as rapidly as those with a southerly exposure, regardless of the orientation of the strata underlying the slope. Rocks and soil on northerly facing slopes therefore quickly become saturated during the rainy season, commonly with resultant landsliding. Because beds dip into the hill slope on many of the northeast-facing slopes in the area studied (pl. 1), it is difficult to determine whether the slope exposure or the geologic setting is the predominant factor influencing sliding in bedrock.

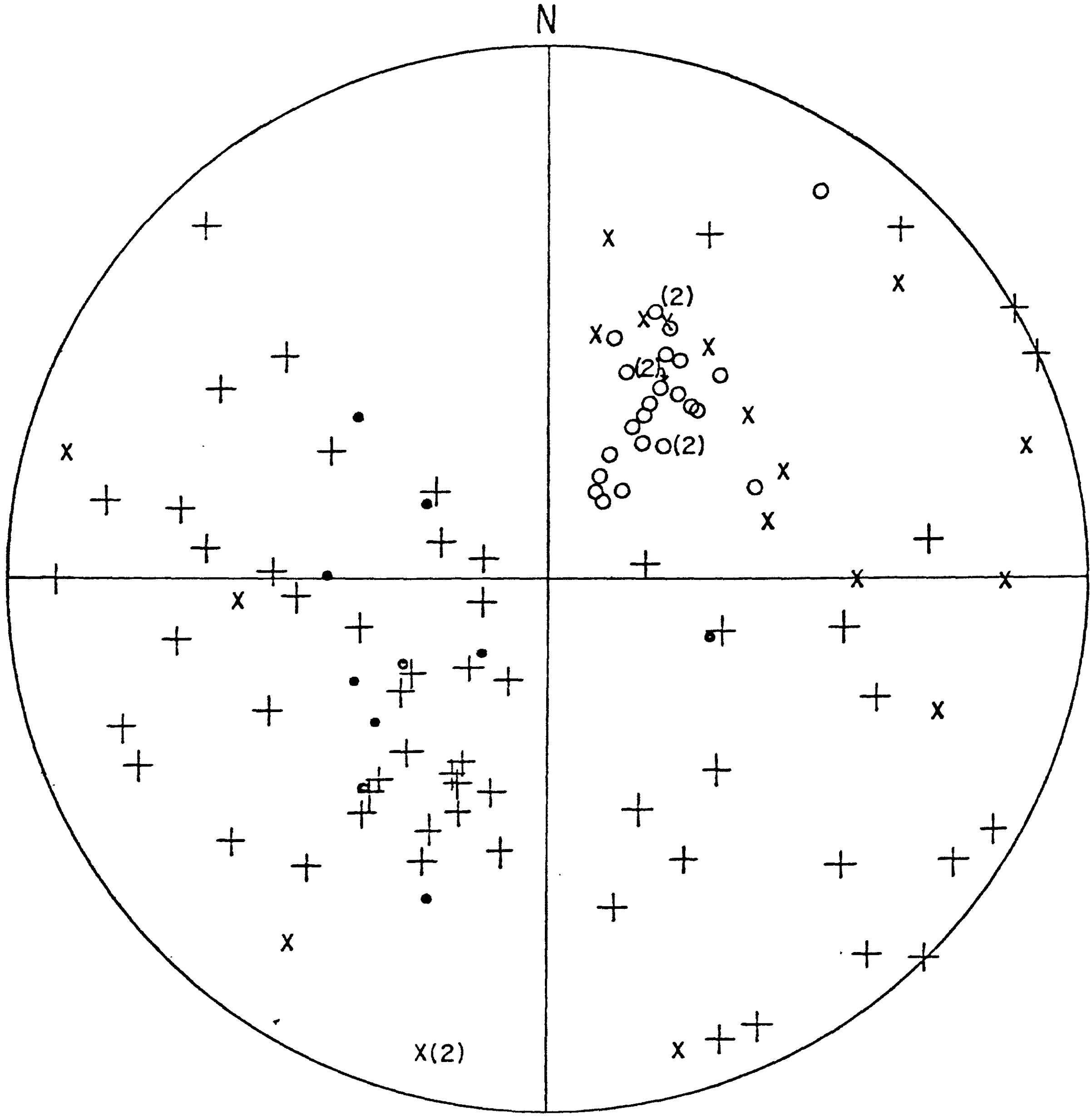

Figure 6. Simplified stereographic diagram showing poles of joint planes and bedding planes. Open circles indicate poles of beds dipping to the southwest; large crosses indicate poles of joint planes measured where beds dip to the southwest. Dots indicate poles of bedding planes dipping in other directions, and small x's indicate poles of associated joint planes.

Geologic setting and exposure of landslides studied for the present report are shown in table 2. Forty-one slides involving bedrock were examined on natural slopes; 31 were on north-, northwest-, or northeast-facing slopes; 26 were on slopes where beds dip in a direction opposite to the slope; 21 were on northeast-facing slopes where beds dip in a direction opposite to the slope.

If exposure is the predominant factor causing landslides in bedrock on natural slopes, as many landslides involving bedrock should form on northeast-facing hillsides where beds are inclined in the same direction as the hill slope, as form on northeast-facing hillsides where the beds are inclined in a direction opposite to the hill slope. If attitude of beds is the predominant factor causing landslides in bedrock, as many slides involving bedrock should form on southwest-facing hillsides where beds dip in a direction opposite to the hill slope as form on northeast-facing hillsides where beds dip in a direction opposite to the hill slope.

Although the area studied has approximately as many southwest-facing as northeast-facing hillsides where beds dip in a direction opposite to the hill slope, only 5 landslides examined involving bedrock were on the southwest-facing slopes, whereas 21 were on the northeast-facing slopes. Beds are inclined in the same direction as the hill slope on very few northeast-facing hillsides, and only two slides examined involving bedrock were in such a geologic setting. Although beds dip in the same direction as the hill slope on the southwest-facing sides of several long ridges in the area studied, relatively few landslides were seen in such a setting, and none examined involving bedrock were in such a geologic setting. Several large landslides which may involve bedrock were seen in the large ravine northeast of slides I7-9 to I7-13 (pl. 1), where the beds dip in the same general direction as the southwest-facing hill slope. These slides, shown as unnumbered circles on the map, were seen from a distance and (or) on aerial photographs and were not examined in detail. However, in some similar places--for example, the southwest-facing slopes northwest of Saint Mary's College--landsliding is conspicuously absent.

The observations indicate that probably a combination of geologic setting and exposure facilitates landsliding rather than either one being predominant. Landslides involving bedrock on natural slopes tend to be least abundant on southwest-facing slopes where the beds are inclined in the same general direction as the hill slope, and most abundant on the northeast-facing slopes where beds are inclined in a direction opposite to the hill slope.

As mentioned on page 18, hill slopes approximately normal to the strike of the bedding, or at 45° to it, are not common in the area studied. However, where hill slopes do cut across the strike--for example, in the places south of Saint Mary's College marked "many landslides" on plate 1--landslides approximately parallel to the strike of the beds are abundant. Five slides examined involving bedrock on natural slopes were

Table 2.—*Distribution of 195 landslides according to geologic setting and exposure*

Geologic setting	Material and type of slope				
	Bedrock (may include some soil and/or fill)		Soil only		Fill (may include some soil but no bedrock)[2]
	Natural	Cut[1]	Natural	Cut[1]	
Dip opposite to slope	26	9	31	9	---
Dip in general direction of slope but more steeply	2	[3]2	13	3	---
Dip in general direction of slope but less steeply	---	---	---	---	---
Strike approximately normal to slope	5	9	15	---	---
Strike approximately 45° to slope, dip opposite to slope	3	4	1	---	---
Strike approximately 45° to slope, dip in general direction of slope	2	8	4	---	---
Geologic setting uncertain	3	6	11	---	---
Totals	41	38	78	12	---
	Exposure				
Northeast	27	9	40	5	18
Northwest	3	3	11	---	1
North	1	2	3	---	1
East	---	7	---	---	2
West	3	3	6	---	1
South	1	5	1	---	---
Southeast	2	4	6	1	1
Southwest	4	5	11	6	2
Totals	41	38	78	12	26

[1]Any part of the slope cut
[2]Geologic setting not determined for landslides in fill
[3]Includes one slide where beds dip at approximately same angle as slope

where the strike of dipping beds is approximately normal to the hill slope; three were on northwest-facing slopes, one on a south-facing slope, and one on the southeast-facing slope. Three were where strike of dipping beds intersects the hill slope at approximately 45°, and beds dip in a direction opposite to the slope; all three were on west-facing slopes. Two were where the strike of dipping beds intersects the hill slope at approximately 45°, and beds dip in the same general direction as the slope; one was on a northeast- and one on a north-facing slope. Geologic setting was uncertain for three landslides involving bedrock, which were on northeast-facing slopes.

Inasmuch as landsliding is more prevalent on slopes where beds dip in a direction opposite to a hill slope, movement on bedding planes is apparently not a major factor in sliding on natural slopes in the Orinda Formation. One reason for the infrequency of bedding-plane slides may be that the dip of the beds in most places in the Orinda Formation is 30° or more, and natural slopes are most commonly 20° to 30°; the beds are therefore generally supported laterally, even in places where they dip in approximately the same direction as the hill slope.

Sliding on joint planes has been observed on natural slopes, however, even where the joint surfaces dip more steeply than the hill slope and are supported down dip. Slides H6-11 and H7-1 (table 1) are examples of such slides. Slippage seems more probable along joint surfaces than along bedding planes, perhaps because joints are cracks, whereas many contacts between beds are not. Inasmuch as joints show a slight preference for a strike subparallel to the strike of the bedding, with a dip generally opposite to the dip of the beds, some joints striking subparallel to the hill slope, and dipping in the same general direction as the slope but more steeply, can be expected where beds dip in a direction opposite to a hill slope. Such joints may be a major factor contributing to landsliding in bedrock on natural slopes.

A possible factor contributing to the scarcity of bedrock landslides where beds are inclined in the same direction as the hill slope is the relationship of the drainage to the tilted beds of the Orinda Formation. When the rocks were uplifted, downcutting began first in the softer shales and siltstones of the formation (fig. 7A) so that in many places valleys formed roughly parallel to the strike of the beds. Downcutting proceeded until a more resistant sandstone or conglomerate layer was reached, when erosion continued down the dip of the sandstone. The side of a ravine where beds dip in a direction opposite to the slope then consists largely of shale, whereas the side of the ravine where beds dip in the same direction as the slope consists largely of the more resistant rocks (fig. 7B). As the ravine enlarges, resistant beds are cut through, and shale beds are exposed on the side of the ravine where the beds dip in the same direction as the slope of the hill (fig. 7C). During this part of the erosion cycle, some landslides may form in the exposed shale beds. As the ravine becomes wider, alternating sandstone and shale beds are

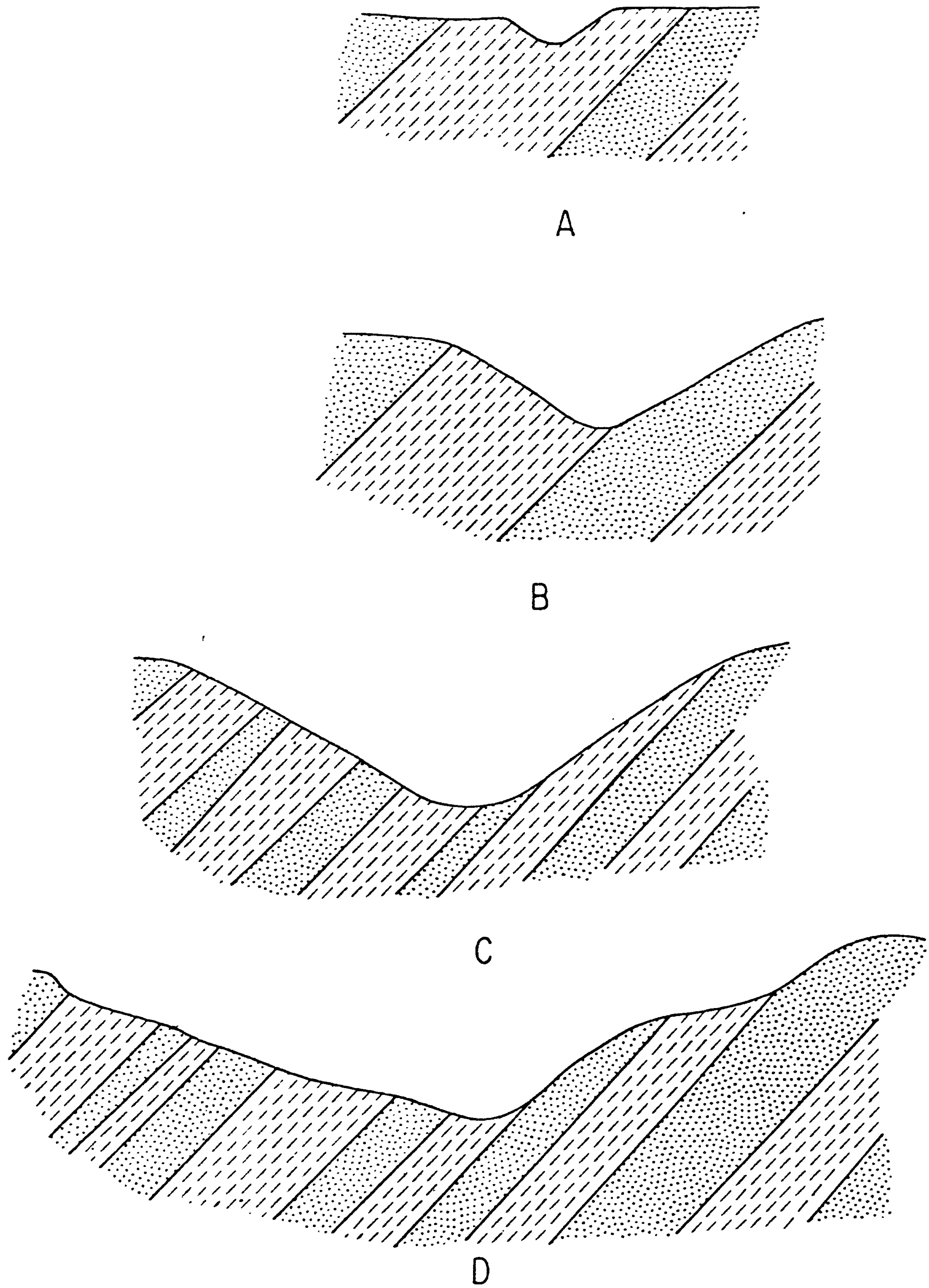

Figure 7. Sketches illustrating four stages in the development of valleys in alternating sandstone (stippled) and shale of the Orinda Formation. *A*, gully in shale; *B*, ravine after erosion down the dip of a resistant sandstone layer; *C*, valley exposing sandstone and shale on both sides; *D*, larger valley exposing sandstone and shale on both sides--sandstone beds dipping in the same direction as the slope on one side of the valley form ridges which act as buttresses to support the shale behind them.

exposed on either side of it. Where the beds dip in the same direction as the slope of the hill, resistant sandstone beds dipping in the same direction as the slope, but more steeply, form ridges which act as buttresses, supporting the shale behind them. However, if the sandstone is soft and clayey, it does not form a buttress but may itself slide. On the side of the valley where the beds dip in a direction opposite to the slope of the hill, the buttressing effect of resistant sandstone is not so pronounced, particularly where shale layers are relatively thick and sandstone layers are thin (fig. 7D). As downcutting by streams continues, the beds on the side of the valley where the beds dip in a direction opposite to the slope are continuously undercut, so that slides continue to form, particularly where the shale layers are thick. If alternating layers of shale and resistant sandstone are thin, slides are less frequent. Slides form throughout this cycle in the sides of tributary ravines, where sliding takes place primarily in shale, approximately parallel to the strike of the beds.

Valleys in each of these stages of development can be seen within the area studied. The first stage of downcutting can be seen at slide I8-10, where a small gully parallel to the strike of the beds is forming in shale. Ravines which have cut roughly down the dip of resistant beds on one side, exposing shale on the other side, are clearly illustrated at the heads of the ravines containing slides I7-5 and J7-6 (pl. 1). The third stage of development is represented by the valley northeast of slide I7-9 (pl. 1). The fourth stage is shown by exposures along Rheem Boulevard, both east and west of Moraga Road, where massive sandstone and conglomerate beds dipping the same general direction as the slope of the hill are exposed in places as bare ridges along the hillside; alternating sandstone or conglomerate and shale beds dip opposite to the slope of the hill on the south side of the road, east of Rheem.

Exposure is a major factor contributing to soil slides. Seventy-eight soil slides on natural slopes were examined. Fifty-four (or 69 percent) were on north, northwest-, or northeast-facing slopes; however, only 34 were on slopes underlain by beds that dip in a direction opposite to the hill slope. A study of slope exposure of landslides in soil by Beaty (1956), in an area overlapping that covered by the present study, showed that 70 percent of the 112 landslides he examined were on north-, northwest-, east-, or northeast-facing slopes. Factors other than exposure were not evaluated in Beaty's study.

Vegetation on the slopes may contribute to landsliding because it slows runoff, allowing more penetration of water. Deep-rooted plants, such as trees and brush, aid in holding the slopes but grass, particularly annual grass with shallow roots, allows penetration of the water without providing much protection against landsliding. The role of vegetation in inhibiting landslides is dramatically shown on the northeast side of the long northwest-trending ridge north of Rheem. Numerous landslides are visible on the southeast end of the ridge, which is covered with grass; only one slide was observed on the northwest end of the ridge, which is covered with brush and trees. A long-time local resident provided the information that the trees and brush on the north end of the ridge have grown up within the last 50 years. None grew on the south end of the ridge because cattle grazed there constantly during the 50-year period. He reported that although some landslides existed on the south part of the hillside 50 years ago, they were not as extensive as they now are. Landslides that formerly existed in the area now covered with brush have apparently been halted and covered by the growing brush and trees, whereas sliding has continued in the grassy area. It is not known why the growth of brush and trees accelerated during the last 50 years.

The activities of man are a major factor contributing to landsliding. Landslides in both cut and fill slopes are due directly to the activities of man, in combination with geologic and climatic factors.

Landslides in cut slopes are due largely to steepening of the slope and removal of lateral support. These factors alone do not necessarily contribute to landsliding, but will do so under certain geologic conditions. The same conditions that facilitate landsliding on natural slopes by allowing penetration of water are also operative on cut slopes. (See p. 17.) The relationship of the bedding and jointing to the cut face also influences sliding in cut slopes.

Many of the landslides that move approximately parallel to the strike of the beds form initially in shale, which slides out leaving the more resistant sandstone or conglomerate layers as ribs. The shale appears to move on both bedding and joint planes. In some cuts sandstone and conglomerate are involved, or move later as the landslide enlarges.

Definite movement on joint planes was noted in two landslides (nos. H6-4 and H7-1, table 1) involving bedrock in cuts, where the beds dip in a direction opposite to the slope of the cut face. In both of these landslides the joints dip in the same direction as the cut face, but more steeply. Movement on joint planes was also observed in two landslides (nos. E5-1 and H7-23, table 1) where the strike of dipping beds intersects the cut face at approximately 45°, and beds dip in a direction opposite to the cut face. Definite evidence of movement on both joint and bedding planes was observed at most of the landslides where the strike of the dipping beds intersects the cut face at approximately 45°, and beds dip in the same general direction as the cut face. In many of these landslides the bedding planes and prominent joint planes intersect each other in such a manner that they form a V, with the trough of the V inclined toward the face of the cut. Landslides G4-2, H6-17, and J7-2 (table 1) are examples of such slides.

Two landslides were examined where beds dip in the same direction as a cut face. At landslide no. G6-1, both natural and cut slopes were involved in sliding; beds dip at approximately the same angle as the natural slope, but there was no definite field evidence to indicate whether any part of the sliding was on bedding planes. Slide no. G6-10, where the beds dip in the same direction as the cut but more steeply, did not move on bedding planes, but across them.

Only one landslide (no. B2-6, on San Pable Dam Road) was examined where beds dip in the general direction of a cut face, but at a lesser inclination than that of the cut, so that the beds "daylighted" in the face of the cut. Here the strike of the dipping beds intersects the cut face at an angle of approximately 45°, and sliding apparently took place on both joint and bedding planes.

Curiously, no landslides were seen in the area of study where the beds dip in the same direction as a cut face, but more gently. One such cut was examined northwest of Glorietta School, northeast of landslide no. F6-8. Here the attitude of the cut was approximately N. 55° W., 30° SW., and the attitude of bedded sandstone and shale in the cut was approximately N. 50° W., 25° SW., so that the beds "daylighted" in the face of the cut. The beds broke in some places along two sets of joints with attitudes of N. 45° W., 85° SW., and N. 35° E., 85° NW., so that some small pieces 1 inch to 8 inches in diameter fell to the base of the cut, but no actual sliding was observed.

Slope exposure does not appear to be a major factor contributing to landsliding in cuts; 21 of the 38 landslides involving bedrock in cuts were on north-, east-, northwest-, or northeast-facing slopes. Most cuts examined were only a few years old; exposure may be a factor in older, more weathered cuts.

Insufficient data are available to determine the most suitable height and angle of slope or benching procedures for cuts under various conditions of geology and exposure.

Many landslides in cut slopes involve very little, if any, of the bedrock. Some cuts are entirely in soil, soil and weathered bedrock, or old slide deposits. Any of these materials may be susceptible to sliding when saturated, particularly if they contain large amounts of clay. In many places where cuts have exposed bedrock overlain by several feet of clayey soil, the soil has slid on the weathered bedrock surface, moving down over the bedrock cut face and onto cleared areas below. In this type of slide, water percolates down through the cracks, wormholes, and root-holes in the soil during the rainy season, and may flow along the weathered surface of the bedrock to the face of the cut. The water saturates the soil, increases its weight, and decreases the shearing strength of both the soil and the top clayey part of the weathered bedrock, which then develops a slide surface.

Other cuts develop landslides because they have been made across a small drainageway or depression in the hillside, thus removing lateral support for clayey soil or alluvial material in the drainageway. During a rainy season the clayey material in the drainageway becomes saturated and moves downhill into the cut.

Landslides in some cuts are due to cutting across old slides. If a slide has come to rest and stabilized itself, it may move very little or not at all for many years. However, if the support of the lower part of the slide is removed by cutting the toe, the slide will tend to move down into the cut into a more stable position.

Landslides in artificial fills are primarily due to works of man, and are only incidentally influenced by other factors, such as exposure or geology (type of material used as fill or foundation for fill). Exposure appears to be a factor contributing to landslides in fill. Twenty-six landslides in fill were examined; 22 of these were on north-, east-, northeast-, or northwest-facing slopes.

Triaxial shear tests were performed on a sample of material from the Orinda Formation. The resulting data given below are intended to be an example only, and should not be used in designing fill slopes. The properties of the rocks of the Orinda Formation vary considerably from place to place, and these data are applicable only to the specific rocks tested. Each fill requires its own tests and design, which should be determined by engineers experienced in this type of design.

The sample was taken from a cut between Saint Mary's College and Burton School, and consisted of a number of approximately 1-pound grab samples taken at 2-foot intervals for about 200 feet along the cut face. The cut lies across the strike of the beds, so that the sample contained sandstone, shale, and conglomerate in amounts reasonably representative of these materials in the cut. Specimens of the sample were compacted to 90 percent of the maximum density as determined by State of California test method no. 216E (California Division of Highways, 1960), and saturated, consolidated triaxial shear tests performed.

Test data indicated that the material sampled has a friction angle of about 20° and a cohesion of about 600 pounds per square foot. Using a chart of stability numbers (Taylor, 1948, p. 459), and <u>neglecting seepage forces</u>, these data indicate that a compacted fill composed of this particular mixture of material should be stable in 2:1 slopes more than 50 feet in height. Even though this material may make good fill if properly compacted, it may not be stable in cuts because of inherent geologic properties of the undisturbed bedrock. For example, a slide which moved on both joint and bedding planes formed in the cut from which the sample for the triaxial test was taken. The bedding and jointing of the undisturbed bedrock are major factors contributing to landsliding in cuts, for they facilitate the penetration of water and building up of pore pressure in confined sandstone beds, and joint and bedding planes in undisturbed bedrock may become slide planes. In a compacted fill the bedding and jointing are essentially destroyed. The fill is generally quite thoroughly mixed, so that there are no layers of clayey material alternating with sandy material, and the overall composition of the fill is then a reasonably dense, uniform mixture, containing sand, clay, silt, and pebbles. If, however, the fill is not sufficiently compacted, it may slide if saturated.

Gophers are a factor contributing to sliding, for their burrows form channels for water to penetrate the ground. Gopher holes were observed extending from the surface of the ground to the slide scarp in several landslides; water was issuing from the holes. Gophers burrow in shale, soft sandstone, soil, and fill; a well-compacted fill is less likely to be riddled with gopher holes, however, as gophers prefer soft ground in which to dig.

It is not known how many slides in the area studied may have been caused by earthquakes. It is well known that earthquakes have triggered some landslides (Varnes, 1958, p. 43), and landslides in other parts of the seismically active San Francisco Bay area were precipitated by the earthquakes of 1906 (Lawson and others, 1908) and 1957 (Bonilla, 1959, p. 34). If a major shock should occur during wet weather, when the hillsides were saturated, undoubtedly many slides would be triggered in the area underlain by the Orinda Formation.

Selected hillsides examined are conspicuously free of sliding. Cuts on such hillsides showed mostly firm conglomerate and sandstone, or almost entirely clay shale. None of the cuts examined on slide-free hills exposed alternating thick sandstone or conglomerate and shale beds. A reason for lack of sliding may be the homogeneity of the rocks; there are no confined sandstone layers which can carry water into the formation, and in which pore water pressures can build up. Most hills underlain predominantly by shale are gently rolling, with slopes that generally do not exceed 18°. One might assume that sliding on these hills is infrequent because the shale has been eroded to relatively low hills with flat, stable slopes; however, this does not explain why some cuts steeper than 18° in shale showed no indication of sliding.

Prevention of landsliding

A complete discussion of prevention and correction of landslides is beyond the scope of this report. Methods of prevention and (or) correction are described by Bonilla (1960), Baker and Marshall (1958), Baker and Yoder (1958), and Root (1958). Articles by these authors also contain additional references on the subject in their bibliographies.

In highway construction, major slide areas are commonly treated by avoidance, removal of material from the slide, installation of subdrains, construction of restraining structures, hardening of the slide mass, or some combination of these methods (Root, 1958). In much highway construction, it is more economical to consider relatively minor sliding as a maintenance problem rather than to cut slopes excessively flat or resort to expensive preventive measures.

Although much relatively minor sliding is an acceptable maintenance problem to highway departments, it may be a source of a major damage and expense to a business establishment or home owner. Landslides in a housing area may undermine or damage patios, driveways, swimming pools, and foundations that are constructed on a slope or close to the top edge of a slope and push out retaining walls, slough down into parking lots and patios or against buildings, and damage lawns and gardens constructed at the base of a slope. Most home owners do not have the financial resources to correct even a small landslide that may require several thousand dollars to repair properly. In constructing dwellings, therefore, it is essential to prevent even small amounts of landsliding.

Damage to dwellings and other structures may possibly be avoided if a thorough geological and engineering investigation is made of proposed building sites to determine slide and potential slide conditions, and other problems inherent in the natural setting. Suitable engineering design may then be possible to prevent or reduce damage. Sliding in some parts of the Orinda Formation probably cannot be prevented; in some parts it may be prevented only by extensive drains and special engineering design and construction. Land that would be highly expensive to develop for housing might be used for parks or other recreational facilities.

Water, both on the surface and underground, is a major factor contributing to landsliding. Therefore, a common approach to preventing and correcting landslides is to prevent as much water as possible from entering the ground, and remove it as rapidly as possible if entrance cannot be prevented. Prevention and correction by drainage are discussed by Root (1958) and by Baker and Marshall (1958).

In addition to the methods suggested by the above authors, water from the roof drains of a building should be collected into one main drain and run to street gutters or storm sewers. Gophers should be exterminated in hillside developments, as their burrows provide a way for water to enter the ground.

The data assembled in this preliminary report indicate that landslides involving bedrock of the Orinda Formation on natural slopes tend to be most abundant on northeast-facing slopes where beds dip in a direction opposite to the hill slope. Exposure is a major factor contributing to soil slides on natural slopes; soil slides are most abundant on north-, northwest-, or northeast-facing slopes. The possibility of both bedrock and soil slides should be considered in planning development of a northerly facing hillside.

Landslides involving bedrock in cut slopes commonly show evidence of movement on joint planes. Landslides in cuts approximately normal to the strike of the beds, or in cuts where the strike of dipping beds intersects the cut slope at approximately 45° may move on both joint and bedding planes. Some landslides in cuts where the beds dip in a direction opposite to the cut face also show evidence of movement on joint planes. Cuts in which the beds dip in the same direction as the cut but more gently may slide on bedding planes. Slope exposure does not appear to be a major factor contributing to landsliding of bedrock in cuts. When planning cuts in bedrock, special attention should be paid to the relationship of cuts to the bedding and jointing of the rock.

Exposure appears to be a major factor contributing to landslides in artificial fill. Fills with north, east, northwest, or northeast exposure should be designed and placed with particular care, as they will be especially prone to surficial sliding because of their exposure.

Additional precautions that might be observed to help prevent landsliding are:

1. Do not cut off the toe of a known slide without first assuring stabilization of the remaining slide material.

2. Do not make cuts or place fills across even minor hillside drainage channels without providing drainage for water that may flow down them in the wet season.

3. Plant deep-rooted plants which do not require intensive watering, to aid in holding slopes against sliding. The effectiveness of planting is limited, however, and planting alone will not retain extensive or deep-seated landslides.

4. Be cautious regarding irrigation in hillside areas.

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APPENDIX

Form used to compile landslide data in the field

Date of slide, if known:

Location:

Type of slide (slump, block, debris, rockslide or rockfall, mudflow or earthflow, sand run, avalanche, complex):

Size of slide (length, width, height):

Maximum height of scarp(s):

Nature of surface of rupture:

Single, multiple, or coalescent slide:

Reactivated or new slide:

Angle of slope before sliding:

Natural, cut, or fill slope:

Height of cut or fill slope, benching if any:

Exposure (direction slope is facing):

Wet or dry when examined:

Geologic formation:

Lithology (sample number if any):

Condition of rock (fresh, weathered, or otherwise altered):

Bedding (thickness, attitude):

Vegetation:

Jointing or fracturing (width and spacing, attitude):

Faults or shear zones (width, attitude, displacement):

Source of water, if any (rain, human agents, seep or spring):

Weather conditions prior to slide if known:

Probable contributing factors (water, removal of toe of slope or toe of previous slide, earthquake):

Damage (nature and cost):

Correction (nature and cost):

Source of date:

Date visited in field:

TABLE 1.--Data on selected landslides in a part of the Orinda Formation, Contra Costa County, California.

[Abbreviations used: ss, sandstone; sh, shale; cgl, conglomerate. In Map no. and size columns, letter designations a, b, c, ...for multiple landslides indicate component parts of a multiple slide (not shown on map.) In size columns, d after length figure indicates debris length.]

Map no. (by grid squares)	Date of landslide	Date examined	Form of landslide	Type of landslide	Type of material	Geologic setting	Approximate size (feet) Length	Width	Maximum scarp height	Wet or dry when examined; source of moisture	Weather immediately prior to landslide	Slope: Exposure	Natural, cut, or fill	Approximate angle before sliding (degrees)	Estimated height of cut or fill (feet)	Vegetation	Damage	Remarks
B1-1	---	6/19/61	Single	Rockfall	Ss with clay interbeds	Beds dip in direction opposite to hill slope (N. 64° W., 24° SW.); joints trend N. 52° W., 58° NE., and N. 30° E., 87° NW.	20	40	1	Dry	---	NE	Natural	90	---	Grass[1] and brush	---	Rock broke on joint planes.
B2-2	---	6/19/61	Single	Slump and earthflow	Fill	Fill	20	40	2	Dry	---	NE	Fill	31	---	Grass, brush, and trees	Road and drains cracked	Reactivated landslide.
B2-3	---	6/16/61	Single	Slump and earthflow	Soil, ss	Geologic setting uncertain	6	40	2	Dry	---	NE	Cut	30	---	Grass	Slid onto road	---
B2-4	---	6/21/61	Coalescent	Slump and earthflow	Soil, fill	Fill	150d	100	6	Wet due to rain	---	NE	Fill	---	---	Brush and trees	---	---
B2-5	---	6/21/61	Coalescent	Slump and earthflow	Soil, fill	Fill	600d	500	1	Dry	---	NE	Fill	---	---	Grass, brush, and trees	Impaired fill around military installation	---
B2-6	---	10/3/62	Single	Slump and earthflow	Ss, sh	Strike of dipping beds (N. 60° W., 20° SW.) intersects cut slope at approximately 45°; beds dip in general direction of cut slope; landslide on bedding and joint planes; joints trend N. 10° W., 65° SW.; N. 65° W., 70° SW.; N. 20° W., 80° NE.	40d	40	3	Dry	---	W	Cut	35	---	Grass	Slid onto road	Attitude of cut slope approximately N. 15° W., 35° SW.
B3-1	---	6/21/61	Single	Slump and earthflow	Soil, fill	Fill	60d	30	2	Dry	---	NE	Fill	28	---	Grass	---	---
C2-1	---	6/19/61	Coalescent	Slump and earthflow	Soil, ss	Geologic setting uncertain	30	48	3	Wet due to rain	---	NE	Cut	41	---	Brush	---	---
C3-1	---	6/14/61	Single	Slump and earthflow	Soil, ss interbedded with cgl	Strike of dipping beds (N. 50° W., 41° SW.) approximately normal to cut slope	20	20	4	Dry	---	NW	Cut	30	---	Grass and brush	---	Attitude of cut slope approximately N. 30° E., 30° NW.
C3-2	---	6/14/61	Single	Slump and earthflow	Soil, fill	Fill	200d	50	3	Dry	---	N	Natural and fill	20-30	---	Brush and trees	Impaired road	---
C3-3	---	6/14/61	Coalescent	Slump and earthflow	Soil, fill	Fill	50d	60	4	Wet due to rain	---	NE	Cut and fill	33	---	Grass	Slid onto road	---
C3-4	---	6/14/61 and 11/13/62	Coalescent	Slump and earthflow	Soil, fill	Fill	220d	500	10	Wet due to rain and springs	---	NE	Natural, cut, and fill	20-33	---	Grass and brush	Slid onto road	Within old landslide area.
C3-5	---	6/27/61	Single	Slump and earthflow	Soil, fill	Fill	40	20	7	Dry	---	NE	Fill	31	---	Grass	---	---
D4-1	---	6/27/61	Single	Slump	Ss, sh exposed in road below slide	Geologic setting uncertain	600+	900	20+	Wet	---	NE	Natural	---	---	Grass	---	Appears to be large weathered slump block with pond on the block.
D4-2	---	6/27/61	Coalescent	Earthflow	Soil	Geologic setting uncertain	80	90	3	Wet due to rain	---	N	Natural	19-24	---	Grass	---	---
D4-3	---	6/27/61	Single	Slump and earthflow	Soil, silty clay	Geologic setting uncertain	15	30	6	Dry	---	NE	Natural	28	---	Grass	---	Appears to be within old landslide area.
D4-4	---	6/27/61	Single	Slump and earthflow	Soil (with boulders)	Geologic setting uncertain	20	20	4	Dry	---	NE	Natural	28	---	Grass	---	Appears to be within old landslide area.
D4-5	---	6/21/61	Coalescent	Slump and earthflow	Soil, ss, clay sh	Beds dip in direction opposite to cut slope	15	55	3	Wet due to rain	---	E	Cut	45	---	Brush and trees	Slid onto road	---
E1-1	---	6/14/61	Single	Slump and earthflow	Clay, silty clay, ss, cgl	Strike of dipping beds (N. 20° E., 35° NW.) intersects cut slope at approximately 45°; beds dip in direction opposite to cut slope; landslide moved on joints trending N. 5° W., 60° NE.; N. 75° E., 85° NW.; N., 80° W.	15 100d	100	12	Dry	---	NE	Cut	41	30	Grass	---	Attitude of cut slope approximately N. 35° W., 41° NE.

...of table for footnote

TABLE 1.--Data on selected landslides in a part of the Orinda Formation, Contra Costa County, California--Continued

[Abbreviations used: ss, sandstone; sh, shale; cgl, conglomerate. In Map no. and size columns, letter designations a, b, c, ...for multiple landslides indicate component parts of a multiple slide (not shown on map.) In size columns; d after length figure indicates debris length.]

Map no. (by grid squares)	Date of landslide	Date examined	Form of landslide	Type of landslide	Type of material	Geologic setting	Approximate size (feet) Length	Width	Maximum scarp height	Wet or dry when examined; source of moisture	Weather immediately prior to landslide	Slope Exposure	Natural, cut, or fill	Approximate angle before sliding (degrees)	Estimated height of cut or fill (feet)	Vegetation	Damage	Remarks
F4-1	---	6/20/61	Single	Slump and earthflow	Soil, clayey ss and sh	Geologic setting uncertain	120d	60	6	Dry	---	E	Natural and cut	20 (natural)	---	Grass	---	Attitude of cut slope approximately N. 10° E., 20° SE.
F5-1	---	6/23/61	Single	Earthflow	Silty clay sh, clayey ss	Strike of dipping beds (N. 55° W., 20° SW.) intersects cut slope at approximately 45°; beds dip in general direction of cut slope; joints trend N. 30° W., 75° NE., and N. 45° E., 75° NW.	75d	30	8	Dry	---	S	Cut	30-40	20	Grass	Minor damage to road	Attitude of cut slope approximately N. 70° E., 40° [illegible]. Apparently moved on both joint and bedding planes.
F6-1	---	5/14/61	Coalescent	Slump and earthflow	Soil, sh	Beds dip in direction opposite to hill slope	100d	100	1	Dry	---	NE	Natural	20	---	Grass and brush	---	Flowed out onto cut slope.
F6-2	---	5/14/61	Coalescent	Earthflow	Soil	Beds dip in direction opposite to hill slope	120d	160	2	Dry	---	NE	Natural	22	---	Grass and brush	---	Flowed out onto cut slope.
F6-3 a	---	5/14/61	Multiple	Slump and earthflow	Fill material--clay, soil, sand, and gravel	Fill	200	100	5	Wet due to rain	---	NE	Fill	23	---	Grass and brush	Damage to yard of house	---
F6-3 b	---	5/14/61	Multiple	Slump and earthflow	Fill, old slide material, soil	Beds dip in direction opposite to hill slope	140d	120	3	Wet due to rain	---	NE	Natural	19	---	Grass and brush	---	---
F6-4	---	5/14/61	Single	Slump and earthflow	Fill and old slide material--sand, clay, gravel, and soil	Beds dip in direction opposite to slope	150d	25	3	Wet due to rain	---	NE	Natural, cut, and fill	22	---	Grass and brush	---	---
F6-5	---	5/14/61	Single	Earthflow	Soil	Beds dip in direction opposite to hill slope	80d	50	2	Wet due to rain	---	NE	Natural	22	---	Grass and brush	---	Flowed out onto cut slope.
F6-6	---	5/15/61	Single	Earthflow	Soil, sh	Beds dip in direction opposite to hill slope	100d	60	1	Wet due to rain	---	NE	Natural	22	---	Grass and brush	---	Flowed out onto cut slope.
F6-7 a	---	5/11/61	Multiple	Slump and earthflow	Very clayey, slightly sandy fill with gravel and soil	Fill	220d	125	3	Wet due to rain and seeps	---	NE	Fill	30	---	Grass and brush	---	---
F6-7 b	---	5/12/61	Multiple	Slump and earthflow	Fill and soil	Fill	140d	30	3	Wet due to rain	---	NE	Fill	28	---	Grass and brush	---	---
F6-7 c	---	5/9/61	Multiple	Slump and earthflow	Old slide material, fill, and soil	Beds dip in direction opposite to hill slope	150d	40	1.5	Wet due to rain	---	NE	Natural	20	---	Grass and brush	---	---
F6-8 a	---	5/11/61	Multiple	Slump and earthflow	Sand-clay-pebbles; fill?	Fill	100 200d	50	3	Wet due to rain and seeps	---	NE	Natural and fill	30	---	Grass and brush	---	---
F6-8 b	---	5/11/61	Multiple	Slump and earthflow	Old slide material, fill, and soil	Beds dip in direction opposite to hill slope	60 140d	40	3	Wet due to rain and seeps	---	NE	Natural	20	---	Grass and brush	---	---
F6-9	---	5/22/61	Single	Slump and earthflow	Soil	Geologic setting uncertain	60d	30	1	Wet due to rain	---	NE	Natural and cut	28 (cut)	---	Grass and brush	Damaged fence	---
G4-1	2/62 and 10/62	6/20/62 and 11/13/62	Single	Slump and earthflow	Soil, clay sh, ss, cgl	Strike of dipping beds (N. 40° E., 35° to 50° SE.) approximately normal to slope; landslide moved on joint trending N. 15° W., 85° SW.; may also have moved on bedding	250	150	15	Wet due to rain	Rain	S	Natural and cut	25-55	30	Grass and trees	Broke up slope below house, damaged part of road and road gutter	Attitude of cut slope approximately N. [illegible]

TABLE 1.--Data on selected landslides in a part of the Orinda Formation, Contra Costa County, California--Continued

[Abbreviations used: ss, sandstone; sh, shale; cgl, conglomerate. In Map no. and size columns, letter designations a, b, c, ...for multiple landslides indicate component parts of a multiple slide (not shown on map.) In size columns, d after length figure indicates debris length.]

Map no. (by grid squares)	Date of landslide	Date examined	Form of landslide	Type of landslide	Type of material	Geologic setting	Approximate size (feet): Length	Width	Maximum scarp height	Wet or dry when examined; source of moisture	Weather immediately prior to landslide	Slope: Exposure	Natural, cut, or fill	Approximate angle before sliding (degrees)	Estimated height of cut or fill (feet)	Vegetation	Damage	Remarks
04-2	2/62 and 10/62	2/20/62 and 11/13/62	Single	Slump and earthflow	Soil, clay sh, cgl	Strike of dipping beds (N., 45° E.) intersects cut slope at approximately 45°; beds dip in general direction of slope; landslide apparently moved on bedding, on joint plane trending N. 15° W., 45° SW., and on slickensided fault surface trending N. 25° W., 55° SW.; minor joint set trends N. 75° W., 85° NE.	200	35	10	Wet due to rain	Rain	SE	Cut	25	---	---	Damaged road surface and gutter	Attitude of cut slope approximately N. 60° E., 25° SE. Reactivated landslide.
04-3	2/62 and 10/62	2/20/62 and 11/13/62	Single	Slump and earthflow	Clay sh, cgl	Strike of dipping beds (N. 30° E., 30° SE.) intersects cut slope at approximately 45°; beds dip in general direction of slope; landslide apparently moved on bedding and on joints trending N. 75° W., 85° NE., and N. 15° E., 85° SE.	225	50	15	Wet due to rain	Rain	SE	Cut	25	---	---	Cracked gutter and road	Attitude of cut slope approximately N. 60° E., 25° SE. Reactivated landslide.
05-1	2/15/62	2/21/62	Single	Earthflow	Soil, silty clay, fill	Beds dip in direction opposite to cut slope	40	20	6	Wet due to rain	Rain	NE	Cut and fill	27	30	Grass	Came down against house	---
06-1 a	---	5/3/61	Multiple	Slump and earthflow	Soil and colluvium--sand, clay, silt, gravel	Beds dip in general direction of hill slope at approximately same angle as slope; no field evidence to indicate whether any part of sliding was on bedding planes	260d+	320	5	Wet	---	SW	Natural, cut, and fill	20-40	---	Grass, brush, and trees	---	Landslide shown here on aerial photos dated 1946.
06-1 b	1958	5/3/61	Multiple	Slump and earthflow	Colluvium, fill		250d+	100	5	Wet	Rain	SW	Natural, cut, and fill	20-40	---	Grass and brush	Damaged Ball Drive, and house at 1 Easton Court	Colluvium and fill apparently slid on shale and sandstone bedrock.
06-1 c	1958 and 1962	5/3/61 and 2/16/62	Multiple	Slump and earthflow	Colluvium, sh		200d	90	8	Wet	Rain	SW	Natural, cut, and fill	20-40	---	Grass	Damaged Ball Drive (abandoned) and came down against house at 1 Easton Court	Clay shale overlain by colluvium exposed in scarp.
06-2	---	5/16/61	Single	Slump and earthflow	Soil, old slide material, fill	Strike of dipping beds approximately normal to hill slope; landslide approximately parallel to strike of beds	100d	80	---	Wet due to rain	---	NW	Cut and fill	20-30	---	Grass	---	This landslide was reactivated and slumped onto road February 1962.
06-3	---	5/16/61	Coalescent	Slump and earthflow	Soil, ss, cgl	Strike of dipping beds approximately normal to hill slope; landslide approximately parallel to strike of beds	400d	160	6	Wet due to rain and seeps	---	NW	Natural	20-30	---	Grass and brush	Damaged house and drive; lot abandoned	---
06-4	---	5/9/61	Single	Earthflow	Soil	Beds dip in general direction of hill slope, but more steeply	60	15	2	Dry	---	W	Natural	21	---	Grass	---	---
06-5	---	5/9/61	Single	Slump and earthflow	Soil with some cgl pebbles	Beds dip in general direction of hill slope, but more steeply	50	20	3	Wet due to rain and springs	---	W	Natural	35	---	Grass	---	---
06-6	---	5/12/61	Single	Slump and earthflow	Soil with pebbles	Beds dip in general direction of hill slope, but more steeply	40d	30	1	Dry	---	W	Natural	20	---	Grass and brush	---	---
06-7	---	5/5/61	Single	Earthflow	Soil and colluvium--clay, sand, pebbles, and organic material	Beds dip in general direction of hill slope, but more steeply	60	15	7	Wet due to rain	---	SW	Natural	[illegible]	---	Grass and brush	---	---
06-8	2/62	2/26/62	Single	Earthflow	Fill--clay, silt, sand, and pebbles	Fill	50d	35	7	Wet due to rain	---	SW	Fill	34	---	Grass	Cracked 2 ft of pavement on Sunset Terrace and flowed against house below	---

TABLE 1.--Data on selected landslides in a part of the Orinda Formation, Contra Costa County, California--Continued

[Abbreviations used: ss, sandstone; sh, shale; cgl, conglomerate. In Map no. and size columns, letter designations a, b, c, ...for multiple landslides indicate component parts of a multiple slide (not shown on map.) In size columns, d after length figure indicates debris length.]

Map no. (by grid squares)	Date of landslide	Date examined	Form of landslide	Type of landslide	Type of material	Geologic setting	Approximate size (feet): Length	Approximate size (feet): Width	Approximate size (feet): Maximum scarp height	Wet or dry when examined; source of moisture	Weather immediately prior to landslide	Slope: Exposure	Slope: Natural, cut, or fill	Slope: Approximate angle before sliding (degrees)	Slope: Estimated height of cut or fill (feet)	Vegetation	Damage	Remarks
G6-9	10/62	10/17/62	Single	Slump and mudflow	Soil	Beds dip in general direction of hill slope, but more steeply	120d	25	2.5	Wet due to rain	Rain	S	Natural	30	---	Grass	Flowed into back yard of house	Landslide debris consists of turf and soil which flowed out of small (20- by 25-ft) pocket and down hillside, leaving a train of mud, turf and soil balls on hill slope
G7-1	2/15/61	2/28/62	Single	Earthflow	Soil, fill, and clay probably derived from clay shale	Beds dip in direction opposite to slope	100 130d	65	3	Wet due to rain	Rain	SW	Natural, cut, and fill	18-30	---	Grass	Cracked sewer line	Rupture surface in gray clay trends N. 60° W., 40° SW.
G7-2	1958	5/16/61	Coalescent	Slump and earthflow	Soil, sh	Beds dip in direction opposite to hill slope	80	30	5	Wet due to rain	---	SW	Natural	15-20	---	Grass	Affected house on Ivy Drive	---
G7-3	3/7/62	3/13/62	Single	Earthflow	Soil and fill--sand, silt, clay, pebbles	Fill	300d	70	8	Wet due to rain	Rain	E	Natural and fill	20-35	25	Grass	Flow carried away yard and patio, broke concrete drain, flowed onto school yard below	Fill 25 ft or more in thickness placed in former ravine
G7-4	2/9/62	2/26/62	Single	Earthflow	Fill--silty clay with pebbles	Fill	30d	120	3	Wet due to rain	Rain	W	Fill	35	20	---	Carried away yards of two houses, left foundation exposed	---
G7-5	2/62	2/26/62	Single	Earthflow	Soil, clay, sh	Beds dip in direction opposite to cut slope	20 40d	25	2	Wet due to rain	Rain	SW	Cut	30	---	---	Slight damage to cut slope	---
G7-6	2/15/62	2/21/62	Single	Earthflow	Fill, clay, sh, ss	Strike of dipping beds approximately normal to cut slope; landslide approximately parallel to strike of beds	30 40d	50	3	Wet due to rain	Rain	SE	Cut and fill	33-35	20	---	Exposed foundation of house above, moved down against house below	---
H6-1	---	1/26/62	Single	Earthflow	Clay soil, weathered clay sh	Beds dip in direction opposite to hill slope	30	15	5	Wet due to snow and seeps	---	NE	Natural	35	---	Grass and brush	---	---
H6-2	---	1/26/62	Single	Earthflow	Soil	Beds dip in general direction of hill slope, but more steeply	35d	15	1.5	Wet due to snow	---	SW	Natural	25	---	Grass	---	---
H6-3	---	1/26/62	Multiple	Earthflow	Damp plastic clay soil	Beds dip in general direction of hill slope, but more steeply	a= 20 b=140d	50 35	1.5 ---	Wet due to snow	---	SW	Natural	22	---	Grass	---	---
H6-4	2/62 and 10/62	2/28/62 and 11/14/62	Single	Slump and earthflow	Soil, clay sh with thin ss layers	Beds dip in direction opposite to cut slope (N. 60° W., 45° SW.); landslide moved on several joint sets trending N. 10° W., 70° NE.; N. 60° E., vertical; N. 50° W., 70° NE.; and N. 15° E., 75° NW.	40d	60	10	Wet due to rain	Rain	NE	Cut	45	25	Grass and brush	Slid onto building pad	Attitude of cut slope approximately N. 55° W., 45° NE.
H6-5	---	5/24/61	Single	Slump and earthflow	Fill--soil, sand, clay, silt	Fill	15	40	4	Dry	---	SE	Fill	30	20	Grass	Damage to building pad	---
H6-6	---	5/23/61	Single	Slump and earthflow	Soil	Beds dip in direction opposite to slope	4	75	2	Wet	---	NE	Cut	30	---	Grass	Fence and drain damaged	Reactivated toe of old landslide.
H6-7	---	5/23/61	Coalescent	Earthflow	Soil	Beds dip in direction opposite to hill slope	260d	60	1	Wet	---	NE	Natural	16-30	---	Grass	---	Beds of shale, sandstone, and conglomerate exposed near landslide.
H6-8	---	5/23/61	Coalescent	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	500d	100	3	Dry	---	NE	Natural	20-25	---	Grass	---	---

TABLE 1.--Data on selected landslides in a part of the Orinda Formation, Contra Costa County, California--Continued

[Abbreviations used: ss, sandstone; sh, shale; cgl, conglomerate. In Map no. and size columns, letter designations a, b, c, ...for multiple landslides indicate component parts of a multiple slide (not shown on map.) In size columns, d after length figure indicates debris length.]

Map no. (by grid squares)		Date of landslide	Date examined	Form of landslide	Type of landslide	Type of material	Geologic setting	Approximate size (feet) Length	Width	Maximum scarp height	Wet or dry when examined; source of moisture	Weather immediately prior to landslide	Slope Exposure	Natural, cut, or fill	Approximate angle before sliding (degrees)	Estimated height of cut or fill (feet)	Vegetation	Damage	Remarks
B6-9		---	5/23/61	Coalescent	Slump and earthflow	Soil, weathered clayey ss	Beds dip in direction opposite to hill slope	400d	140	3	Wet	---	NE	Natural	20	---	Grass	---	Small slumps where toe cut.
B6-10		---	5/23/61	Single	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	220d	30	1	Wet	---	NE	Natural	20	---	Grass	---	---
B6-11		---	5/23/61	Coalescent	Slump and earthflow	Soil, weathered ss and cgl	Beds dip in direction opposite to hill slope (N. 60° W., 35° SW.); movement on joints trending N. 65° W., 45° NE.; other joints trend N. 45° E., 85° SE., and N. 20° W., 15° NE.	500d	160	2	Wet	---	NE	Natural	26	---	Grass	---	Attitude of hill slope approximately N. 55° W., 26° NE.
B6-12		---	5/23/61	Coalescent	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	400d	60	3	Dry	---	NE	Natural	20	---	Grass	---	Smaller landslides at toe where cut.
B6-13		---	5/23/61	Single	Slump and earthflow	Soil	Beds dip in direction opposite to cut slope	15	10	1	Wet	---	NE	Cut	26	---	Grass	---	Several similar landslides in roadcut.
B6-14		---	5/23/61	Single	Earthflow	Soil	Beds dip in direction opposite to hill slope	280d	60	0.5	Wet	---	NE	Natural	20	---	Grass	---	---
B6-15		---	2/24/61	Single	Slump and earthflow	Soil	Strike of dipping beds intersects hill slope at approximately 45°; beds dip in direction opposite to slope; landslide approximately parallel to strike of dipping beds	50	30	1	Dry	---	NE	Natural	20	---	Grass	---	---
B6-16		---	5/29/61	Coalescent	Slump and earthflow	Soil, clayey sh	Strike of dipping beds intersects cut slope at approximately 45°; beds dip in general direction of slope; landslide approximately parallel to strike of beds	100d	15	3	Wet due to rain	---	S	Cut	30	---	Grass	Damage to road	---
B6-17		---	5/29/61	Single	Slump and earthflow	Soil, sh	Strike of dipping beds intersects cut slope at approximately 45°; beds dip in general direction of slope; landslide approximately parallel to strike of beds; moved on bedding (N. 60° W., 40° SW.), and joint plane trending N. 25° W. 80° NE; joints also trend N. 40° E., 65° SE.	15	6	2	Dry	---	S	Cut	28-45	---	Grass	Slumped onto road	Attitude of cut slope approximately N. 70° E., 40° SE. The two planes on which movement took place form a V dipping toward the cut.
B6-18		---	5/24/61	Single	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	250d	50	3	Wet due to rain and springs	---	NE	Natural	21	---	Grass	---	---
B6-19	a	---	5/24/61	Multiple	Slump and earthflow	Soil, ss, cgl	Beds dip in direction opposite to hill slope	100d	40	4	Wet due to rain and springs	---	NE	Natural	27	---	Grass	---	---
	b	---	5/24/61		Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	120d	30	1	Wet due to rain and springs	---	NE	Natural	24	---	Grass	---	---
B6-20		---	6/9/61	Single	Slump and earthflow	Soil, ss, cgl	Beds dip in direction opposite to cut slope (N. 70° W., 55° SW.); joints trend N. 70° E., 50° NW. and N. 70° W., 50° NE.	40	20	4	Wet	---	NE	Cut	27	---	Grass	Cut slope	This landslide moved again in February 1962. Attitude of cut slope approximately N. 65° W., 27° NE.
B6-21	a	---	5/22/61	Multiple	Slump and earthflow	Soil with gravel and cgl		40	120	5	Wet due to rain	---	NE	Cut	22	---	Trees and grass		
	b	---	5/22/61		Slump and earthflow	Soil with gravel	Beds dip in direction opposite to slope (N. 70° W., 55° SW.); joints trend N. 65° W., 55° NE.; N. 10° E., 80° SE.; and N. 35° E., 30° SE.	40	90	3	Wet due to rain	---	NE	Cut	20-30	---	Grass	Toe pushed up under asphalt parking lot	In February 1962 slide moved again in spite of drains, benching, and planting. Cut slope trends approximately N. 65° W., 20° to 30° NE.
	c	...	5/22/61		Slump and earthflow	Soil		220d	50	4	Wet due to rain	---	NE	Natural	30	---	Grass	Flowed onto cut slope	

TABLE 1.--Data on selected landslides in a part of the Orinda Formation, Contra Costa County, California--Continued

[Abbreviations used: ss, sandstone; sh, shale; cgl, conglomerate. In Map no. and size columns, letter designations a, b, c, ...for multiple landslides indicate component parts of a multiple slide (not shown on map.) In size columns, d after length figure indicates debris length.]

Map no. (by grid squares)	Date of landslide	Date examined	Form of landslide	Type of landslide	Type of material	Geologic setting	Approximate size (feet) Length	Width	Maximum scarp height	Wet or dry when examined; source of moisture	Weather immediately prior to landslide	Slope: Exposure	Natural, cut, or fill	Approximate angle before sliding (degrees)	Estimated height of cut or fill (feet)	Vegetation	Damage	Remarks
M6-22	---	5/22/61	Single	Slump and earthflow	Soil, sh	Beds dip in direction opposite to cut slope; nearest bedding trends N. 70° W., 55° SW.; joints at landslide trend N. 80° W., 55° NE.	80	60	6	Wet due to rain	---	NE	Cut	---	---	Grass	Some buckling of parking lot	In February 1962 this slide moved again in spite of drains, benching, and planting. Attitude of cut slope approximately N. 65° W., 20° to 30° NE.
M6-23	10/62	10/17/62	Single	Slump and earthflow	Soil and sh	Beds dip in general direction of slope, but more steeply	70d	25	8	Wet due to rain	Rain	S	Natural and cut	30-35	---	Grass	Flowed into back yard of house	This landslide involving bedrock did not move on bedding planes, but across them, although the beds dip in the general direction of the hill slope; no well-defined surface of rupture or joint sets could be seen.
M7-1	---	5/26/61	Single	Slump and earthflow	Soil, ss	Beds dip in direction opposite to slope (N. 65° W., 29° SW.); movement on joints trending N. 65° W., 45° NE.; other nearby joints trend N. 20° E., 65° NW.; N., 85° E.; and N. 50° W., 45° NE.	18	25	3	Wet due to rain	---	N	Natural and cut	25-40	5	Grass and brush	---	Attitude of cut slope approximately N. 70° W., 40° NE.
M7-2	---	5/22/61	Coalescent	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	260d	100	5	Wet	---	NE	Natural	20	---	Grass	---	---
M7-3	---	5/22/61	Single	Slump and earthflow	Soil, cgl	Strike of dipping beds approximately normal to cut slope; landslide approximately parallel to strike of beds	10	20	2	Wet	---	N	Cut	41	20	Grass	---	
M7-4	---	5/22/61	Single	Slump and earthflow	Soil, cgl	Strike of dipping beds approximately normal to cut slope; landslide approximately parallel to strike of beds	15	20	2	Wet	---	E	Cut	41	20	Grass	---	
M7-5	1958	5/17/61	Single	Slump and earthflow	Sandy clay, cgl	Strike of dipping beds (N. 60° W., 50° SW.) approximately normal to out slope; slide approximately parallel to strike of beds; joints trend N. 5° W., 50° NE. and N. 50° E., 50° NW.	10	40	6	Wet due to rain and seeps	---	E	Cut	41	---	---	---	These slides appear to have moved many times, in small increments. Attitude of cut slope approximately N. 20° E., 40° to 45° SE.
M7-6	---	5/22/61	Single	Slump and earthflow	Clayey sh, clayey ss, cgl	Strike of dipping beds approximately normal to cut slope; slide approximately parallel to strike of beds	10	10	2	Wet, saturated below slide	---	E	Cut	41	20	Grass	---	
M7-7	---	5/22/61	Single	Slump, flow, and minor rock fall	Ss, sh, cgl	Strike of dipping beds approximately normal to cut slope; slide approximately parallel to strike of beds	8	10	---	Wet	---	N	Cut	41	20	---	---	
M7-8	2/62	3/16/62	Single	Earthflow	Fill--clay, silt, with rock and sand	Fill	110d	90	20	Wet due to rain and seeps	---	NE	Fill	25	25	Grass	Took out half of abandoned road	Appears to be fill across former small ravine.
M7-9 a	---	3/21/62	Multiple	Earthflow	Soil		220d	80	3	Wet due to rain and seeps	---	NE	Natural	25	---	Grass and brush	---	---
M7-9 b	---	3/21/62	Multiple	Earthflow	Soil, weathered clay sh, clayey ss and cgl	Beds dip in direction opposite to slope	115d	80	3	Wet due to rain and seeps	---	NE	Natural and cut	10-35	6	Grass and brush	Slid onto building pad	Reactivated old landslide.

TABLE 1.--Data on selected landslides in a part of the Orinda Formation, Contra Costa County, California--Continued

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Map no. (by grid squares)	Date of landslide	Date examined	Form of landslide	Type of landslide	Type of material	Geologic setting	Approximate size (feet) Length	Width	Maximum scarp height	Wet or dry when examined; source of moisture	Weather immediately prior to landslide	Slope Exposure	Natural, cut, or fill	Approximate angle before sliding (degrees)	Estimated height of cut or fill (feet)	Vegetation	Damage	Remarks
N7-10	1961-62	3/21/62	Single	Slump and earthflow	Soil, ss	Strike of dipping beds intersects cut slope at approximately 45°; beds dip in direction opposite to cut slope	25 65d	15	4.5	Dry	---	N	Cut	35	10	Grass	Slide material flowed into driveway below	Attitude of cut slope approximately N. 80° E., 35° NW.
N7-11	2/62	3/21/62	Single	Earthflow	Fill--clay, silt, gravel	Fill	35d	40	1.5	Wet due to rain and seeps	---	NE	Cut and fill	33	9	Grass	Destroyed part of building pad	---
N7-12	---	5/29/61 and 3/21/61	Single	Slump and earthflow	Fill--silt, sand, and pebbles	Fill	8	15	1	Wet due to rain and seeps	---	NE	Fill	28	7	Grass	---	Typical of several landslides in fill for building pads.
N7-13	---	3/21/62	Single	Slump and earthflow	Soil, clay	Beds dip in direction opposite to cut slope	10	30	4	Wet due to rain and seeps	---	NE	Cut	35	12	Grass and brush	---	Typical of several landslides on large cut slope of abandoned housing project.
N7-14	---	3/23/62	Single	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	200d	90	4	Wet due to rain	---	NE	Natural	25	---	Grass and brush	---	Landslide includes some fill from Donald Drive above.
N7-15	---	5/31/61	Single	Slump and earthflow	Clayey soil	Beds dip in general direction of hill slope, but more steeply	10	35	3	Dry	---	SW	Natural	28	---	Grass	---	---
N7-16	---	5/31/61	Single	Earthflow	Soil	Near syncline axis	15	10	3	Dry	---	SE	Cut	30	6	Grass	---	---
N7-17	---	5/31/61	Single	Slump and earthflow	Fill--soil and clay	Fill	20	30	---	Wet due to rain	---	E	Fill	35	4	Grass	Damage to private road	---
N7-18	---	5/31/61	Single	Slump and earthflow	Fill	Fill	20	30	---	Dry	---	NE	Fill	35	8	Grass	---	---
N7-19	---	5/31/61	Single	Slump and earthflow	Soil	Beds dip in general direction of cut slope, but more steeply	6	4	2	Dry	---	SW	Cut	25	---	Grass	---	Several small similar landslides here
N7-20	---	3/23/62	Single	Slump and earthflow	Soil	Near syncline axis	100d	40	4	Wet due to rain	---	NE	Natural	25	---	Grass	---	Road cuts across landslide.
N7-21	---	5/31/61	Single	Slump and earthflow	Soil	Near syncline axis	120d	30	2	Wet due to rain	---	NE	Natural	25	---	Grass	---	Road cuts across landslide.
N7-22	---	5/31/61 and 11/16/62	Coalescent	Slump and earthflow	Soil, soft clayey ss and cgl	Beds dip in general direction of hill slope, but more steeply	550d	220	8	Dry	---	NE	Natural	20	---	Grass	---	---
N7-23	---	11/16/62	Single	Slump and rockfall	Soil, ss, cgl, sh	Strike of dipping beds (N. 70° W., 45° SW.) intersects slope at approximately 45°; beds dip in direction opposite to slope; slide on joint planes trending N. 15° W., 40° NE.	50d	25	20	Dry	---	NE	Natural and cut	30-35	---	Grass and brush	---	Attitude of cut slope approximately N. 35° W., 35° NE.
N7-24	---	3/23/62 and 11/16/62	Coalescent	Earthflow	Soil	Beds dip in direction opposite to slope	100d	50	3	Wet due to rain and seeps	---	NE	Natural and cut	25-40	5	Grass and brush	Flowed onto road below	---
N7-25	---	5/29/61 and 11/16/62	Single	Slump, earthflow, mudflow	Fill and soil	Beds dip in direction opposite to slope	225d	50	12	Wet	---	NE	Natural, cut, and fill	30-40	---	Grass and brush	Slid onto abandoned road	May lie at site of older smaller slide but could not be sure as slope covered with landslide debris.
N7-26	2/62	3/16/62	Single	Earthflow	Fill (sand-clay-silt with rocks), soil	Fill	400d	150	20	Wet due to rain	Rain	NE	Fill	34	25	Grass and brush	Impaired abandoned road	---
N7-27	---	6/16/61	Single	Slump and earthflow	Soil, ss	Geologic setting uncertain	15	8	1	Dry	---	SW	Natural	25	---	Grass	---	---
N7-28	---	6/16/61	Single	Slump and earthflow	Soil	Geologic setting uncertain	10	15	3	Dry	---	SW	Natural	24	---	Grass	---	---

TABLE 1.--Data on selected landslides in a part of the Orinda Formation, Contra Costa County, California--Continued

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Map no. (by grid squares)	Date of landslide	Date examined	Form of landslide	Type of landslide	Type of material	Geologic setting	Approximate size (feet): Length	Width	Maximum scarp height	Wet or dry when examined; source of moisture	Weather immediately prior to landslide	Slope: Exposure	Natural, cut, or fill	Approximate angle before sliding (degrees)	Estimated height of cut or fill (feet)	Vegetation	Damage	Remarks
E7-29	---	6/16/61	Coalescent	Slump and earthflow	Soil--sandy with pebbles	Geologic setting uncertain	350d	60	3	Dry	---	SW	Natural	24	---	Grass	---	---
E7-30	---	5/31/61	Single	Slump and earthflow	Soil	Near syncline axis	15	30	4	Dry	---	W	Natural	25	---	Grass	---	---
E7-31	---	5/31/61	Coalescent	Slump and earthflow	Soil, coarse ss	Beds dip in direction opposite to hill slope	40	20	3	Dry	---	SW	Natural	29	---	Grass	---	Water flowing in gully has removed toe of landslide.
E7-32	---	5/31/61	Single	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	100	20	4	Wet due to rain	---	SW	Natural	20	---	Grass	---	---
E7-33	---	6/2/61	Single	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	12	20	5	Dry	---	SW	Natural	23	---	Grass	---	Many landslides on hillside.
E7-34	---	6/2/61	Single	Slump and earthflow	Soil, cgl	Beds dip in direction opposite to hill slope	40	20	4	Dry	---	SW	Natural	22	---	Grass	---	---
E7-35	---	6/2/61	Coalescent	Slump and earthflow	Soil	Beds dip in general direction of hill slope, but more steeply	400d	80	4	Dry	---	NE	Natural	20	---	Grass and brush	---	---
E7-36	---	6/16/61	Coalescent	Slump and earthflow	Soil	Geologic setting uncertain	20	80	1	Dry	---	SW	Natural	24	---	Grass	---	---
E7-37	---	6/16/61	Single	Slump and earthflow	Soil, ss, cgl	Geologic setting uncertain	300d	30	5	Dry	---	NE	Natural	25	---	Grass and brush	---	---
E7-38	---	5/29/61	Single	Slump and earthflow	Ss, cgl	Strike of dipping beds intersects hill slope at approximately 45°; beds dip in general direction of slope	10	10	3	Dry	---	NE	Natural	30	---	Grass	---	---
E7-39	---	6/16/61	Single	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	15 30d	10	2	Dry	---	NE	Natural	20	---	Grass	---	---
E7-40	2/62	3/23/62	Single	Slump and earthflow	Soil	Beds dip in direction opposite to slope	10	40	1	Wet due to rain	Rain	NE	Natural and cut	27-33	10	Grass	---	Several similar landslides in this area.
E7-41	---	6/5/61	Single	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	30 80d	35	2	Wet due to rain	---	NE	Natural	23	---	Grass	---	---
E7-42	---	6/5/61	Coalescent	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	10	15	2	Dry	---	NE	Natural	24	---	Grass	---	---
E7-43	2/62	3/23/62	Single	Slump and earthflow	Soil, old landslide debris with ss and cgl	Beds dip in direction opposite to slope	20	25	3	Wet due to rain	Rain	NE	Natural and cut	22-33	7	Grass	Slide flowed into cut	---
E7-44	---	6/5/61	Single	Slump and earthflow	Soil, cgl	Beds dip in direction opposite to hill slope	30 100d	60	6	Dry	---	NE	Natural	20	---	Grass	---	---
E7-45	---	6/5/61	Single	Slump and earthflow	Soil	Geologic setting uncertain	100	50	10	Dry	---	NE	Natural	21	---	Grass	---	---
E7-46	1961(?) and 2/62	6/2/61 and 3/13/62	Single	Slump and earthflow	Soil	Beds dip in direction opposite to slope	35d	25	4	Dry (1961) Wet (1962)	---	SW	Natural and cut	22-35	15	Grass	Moved onto building pad	Soil moved on weathered surface of clay shale bedrock.
E7-47	1961(?) and 2/62	3/13/62	Single	Slump and earthflow	Soil, sh	Beds dip in direction opposite to slope	120d	90	4	Wet	---	SW	Natural and cut	22-35	15	Grass	Moved onto building pad	Part of landslide consisted of soil moving on surface of weathered clay shale; surface has attitude N. 35° W., 25° SW.; rest of slide in weathered clay shale moved on two planes (joints?) trending N. 50° W., 75° SW., and N. 10° W., 45° SW.

TABLE 1.--Data on selected landslides in a part of the Orinda Formation, Contra Costa County, California--Continued

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Map no. ([illegible] squares)	Date of landslide	Date examined	Form of landslide	Type of landslide	Type of material	Geologic setting	Approximate size (feet) Length	Width	Maximum scarp height	Wet or dry when examined; source of moisture	Weather immediately prior to landslide	Slope: Exposure	Natural, cut, or fill	Approximate angle before sliding (degrees)	Estimated height of cut or fill (feet)	Vegetation	Damage	Remarks
[illegible]	1961(?) and 2/62	6/5/61 and 3/13/62	Single	Earthflow	Soil, clay	Beds dip in direction opposite to cut slope	55d	35	5	Dry (1961) Wet (1962)	---	SW	Cut	35	15	Grass	Moved onto building pad	---
[illegible]-1	1961(?) and 2/62	6/5/61	Single	Slump and earthflow	Soil	Beds dip in direction opposite to cut slope	10	28	6	Wet due to rain	---	SW	Cut	35	15	Grass	Moved onto building pad	Soil moved on surface of shale and sandstone bedrock.
I5-1	12/55 to 1/56	6/27/61 and 1/31/62	Single	Slump and earthflow	Soil	Beds dip in direction opposite to slope	325d	400	3	Wet	Heavy rain	NE	Natural and cut	---	---	Grass and brush	Several houses damaged beyond repair, street cracked and heaved slightly	Landslide area very wet. Water standing in trenches above landslide each time examined.
I6-2	---	6/12/61	Coalescent	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	400d	50	3	Wet	---	N	Natural	20	---	Grass	---	---
	---	6/12/61	Coalescent	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	400d	120	4	Wet due to rain and seeps	---	N	Natural	18-30	---	Grass	---	---
I6-4	---	6/12/61	Coalescent	Slump and earthflow	Soil, ss	Beds dip in direction opposite to hill slope	300d	100	4	Wet	---	NE	Natural	23	---	Grass	---	---
I6-5	---	6/12/61	Single	Slump and earthflow	Soil, ss	Beds dip in direction opposite to hill slope	60d	30	3	Dry	---	NE	Natural	24	---	Grass	---	---
I6-6	---	6/12/61	Coalescent	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	400d	100	---	Wet due to rain and springs	---	NE	Natural	18-30	---	Grass	---	---
I6-7	---	6/23/61	Coalescent	Slump and earthflow	Soil, clayey ss	Beds dip in direction opposite to hill slope (N. 50° W., 35° SW.); joints trend N. 65° W., 60° NE. and N. 5° E., 65° SE.	650d	50	4	Dry	---	NE	Natural	18-30	---	Grass	---	---
I6-8	---	6/23/61	Coalescent	Slump and earthflow	Soil, clayey sand	Beds dip in direction opposite to hill slope (N. 50° W., 35° SW.)	500d	150	4	Dry	---	NE	Natural	20-30	---	Grass	---	---
I7-1	---	6/23/61	Single	Slump and earthflow	Soil, clayey ss, clay sh	Beds dip in direction opposite to hill slope (N. 55° W., 45° SW.); joints trend N. 50° W., 55° NE. and N. 5° W., 70° SW.	350d	150	5	Dry	---	NE	Natural	18-30	---	Grass and brush	---	---
I7-2	---	6/23/61	Single	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	40	30	4	Dry	---	NE	Natural	19-20	---	Grass	---	Soil is sliding on top of clayey and silty bedrock.
I7-3	---	6/26/61	Coalescent	Slump and earthflow	Soil, silty ss, weathered clay sh	Beds dip in direction opposite to hill slope	150d	220	3	Dry	---	NE	Natural	18-30	---	Grass	---	
I7-4	---	6/26/61	Coalescent	Slump and earthflow	Soil, old slide material, clayey bedrock	Beds dip in direction opposite to hill slope	700d	450	4	Dry	---	NE	Natural	18-30	---	Grass	---	This landslide is very large and complex.
I7-5	---	2/2/62	Multiple	Slump and earthflow	Clayey sand	Beds dip in direction opposite to hill slope (N. 55° W., 45° SW.)	a=200d b=100d c=120d	100 20 20	10 5 5	Dry	---	NE	Natural	20	---	Grass	---	---
I7-6	---	2/2/62	Single	Slump and earthflow	Soil, clayey ss, and sandy clay	Beds dip in direction opposite to hill slope	80d	40	3	Dry	---	NE	Natural	20	---	Grass	---	---
I7-7	---	2/2/62	Multiple	Slump and earthflow	Soil, sandy clay, clayey ss	Beds dip in direction opposite to hill slope (N. 50° W., 35° SW.); joints trend N. 25° W., 60° NE.	a=550d b= 50d c= 80d d=100d e= 35	120 50 40 25 25	10 8 8 10 5	Dry	---	NE	Natural	20-26	---	Grass	---	Landslide "a" is coalescent and has been frequently reactivated; many debris tongues.

TABLE 1.--Data on selected landslides in a part of the Orinda Formation, Contra Costa County, California--Continued

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Map no.	Date of landslide	Date examined	Form of landslide	Type of landslide	Type of material	Geologic setting	Approximate size (feet) Length	Width	Maximum scarp height	Wet or dry when examined; source of moisture	Weather immediately prior to landslide	Slope Exposure	Natural, cut, or fill	Approximate angle before sliding (degrees)	Estimated height of cut or fill (feet)	Vegetation	Damage	Remarks
I7-8	---	6/9/61 and 3/19/62	Coalescent	Slump and earthflow	Soil, clayey sh, clayey ss	Beds dip in direction opposite to hill slope	360d	650	3	Dry	---	NE	Natural	23	---	Grass	Damage to road	---
I7-9	---	6/26/61	Coalescent	Earthflow	Soil, weathered clay sh and ss	Beds dip in direction opposite to hill slope	200d	80	2	Wet from spring flow	---	NE	Natural	18-30	---	Grass, brush, and trees	---	Spring in landslide issues from sandstone bed dipping into hill; water probably moves laterally from higher on hill within confined sandstone bed, issuing as spring where sandstone exposed in gully occupied by landslide.
I7-10	---	6/26/61	Single	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	60	40	2	Dry	---	NE	Natural	16	---	Grass	---	---
I7-11	---	6/23/61	Single	Earthflow	Soil	Beds dip in direction opposite to hill slope	200d+	60	2	Dry	---	NE	Natural	13-30	---	Grass	---	---
I7-12 a	---	6/27/61	Multiple	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	100d	60	3	Dry	---	NE	Natural	20-30	---	Grass	---	---
I7-12 b	---	6/27/61	Multiple	Slump and earthflow	Soil over silty clay bedrock	Beds dip in direction opposite to hill slope	90	20	8	Dry	---	NE	Natural	22	---	Grass	---	Toe of this landslide flowed over scarp of slide "a".
I7-12 c	---	6/27/61	Multiple	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	100d	20	2	Dry	---	NE	Natural	15	---	Grass	---	---
I7-13	---	6/27/61	Coalescent	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	80 150d	50	10	Dry	---	NE	Natural	15-23	---	Grass	---	Large slide with minor scarps forming hummocky topography.
I7-14	2/62	3/27/62	Single	Earthflow	Soil, old slide debris	Beds dip in general direction of slope, but more steeply	140d	25	2	Wet due to rain	Rain	SW	Natural and cut	20-35	15	Grass	Slid into back yard of house	---
I7-15	---	6/9/61 and 3/19/62	Coalescent	Slump and earthflow	Soil, some ss and sh	Beds dip in direction opposite to hill slope	480d	180	1	Wet due to rain	---	NE	Natural	23	---	Grass	Damage to road	---
I7-16	---	6/9/61 and 3/19/62	Coalescent	Slump and earthflow	Soil, clayey sh	Beds dip in direction opposite to hill slope	300d	560	---	Dry	---	NE	Natural	23	---	Grass and brush	---	Dimensions of landslide are difficult to obtain because most of the hillside is involved in sliding.
I7-17	---	6/28/61	Single	Earthflow	Soil	Beds dip in direction opposite to hill slope	40d	40	1	Dry	---	NE	Natural	20	---	Grass	---	---
I7-18	---	6/27/61	Single	Slump and earthflow	Soil	Beds dip in general direction of cut slope, but more steeply	20	15	2	Dry	---	SW	Cut	24	---	Grass	---	---
I7-19	---	6/27/61	Single	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	90	50	3	Dry	---	NE	Natural	22	---	Grass	---	---
I7-20	---	6/9/61	Single	Slump and earthflow	Soil (some cgl in slide debris)	Beds dip in direction opposite to hill slope	20	30	2	Dry	---	NE	Natural	25	---	Grass	---	---
I7-21	---	1/30/62	Single	Earthflow	Soil	Strike of dipping beds approximately normal to hill slope; slide parallel to strike of beds (exactly)	10	40	5	Dry	---	W	Natural	25	---	Grass	---	---
I7-22	2/62	2/16/62	Single	Slump and earthflow	Sh, fill	Geologic setting uncertain	50	100	0.5	Wet due to rain	Rain	SW	Cut and fill	40	---	Grass	Road slumped on downhill side	---
I7-23	10/62	10/16/62	Single	Mudflow	Soil	Beds dip in general direction of hill slope, but more steeply (N. 15° W., 65° SW.); bedrock surface dips 40° to SW.; soil slid on weathered bedrock surface	400d	25	3	Wet due to rain	Rain	SW	Natural	30	---	Grass	---	Flow debris consists of turf and soil which flowed out of small (35- by 25-ft) pocket and down hillside, leaving train of mud, turf, and soil balls on the hill slope.

TABLE 1.--Data on selected landslides in a part of the Orinda Formation, Contra Costa County, California--Continued

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Map no. (grid squares)	Date of landslide	Date examined	Form of landslide	Type of landslide	Type of material	Geologic setting	Approximate size (feet) Length	Width	Maximum scarp height	Wet or dry when examined; source of moisture	Weather immediately prior to landslide	Slope Exposure	Natural, cut, or fill	Approximate angle before sliding (degrees)	Estimated height of cut or fill (feet)	Vegetation	Damage	Remarks
I8-1 a	---	6/28/61	Multiple	Slump and earthflow	Soil	Strike of dipping beds approximately normal to hill slope; landslide approximately parallel to strike	300d	50	10	Dry	---	NW	Natural	30	---	Grass and brush	---	
I8-1 b	---	6/28/61		Slump and earthflow	Soil, clay		100d	50	6	Dry	---	NW	Natural	28	---	Grass and brush	---	
I8-2	---	6/6/61	Single	Slump and earthflow	Soil	Strike of dipping beds approximately normal to hill slope; landslide approximately parallel to strike	200d	40	5	Dry	---	NW	Natural	24	---	Grass	---	
I8-3	---	6/6/61	Single	Slump and earthflow	Soil	Strike of dipping beds approximately normal to hill slope; landslide approximately parallel to strike	100d	30	2	Dry	---	NW	Natural	23	---	Grass	---	
I8-4	---	6/6/61	Single	Slump and earthflow	Soil--very clayey	Strike of dipping beds approximately normal to hill slope; landslide approximately parallel to strike	100d	40	3	Dry	---	NW	Natural	23	---	Grass	---	
I8-5	---	6/6/61	Coalescent	Slump and earthflow	Soil	Strike of dipping beds approximately normal to hill slope; landslide approximately parallel to strike	140d	60	6	Dry	---	NW	Natural	32	---	Grass	---	Some mud flowed out of these landslides during the heavy rains of October 1962. (Mudflows not examined in detail.)
I8-6	---	6/6/61	Single	Slump and earthflow	Soil	Strike of dipping beds approximately normal to hill slope; landslide approximately parallel to strike	150d	50	4	Dry	---	NW	Natural	32	---	Grass	---	
I8-7	---	6/28/61	Single	Earthflow	Soil	Beds dip in general direction of hill slope, but more steeply; flow approximately 45° to bedding	70	50	1	Dry	---	NE	Natural	17	---	Grass	---	
I8-8	---	6/28/61	Single	Earthflow	Soil	Beds dip in general direction of hill slope, but more steeply; flow approximately 45° to bedding	100d	40	1	Dry	---	NE	Natural	15	---	Grass	---	
I8-9	---	6/28/61	Single	Earthflow	Soil	Beds dip in general direction of hill slope, but more steeply; flow approximately 45° to bedding	180d	30	1	Dry	---	NE	Natural	15	---	Grass	---	
I8-10	---	3/12/62	Coalescent	Earthflow	Soil, clay	Strike of dipping beds intersects hill slope at approximately 45°; beds dip in general direction of slope. Part of flow parallel to strike, part about 45° to bedding	300d	75	3	Wet	---	SE	Natural	20-25	---	Grass	---	This landslide is partly in one of several saddles forming along a bed of clay shale, between sandstone and conglomerate beds.
I8-11	---	3/13/62	Single	Earthflow	Soil	Strike of dipping beds intersects hill slope at approximately 45°; beds dip in general direction of slope; Flow parallel to strike (exactly)	200d	20	2	Wet	---	SE	Natural	22	---	Grass	---	Reactivated many times.
I8-12	---	3/12/62	Coalescent	Earthflow	Soil	Strike of dipping beds intersects hill slope at approximately 45°; beds dip in general direction of slope. Flow approximately parallel to strike	220d	300	1	Wet	---	SE	Natural	22	---	Grass	---	Reactivated many times.
I8-13	---	3/12/62	Coalescent	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	350d	50	4	Dry	---	SW	Natural	21	---	Grass	---	
I8-14	---	3/12/62	Single	Earthflow	Soil	Strike of dipping beds approximately normal to hill slope; flow approximately parallel to strike of beds	65	15	1	Wet due to rain and seepe	---	SE	Natural	27	---	Grass	---	

TABLE 1.--Data on selected landslides in a part of the Orinda Formation, Contra Costa County, California--Continued

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Map no. (by grid squares)	Date of landslide	Date examined	Form of landslide	Type of landslide	Type of material	Geologic setting	Approximate size (feet) Length	Width	Maximum scarp height	Wet or dry when examined; source of moisture	Weather immediately prior to landslide	Slope Exposure	Natural, cut, or fill	Approximate angle before sliding (degrees)	Estimated height of cut or fill (feet)	Vegetation	Damage	Remarks
IB-15	---	3/12/62	Single	Slump and earthflow	Soil	Strike of dipping beds intersects hill slope at approximately 45°; beds dip in general direction of slope; slide approximately parallel to strike of beds	400d	120	2.5	Wet due to rain and seeps	---	SE	Natural	20	---	Grass	---	---
IB-16	---	3/12/62	Coalescent	Slump and earthflow	Soil, clay with pebbles	Strike of dipping beds approximately normal to hill slope; slide approximately parallel to strike of beds	400d	100	4	Wet due to rain	---	NW	Natural	24	---	Grass and brush	---	---
IB-17	3/62	3/13/62	Single	Slump and earthflow	Soil, sandy clay sh	Geologic setting uncertain	30d	30	1.5	Wet due to rain	Rain	W	Natural and cut	25-35	12	Grass	Flowed onto yard behind new house	---
IB-18	---	3/12/62	Single	Earthflow	Soil	Strike of dipping beds approximately normal to hill slope; flow approximately parallel to strike of beds	260d	40	1	Wet due to rain	--	SE	Natural	22	---	Grass	---	Reactivated many times apparently by cutting of toe by stream.
IB-19	---	3/12/62	Multiple	Earthflow	Soil	Strike of dipping beds approximately normal to hill slope; flow parallel to strike of beds (seems to be exactly parallel)	a=55d b=30d	125 30	3 1.5	Dry	---	NW	Natural	23	---	Grass	---	This landslide has been reactivated many times apparently by removal of toe by stream.
IB-20	2/62	3/13/62	Single	Slump and earthflow	Soil, clay sh, ss	Strike of dipping beds intersects cut slope at approximately 45°; beds dip in direction opposite to cut slope (N. 55° W., 40° NE); slide approximately parallel to strike of beds	25d	45	20	Wet	Rain	SE	Cut	34	20	Grass	Flowed onto building pad	Attitude of cut slope approximately N. 70° E., 34° SE.; Surface of rupture in shale trends N. 50° E., 50° SE. (joint plane?).
IB-21 a	---	3/13/62	Multiple	Slump and earthflow	Soil, clay	Geologic setting uncertain	250d	115	2	Wet due to rain	---	W	Natural	25	---	Grass	---	---
IB-21 b	2/15/62	3/13/62	Multiple	Earthflow	Old slide debris, clayey ss, sandy clay, sandy sh	Geologic setting uncertain	70d	75	4	Wet due to rain and seeps	Rain	W	Cut	30	15	Grass	Flowed onto building pad	This earthflow is at toe of landslide upslope.
IB-22	---	3/12/62	Single	Slump and earthflow	Soil? (scarp covered)	Strike of dipping beds approximately normal to hill slope; landslide approximately parallel to strike of beds	120d	180	3	Wet due to rain and seeps	---	NW	Natural	23	---	Grass	---	---
IB-23	---	2/27/62	Coalescent	Earthflow	Soil, silty clay sh, ss, cgl	Strike of dipping beds approximately normal to hill slope; flow approximately parallel to and across strike of beds	300d	80	4	Wet due to rain	---	S	Natural	20-25	---	Grass	---	---
IB-24	---	2/27/62	Coalescent	Earthflow	Clay sh	Strike of dipping beds approximately normal to hill slope; flow parallel to strike (exactly)	200d	70	6	Wet due to rain	---	NW	Natural	20	---	Grass	---	Reactivated landslide.
IB-25	---	2/27/62	Coalescent	Slump and earthflow	Soil, very soft clay sh, loose ss and cgl	Strike of dipping beds intersects hill slope at approximately 45°; beds dip in general direction of hill slope; landslide parallel to and across strike of beds	700d	125	12	Wet due to rain	---	N	Natural	20-30	---	Grass	---	Pond on one slump block, rest earthflow.
IB-26	---	5/26/61	Coalescent	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	160d	80	4	Dry	---	NE	Natural	25	---	Grass	---	---
IB-27	---	5/26/61	Single	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	30	70	3	Dry	---	NE	Natural	22	---	Grass	---	---
IB-28	---	5/26/61	Single	Earthflow	Soil	Beds dip in direction opposite to hill slope	10	30	3	Dry	---	NE	Natural	20	---	Grass	---	---
IB-29	---	1/2/63	Coalescent	Slump and earthflow	Soil, sh, ss, cgl	Beds dip in general direction of hill slope, but more steeply	900d	300	10	Wet due to rain and springs	---	NE	Natural	20-30	---	Grass, brush, and trees	---	---

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I9-1	---	3/7/62	Coalescent	Slump and earthflow	Soil, sandy clay sh, loose clayey ss and cgl	Strike of dipping beds approximately normal to hill slope; landslide parallel to strike (seems to be exactly parallel)	300d	80	3	Wet due to seep in center of slide	---	SE	Natural	20	---	Grass	---	---
I9-2	---	3/7/62	Coalescent	Slump and earthflow	Soil, clay sh, soft clayey ss and cgl	Beds dip in direction opposite to hill slope; slide moved both across and parallel to strike of beds	800d	400	8	Wet due to rain and springs	---	SW	Natural	25	---	Grass, brush, and trees	---	Water flowing down center of landslide. Small cross faul seen in cut below landslide trends N. 75° E., 85° NW.
I9-3	---	3/7/62	Coalescent	Earthflow	Soil, clay	Strike of dipping beds approximately normal to hill slope; flow both parallel to and across strike of beds	360d	160	3	Wet due to rain	---	W	Natural	20	---	Grass	---	---
I9-4	---	3/9/62	Single	Earthflow	Soil	Strike of dipping beds approximately normal to hill slope; flow approximately parallel to strike of beds	200d	100	1	Wet due to rain	---	NW	Natural	20	---	Grass	---	---
I9-5	---	3/9/62	Coalescent	Slump and earthflow	Clay soil, ss, cgl	Strike of dipping beds approximately normal to hill slope; landslide approximately parallel to strike of beds	750d	250	3	Wet due to rain and seeps	---	NW	Natural	20	---	Grass and brush	Fence leaning	---
I9-6	---	3/9/62	Coalescent	Slump and earthflow	Soil	Strike of dipping beds approximately normal to hill slope; landslide approximately parallel to strike of beds	700d	100	2	Wet due to rain and seeps	---	NW	Natural	20-25	---	Grass and brush	Fence leaning	---
I9-7	---	3/9/62	Coalescent	Slump and earthflow	Clay sh, ss	Strike of dipping beds intersects hill slope at approximately 45°; beds dip in direction opposite to slope; flow both parallel to and across strike of beds	700d	180	2	Wet due to rain and seeps	---	W	Natural	25	---	Grass		---
I9-8 2/	---	3/9/62	Coalescent	Earthflow	Clay soil, clay sh, clayey ss	Strike of dipping beds intersects hill slope at approximately 45°; beds dip in direction opposite to slope; flow both parallel to and across strike of beds	750d	220	3	Wet due to rain	---	W	Natural	25	---	Grass	Fence leaning, slight damage to farm road across toe	---
I9-9 2/	---	3/9/62	Coalescent	Slump and earthflow	Soil, clay sh, ss, cgl	Strike of dipping beds intersects hill slope at approximately 45°; beds dip in direction opposite to slope; landslide both parallel to and across strike of beds	400d	180	4	Wet due to rain and spring	---	W	Natural	25	---	Grass	---	---
J7-1	---	1/31/62	Single	Slump and earthflow	Clayey sh	Strike of dipping beds approximately normal to cut slope; landslide approximately parallel to strike	6	12	1.5	Wet	---	NW	Cut	35	12	---	---	Bedding a few inches to 20 feet in thickness.
J7-2	10/62	10/16/62	Single	Slump	Ss, sh, cgl	Strike of dipping beds (N. 75° W., 50° SW.) intersects cut slope at approximately 45°; beds dip in general direction of slope; slide moved on bedding planes and on joints trending N. 70° E., 85° NW.; N. 45° E., vertical; and N. 25° W., vertical	105d	80	6	Wet due to rain	---	NW	Cut	33	12	---	Damaged cut and slid onto building pad	Attitude of cut slope approximately N. 40° E., 35° NW.

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							Length	Width	Maximum scarp height			Exposure	Natural, cut, or fill	Approximate angle before sliding (degrees)	Estimated height of cut or fill (feet)			
J7-3	---	1/31/62	Single	Slump and earthflow	Soil, weathered clay sh	Strike of dipping beds intersects cut slope at approximately 45°; beds dip in general direction of cut	15	20	6	Wet	---	SW	Cut	33	15	---	Slid onto flat area graded for housing	This landslide is in an old ravine which contains some old slide material.
J7-4	---	1/31/62	Single	Slump and earthflow	Very soft, loose pebbly ss overlain by sandy silty clay	Beds dip in direction opposite to hill slope	20	65	8	Dry	---	NE	Natural	25	---	Grass and brush	---	This landslide is in an old slide area.
J7-5	---	1/31/62	Single	Slump and earthflow	Soil	Beds dip in direction opposite to hill slope	60	30	3	Dry	---	NE	Natural	26	---	Grass	---	---
J7-6	---	1/31/62	Multiple	Slump and earthflow	Soil (clay sh in debris)	Beds dip in direction opposite to hill slope	a=140d b=100d c= 35d	55 65 40	15 6 3	Wet due to rain	---	NE	Natural	20-35	---	Grass, brush, and trees	---	Reactivated old landslide.

1/ The term "grass" includes miscellaneous herbaceous plants such as thistles, yarrow, tarweed, aster, and dock, as well as grasses.

2/ This landslide falls outside the boundaries of the Orinda Formation as mapped by Lawson (1914). Recent mapping indicates that it is probably within the Orinda Formation, but because the mapping is incomplete, the boundaries of the formation were not revised for this report.

CALENDAR OF EVENTS

May 17 -- Honor Night

June 7 -- "Summertime And The Livin' Is Easy" Election of Officers

September 6 -- "Hail! Hail! The Gang's All Here!" Last Meeting of 1987-88

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Areme responds to Lorraine

Pentalpha Responses:

Lorraine responds to Radiant
Manzanita responds to Lorraine

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La Vonne Lamosh, Excelsior

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