DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

MISCELLANEOUS GEOLOGIC INVESTIGATIONS
MAP I–747

Figure 1. Physiographic provinces of California. From Wahrhaftig and Birman (1965, p. 300).

INTRODUCTION

The accompanying map of California shows the estimated relative proportion of area covered by landslides within various bedrock and surficial units throughout the State. It was prepared in response to a request from the U.S. Coast and Geodetic Survey, in October of 1968, that the U.S. Geological Survey provide information on landslide distribution in California to be used in a study of damage that might be expected in the event of another major earthquake in the State. The data were needed within a few months in order to be included in that computerized study; the map was compiled by D. H. Radbruch and K. C. Crowther in 3 months' time, with support provided by the Coast and Geodetic Survey. Inasmuch as the map may be useful to other groups and individuals for a wide variety of purposes, including regional long-range planning, it has subsequently been prepared for publication with the addition of this explanatory text.

For purposes of this study, all gravitational movements of earth material downslope are considered landslides excepting only creep and the falling or rolling of rock fragments downhill one at a time (generally to accumulate as talus). Landslides are distinguished from transport of earth material by moving water, although the boundary between watery mudflows or debris flows and sediment-laden stream flow is indistinct.

The map uses a dual classification scheme: areas are ranked according to estimated relative amount of area covered by landslides, with amount increasing from 1 to 6, and classified by type of rock or surficial deposit (geologic unit) as shown by letter(s). Thus the symbol for each area on the map consists of a number and a letter, as described in the map explanation. An exception is that areas with average slopes less than 5° and most areas that receive less than 10 inches mean annual precipitation are assigned to rank 1 and are not further distinguished by geologic unit. Faults are drawn throughout the map area as indicators of possibly large numbers of landslides in sheared rock that are independent of the ranking of adjacent map units.

METHOD OF COMPILATION

In order to show on a map the relative amounts of landslides per unit area in California, where quantitative data on landslides are scarce, it was necessary to consider and evaluate a number of complexly interrelated factors that contribute to landsliding in combination with the available qualitative information.

Data on slope, precipitation, and geologic units—major factors contributing to landsliding—were generalized and plotted on maps for the entire State, which were then evaluated and combined. The resulting map units were subsequently modified by consideration of (1) other factors contributing to landsliding; (2) information gained through correspondence and conversation with persons working on geologic mapping, some as yet unpublished, in scattered parts of California; and (3) reconnaissance and spot-checking in the field, both on the ground and from the air. The map units, therefore, indicate only the estimated relative amounts of area covered by landslides for each map unit as well as can be determined within the limitations of the present study. No quantitative measurements were made. Many areas that were neither observed in the field nor covered by published or unpublished data were assigned numbers on the basis of the general aspect of similar geologic units in a comparable setting.

Areas in which the slope averages less than 5° or the rainfall less than 10 inches were observed to have a minimum amount of area covered by slides and were assigned a number 1; areas observed or estimated to have a maximum amount of area covered by slides (such as most of the Franciscan terrane in the northern Coast Ranges) were assigned a number 6; areas estimated to have a very large amount of area covered by slides but not quite as much as those rated as 6, a number 5; areas estimated to have very few slides, but slightly more than those rated as 1, a number 2. Areas were assigned to 3 or 4 according to the best relative numbers on that scale that could be made. No attempt was made to evaluate the absolute differences between the landslide ratings, which are not to be construed as indicating which areas are safe or unsafe for construction. Whether unit 6, for example, contains three times as much area covered by landslides as unit 5, or unit 4 only twice as much area of landslides as unit 3, cannot be determined from this study. The rating assigned to any map unit reflects the overall generalized aspect of the area. It must be emphasized that even the areas rated as having the largest amount of area covered by landslides contain parts that lack landslides, and parts of the lowest ranked units contain landslides.

MAP LIMITATIONS

In using the map, it is essential to consider the following circumstances under which the study was made:

1. The study was undertaken for a special purpose, with a strict time limitation.

2. The study was made and presented on a very small (synoptic) scale, so that it is highly generalized. Amount of data and time available did not warrant preparation or presentation on a larger scale.

3. Because of the small scale and the scarcity of pertinent landslide data of all kinds throughout the State, many factors influencing the formation of landslides could not be systematically considered. Therefore, the study includes much highly subjective interpretation that reflects the experience, opinions, and prejudices of the compilers more than they would like.

FACTORS CONSIDERED IN COMPILING MAP

Many complexly interrelated factors contribute to landsliding, chiefly the natural geologic conditions and the processes that act upon earth materials to cause changes that increase the tendency of a mass to move downslope under the influence of gravity. Most such changes either decrease average shearing resistance or increase the shearing forces without changing the resistance to shear, generally by removing lateral support or differentially loading a slope. (See Terzaghi, 1950). The main contributing factors considered in distinguishing the six ranks on the map are slope, precipitation, and generalized geologic unit. Other factors were considered to a limited extent.

MAIN FACTORS

Slope.—A sloping land surface is generally assumed to be necessary for landsliding. Although slides may form on very low slopes—for example, the slide at Otowska, New Zealand, which moved on a slope of 3½° during the Inangahua earthquake (Lensen and Suggate, 1968) and one at Ullensaker, Norway, which moved on a slope of 3 to 4 percent (Bjerrum, 1955)—their number is relatively small compared with those on the steeper slopes. Most movement does not take place in flat unbroken areas with no free faces.

An attempt was made to determine the angles of slopes susceptible to sliding by referring to publications that mentioned this subject (Beaty, 1956; Blanc and Cleveland, 1968; Varnes, 1958; Coogan, 1936; Kachadoorian, 1956; Kessel, 1943; Leighton, 1966; McGill, 1951; Radbruch and Weiler, 1963); by making measurements of slopes adjacent to landslides shown on maps of various parts of the State (Allen, 1946; Blanc and Cleveland, 1968; Cleveland, 1962; Irwin, 1963); by correspondence and conversations with persons working on geologic mapping in various parts of California (L. D. Clark, T. W. Dibblee, W. P. Irwin, oral commun., 1969; T. H. Nilsen, oral commun., 1970; Michael Duncan, written commun., 1963); and field reconnaissance in various parts of California. From these sources it appeared that most landslides form on slopes ranging from 15° to 35°, with a rather sharp break in frequency near each end of the range. A smaller but appreciable percentage of slides was found on slopes ranging from 5° to 15° and above 35°, and very few on slopes below 5°.

A map was prepared showing areas of slopes below 5°, using the 1:500,000-scale topographic map of the State with 500-foot contours. All slopes that appeared to fall below 5° were classed as having a minimum area covered by landslides. Much dissected rolling or flat terrain with less than 500 feet of local relief was therefore assumed to have an extremely small area covered by slides except where known to contain steep slopes and(or) to contain extensive landslides, such as the Pacific Palisades area of Los Angeles (McGill, 1963). Where such exceptions were known or suspected from the available literature, they were given a number of 2 or 3.

An isohyetal map of mean annual precipitation in California, prepared by the U.S. Geological Survey (Rantz, 1968) on a scale of 1:1,000,000, was generalized and enlarged to the scale of 1:500,000. Landsliding is rare in areas where the mean annual precipitation is less than 10 inches. These areas were therefore classified as having a minimum area covered by landslides regardless of other factors, except for a few slopes immediately adjacent to areas having high precipitation, such as the northeastern slopes of the San Bernardino Mountains. In these excepted areas, slopes greater than 5° were further evaluated for the slide susceptibility of the various geologic map units. The reasons for the slides at certain places on the margins of desert areas, but not within them, are not clear but may include the influence of runoff from adjacent areas of high precipitation, a cutoff point lower than 10 inches, seasonal rainfall higher than 10 inches, extreme variation in intensity from year to year, ground water moving from adjacent areas of high precipitation, or a combination of these or other, unknown, factors.

Slope material.—The second major factor used in preparation of the accompanying map is precipitation. Precipitation largely determines the amount of water available for stream erosion with consequent steepening of slopes and undercutting by stream channels; it can differentially load a slope or decrease the shearing resistance of material on slopes, and it contributes to fluctuations in ground- and surface-water conditions. Any of these changes in conditions can increase the tendency of slopes to slide.

Within areas receiving more than 10 inches mean annual precipitation, no direct correlation generally could be established between amount of precipitation and number of landslides. Even in the Northern Coast Ranges, where mean annual precipitation ranges in general from 40 to more than 100 inches per year, rock conditions appear to be more of a factor in determining slide distribution than amount of precipitation. In any given area, however, landsliding is more frequent in wet years than dry, which indicates that seasonal distribution or differences in intensity of precipitation and annual variation in precipitation may be locally more significant factors in causing landsliding than mean annual precipitation. Lack of correlation between number of landslides and amount of precipitation could also be due to a change in climate, as more landslides probably formed during Pleistocene time when the climate was wetter than it is now.

Generalized geologic unit. The third main factor used in preparing the map is the type of rock or soil underlying the surface. The effect of slope and precipitation, and numerous other factors that contribute to landsliding, is dependent upon the nature of the earth material influenced by these factors.

Areas with slopes in excess of 5° and(or) precipitation of 10 inches or more per year—primarily the Coast Ranges, Transverse and Peninsular Ranges, the Klamath Mountains, the Cascade Range and Modoc Plateau, and the Sierra Nevada—were divided into areas underlain by various generalized geologic map units.

In order to select these geologic units, a generalized geologic map was compiled from the California Division of Mines and Geology 1:250,000-scale geologic series, and a brief survey of readily available literature dealing with landslides in California was undertaken before the selection of the generalized geologic units to aid in determining which geologic units on the State geologic map might have similar landslide characteristics and should therefore be combined. State geologic map units with apparent similarities in slide susceptibility were combined, generalized, and plotted on a 1:500,000-scale topographic base map in the units shown in the explanation.

OTHER FACTORS

Faults. Faults were not used to estimate relative amount of sliding in the generalized geologic units on the final map, but because their presence appears to be a critical factor in some landslides in the State, most known large faults on the 1:250,000-scale map of California were included. Where feasible, areas of intense shearing caused by faulting were indicated by showing some of the short, anastomosing faults in these areas. Intense shearing within parts of the Franciscan Formation is a special problem, discussed in the section on the Northern Coast Ranges.

The following conditions and processes contributing to landsliding were used directly or indirectly to estimate relative amounts of landslides in the generalized geologic units wherever available information permitted; data on these additional factors were not available for the entire map area.

Physical conditions of rocks. The State of California geologic map used in the compilation shows primarily lime-stratigraphic units, not lithologic units. Therefore many of the geologic units on the State map and on the landslide map are not defined on the basis of lithology, or vary widely in lithology and in physical properties both horizontally and vertically. Lithology and physical properties, or differences in them within a single map unit, were evaluated where possible.

Slides are frequent on slopes where the upper part consists of harder rock than the lower part, such as basalt above clay (Nemčok, 1964; 1966; Rybar and Nemčok, 1968; Russell, 1900, 1927; Creely, 1965; Shreve, 1968). This slope condition is an indirect factor influencing the amount of landsliding in the various geologic units. Most of the Tertiary sedimentary units, which are among the most susceptible to landsliding in the State, are poorly consolidated rocks consisting of interbedded sedimentary layers of varying hardness, so that many slopes undertain by Tertiary rocks consist of hard rocks overlying or interbedded with softer ones. Shear zones also create this condition on some slopes (Putnam and Sharp, 1940), particularly if the zones are rather flat, because the fault movement may have brought hard rocks into superposition or juxtaposition with soft ones, or soft sheared rocks within a shear zone may act as a soft unit under or between harder unsheared rocks.

The fractured or sheared condition of an entire rock unit, as distinguished from locally crushed or sheared rock along a fault or fault zone, was evaluated in assigning numbers to the map units where possible. Fractured rock is more susceptible to sliding than unbroken rock because it is more easily weathered and eroded, absorbs water more easily, and has less shearing resistance.

Works of man.—The works of man are a major factor contributing to landsliding in California. Construction of streets and building pads may remove lateral support from slopes, as well as differentially load and oversteepen them, thereby making them more susceptible to sliding. Moreover, improperly placed fills on hillsides commonly slide. Watering of lawns and gardens and drainage from septic tanks add moisture to the ground, decreasing the shearing strength, and may differentially increase the weight.

Development in urban and suburban areas has been a "hidden" factor in some of the reference material used for estimating relative amounts of landslides in the geologic units; for example, Leighton's report (1966) on the southern California area deals slides in fill and on graded hillsides which might not have formed had the slopes remained undisturbed by urban development.

Tectonic setting. Tectonic history is a general consideration in the evaluation of landslide conditions in California, as it is obvious that intense and long-continued tectonic activity is one of the major underlying reasons for the unusual amount of landsliding in this part of the United States. Past tectonic activity has resulted in the formation of thick deposits of young, poorly consolidated sediments and their subsequent deformation, considerable distortion and crushing of older rocks, and regional or local uplift of varying ages and amounts. Present tectonic activity, especially along active faults, also results in shearing of rocks and uplift, with resultant rapid erosion and removal of lateral support. It also causes earthquakes that can trigger landslides (Buwalda and St. Amand, 1955; Close and McCormick, 1922; Davis and Karnilovic, 1963; Fuller, 1912; Hadley, 1964; Hansen, 1966; Lawson, 1908; Lensen and Suggate, 1968; Miller, 1960; Muir, 1962). Earthquakes can reduce shearing resistance and cause liquefaction of soils (Seed, 1968).

Tectonically influenced landsliding can be found in many places throughout California. For example, in the San Francisco Bay area, landslides are numerous on the southwest side of the active Calaveras fault, where it extends northwest and southeast from Dublin (concealed) not shown on map). Rapid uplift on the west side of the fault, indicated by the apparent downcutting of Alameda Creek through a rising landmass (Wahrhaftig, 1963), may have accelerated erosion in the high hills on that side of the fault, where landslides are more abundant than in the low hills on the northeast side.

Factors considered but not evaluated. Factors contributory to landsliding but not evaluated because of time limitations and lack of data include vegetation, climatic variations, progressive loss of cohesion with time, topographic features, pore-fluid or uplift pressure and tectonic stress patterns. They should be investigated in any future similar studies wherever possible.

The relation of vegetation to landsliding is not thoroughly understood. Deeply rooted trees may inhibit sliding, primarily by the binding effect of the roots and the drying out of the slope by transpiration, but this probably applies only to relatively shallow slides (Zaruba and Menel, 1969). The failure surface of many large slides in various parts of California lies well below the root zone of even the largest trees.

Climatic factors, such as seasonal and areal variations in distribution, intensity, and type of precipitation are important locally. Frost wedging can widen fractures in rocks and dislodge rock fragments. South-facing hillsides dry out more quickly than north-facing ones. The influence of differences between present climate and Pleistocene climate was not evaluated.

Progressive loss of cohesion in the material of slopes with time as discussed by Skempton (1948) and Terzaghi (1950) is also a factor in landslide formation as are other types of change, including spalling of granitic rocks, chemical alteration of rocks, soil formation, and weathering of various types of rocks under different climate conditions.

Topographic features such as projecting spurs along rivers or at the junction of streams may be particularly susceptible to landsliding (Blanc and Cleveland, 1968; Fuller, 1912).

Pore-fluid pressure or uplift pressure is important in the formation of many types of landslides, ranging from those where water-bearing sediments are overlain by less permeable material (Zaruba and Menel, 1969; Terzaghi, 1950) to large-scale gravity sliding that is of such magnitude that it has been considered tectonic (Hubbert and Rubey, 1959; Rubey and Hubbert, 1959; Hsü, 1969). Other ground- and surface-water conditions and fluctuations can contribute to sliding.

Tectonic stress patterns may influence the stability of slopes (Hast, 1958; Zaruba and Menel, 1969).

DISCUSSION OF LANDSLIDES IN CALIFORNIA BY PHYSIOGRAPHIC PROVINCE

Landslides in California can be discussed by physiographic province (see fig. 1 in ⁰) because the complex interrelated processes and conditions that cause sliding also form the distinctive landscape of each province. The physiography of California has been described by Hinds (1952), and only those features that seem to be closely related to landsliding will be mentioned here.

The general angle and height of slope is a characteristic feature of each province; one obvious difference between the Great Valley and the Klamath Mountains is the flatness of one and the steep slopes of the other. Climate, especially precipitation, is instrumental in shaping landforms as well as in causing landslides; stream action is one of the prime factors in shaping the landscape, and the amount of water available to streams depends largely on climate. Many of the differences in landforms between a humid area like the Klamath Mountains and an arid one like the Mojave Desert are due to differences in climate.

Rock type, faulting, and regional uplift are major determinants of physiographic form. The rolling hills that have formed on the soft sedimentary rocks of much of the Coast Ranges differ considerably in outline from the harsh, barren surfaces of volcanic flows and cinder cones in the Modoc Plateau. Fault movement has sheared large volumes of rock in the Franciscan Formation, making it more susceptible to widespread sliding that gives the land surface over extensive areas of the Northern Coast Ranges a characteristic plastic, undulating appearance. The high and spectacular eastern front of the Sierra Nevada and the steep fronts of many ranges in the Basin and Range province are a result of relative vertical movement along faults. Uplift and warping of the surface of the land have produced tilted shoreline terraces along the Pacific Coast. Uplift also promotes rapid downcutting by streams, which causes landsliding by removal of lateral support and has resulted in the gorges of the western Sierra Nevada and the Klamath Mountains as well as steepsided canyons and ravines in many other parts of the State.

Geologic structures other than faults influence both the physiographic character and the nature of landsliding—for example, the northwest-trending folds of parts of the Coast Ranges are differentially eroded to produce northwest-trending ridges and valleys; this affects the distribution of landslides in some of the folded sediments (Radbruch and Weiler, 1963).

⁰Tectonic. Of, pertaining to, or designating structures resulting from deformation of the earth's crust, especially faulting (Webster's New Collegiate Dictionary, 2d ed., 1953).

The landslides that form in the different conditions of each physiographic province are characteristic of the province and contribute to its physiographic character.

In a general way, the physiographic provinces of the State can be classified as follows, in decreasing order of the amount of landslides: Northern Coast Ranges, Southern Coast Ranges, Transverse Ranges, Klamath Mountains, Sierra Nevada, Peninsular Range, province of Southern California, Cascade Range, Modoc Plateau, Basin and Range (with its subprovinces of Mojave Desert and Colorado Desert), and Great Valley.

NORTHERN COAST RANGES

The Northern Coast Ranges lie along the Pacific Coast, extending from San Francisco Bay northwestward nearly to the Klamath River, and are bounded on the east and northeast by the Great Valley and the Klamath Mountains. The climate ranges from semiarid⁰ (Fairbridge, 1967) in the southeastern part to very wet in the northern part of the province. Rainfall is seasonal.

The predominant map unit is the Jurassic and Cretaceous Franciscan Formation, but Mesozoic sedimentary rocks, Tertiary and Quaternary sedimentary and volcanic rocks, serpentinite, and metamorphic rocks are also represented. Many of these rocks are poorly consolidated, and in addition are sheared and contorted. Parts of this province have been uplifted during Quaternary time (Wahrhaftig and Birman, 1965, p. 324), and tectonic activity continues into the present. Downcutting by streams is rapid and canyon slopes are steep.

The most slide-prone large area in the State is in Franciscan terrane of this province. From Marin County (Twiss and others, 1969) northwestward through Humboldt County, north of Eureka, parts of the Franciscan Formation are unusually susceptible to landsliding. Landslides are numerous in sheared and shattered sandstones and shales, which commonly contain fist-sized to house-sized exotic blocks of more resistant greenstone, chert, and metamorphic rocks of various kinds. Landslides of several square miles in extent are common. The entire region underlain by this particular rock unit gives an impression of plastic movement, with the sheared material flowing downhill around the larger protruding exotic blocks to form a soft, creeping, Dali-esque landscape.

These rocks have been likened to the "argille scagliosa" of Italy's Apennines (Page, 1966). They also appear to resemble, in physical characteristics and appearance, if not in origin, the "colored melange" of the Alps, the Himalayas, and Iran (Ganser, 1964); the Oneraki chaos-breccia of New Zealand (Kear and Waterhouse, 1967); and the Klippen Belt of the Czechoslovakian West Carpathians (Maheľ and others, 1968). All these units are extremely prone to landsliding.

Recent studies have been made of the Franciscan Formation north of San Francisco Bay (Bailey and others, 1964; Brown, 1964), but very little detailed mapping has been completed. Some mapping by geologists of various State and federal agencies is now in progress, but it is not possible at this time to accurately divide the Franciscan Formation, which occupies such a large part of the Northern Coast Ranges, into areas that are relatively stable and those that are underlain by sheared, slide-prone rocks.

The exact origin of the sheared part of the Franciscan Formation is currently a matter of active study and debate among geologists working in California, although there is little doubt that at least some part of its distinctive character is the result of large-scale thrusting (Bailey and others, 1964; Brown, 1964; Bailey and Blake, 1969).

The type and amount of landslides in the sheared rocks make these rocks a subject of great interest to engineering geologists and engineers, especially as they occupy such a large part of the Northern Coast Ranges. If engineering structures are planned on slopes underlain by the sheared part of the Franciscan Formation, the likelihood of construction and maintenance difficulties due to landsliding should be considered. To date there has not been much urban development in the Northern Coast Ranges, where the sheared rock is predominant, but suburban development is now extending northward from San Francisco Bay into such landslide areas in Marin County (Twiss and others, 1969), and engineering works such as highways, bridges, railroads, dams, and reservoirs are being built in increasing numbers in this terrane.

Other parts of the Franciscan Formation (Irwin, 1960) are also prone to sliding, but not quite to the extent of the intensely sheared rocks. Parts of the Franciscan Formation which consist of comparatively undisturbed, more massive rocks, like those immediately north of the Golden Gate, are relatively stable.

The Northern Coast Ranges have been uplifted since late Pliocene time; deformation has affected the ranges throughout the Quaternary (Wahrhaftig and Birman, 1965). Stream erosion is intense; the lower one-third of the Eel River drainage basin annually discharges 7,899 tons of suspended sediment per square mile, more than any basin of similar size in the United States (Hawley and Jones, 1969); numerous landslides along the Eel River contribute to this sediment load (Brown and Ritter, 1969). However, not all of this unusual discharge is due to normal geologic processes; part of it is the result of man's activities, particularly road-building, logging, and conversion of forest to grassland, which remove vegetation and expose the slopes to erosion (Wahrhaftig and Curry, 1966).

Extensive sliding could be expected in this province at the time of a strong earthquake and would probably include much sliding into stream channels, with consequent damming of the streams, reactivation of existing slides; slumping of seacliffs; and slumping, cracking, and lurching in alluvial plains and along stream banks. Many slides along the seacoast, as well as elsewhere in the province, were reported at time of the 1906 earthquake (Lawson, 1908).

SOUTHERN COAST RANGES

The Southern Coast Ranges lie between the Pacific Ocean on the west and the Great Valley on the east, and extend from San Francisco Bay southward to the Transverse Ranges. The province consists of a number of complex ranges and depressions, underlain by a great variety of rocks, including granite, Franciscan rocks, Mesozoic rocks other than Franciscan, Tertiary sedimentary and volcanic rocks, and poorly consolidated Quaternary deposits. The rocks are folded and faulted, and the province is sired by the historically active northwest-trending San Andreas fault system, along which extensive right-lateral displacement has occurred.

Slopes are dissected by numerous steep-sided canyons and ravines. The climate is predominantly semiarid but ranges from arid at the edge of the Great Valley to humid at places along the coast. Landslides of various types are abundant, and areas have been ranked from 1 to 6.

The largest and most numerous slides, of the slump-earthflow type, are on and near the coast in a humid area underlain by sheared Franciscan rocks, between Cape San Martin and Morro Bay, and in Franciscan terrane of the Diablo Range both north and south of Pacheco Pass. They resemble the landslides in similar material in large parts of the Northern Coast Ranges. The numerous slides in the Santa Ynez Mountains are a mixed assemblage of predominantly crystalline rocks that is partly bounded on the northwest side by the Tejon Canyon fault and the historically active White Wolf fault, and on the southeast side by the Garlock and other faults; however, uplift on the southeast side apparently consisted largely of warping, not fault movement (Rwanika, 1954). During Quaternary time the Tehachapi block was uplifted as much as 5,000 feet in relation to the Great Valley. Erosion is intense and rapid. Large slides over most of the northwest-facing scarp of the White Wolf fault; landslides also occur in some of the mountains of shaking rock on the southeast side of the range and in some Tertiary sedimentary rocks on the northwest side.

Earthquakes might trigger rockfalls, avalanches, and rock debris flows (rock fragment flows—Varnes, 1958) in this province, perhaps large slump landslides where volcanic rocks overlie softer deposits. Muir (1962) described a large and spectacular rockfall in Yosemite Valley during the 1872 earthquake. Widespread landsliding in the Tehachapi Mountains was a conspicuous result of the 1952 Arvin-Tehachapi earthquake (Buwalda and St. Amand, 1955).

PENINSULAR RANGE

The Peninsular Range is a mountainous arid to humid province that extends southeastward from the Los Angeles basin into Baja California, and eastward from the seacoast to the desert. It includes a wide variety of topography and rock types, ranging from flat alluvial valleys and marine terraces to granite mountain peaks. Slide ratings in the province range from 1 to 6.

The bulk of the province consists of an uplifted and tilted block of granitic and metamorphic rocks which has been broken into several smaller blocks by major faults. Most of these faults have apparently been active throughout Cenozoic time, and movement on some of them continues up to the present (Jahns, 1954). Younger Mesozoic and Tertiary sedimentary rocks are exposed in parts of the province, particularly along the coast.

The granitic and metamorphic rocks are not very extensively involved in sliding; most of them are rated as 2 and 3 on the accompanying map. However, much of the granitic rock is highly jointed, and has weathered into large blocks, house-sized and smaller, that accumulate on the surface as weathering and erosion proceed. They have been described by Larsen (1951) as "boulders of disintegration." Numerous slopes in this province are mantled by such blocks, many of which are precariously balanced on the steep hillsides. These unstable blocks constitute a definite hazard to any structures below them, particularly at the time of a major earthquake, as many boulders would be loosened by the tremors and roll downhill, crushing anything in their path. This behavior of boulders at the time of an earthquake is well documented (Buwalda and St. Amand, 1955).

The Tertiary formations at the north end of the province have abundant landslides and are rated as 5 and 6. Sliding is common along some of the currently active faults; according to Jahns (1954) much of the trace of the Elsinore fault is buried by landslide material.

Recent relative uplift of the coastal part of the province is indicated by raised marine terraces. This uplift has resulted in rapid erosion of the soft Tertiary sediments along the west side of the range; they possibly 2,000 feet in the western part of the area resulted in severe erosion with formation of steep-sided V-shaped canyons and sharp ridges; lateral deflection of stream channels along the Santa Ynez fault indicates that this fault may still be active (Dibblee, 1966).

Some of the most slide-prone areas in the State of California are in the Transverse Ranges; much of the area is rated as 5 and 6 on the accompanying map. Landslides, particularly debris flows, are abundant in the intensely sheared granitic and metamorphic rocks of the San Gabriel Mountains (Morton and Streitz, 1969). These badly sheared rocks are similar to those in New Zealand that slid extensively at the time of the 1968 Inangahua earthquake (Lensen and Suggate, 1968). The well-known recurring debris flows at Wrightwood, on the northeast side of the San Gabriel Mountains, originate in thoroughly fractured rocks between the San Jacinto and San Andreas fault zones (Sharp and Nobles, 1953). The granitic and metamorphic rocks that form most of the San Bernardino Mountains are less fractured and landslides are less abundant (rated as 2 and 3), although the huge Blackhawk slide originated in these mountains (Shreve, 1968).

In many of the Tertiary sedimentary rocks of the Santa Monica and Santa Ynez Mountains, in the western part of the province, thin slides and flows of surficial material (locally called "skin slides") originating near the tops of ridges are so numerous that they form a characteristic pattern of triangular landslide scars along one or both sides of many sharp ridges in these ranges. Larger, deeper slides are also common in the Tertiary sedimentary units, particularly on the south side of the Santa Monica Mountains (Campbell and others, 1970).

Trenches along the lines of ridges in the Santa Ynez Mountains north of Ventura (T. W. Dibblee, Jr., oral commun., 1970; Radbruch, field observation, 1970) appear to be the result of very large-scale creep or sliding, possibly during late Pleistocene time. They are similar to features observed in Alaska (G. Plafker, oral commun., 1970), Venezuela (L. S. Cluff, oral commun., 1970), the Olympic Mountains of Washington (R. W. Tabor, 1971), and described in New Zealand (Beck, 1967), Japan (Kobayashi, 1956), and Czechoslovakia (Nemčok and Pašek, 1969). The trenches in the Santa Ynez Mountains extend for as much as 3,500 feet along the tops and sides of ridges and may be as much as 50 feet wide and 20 feet deep. Some have no exterior drainage and contain intermittent ponds.

⁰Climatic designations in inches of mean annual precipitation:

Arid: 0–10	Humid: 40–80
Semiarid: 10–20	Very wet: greater than 80
Subhumid: 20–40	

CASCADE RANGE

The Cascade Range, extending into California from the north, is primarily a volcanic field, characterized by large recently active volcanoes along its length. It includes some relatively flat lava plateaus, lava and cinder cones, plug domes, ash beds, and glacial deposits, as well as the prominent composite and shield volcanoes. Lassen Peak, near the southern end of the range, erupted during the period between 1914 and 1917. Mount Shasta, northwest of Lassen Peak, has probably been active within the last 200 years (Hinds, 1952). The province has been cut by faults and in some places eroded by streams. The climate is semiarid to very wet.

Mudflows have accompanied volcanic eruptions in this area in the past, and might again (Crandell and Waldron, 1969; MacDonald, 1966). Snow and ice are abundant on Mount Shasta, and traces of avalanches are numerous there (Hinds, 1952). Glaciers cover a small part of the mountain; in the spring, water from melting ice sometimes undermines the tuff and breccia walls of canyons, causing mudflows. Rockfalls on steep slopes are common. Both rockfalls and snow and rock avalanches could be expected at the time of an earthquake in this province.

MODOC PLATEAU

The Modoc Plateau is a high, generally semiarid region of northeastern California that is part of the vast Columbia Plateau, which covers much of Washington, Oregon, and southern Idaho. Most of the Modoc Plateau consists of Pliocene and younger lava flows with very flat surfaces broken by cinder cones. The flows have been cut by numerous faults that have formed pronounced scarps. Because of high porosity and permeability of the flows, and low rainfall, the water table is generally low except along watercourses and bodies of standing water. The relative aridity, hard rock, and low water table characteristic of this province tend to reduce the rate of erosion and weathering. A few landfalls may form along steep slopes, mainly along the fault scarps, but otherwise there seem to be very few landslides of any kind. The flat areas are rated as 1 and the rest of the province as 2.

It is well known that dense, jointed rocks of volcanic flows overlying softer material are susceptible to massive sliding (Russell, 1900; Záruba and Menel, 1969), but sliding is extremely rare in this area because the flows are so thick and the interbeds of softer material so few.

BASIN AND RANGE

The Basin and Range province is part of the Great Basin, which includes part of California and most of the adjacent State of Nevada. Most of the province is arid and therefore low in slide susceptibility; the arid parts are rated as 1. This province is characterized by the many discontinuous north-trending subparallel mountain ranges and intervening basins that have been formed by uplift and depression along faults; many of the ranges are tilted blocks separated by basins that are alluvium-filled grabben with no exterior drainage. One of the best known of these basins is Death Valley, the floor of which reaches 270 feet below sea level. Granitic, metamorphic, and Paleozoic sedimentary rocks are the predominant geologic units in the ranges.

Rockfalls on steep slopes, minor slumps of the steep sides of washes, and mudflows are landslide types typical of desert regions that are prevalent in the arid parts of the Basin and Range province. Some very large landslides, ranging in type from rotational slumps (Russell, 1927, 1928) to debris flows, also are present in the province, both in California and in adjacent Nevada. Two outstanding examples are the Tin Mountain landslide, west of Death Valley (Burchfiel, 1966), and the Blackhawk landslide, at the western edge of the province, on the north side of the San Bernardino Mountains (Shreve, 1968). These large inactive slides may be Pleistocene landslides, which formed when the climate of the Great Basin was much wetter than it is now. Morrison (1965) cites evidence that rainfall there during the Pleistocene may have been approximately twice what it is at the present time.

The Mojave Desert subprovince is extremely arid, so that landslides are few. It is characterized by alluvial basins and low mountain ranges. It differs from the northern part of the Basin and Range province primarily in the lower elevation of the ranges and the lack of conspicuous parallel arrangement of ranges and basins. There is much evidence of geologically recent faulting; in some places the fronts of the ranges are obvious, rather steep fault scarps. Rockfalls occur where mountain slopes are steep. Rockfalls and slumps along the banks of dry washes could be expected at the time of a major earthquake.

The Colorado Desert subprovince is a broadly V-shaped structural trough with a generally flat alluvial bottom and an extremely dry climate. At one time the southeastern end of the desert was the head of the Gulf of California, which was cut off by the delta of the Colorado River. Part of this area is now occupied by the Salton Sea. Most of the central part of the desert is a rather flat alluvial plain. In places bedrock masses project above the alluvium, and there are some badland areas near the edges of the subprovince. The badlands and some alluvial areas are cut by steep-walled dry washes formed by infrequent flash floods, but there is very little sliding of the walls (Hinds, 1952).