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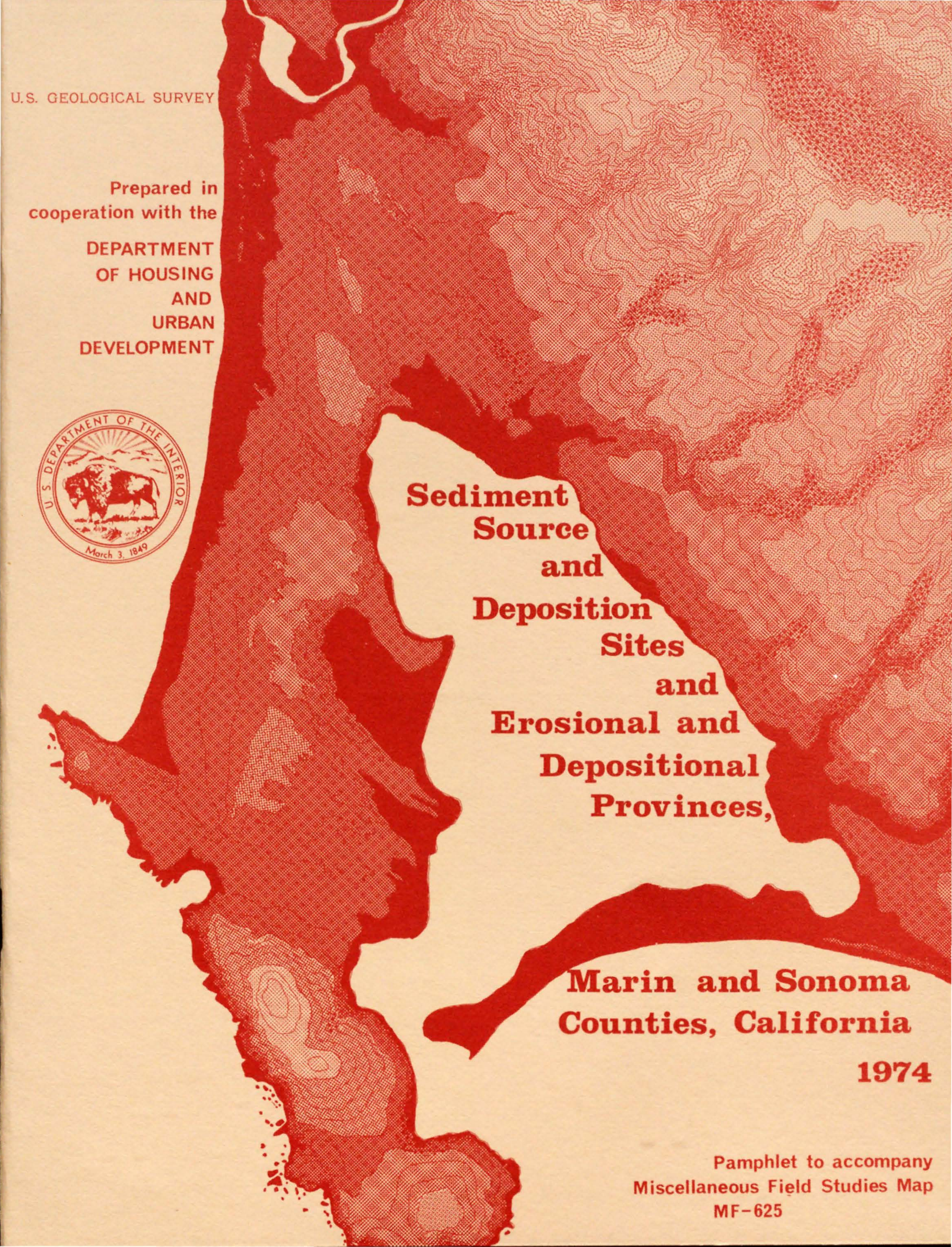

Sediment Source and Deposition Sites and Erosional and Depositional Provinces, Marin and Sonoma Counties, California

1974

Pamphlet to accompany
Miscellaneous Field Studies Map
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SEDIMENT SOURCE AND DEPOSITION SITES AND EROSIONAL AND DEPOSITIONAL PROVINCES

MARIN AND SONOMA COUNTIES, CALIFORNIA

By William M. Brown III and Lionel E. Jackson, Jr.

INTRODUCTION

The land surface of Marin and Sonoma Counties is a precise recorder of the natural and artificial factors that have shaped it. It is also an excellent predictor of the forms it will probably have in the future, given an estimate of the human and natural factors expected to act upon it. Studying the land surface for clues about its past and future, therefore, is a necessary aspect of thorough land-use planning and decisionmaking about land-use designs.

This report is intended to aid the planner and decisionmaker in studying the land surface of Marin and Sonoma Counties. It is primarily concerned with the erosion, transportation, and deposition of sediment as a process that alters the land surface. It attempts to explain what sediment is, where sediment comes from, and where sediment goes. This report also describes how and why sediment moves from one point to another and for areas where data are available describes rates and quantities of sediment movement.

The report consists of two map sheets and an explanatory pamphlet. The pamphlet explains the purpose, scope, organization, and format of the map sheets, describes in detail the map units shown on sheet 1, and contains a list of selected references that provide more detailed information about the study area.

Sheet 1 contains a map of Marin and Sonoma Counties at a scale of 1:125,000 and a brief explanation of the various map symbols. Basically, the map shows the principal places from where sediment is eroded and the principal sites where sediment is deposited. Each of the processes represented by a symbol on the map is explained in some detail beginning on page 5 of this pamphlet.

The map on sheet 1 shows division of the land surface into numerous regions. Each region has been given a number, 1 through 8, which designates the region according to the dominant erosional or depositional process acting on a particular land mass. Numeral 1 designates areas of highly transitional, erosional, and depositional processes. Numeral 2 designates areas where sediment deposition is the major process acting on the land surface. Numerals 3 through 7 designate areas where erosion is the dominant process acting on the land surface, and numeral 8 designates isolated areas of erosion and deposition within the larger regions. These land surface regions are termed *erosional and depositional provinces* and are described beginning on page 16 of this pamphlet.

Sheet 2 describes what sediment is, how sediment transport is measured, and how sediment-transport data are used to help understand land-surface processes in Marin and Sonoma Counties. Sheet 2 contains data that can be used primarily by engineers and designers concerned with canals, reservoirs, water-treatment plants, culverts, and similar structures that must accommodate the sediment carried by water. The sediment-transport data also have been converted into land-surface denudation rates. These rates are of interest primarily to soil scientists, geologists, and others concerned with regional land-surface changes. The data on sheet 2 have been condensed into a systematic form for ease of comparison with similar data from other areas. Detailed explanations of these data and how they relate to the provinces shown on sheet 1 are given in the text on sheet 2.

This preliminary report is intended to elicit comments from users on format, style, and overall adequacy as a planning aid and an educational device. Such comments will be reviewed and incorporated into the design of future versions of this and related reports. Please direct questions and comments to:

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For use of those readers who may prefer to use metric units rather than English units, the conversion factors for terms used in this pamphlet and on sheets 1 and 2 are listed below:

Multiply English unit	*By*	*To obtain metric unit*
acres	4.047×10^3	square metres (m^2)
acre-feet (acre-ft)	1.233×10^3	cubic metres (m^3)
cubic feet per second (cfs)	2.832×10^{-2}	cubic metres per second (m^3/s)
feet (ft)	3.048×10^{-1}	metres (m)
inches (in)	2.54×10^1	millimetres (mm)
miles (mi)	1.609	kilometres (km)
square miles (sq mi)	2.590	square kilometres (km^2)
100 pounds per cubic foot (100 lbs/ft^3)	1.602×10^3	kilograms per cubic metre (kg/m^3)
tons (short)	9.072×10^{-1}	tonnes (t)
tons per square mile (tons/sq mi)	3.503×10^{-1}	tonnes per square kilometre (t/km^2)

A PERSPECTIVE ON SOME SEDIMENT PROBLEMS

In general, man's alteration of the land surface of Marin and Sonoma Counties has been continuous and widespread for at least a century. During that time, three basic elements affecting normal land-surface changes--vegetation communities, runoff from precipitation, and the soil mantle--have been greatly altered by human activities. In response to the alterations of these elements, many parts of the land surface have been continually readjusting. The readjustment is still in progress, reflecting the past and portending future land-surface forms.

In northern Sonoma County, for example, accelerated erosion is occurring over wide areas. This erosion has exposed forest soils on grassy slopes and marks land improperly converted from forest to grassland. Much of the land conversion was begun in the late nineteenth century to gain grassland areas primarily for grazing purposes. Some of the areas are now so severely eroded that the natural regeneration of a forest covering is unlikely for at least several decades. In the meantime, erosion will persist and may cause severe limitations on land use unless corrective measures are employed.

Throughout the study area, road building and road maintenance consistently expose loose sedimentary debris and cutaway hillslopes to erosional agents. Particulary in logging areas in mountainous terrain, road building has greatly altered the land surface. For example, closely spaced, unpaved logging roads and skid trails in the mountains of western Sonoma County have commonly accrued to 10 linear miles of roadway per 1 square mile of terrain. The roadways, including cuts and fills, thus expose about 20 acres of soil and rock per square mile to erosional agents. That amount of exposure is ample to induce areal erosion rates that are many times normal rates. Also, the high erosion rates will persist, diminishing only in relation to the regenerative capacity of the altered land surface or to the engineered protective measures employed.

Accelerated upland erosion has resulted in concomitant accelerated deposition in lowlands--notably in stream channels. Accelerated erosion generally adds more sediment to stream channels than the stream can carry away under average flow conditions. Therefore, the stream channels slowly fill, and the streams tend to become wider and shallower. These streams then have a greater tendency to flood and to erode previously stable channel banks. The stream channels of the South Fork Gualala River drainage basin in western Sonoma County are exemplary of the conditions of accelerated sediment deposition. Smaller tributary channels are characterized by sediment deposits behind debris jams of rocks and logs. The smaller channels locally readjust their dimensions and gradient with the passage of storm runoff and discharge "slugs" of sediment into the main channels as debris jams break. The main channel of the South Fork Gualala River is characterized by a progressively aggrading channel bed in its lower reaches and scoured and unstable channel banks throughout its course. Such channel instability is a basin-wide trait of the channel system that can be remedied only locally until basin-wide erosion-control methods are adopted.

The present-day channel of the Russian River reflects a complex situation of channel adjustment to numerous interacting factors. Accelerated erosion has caused the accumulation of sediment in the channels of the Russian River and its tributaries. Concurrently, the natural river channel has been encroached on to gain land for farming and other development purposes. The encroachment on the river channel and floodplain has shortened the main river channel, especially in the reach between Healdsburg and Rio Dell. In many places, the channel and floodplain encroachment is semipermanent; riprap, concrete constrictions, dikes, and similar human constructions attempt to prevent the river from making natural adjustments of its channel and floodplain to accommodate the flows it must carry. The artificially induced adjustments that the river must make are often damaging to riparian property downstream from the constricted channel. In southern Alexander Valley riprap, auto bodies, and debris-retention fences testify to human efforts at riparian-property protection. However, such protection has only been local and temporary as the Russian River has initiated bank and channel scour in unprotected (but previously undisturbed) areas. The river also has destroyed some of the older revetments in response to channel confinements by newer constructions. Ultimately, the bank and channel scour induced in the Alexander Valley must be balanced by subsequent deposition of sediment downstream.

Superposed on the problems of accelerated erosion are the effects of a reservoir[1] and of gravel mining. The reservoir traps a part of the sediment that would normally move in the stream channel. Simultaneously, the reservoir causes a reduction of the higher flows that normally transport most channel-bed sediment. Thus, sediment from tributary basins downstream from the reservoir tends to accumulate in the main channel. By contrast, gravel mining removes some of the accumulated sediment. However, gravel mining commonly includes the removal of the more stable floodplain sediment deposits not in the active part of the channel. Gravel mining also typically includes some revetment work that tends to constrict the active channel.

The balance among channel scour and deposition, gravel mining, effects of reservoirs, and related factors is certainly complex and has not been well measured. However, much can be done by planners, designers, and engineers to minimize the ill effects of channel adjustment. The river channel needs to be recognized as a part of a continuous sytem encompassing the entire drainage basin of the river. Local problems of erosion of riparian property must be solved with a holistic view of the basin. Otherwise, the problems are simply transferred to another point along the river and continue to be problems to other occupants of the basin.

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[1]The principal reservoir in the Russian River basin is Lake Mendocino, (not shown on the map) about 30 miles north of Cloverdale. Major reservoirs are planned by the U.S. Army, Corps of Engineers, on Dry Creek just west of Geyserville and on Redwood Creek in Knights Valley.

DEFINITION OF THE MAP SYMBOLS

The land surface of Marin and Sonoma Counties has a variety of features that indicate active erosion and deposition of sediment. It was attempted to locate and describe a number of these features and to show their general distribution on the landscape. This study began with an extensive review of high-resolution imagery[2] of the study area and several field-checking trips to determine a set of mappable features. The features that were mapped, and to which the first part of the subsequent text is devoted, are those that showed signs of activity during the study period only, and the following restrictions apply:

1. The mapped sites are by no means comprehensive. The sites where erosion or deposition of sediment was in progress during the study period were commonly too closely spaced to be mapped accurately on a regional scale. More detailed investigations at each mapped site are suggested for studies on a local scale.

2. The mapped sites do not necessarily indicate problem areas. Erosion and deposition of sediment are basic elements of landscape change. The human perspective on those elements is highly variable; thus, a symbol does not suggest, for example, whether gullying is or is not a problem. The symbols should help imply the interrelation of erosional and depositional processes and help the reader visualize, for example, a continuity between gully erosion and the filling with sediment of a farm pond or a stream channel downstream from that gully.

3. The mapped sites indicate an estimate of a dominant process, and the estimate may be incomplete with respect to a given site. For example, gullies may be superposed on grazed land, which in turn may be superposed on a large area of gravitational mass movement. It is implied that at each mapped site more than one process was probably active during the study period. Therefore, other investigators might delineate a different group of process areas because of the vagaries in image interpretation.

4. Many of the mapped sites are highly transitional; that is, a site of erosion during one year may be obliterated or changed by natural or artificial means by the next year. Thus, the mapped sites pertain only to the study period, March 1971-October 1972, and do not reflect changes since October 1972. Most of the sites of erosion and deposition will remain active for many years. The reader should be alert to the potential for rapid variations at the mapped sites.

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[2]The high-resolution imagery includes stereoscopically paired color infrared vertical aerial transparencies, scale 1:120,000 and 1:60,000, taken of the San Francisco Bay region on March 30-31, 1971. These transparencies were produced expressly for the San Francisco Bay Region Environment and Resources Planning Study by personnel of the National Aeronautics and Space Administration, Manned Spacecraft Center, Houston, Texas. The transparencies were examined on a large scanning stereoscope having high magnification capabilities. Following the examination of the transparencies and notations of principal erosional and depositional features, the features were transferred to a 1:125,000-scale base map using an enlarger-reducer map-transfer apparatus. The resolution of the imagery far exceeds the apparent size of the map symbols at the 1:125,000 scale.

GULLY

A *gully* is usually a steep-sided, miniature valley or gorge through which water commonly runs only during and immediately after precipitation (fig. 1). A presently or recently active gully is nearly barren of vegetation. However, stabilized gullies are commonly filled with brush and small trees, and their side slopes are at least partly covered with grass. Miller (1972, p. 187) distinguishes gullies from rills on the basis of depth as follows:

> "A *gully* generally is an obstacle to farm machinery and is too deep to be obliterated by normal tillage; a *rill* is of lesser depth and can be smoothed over by ordinary tillage." [authors' emphasis]

Gullying is a form of accelerated erosion that is common in varying degrees of size and activity throughout the study area. Gullying generally begins during runoff that is accelerated as a result of thinning or removal of vegetative cover. Gullying may also begin from the flow of ground water that creates subsurface voids, concentrating the flow and leading to the eventual collapse of the land surface.

Gullies in the foothills and alluvial valleys of Marin and Sonoma Counties are commonly associated with grazing and cultivation on sloping ground. Gullies in the mountainous areas are commonly associated with roadbuilding, land conversion, grazing, and *gravitational mass movement*.

FIGURE 1.--Photograph showing a gully on heavily grazed terrain near Hicks Valley in central Marin County. The terraced hillsides are commonly caused by the narrowly spaced trails of grazing animals.

GRAVITATIONAL MASS MOVEMENT

Gravitational mass movement describes a variety of processes by which sediment is transferred downslope predominantly by the force of gravity. These processes in the study area include:

1. *Creep*, the very slow downslope movement of soil and rock debris,
2. *Landsliding*, the more rapid, perceptible, and well-defined downslope movement of rock and soil masses, and
3. *Complex landsliding*, the combination and superposition of different types of downslope movement, which is probably the most common process of gravitational mass movement in the study area.

Many reports describe several types of creek and landsliding or make other distinctions as to the classifications of *gravitational mass movement*. Nilsen (1972) describes several forms of gravitational mass movement common in the San Francisco Bay region. Rice and Strand (1971) describe some of the detailed aspects of landslides and slope stability for selected areas of Marin County.

For this report, areas of *gravitational mass movement* having pronounced, fresh exposures were distinguished (fig. 2). The mapped areas showed fresh, unvegetated scarps and other rupture surfaces, broken masses of rock, soil, and other debris, severely rilled or gullied surfaces, freshly exposed lobes or toes, and other similar features.

Gravitational mass movement is a common and widespread erosional process in the study area, and it occurs to some degree in almost every other sediment source area mapped. *Gravitational mass movement* may become a severe problem with respect to accelerated erosion due to the difficulty encountered in stopping or slowing the process once it has been accelerated by human activities.

FIGURE 2.--A small landslide (commonly called an earthflow, soil slip, or slump) on a hillside southwest of Petaluma in Sonoma County. A layer of soil and rock, saturated with water during the winter rainy season, has moved downslope under the influence of gravity.

◒ GRAZED LAND

Grazed land is land used for grazing that showed signs of active or accelerated erosion during the study period. Such land was identified by the presence of grazing animals, the distinctive terraced appearance of hillsides resulting from the trails made by the animals (fig. 1), and, in some cases, evidence of mass movements. These trails are generally parallel, narrowly spaced, and perpendicular to the natural slope of the land. On steeper slopes, the close spacing of the trails may result in almost continuous areas of barren ground, although vegetation commonly grows between trails on gentler slopes. The combination of thinning vegetation by heavy grazing and soil disturbance by animal trails often leads to the initiation of rilling and gullying and may begin or accelerate slump movement and soil creep.

Grazed land occurs throughout Marin and Sonoma Counties; however, much of the *grazed land* occurs in combination with other, more dominant erosional processes. (For example, compare *grazed land* with *converted land* described on sheet 1.) Therefore, the sediment source described is dominantly confined to the *foothills erosional province* of northern Marin and southern Sonoma Counties.

⊕ PLOWED AREA ON SLOPING GROUND

A *plowed area on sloping ground* is a common feature on an agricultural landscape and may be either a temporary or a potential sediment-source area. Such areas may experience rilling that is commonly repaired seasonally, but rilling that is not repaired may lead to gullying. In the study area, plowed areas are most common in the *foothills erosional province*.

⊛ GRADED AREA

A *graded area* is typically a temporary sediment-source area that occurs in urban and suburban settings. The sediment contribution of such areas is highly variable, depending on a variety of factors that include:

1. The area of graded land and the duration that the graded land is is exposed to the local agents of erosion;

2. The degree of protection of graded land afforded by compaction, vegetative or other slope stabilization, routing of runoff from precipitation, installation of debris basins, and other related measures;

3. The coincidence of grading and intense precipitation or wind; and

4. The natural stability of the graded area, particularly on sloping ground.

Because graded areas commonly are rapidly covered with pavement, vegetation, or some other covering, the sites mapped from 1971 aerial photography may not show the erosional effects of grading in subsequent investigations.

◉ EXCAVATION

An *excavation* is a cavity on the land surface formed by man's digging out and removing rock and soil. In the study area, *excavations* principally include roadcuts and gravel-mining operations in stream channels. Roadcuts are potential major contributors of sediment to natural erosional agents and are a primary cause of accelerated erosion, especially in mountainous terrain. Gravel-mining operations in stream channels act complexly in the sediment system. The operations are commonly the sources of fine-grained, turbidity-causing sediment that is washed from the coarser gravel. The operations may be sources of artificial fill and may act as seasonal or periodic depositional sites if located in active stream channels. When they interfere with the active channel, the operations commonly contribute to downstream channel and streambank erosion.

◯ WAVE-ERODED CLIFF

A *wave-eroded cliff* is a major sediment source area in the *coastal province*. The cliff may erode because of the actions of running water and gravity that supply sediment to the cliff base. That sediment is then removed by wave action, thus reducing the stability of the cliff, and the process is repeated. Water waves may also abrade the cliff base directly without the major assistance of running water and gravity.

The *wave-eroded cliffs* are as variable in aspect and activity as the many combinations of rock types and wave action found in the *coastal province*. For example, the cliff between Duxbury Point and Bolinas has retreated at an average rate of 2.3 feet per year for about 60 years (Ritter, 1970, p. 3; A. J. Galloway, oral commun., 1967). Other cliffs in the study area probably retreat by erosion at rates much less than 1 foot per year, and some may retreat more rapidly than the Bolinas cliff, although exact documentation of cliff erosion rates has not been made for the study area (K. E. Lajoie, oral commun., 1973).

Cliff erosion produces a part of the striking seascapes common to the study area, and many areas where cliff erosion is active are included in parks and other preserves. In some cases, however, cliff erosion is a threat to near-coastal property and manmade structures (such as in Bolinas) and is viewed as a problem to be treated.

◑ CONVERTED LAND

Converted land refers to land that has been cleared of forest and woodland and seeded to grassland, commonly for grazing purposes. The methods used in converting forest or woodland to grassland vary considerably but typically follow this sequence (Poli and Roberts, 1958, p. 8-17):

1. The removal of marketable trees by various logging practices;
2. Slashing or felling of trees left standing after logging;
3. Burning of fallen trees and slash;
4. Seeding of the burned area;
5. Grazing (to control the sprouting of woody vegetation);
6. Slashing and burning of woody vegetation that has grown since the initial burning; and
7. Repetition of grazing and burning sequences until complete conversion has occurred (fig. 3).

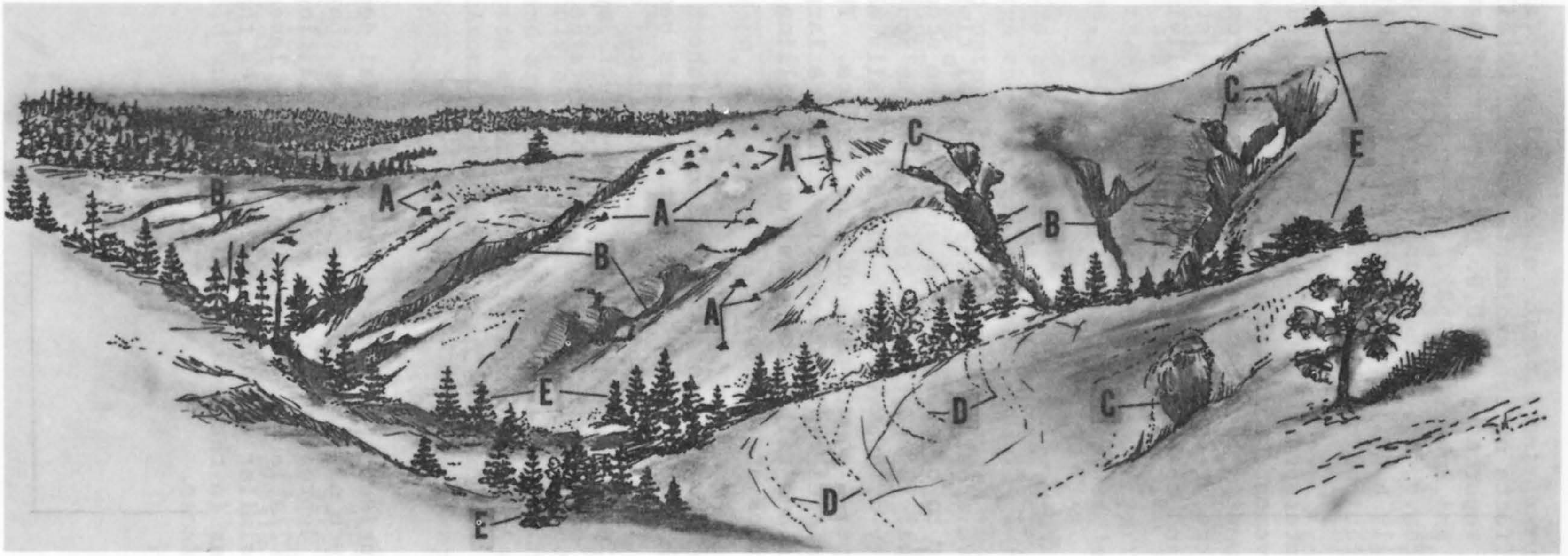

FIGURE 3.--Panoramic sketch showing converted, grazed, and heavily eroded terrain in northwestern Sonoma County. A, tree stumps and deadfalls; B, gullies; C, landslide scars at heads of gullies; D, sheep trails; E, young sprouting species of trees, dominantly oak and laurel. The native conifer species have almost been eliminated and replaced by grasses and hardwood trees.

These practices occur during a period of several years and commonly have dramatic and long-term effects on the sediment system. Details of these effects are presented in reports by the U.S. Department of Agriculture (1966), Burchem (1957), and Poli and Roberts (1958). These reports support the conclusion that the converted, burned, and grazed lands of northern Sonoma County are typically heavily eroded and that the results of the erosion pose severe limitations on the use of such lands.

Converted land is interspersed with forest lands, grazed lands, and areas of gravitational mass movement principally in the *western Sonoma uplands erosional province*. *Converted land* can be distinguished from naturally occurring grasslands by the presence of forest soils, tree stumps, nonnative grasses and forbs, ashes and charred wood, and rilling, gullying, and slumping.

TIMBERLAND ACCESS AREA

The density of active erosional processes in several timberland areas of the province is too great to be shown at the scale of the accompanying map. For example, in the headwaters and central reaches of the South Fork Gualala River, the density of unpaved roads and skid trails may be more than 10 linear miles of road per 1 square mile of land surface. These roads are closely spaced on steep slopes and consequently exhibit a large number of cuts and fills. The cuts and fills show considerable rilling, and evidence of culvert and fill failures are common.

Basically, the *timberland access areas* outlined on sheet 1 are areas of exposed soil that lack protection from erosional agents because of severe artificial disturbance. Throughout these areas, the vegetal covering on the land surface has been thinned or removed; thus, the direct impacts of precipitation and runoff on the soil covering are not retarded.

ARTIFICIAL FILL

Artificial fill comprises sediment and other material deposited by man to fill or partly fill such natural depositional areas as channels, lagoons, marshes, sinks, or other depressions, or to raise the existing ground elevation. *Artificial fills* located on this map include levees, causeways, sanitary landfills, and similar manmade landscape features that occur within natural depositional areas in the *coastal province* and *bay plain and alluvial valley depositional provinces*.

■ DELTAIC DEPOSIT IN RESERVOIRS, ESTUARIES, OR BAYS

Reservoirs, *estuaries*, and *bays* commonly are the long-term resting places for sediment derived from and transported about the study area. *Deltaic deposits*, therefore, are only one of several depositional features that may exist in all three places. *Deltaic deposits* are built principally by streams, as distinguished from deposits that are a composite product of wind, water waves, and other factors.

As the moving water and sediment mixture that constitutes streamflow enters a body of relatively still water, the stream velocity and turbulence needed to carry the sediment are rapidly reduced. The sediment particles carried as bedload then come to rest, and suspended particles settle out of suspension. In time, the accumulation of these particles builds the delta.

Deltaic deposits are a major problem in artificial reservoirs when the deposits become large enough to reduce substantially water-storage space. *Deltaic deposits* in naturally occurring water bodies tend to increase land volume at the expense of the volume of the water body. In either case, it is the rate of the buildup of the deposits that characteristically elicits concern, and that rate is related to the erosion rate of the source areas of the deposits.

◪ BEACH, RIVERMOUTH AND BAYMOUTH BAR, OR SANDSPIT

Many of the common shoreline landscape features of the *coastal province* are the areas where sediment is temporarily deposited. *Beaches* commonly are seasonal stockpiles of sediment moving in the littoral zone. *Rivermouth* and *baymouth bars* commonly block the mouths of coastal streams and estuaries during the summer and are moved away by flowing water and wave action during the winter. *Sandspits* are bar features that include areas of beaches and dunes and change shape seasonally, especially in the vicinity of their tips. Doran Beach, Limantour Spit, and Stinson Beach are examples of *sandspits* in the study area.

Exact distinctions among beaches, bars, spits, and related features are presented in many textbooks and reports, including Strahler (1969, p. 525-547) and Bascom (1964). For the purposes of this report, the shoreline features described above are distinctive in that they are mobile and are composed predominately of sediment of sand size (sheet 2).

◪ SEDIMENT TEMPORARILY STORED IN STREAM CHANNEL

Sediment moves continuously in stream channels only for limited periods of time, and different sizes of sediment particles move at different rates. A sediment particle moving in a stream channel may be transported and deposited many times from the time it enters the channel until it is ultimately discharged or otherwise removed from the channel. (In the case of a very large particle, such as a boulder, the particle might not move for many years until it is worn down to a size small enough for the stream to carry, or until a relatively rare high-water event with sufficient competence occurs.)

On the map (sheet 1), the *sediment temporarily stored in stream channel* is predominantly sand and gravel that moves primarily during the high flows accompanying winter rainstorms. Such sediment commonly rests in the active stream channel (at elevations between the low- and high-water stages of the stream) and occurs as bars that may support scattered vegetation during the dry season. Particularly along the Russian River, the sand and gravel bars are used as recreational beaches and sources of material for aggregate-mining industries.

Where the input of sediment to the channels is accelerated by the excessive erosion of sediment source areas, the channel may begin to fill with the sediment that the stream is unable to carry away. This process is called channel aggradation, and it is a common aspect of many streams in the study area. Where accelerated erosion persists, channel aggradation commonly persists, and its effects can be severe with respect to streamside property. That is, as the channel aggrades, the dimensions of flow in the channel tend to change from narrow and deep to wide and shallow. Thus, for a given flood flow, the extent and frequency of flooding may be noticeably changed, and areas previously not affected by that flow may be damaged.

⊞ SAND DUNE

Sand dunes are depositional features developed where loose sediment particles of sand size accumulate downwind from a sand source area. The transporting agents of the sand are wind and gravity, and the sand source area is characteristically a depositional feature of some other part of the sediment system. For example, the sand dunes inland from Salmon Creek Beach near the town of Bodega Bay are derived from beach deposits that are in turn derived from wave-eroded cliffs, landslides, and sediment discharges of the Russian River.

Sand dunes mapped in the study area occur almost exclusively within the *coastal province* inland from principal beach areas. These dunes tend to migrate inland, and dune migration may be a problem where valuable property is threatened with burial by dunes. Sand dunes also act as barriers that prevent storm waves from inundating low interior areas and may act as temporary stockpiles of beach-forming materials if the dunes build seaward into the littoral zone.

◧ MUDFLAT OR MARSHLAND

Mudflats and *marshlands* are the sites of deposition of fine-grained sediment such as silt, clay, and light organic material (sheet 2). These sites occur in the study area in the intertidal zone where the periodic stillness of a water body allows the settlement of fine sediment from suspension. *Mudflats* typically are the unvegetated, nearshore areas that are inundated almost daily at high tide and are exposed at low tide. *Marshlands* typically are the vegetated areas shoreward of the *mudflats* that are inundated only during periods of very high tide or flooding.

⧓ FLOODPLAIN AND ALLUVIAL FAN

Sediment moved by streams from higher to lower ground is deposited in a variety of forms. An *alluvial fan* is a body of stream deposits whose surface shape approximates a cone that radiates downslope from the point where the stream leaves a mountainous area (Bull, 1968, p. 7). For example, broad, gently sloping alluvial fans emanate from the mouths of canyons around the periphery of Cotati Valley and merge together to form a part of the valley margins.

A *floodplain* is a dynamic surface that may be defined in many different ways. For this report, a *floodplain* is the more or less flat area lying adjacent to a stream channel that is subject to periodic inundation by the stream. Such an area may be modified by any of several human alterations of the stream and its channel, including the construction of dams and levees.

In the study area, *floodplains and alluvial fans* are the major sites of human development. Thus, the natural depositional processes expected for those sites are commonly modified to suit local human intentions. In the case where a stream is locally confined to an artificial channel, the natural tendency of the stream to spread its sediment load over its fan, and floodplain deposits may be curtailed. Therefore, the stream must deposit its load of sediment by other methods. The alternative methods of deposition that the stream assumes are highly variable, depending upon local conditions. For example, the deposition may occur upstream from, at, or downstream from the local constriction. It is important to recognize that the deposition must ultimately occur and that it can cause problems elsewhere along the stream.

DESCRIPTION OF THE PROVINCES

The land surface of Marin and Sonoma Counties is generally separated from the rest of the San Francisco Bay region by natural physiographic boundaries that approximate the counties' eastern political boundaries. For example, most of the border between Sonoma and Napa Counties is a natural drainage divide between the Napa River basin to the east and the Russian River and Sonoma Creek basins to the west. Marin County is tied by bridges to Contra Costa and San Francisco Counties but is otherwise set apart along its southeastern border by San Pablo Bay, Richardson Bay, and the Golden Gate.

In terms of the erosion, transportation, and deposition of sediment, Marin and Sonoma Counties together are nearly a separate, subregional unit within the San Francisco Bay region. That is, inputs into the sediment system[3] of Marin and Sonoma Counties are not derived from other parts of the San Francisco Bay region.[4] The sediment system of Marin and Sonoma Counties, therefore, is either wholly contained within the counties or receives inputs from areas north of the San Francisco Bay region.

Marin and Sonoma Counties were divided into numerous regions intended to reflect broad conditions of adjustment among the factors that influence the erosion, transportation, and deposition of sediment. These factors are geology, topography, vegetation communities, soils, precipitation, runoff, and land usage. At a given place and time in any of the regions, any one of the factors may be a dominant control on the sediment system. In general, vegetation communities, soils, and runoff are the fragile, adjustable parts of the sediment system that are most often altered by human uses of the land. Thus, these are the general control on short-term changes in the rates of erosion, transportation, and deposition--the three parts of the sediment system. Geology, topography, and precipitation are the basic, underlying elements of the sediment system. They are affected regionally to a very limited extent by human uses of the land, and they are the general controls on the "background" or "predevelopment" rates of the three parts of the sediment system. (It is noteworthy, however, that only very small parts of the sediment system in the study area are not affected by human uses of the land.)

The regions that are delineated on sheet 1 are land masses that, in general, have a distinctive combination of the seven aforementioned factors affecting the sediment system. The regions are called *erosional and depositional provinces*, depending upon the dominant part of the sediment system acting on a particular land mass. (That is, an erosional province is a mass of land acted upon dominantly by erosion; a depositional province is a mass of land wherein deposition is the dominant active phase of the sediment system.) In the following text, each of the provinces is described briefly in terms of the seven factors affecting the sediment system.

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[3]Refer to "Erosion, transportation, and deposition of sediment" on sheet 1.

[4]An exception must be made for the bay margins of the study area from San Pablo Bay to the Golden Gate that ultimately receive inputs from some 63,000 sq mi of landscape drained by rivers flowing into San Francisco Bay.

(1) COASTAL PROVINCE

The *coastal province* extends along the western boundary of the study area and for an indefinite distance into the Pacific Ocean. It contains a variety of unique features of the sediment system (fig. 4). Within the province, sediment is derived principally from wave erosion of seacliffs and coastal landslide masses. Sediment is also transported into the province by several streams, of which the Russian and Gualala Rivers are the most significant transporters. Sediment in the province is transported primarily by complex water movements in littoral currents whose general net effect is to transport material southwesterly along the coast and offshore into deeper water. Sediment is also transported inland by wind and forms dunes at several locations along the coast such as Dillon and Point Reyes Beaches. Depositional sites for sediment within the province include beaches, dunes, sandspits, lagoons, and the floors of Bodega, Tomales, and Bolinas Bays.

The province may be divided into 19 parts composing a nearly alternating sequence of erosional and depositional areas between the mouth of the Gualala River on the northwestern and the Golden Gate at the southeastern end of the province. Table 1 gives an inventory of the province with respect to the sediment system.

The surficial geology of the *coastal province* is dominated by landslide, beach, dune, and terrace deposits (Blake, and others, 1971, R. H. Wright, written commun., 1972). However, the older exposed and underlying rocks exhibit considerable variety throughout the province. For example, hard, granitic rocks underlie Point Reyes and Bodega Head and are partly responsible for the resistance of the two promontories to wave attack. Alternatively, the fractured and weak sandstone and shale between Mill Gulch and Jenner offer little resistance to the several erosional agents that work on them. In general, geology is the dominant control on erosion in the province, as erosive agents interact directly with exposed rocks. Soil and vegetal covering, however, protect the coastal terraces in the province, and accelerated erosion of the terraces may occur when the covering is disturbed.

Vegetation in the province includes grassland and marshland biotic communities and coastal scrub (Smith, 1960, p. 25-26). The vegetal covering primarily serves partly to stabilize depositional features such as sand dunes, mudflats, and deltaic deposits. Vegetation as a control on erosional features is generally restricted to plants on terrace surfaces and the surfaces of slowly moving landslides.

Land in the province is used primarily for recreation, light residential development, and agriculture (principally grazing). Land uses involving road or trail building, the addition of moisture to the terraces by irrigation, or the artificial concentration of runoff into narrow channels, commonly accelerate erosion within the province. Because the principal agents of erosion in the province are water waves and gravity, the importance of precipitation and runoff are diminished. However, the province receives 18 to 54 inches of precipitation annually, and the effect of precipitation and runoff on landslide masses and gullies is significant locally.

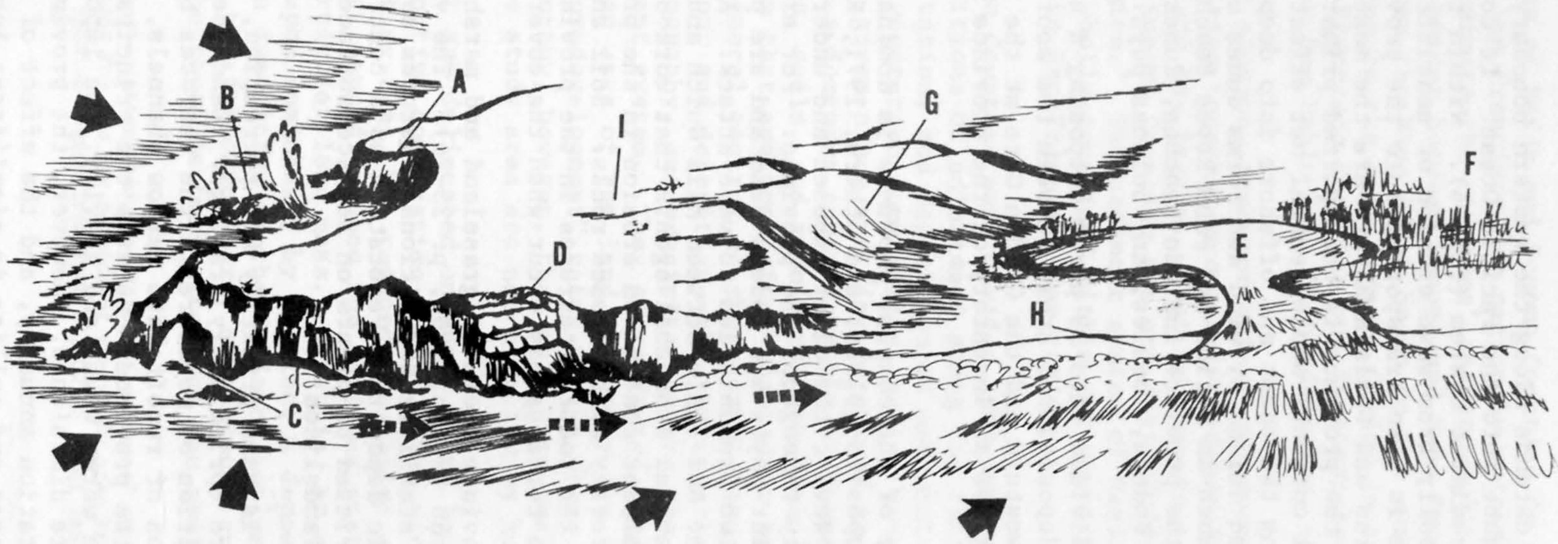

FIGURE 4.--Diagram showing typical marine erosional and depositional features and processes in the *coastal province*. A, wave-eroded cliffs; B, sea stack; C, natural arch and sea cave; D, slope failure (landslide) resulting from or accelerated by wave erosion at base; E, lagoon; F, salt marsh; G, sand dunes; H, beach; I, marine terrace. Solid arrows are wave directions. Broken arrows are the resulting littoral current directions.

TABLE 1.--*Principal divisions of the coastal province in terms of erosional and depositional activity*

Reach or general area	Dominant erosional or depositional processes
Mouth of Gualala River	*Deposition*: Estuarine, beach, and rivermouth bar deposition.
Gualala River to Mill Gulch	*Erosion*: Seacliff retreat; gullying of terraces.
Mill Gulch to Russian River	*Erosion*: Gravitational mass movement, gullying, and seacliff retreat.
Mouth of Russian River	*Deposition*: Estuarine, beach, and rivermouth bar deposition.
Russian River to Salmon Creek Beach	*Erosion-deposition*: Seacliff retreat and beach deposition.
Salmon Creek Beach	*Deposition*: Beach and dune deposition
Bodega Head	*Erosion*: Seacliff retreat
Bodega Head to Doran Beach	*Deposition*: Beach, sandspit, and dune deposition.
Doran Beach to Dillon Beach	*Erosion*: Seacliff retreat, gullying of terraces, and gravitational mass movement.
Dillon Beach to Tomales Bluff	*Deposition*: Beach, dune, and baymouth bar deposition.
Tomales Bluff to McClure's Beach	*Erosion*: Seacliff retreat
McClure's Beach to Point Reyes	*Deposition*: Beach and dune deposition
Point Reyes	*Erosion*: Gravitational mass movement and seacliff retreat.
Point Reyes to Drakes Beach	*Erosion*: Seacliff retreat
Drakes Beach to Limantour Spit	*Deposition*: Beach, dune, and sandspit deposition.
Limantour Spit to Bolinas	*Erosion*: Gravitational mass movement, seacliff retreat, and gullying.
Bolinas to Stinson Beach	*Deposition*: Beach, dune, sandspit, and baymouth bar deposition.
Stinson Beach to Muir Beach	*Erosion*: Seacliff retreat and gravitational mass movement.
Muir Beach to Golden Gate	*Erosion*: Seacliff retreat and gravitational mass movement.

(2) BAY PLAIN AND ALLUVIAL VALLEY DEPOSITIONAL PROVINCE

The *bay plain and alluvial valley depositional province* includes most of the areas of human development in Marin and Sonoma Counties. Thus, this province is often the focus of human problems with the sediment system.

The *bay plain* part, called the *bay plain subprovince* (fig. 5), lies generally between the shoreline of San Francisco Bay and the base of the nearest foothills. It is composed of areas of artificial fill and a broad alluvial apron of fan, flood plain, and deltaic deposits. The alluvial apron sediments interfinger with the mud and peaty organic deposits of San Francisco Bay. The topography is very subdued, comprising slopes ranging from flat to about 5 percent. Precipitation ranges from 18 to 30 inches annually, but most runoff is derived from upland areas feeding into the plains. The land surface is characterized by coastal salt marsh and grassland biotic communities, subdivisions built on artificial fill, and farmlands surrounded by levees or dikes.

The *alluvial valley* part, called the *alluvial valley subprovince*, consists of flat to gently sloping valleys underlain by thick alluvial deposits that are generally higher in elevation than the *bay plain subprovince*. Precipitation is variable, ranging from about 20 to 40 inches per year. Characteristic alluvial valley landscapes include towns and subdivisons, grassland and riparian woodland biotic communities, cultivated crop lands, and pasture lands.

Problems related to the sediment system in the *bay plain and alluvial valley depositional province* include the burial by sediment of low-lying areas, especially those marginal to stream channels. Such burial requires expensive repair work of city streets and residences or the replacement of destroyed crops on farmlands. Sediment deposition in stream channels, especially in artificial channels, may cause the diversion of streamflow or raise the streambed and reduce the ability of the channel to transport floodwaters. The diversion of streamflow also may cause streambank erosion and the loss of riparian property.

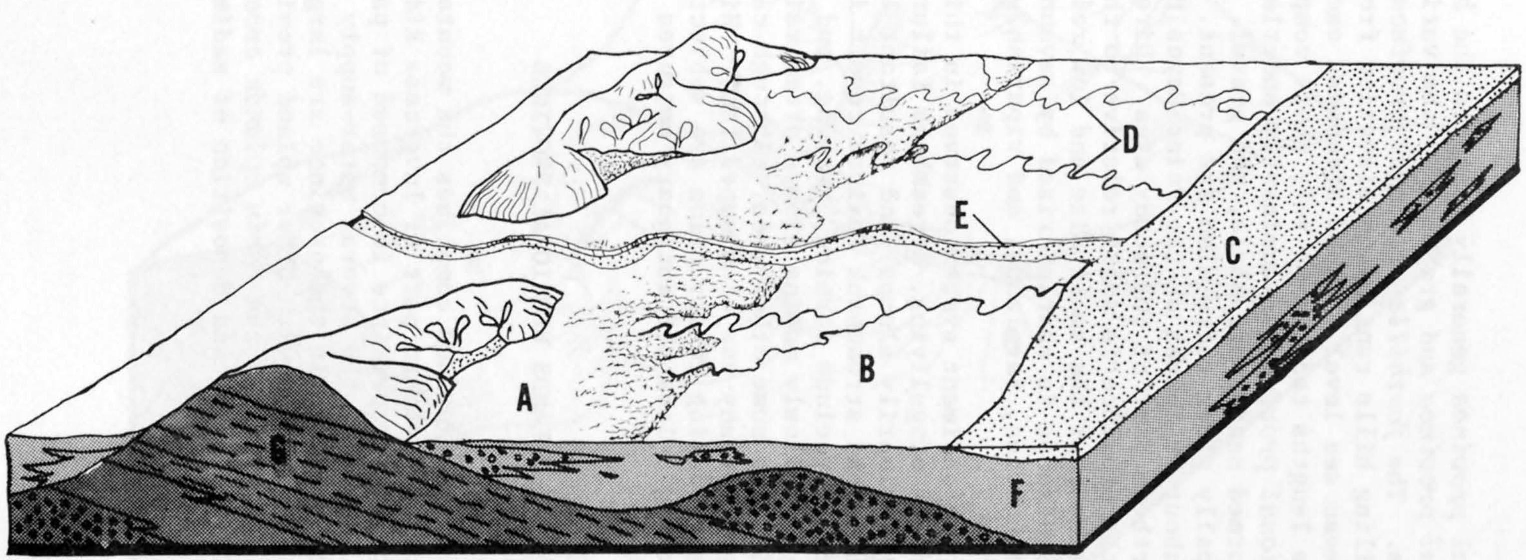

FIGURE 5.--Schematic block diagram showing predevelopment conditions of the bay plain subprovince. A, marshland (vegetated); B, mudflat (unvegetated); C, bay (low-tide condition); D, tidal channel or slough; E, stream channel; F, mud, peat, and other deposits; G, bedrock. Diagram modified from Twiss and others (1969).

(3) FOOTHILLS EROSIONAL PROVINCE

The *foothills erosional province* generally contacts the *bay plain and alluvial valley depositional province* and grades into the various upland provinces of the study area. The *foothills erosional province* is characterized by a terrain of subdued rolling hills ranging in elevation from near sea level to about 1,000 feet above mean sea level. Slope steepness exceeds 20 percent only locally, and the slope lengths tend to be very short compared to upland areas. The *foothills erosional province* is dominantly underlain by poorly consolidated, slightly deformed sandstone, shale, and gravel. Limited areas underlain by other, principally older rocks also are present. Average annual precipitation ranges from about 18 inches on the Point Reyes Peninsula to nearly 40 inches in the northern part of the study area. Direct runoff from stream basins enclosed in the province is small relative to that derived from upland areas principally because of the small size and low relief of the foothill basins. The landscape is characterized by savannah terrain interspersed with rural communities, farmlands, and riparian woodlands.

Dominant processes of the sediment system observed in this province include the erosional processes of gullying, streambank failure, and gravitational mass movement (primarily slumps) and resultant localized deposition (fig. 6). Gullying and streambank failure result in severe land-surface disturbances that preclude farming, grazing, and building until the disturbances are repaired. Slowly moving slumps often maintain a vegetal covering suitable for grazing and some other uses, although careful consideration should be given for any use of slumped land. Hill slopes that are artificially oversteepened during construction are subject to severe erosion by rilling and slumping unless precautionary measures are taken.

(4) MARIN UPLANDS EROSIONAL PROVINCE

The *Marin uplands erosional province* comprises the mountainous parts of central Marin County and the southern part of Inverness Ridge on the Point Reyes Peninsula. Much of the province is composed of parkland or is maintained to some extent to protect the several water-supply reservoirs. However, rates of the sediment system in the province are largely unmeasured, and detailed, quantitative comparisons with other upland provinces are not available for this report. In general, the *Marin uplands erosional province* has the fewest sites of active erosion and deposition of sediment of the upland provinces.

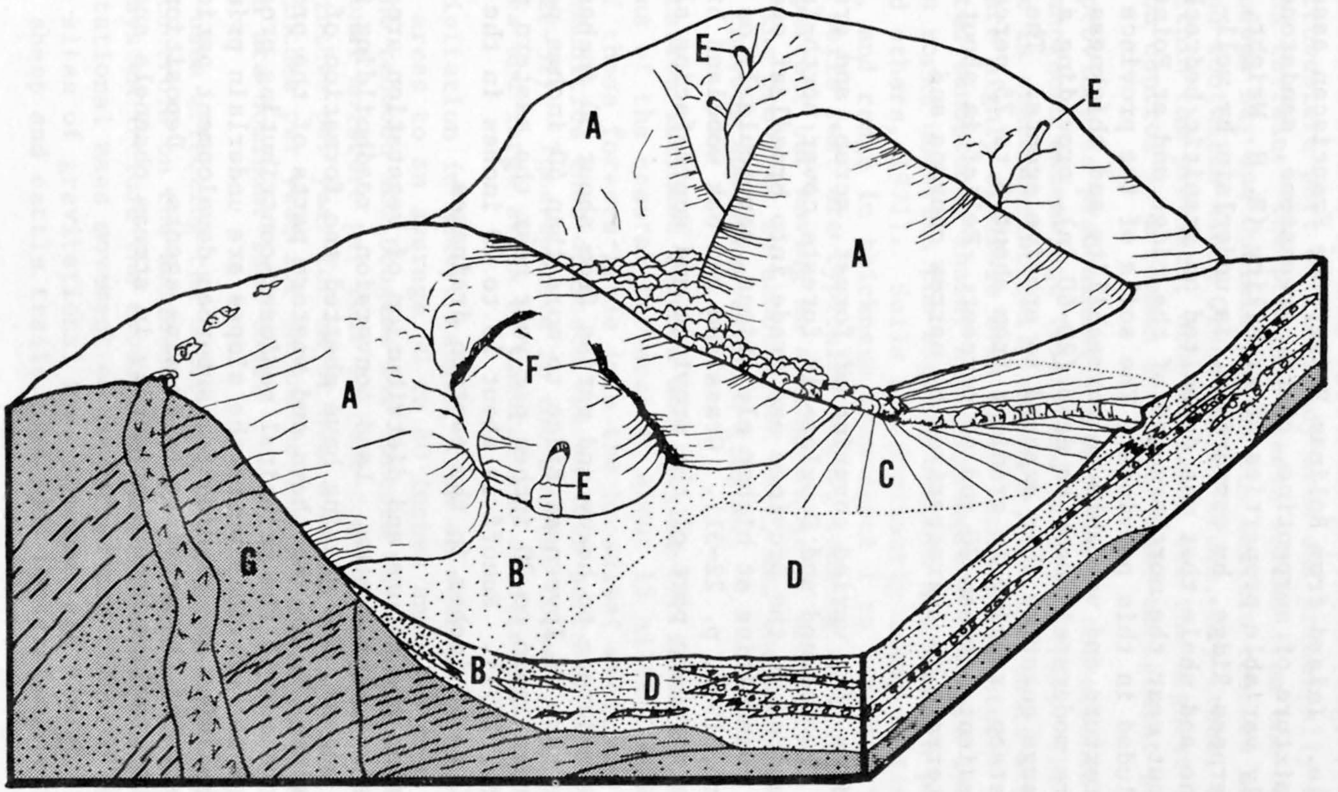

FIGURE 6.--Schematic block diagram showing features of the *foothills erosional province* and the *alluvial valley depositional subprovince*. A, rolling, grassy hills underlain by poorly consolidated bedrock; B, slopewash debris (colluvium); C, alluvial fan deposits of a small stream; D, flood plain and other deposits; E, small earthflows (slumps); F, gullies; G, bedrock. Diagram modified from Twiss and others (1969).

The inland part of the province, separated from Inverness Ridge by the San Andreas fault zone, is dominantly underlain by the Franciscan assemblage (Koenig, 1963). The Franciscan assemblage is highly sheared and naturally unstable along the western side of Bolinas Ridge where it is composed mainly of sandstone and shale. Inland from Bolinas Ridge, the Franciscan assemblage is a highly complex mixture of serpentine, chert, greenstone, sandstone, and shale that has greatly variable properties of stability (R. H. Wright, written commun., 1972). Inverness Ridge, by comparison, is underlain by well-consolidated sandstone and shale that was deposited on granitic bedrock. The granitic rocks crop out near the northern end of the ridge and at Point Reyes, part of which is included in this province. The soils of the province are dominantly loamy in texture and variable in permeability and thickness. In general, the soils are moderately deep to deep (20-60 in), providing a sediment source of large quantity when exposed to erosive agents. The slopes of the province are steep, ranging in gradient from about 5 to 75 percent and having an average gradient between 20 and 40 percent. Relief is about 2,600 feet, and the terrain is characterized by narrow canyons and steep-crested ridges.

Vegetation consists of a varied covering of forest, scrub, and grassland biotic communities. The redwood and Douglas-fir forests cover north-facing slopes at lower elevations in the province and grade into broadleaf evergreen and chaparral biotic communities at higher elevations, particularly on Mount Tamalpais (Smith, 1960, p. 22-31). Grassland and oak woodland biotic communities cover the northern part of the province and south-facing slopes throughout the province.

Precipitation is moderate to heavy and varies from about 30 inches per year near the western base of Inverness Ridge to more than 50 inches per year atop Bolinas Ridge, then again to 30 inches per year near the eastern margins of the province (Rantz, 1971). Runoff is about 15 to 20 inches in the western drainage and about 10 to 15 inches in the eastern drainages.

Land uses affecting the nature and distribution of vegetation are major controls on the sediment system. Land conversion, roadbuilding for timberland and other access, and grazing have abetted the formation of rills, gullies, and slumps in the northern and western parts of the province. Gravitational mass movement is the principal sediment-contributing process in the central part of the province where the slopes are underlain primarily by serpentine. Roadbuilding and grading for suburban development periodically expose the eastern parts of the province to erosive agents. Deposition of sediment within the province occurs primarily in stream channels and water-supply reservoirs.

(5) WESTERN SONOMA UPLANDS EROSIONAL PROVINCE

The *western Sonoma uplands erosional province* (fig. 7) encompasses most of the northwestern part of the study area and principally comprises rugged, mountainous terrain. The province grades inland from the coastal terraces between Bodega Bay and Gualala and in its eastern reaches meets the alluvial valleys and foothills along Green Valley Creek, Dry Creek, and the Russian River. Within the province, erosion rates are the highest in the study area, and erosion control is a common and major land-management problem.

The province is predominantly underlain by the crushed and broken rocks of the Franciscan assemblage (Blake and others, 1971). The Franciscan assemblage is characteristically unstable, and rock units within the assemblage commonly are highly erodible even in an undisturbed state. Well-bedded, consolidated sandstone, shale, and conglomerate that are less sheared than the Franciscan rocks underlie the extreme western and eastern parts of the province (Blake and others, 1971). Soils are dominantly loamy in texture, moderately permeable, and range in thickness from about 1 to 5 feet. The slopes on which the soils rest are typically steep, ranging in gradient from about 10 to 75 percent but having an average range of about 25 to 50 percent. The relief of the province is about 2,600 feet, and the terrain is characterized by narrow canyons and steep-crested ridges.

Vegetation includes redwood and Douglas-fir forests that extend from the margins of the coastal terraces to about 15 miles inland. The eastern margins of these forests grade into the broadleaf evergreen and oak woodland biotic communities that dominate the eastern parts of the province (Smith, 1960, p. 22-31). Interspersed in the several forest communities are chapparal communities and large areas of natural and artificially converted grasslands.

Precipitation is heavy, ranging from an average 40 to 60 inches annually in inland areas to an average 50 to 80 inches annually near the coast. Fog drip in the redwood and Douglas-fir forests may contribute about 10 inches of additional moisture per year in near-coastal areas. Runoff is about 30 to 50 inches per year for major near-coastal river basins and is about 20 to 30 inches per year for inland basins. Timbering, grazing, and recreation are dominant land uses.

Land uses affecting the nature and distribution of vegetation are the dominant controls on the sediment system. Prevailing processes of the sediment system include the erosion of timberland access roads and gullying and gravitational mass movement on converted and timbered lands. Naturally occurring sites of gravitational mass movement are almost invariably affected by roads, sheep and cattle trails, and land conversion, burns, or combinations of these.

The stream channels in the province reflect the generally excessive erosion of adjacent slopes. Channel aggradation is common because the input of sediment to the channels apparently exceeds the average sediment-transporting capacity of the streams.

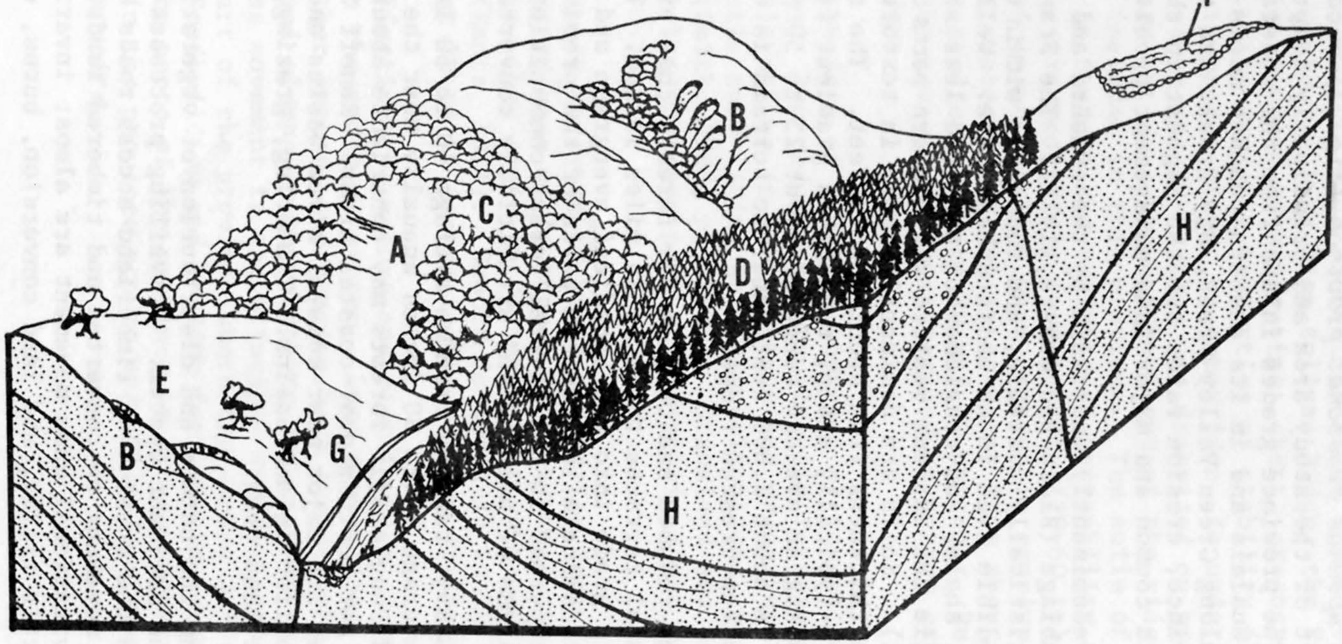

FIGURE 7.--Schematic block diagram showing features of the western Sonoma uplands erosional province. A, large area of gravitational mass movement (note absence of trees); B, small landslides (slumps); C, broadleaf evergreen biotic community; D, redwood and Douglas-fir forest community; E, grassland and oak woodland biotic communities; F, chaparral biotic community; G, streamside road; H, bedrock. Diagram modified from Twiss and others (1969).

(6) EASTERN SONOMA UPLANDS EROSIONAL PROVINCE

The *eastern Sonoma uplands erosional province* principally includes the Mayacamas and Sonoma Mountains of eastern Sonoma County. The province grades eastward from the alluvial valleys and foothills of central Sonoma Creek. The province might be divided into northern and southern subprovinces by the drainage divide between the Sonoma Creek and Russian River basins. However, a clear division of the province is not warranted on the basis of data available for this report. Therefore, the province will be discussed as a single unit although subprovince distinctions will be made.

The northern part of the province, like the *western Sonoma uplands erosional province*, is predominantly underlain by the highly sheared, unstable rocks of the Franciscan assemblage (Blake and others, 1971). However, much of the southern part of the province is underlain by volcanic rocks of Pliocene age called the Sonoma Volcanics (Koenig, 1963; Kunkel and Upson, 1969, p. 15-25). The Sonoma Volcanics are considerably younger, less sheared, and generally softer than the Franciscan rocks. Soils formed on both the Franciscan assemblage and the Sonoma Volcanics are dominantly loamy in texture and moderately permeable. However, soils formed on the Sonoma Volcanics range in thickness from about 1 to 2 feet compared with soil thickness ranging from 1 to 5 feet on the Franciscan rocks. Slope gradients range from about 5 to 85 percent but have an average range of about 20 to 40 percent. The relief of the province is about 4,000 feet, and the terrain is characterized by a mixture of rolling hills, steep cliffs, broken ridges, narrow canyons, and generally irregular, rugged topography.

Vegetation in the province includes oak woodland and chaparral biotic communities (Smith, 1960, p. 28). Scattered areas of conifers, grassland, and cultivated croplands also occur throughout the province. Annual precipitation ranges from an average 40 to 80 inches in the northern part of the province to 24 to 40 inches in the southern part (Rantz, 1971). Annual runoff is also variable, ranging from about 10 to 15 inches in the southern part of the province to about 25 to 30 inches in the northern part. Grazing and limited cultivation and mining are the principal land uses. As in all the upland provinces, roadbuilding for access to the province constitutes the major disturbance of the land surface.

Land uses conflicting with naturally unstable terrain are the dominant controls on the sediment system. The erosion of roadcuts and gullying and gravitational mass movement accelerated by roadbuilding and grazing are the significant active erosional processes. Major deposition occurs in stream channels, and channel aggradation is common in the northern part of the province. However, large quantities of sediment are transported out of the province each season and deposited in the *bay plain and alluvial valley depositional provinces*.

(7) CAZADERO EROSIONAL PROVINCE

The *Cazadero erosional province* includes parts of the study area where the predominant control on the sediment system is the underlying geology. The province is named after the distinctive serpentinized ultramafic rocks that underlie an area named The Cedars north of Cazadero in western Sonoma County. Such rocks occur in Marin and Sonoma Counties as lenses, sheets, and other irregularly shaped masses included in the Franciscan assemblage (Blake and others, 1971). Many of these masses are small and insignificant with respect to the regional scale of this report; however, the smaller masses have been mapped in the study area by Blake and others (1971) and R. H. Wright (written commun., 1972).

The Cazadero mass is rugged and barren over a wide area, except where localized groves of cypress grow, and is characterized by cliffs and reddish-brown, boulder-strewn slopes. Elevations range from about 500 to more than 2,000 feet. Average annual precipitation ranges from about 52 to 60 inches, and average annual runoff is about 40 to 45 inches (Rantz, 1971; Rantz and Thompson, 1967, p. 37). The rugged terrain minimizes land use except for limited mining and grazing activities. The principal erosional process is gravitational mass movement, especially landsliding. Erosion is related to the low strength and high plasticity of the serpentinized rock.

Bailey, Irwin, and Jones (1964, p. 78-81) add an insight into the unusual properties of the Cazadero mass with respect to vegetation and soils as follows:

> "The effect of the ultramafic rocks, and the soils derived from them, on the vegetation is so marked that many geologists have called attention to it.... The Cazadero mass, which is only partly serpentinized, underlies an area known as The Cedars as it supports a dense growth consisting chiefly of Sargent cypress, incorrectly referred to as cedar, and this growth is quite unlike the surrounding vegetation of oak-studded grasslands and redwood-fir forests. The vegetative selectivity observed on both fresh and serpentinized masses seems obviously to be due to the inability of the soil to support most plants, but whether the unusual character of the soil is due to an excess or deficiency of certain elements has not been determined."

Smaller outcrops of serpentinized ultramafic rocks in the study area are generally more subdued topographically than the Cazadero mass; they are vegetated with shrubs, grasses, and scattered oak trees. The landslides and exposed slopes characteristic of the Cazadero mass are not present, and accelerated erosion is minimal and is generally related to roadcuts. More detailed information on the smaller serpentinized outcrops is available in a report by Miller (1972, p. 112).

In general, because of the limited uses of the province, the sediment system acting on those lands is probably more representative of a "natural" or "background" system than that acting on any other province in the study area.

(8) UPLAND VALLEY AND RIDGETOP TERRAIN

Scattered throughout the mountainous regions of the study area are isolated, gently sloping valleys and ridgetops that are distinctive from the surrounding provinces (fig. 8). The rounded grass-covered ridgetops erode very slowly compared to the surrounding slopes. The upland alluvial valleys are small depositional areas in predominantly erosional terrain.

The upland valleys and the ridgetops are characterized by gentle topography, variable precipitation, and grassland biotic communities that grade into forest communities at the valley and the ridgetop margins. The valley soils are predominantly alluvial; however, forest soils are common where timberland has been converted into grassland. Grassy ridgetop terrain may be related to resistant underlying rocks topped by a shallow soil covering that is insufficient in depth or nutrient material to support a forest. However, some ridgetop clearings that appear similar to natural ridgetop grasslands are related to land conversion and may be detected by the presence of forest soil material.

Erosion of natural ridgetop clearings is minimal, but severe erosion of the downslope margins of converted ridgetop lands is common. Upland alluvial valleys experience erosional and depositional processes similar to those described for the larger, low-lying alluvial valleys of the study area.

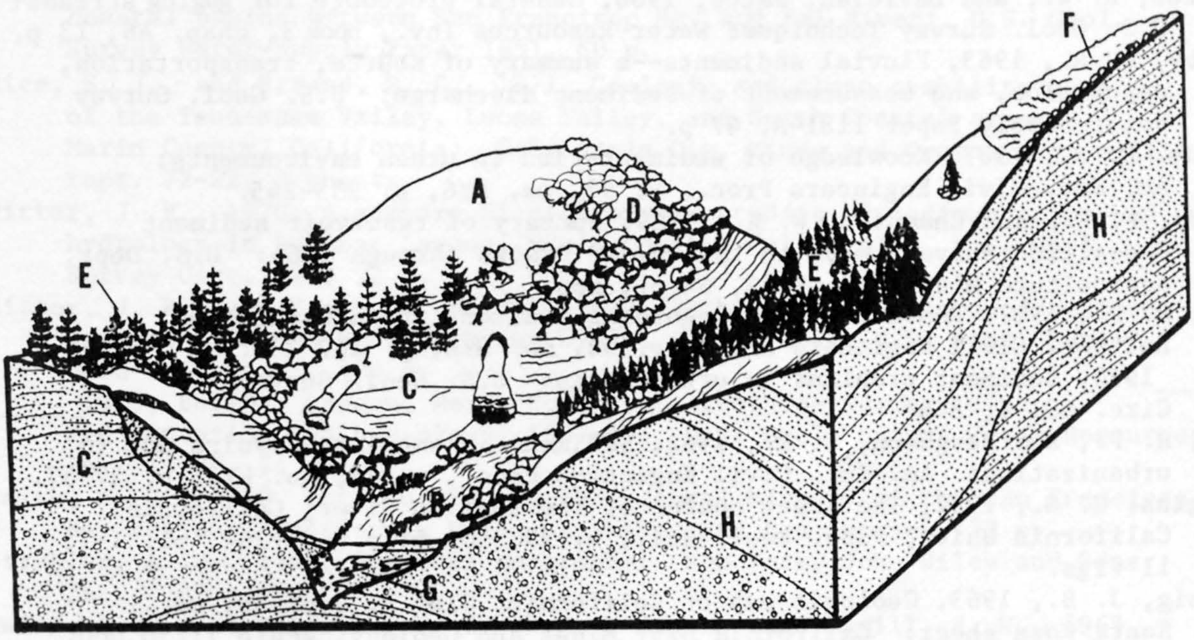

FIGURE 8.--Schematic block diagram showing upland valley and ridgetop terrain within the eastern Sonoma uplands erosional province. A, grassy ridgetop; B, alluvial valley and stream; C, landslides (slumps); D, oak woodland biotic community; E, conifer forest community; F, chaparral biotic community; G, alluvial deposits; H, bedrock. Diagram modified from Twiss and others (1969).

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