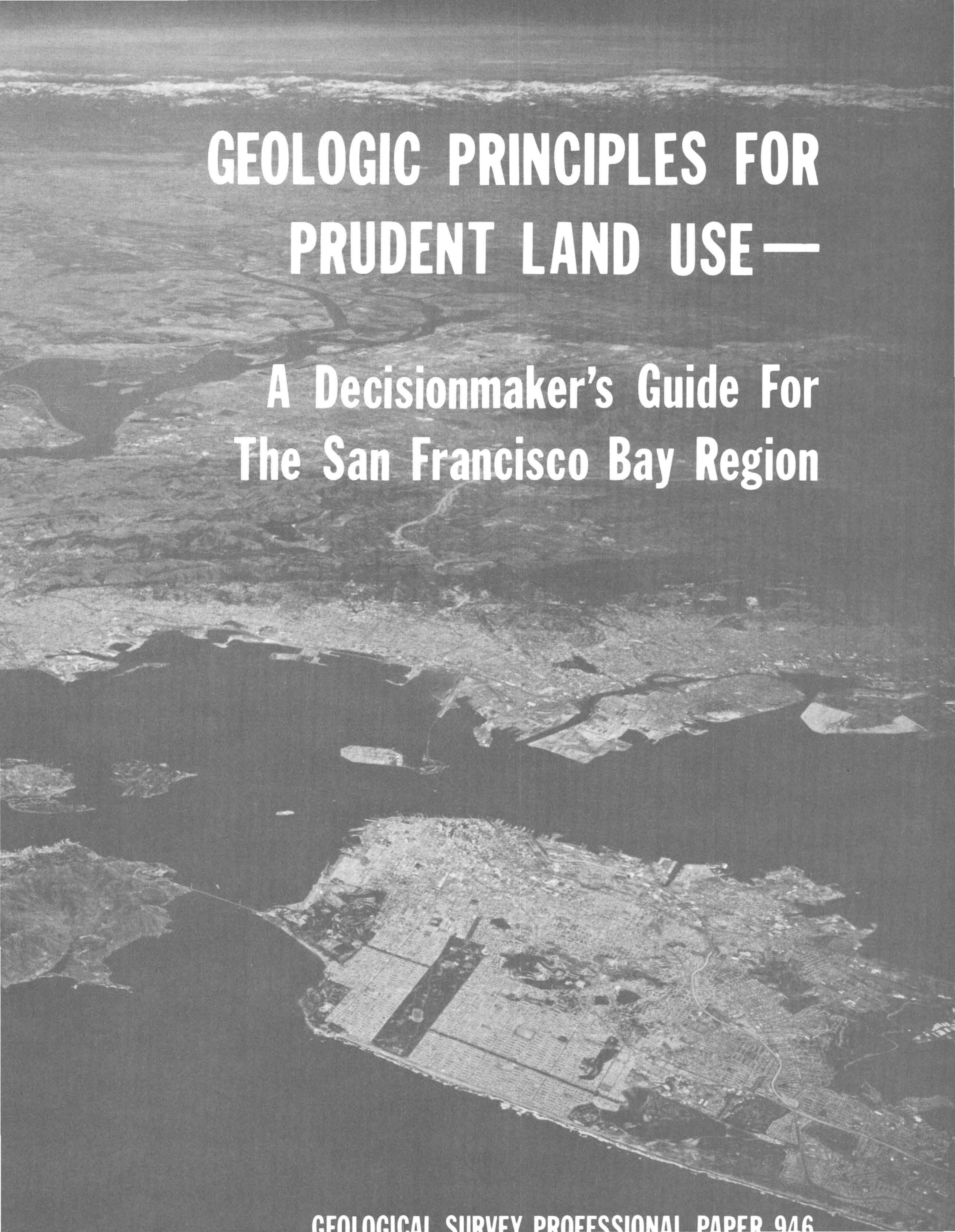
GEOLOGIC PRINCIPLES FOR PRUDENT LAND USE—

A Decisionmaker's Guide For The San Francisco Bay Region



GEOLOGICAL SURVEY PROFESSIONAL PAPER 946

GEOLOGIC PRINCIPLES FOR PRUDENT LAND USE

A Decisionmaker's Guide for the San Francisco Bay Region

by

ROBERT D. BROWN, JR.,
and
WILLIAM J. KOCKELMAN

GEOLOGICAL SURVEY PROFESSIONAL PAPER 946

WASHINGTON • UNITED STATES GOVERNMENT PRINTING OFFICE • 1983

UNITED STATES DEPARTMENT OF THE INTERIOR

MANUEL LUJAN, Jr., *Secretary*

GEOLOGICAL SURVEY

Dallas L. Peck, *Director*

First printing 1983
Second printing 1985
Third printing 1990

Library of Congress Catalog in Publication Data

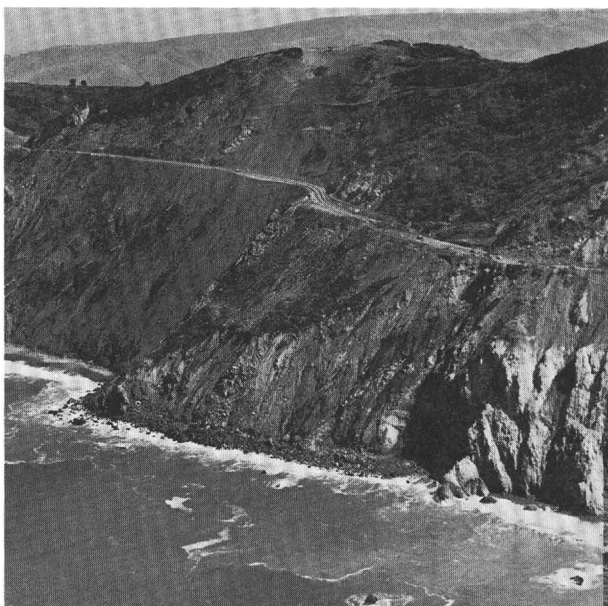
Brown, Robert David, 1925–
Geologic principles for prudent land use: A decisionmaker's guide for the San Francisco Bay region.

(Geologic Survey professional paper 946)
Bibliography: p. 94–97
Supt. of Doc. no.: I 19.16:946
1. Geology—California—San Francisco Bay region. I. Kockelman, William J. II. Title III. Series: United States. Geological Survey. Professional Paper 946.
QE90.S12B76 1983 333.7'09794'6 83–600285

For sale by the Superintendent of Documents, U.S. Government Printing Office,
Washington, D.C. 20402

CONTENTS

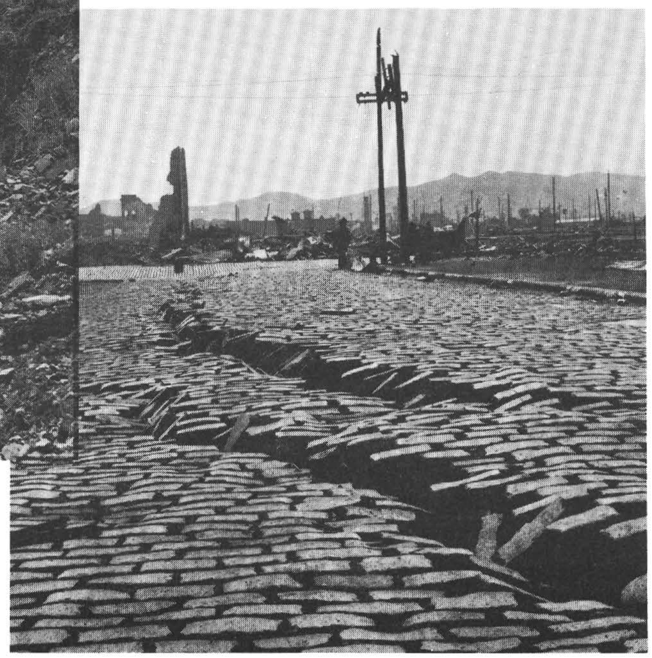
ESTUARY



COASTAL STRIP

LOWLANDS

HILLSIDES AND UPLANDS



FAULTS AND EARTHQUAKES

This report is written for those who decide how land is to be used in the San Francisco Bay region: Elected and appointed officials in State and local government, corporate executives, and those individuals who own or develop land. Its purpose is to remind these people of the intimate relation between geology and land use, and to inform them so that they are better equipped to ask the right questions, to address such questions to those best qualified to answer, and to demand responsive answers that are based on valid technical or scientific evidence. To achieve this purpose, we describe some common problems that arise in converting the land in the bay region to more intensive use and then review several major issues that illustrate how knowledge of the Earth sciences has contributed to improving land-use decisions. Furthermore, our viewpoint is that the experience gained in the bay region can serve as a basis, with appropriate changes, for the acquisition of knowledge and the deployment of strategies of land use elsewhere.

THE NEED

All of us have cause to desire wise use of the land, for all of us pay the price of misuse in higher taxes, increased cost of goods and services, and loss of environmental quality. Mismanagement of land or water resources may even endanger our health or threaten our lives. For these reasons, major decisions on land use are regularly reviewed and approved by public officials—mayors, city councilpersons, or county supervisors—who are as vital in the decision-making process as are the landowners, developers, bankers, and corporate executives who propose, finance, or implement the desired changes. Interests and motives may differ, but both public and private decisionmakers benefit from good decisions and suffer from bad ones.

The distinction between good and bad land-use decisions often depends on how well the decisionmaker understands the land itself—its surface form and drainage, the physical properties of its rock and soil, and the geologic processes that shape it. Where Nature is neglected, it may become a formidable opponent, and most communities bear the scars of such past mistakes in the form of housing tracts that are periodically flooded; roads, sewers, or waterlines that are cut or endangered by landslides; or ponds of effluent that seep from poorly sited septic-tank drainfields. The list is long and varied, but these and other geologically related difficulties can all be avoided.

To alleviate such problems, yet provide for growth and change, decisionmakers need not necessarily be scientists or engineers; they do, however, require some knowledge of rock, soil, and geologic processes. A few of them, chiefly ranchers and farmers, gain this knowledge chiefly from folklore or from daily observation. Many, however, live in cities, where pavement and buildings obscure the natural processes and materials; others are new residents, still unaccustomed to the natural setting and unfamiliar with the local environmental lessons to be learned. For these people, much of the information needed to anticipate and mitigate geologic hazards, though available, is scattered and difficult to interpret. Gathered by geologists, hydrologists, and seismologists, it is published in scientific journals, consultants' reports, and publications of the Federal and State geological surveys. Paradoxically, the very richness and diversity of this data bank lessen its value to nonscientists. The number of accessible sources and their specialized subject matter complicate their application to most decisions, even routine ones. The scientist's cautious language—or, worse, his jargon—may obscure significant findings and permit sharply divergent views, especially over controversial issues.

This report is a simplified presentation, discussing the nature of land-use problems in the bay region, showing how these problems can be identified and evaluated, and, finally, describing some of the methods used to ensure careful appraisal of land-use options. Its brevity and limited scope sacrifice many technical details; for example, it omits all but fleeting mention of ground water, of construction materials, and of saltwater intrusion of freshwater aquifers. The reader may also note other omissions, many of which, however, are considered in the publications cited in the text and listed at the end of this report. These references document more thoroughly the facts, scientific inferences, and experience that we summarize here, and include many typical examples that show how knowledge of the Earth sciences has solved land-use problems. Indeed, one purpose of the report is to inform decisionmakers that these published reports and maps are available, that they contain much useful information which is specifically related to everyday issues, and that they can be successfully used to improve land-use decisions. In this regard, the report might be considered a signpost, directing its readers toward appropriate sources of information and tested methods of evaluating the potential of the land in the bay region to support new uses.

Many of the published maps and reports cited here were prepared between 1971 and 1976 and were issued by the U.S. Geological Survey as part of the San Francisco Bay Region Environment and Resources Planning Study. Funded jointly by the Survey and the U.S. Department of Housing and Urban Development, this study produced more than 100 maps and reports in which the geology, hydrology, geochemistry, and geophysics of the San Francisco Bay region were related to regional, county, and local land-use issues. Much of this information now helps to shape the plans and programs of both government and private enterprise. We describe a few of these applications in the final section of this report and briefly mention others elsewhere in the text. Our examples show that although Earth-science information is widely used, its effective application is still far from uniform, and some bay-region decision-makers remain less well informed than others about how Nature restricts our use of the land.

A PERSPECTIVE

The nine counties that border the San Francisco Bay region make up a 7,400-square-mile (mi^2) area containing 93 cities and 5 million people. More than half these people have arrived since 1950. The annual rate of population increase in the bay region, which reached a maximum of about 4½ percent between 1940 and 1950, is now about 1 percent. This growth, however, has been far from uniform. Some urban centers, such as San Francisco, have lost population since 1950, and some rural communities show little change, but many cities and some counties have sustained decade-long growth rates that are more than twice the regional average. The counties that border the southern San Francisco Bay (fig. 1) have supported most of this past growth and now support most of the present population.

The inflow of newcomers and the migration of city dwellers to the suburbs have steadily expanded the demand for housing and public services. This demand has been met by new construction in existing towns and suburbs and by extensive development of nearby rural areas. Most of the established communities were originally located on gently sloping well-drained alluvial plains, where site conditions presented few major problems. As development spread outward from these centers, however, the builders discovered different terrain with more complex and more difficult site conditions. As ridgecrests, hillsides, and marshes were converted to residential and commercial uses, an array of costly and unfamiliar problems harassed builders, homeowners, and public officials alike.

Floods, drainage problems, and settling foundations beset some of the developments located near the bay and in stream valleys. Hillside projects were mostly free of these problems but faced others—among them landslides, failures in cut slopes and manmade fills, structural damage due to clays that swell when they are wet, and unforeseen difficulties in grading or excavating. Coastal residents lost roads, lots, and structures to the sea. In some places, coastal erosion accelerated when local harbor improvements altered wave patterns and sediment supply along miles of the coastline.

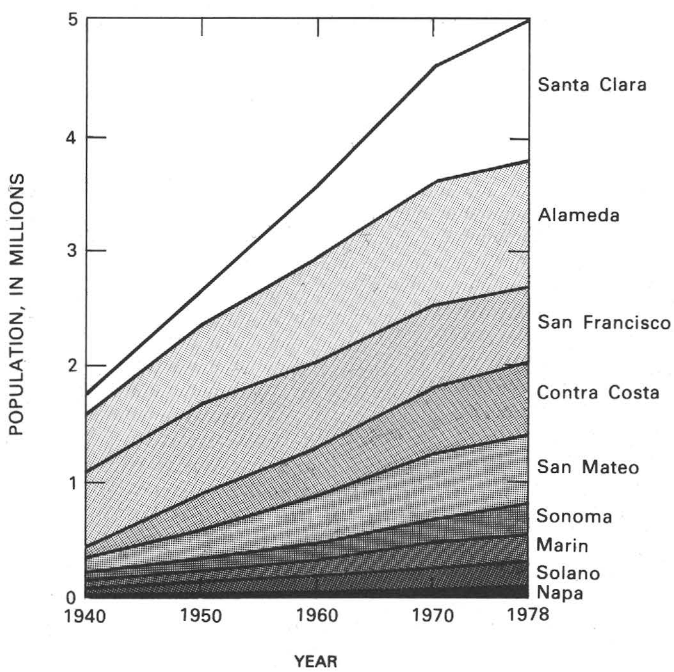


FIGURE 1.—Population growth, by county, in the San Francisco Bay region, 1940-78.

These problems are visible, troublesome, and costly; yet all of them together are overshadowed by the threat of another major earthquake. Since the great San Francisco earthquake of 1906, more than 75 years of relative quiet has blunted our awareness of earthquake hazards. Housing tracts, schools, and hospitals now stand on or near the three largest faults that have ripped the landscape apart five times in the past 150 years. Along these same faults, dams and reservoirs that date from the turn of the century loom over bedroom communities in the flood plains below. In the cities, many tall buildings and other major structures were built to meet codes that we now know seriously underestimated the intensity of earthquake shaking; some buildings predate even the earliest earthquake codes.

Many of the problems that arise during land use and development can be foreseen and either remedied or avoided. In the past, some probably were foreseen but were discounted because they seemed to be acceptable risks when weighed against short-term economic gains. Others were unrecognized or seriously underestimated because so few people understood how geology and hydrology can be used to predict the consequences of land-use decisions. Still others actually were not foreseen as problems but were perceived as such only when new research results broadened our knowledge.

Many of the problems that stem from geologic causes are serious, indeed, and if they are ignored or unattended, they may increase in scope and severity. For example, a single small landslide on a ¼- to ⅓-acre plot of developed land threatens not only the buildings, roads, and utility lines on the landslide itself but also those adjacent to it, as well as on any downstream property that receives the excess sediment or runoff derived from the slide area. Such landslides can easily cost many hundreds of thousands of dollars, even where only one residential lot is directly affected. Although the loss of the dwelling and lot is usually borne by the homeowner, most of the total costs are borne by the community and thus, ultimately, by the taxpayer. These public costs include: Cleanup work to remove and dispose of debris, restoration of roads and essential services, investigation of the soil and geology at the site to determine the cause of sliding, and measures taken to stabilize the slide. Some public costs may also result from the loss of tax revenues. Together, public costs may well amount to 5 to 10 times the preslide value of the lot and dwelling.

By contrast, geologic studies to identify potential slide areas before and during site preparation cost little and can be part of a comprehensive geologic evaluation. For multiunit developments, the cost of geologic site investigations, when passed on to the individual home purchaser, is likely to be less than $300 per lot and rarely amounts to more than a negligible percentage of the total purchase price of the house and lot.

Despite the numerous geologic hazards in the bay region, those that are most likely to occur in any one place are comparatively few and rather easy to identify. This localization permits us to define, for the San Francisco Bay region, four provinces, each of which presents a typical set of problems for those concerned with land development: (1) The estuary, (2) the coastal strip, (3) the lowlands, and (4) the hillsides and uplands. As listed in table 1, the last two provinces together make up more than 90 percent of the total land area in the San Francisco Bay region.

TABLE 1.—*Distribution of land in the San Francisco Bay region, by province*

Province	Area (mi^2)	Percentage of total area
Estuary	240	3
Coastal strip	175	3
Lowlands	2,260	32
Hillsides and uplands	4,293	62
Total	6,968	100

Although most of our discussion concerns these four natural provinces, we also include a fifth topic that is common to the entire bay region—faults and earthquakes. Whereas some earthquake hazards are confined chiefly to specific provinces, others can occur in all of these provinces; in addition, the nature and severity of each such hazard can commonly be determined on the basis of its presence or absence in a particular province.

After identifying the problems within each province, we summarize the geologic relations and processes that characterize each province and then suggest actions that may be taken to assure that new development is both cost effective and consistent with acceptable standards of public health and safety. Some of these problems are so common or so serious that State and local governments have already adopted formal measures to minimize losses and reduce hazards. Several of these measures are discussed briefly in the last section entitled "Examples of the Use of Earth-Science Information."

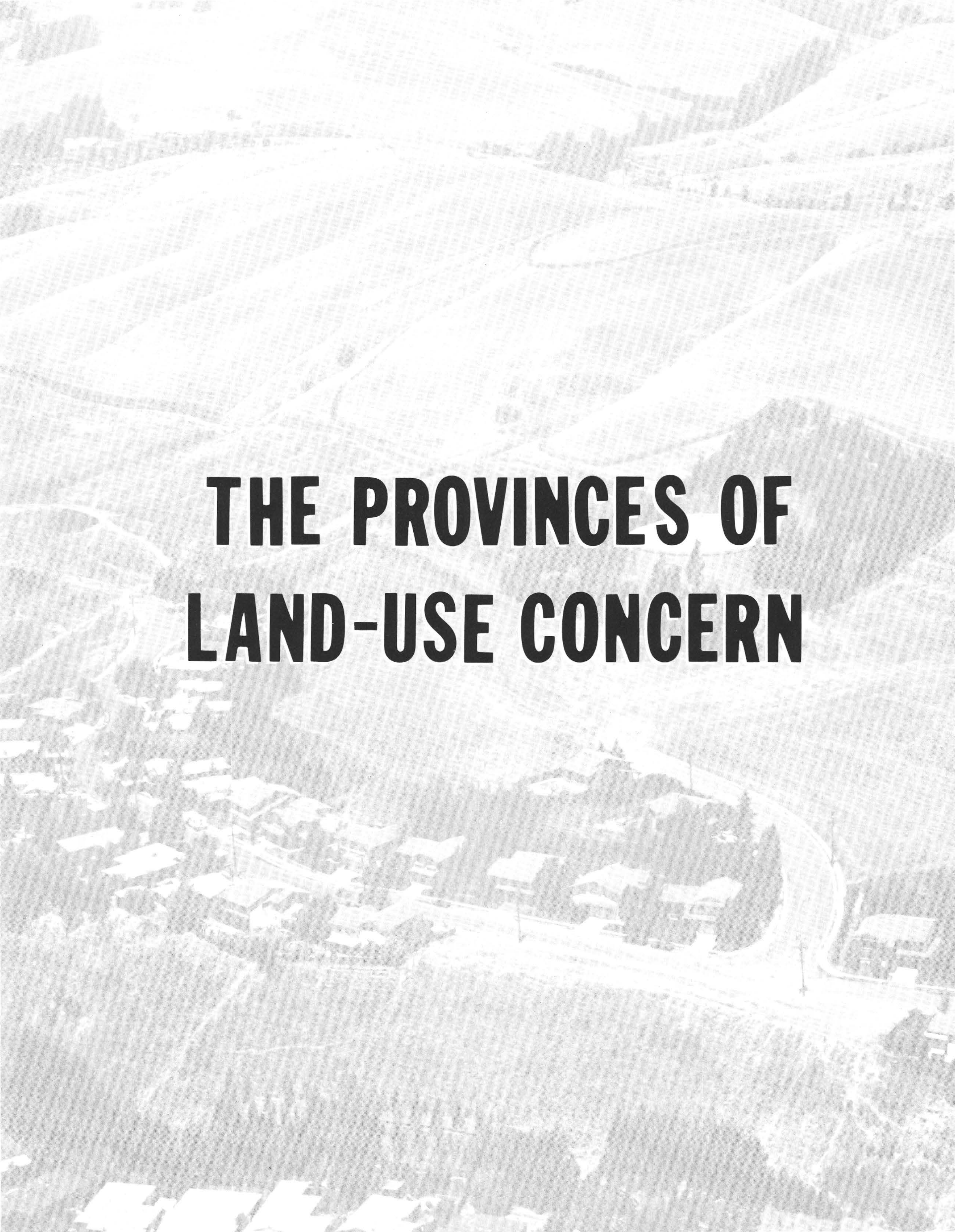
ACKNOWLEDGMENTS

We gratefully acknowledge the many helpful comments of those who reviewed the manuscript: Victor Calvo, former California Assemblyman, 21st District; Nancy Robertson and Jon Silver, councilpersons, Town of Portola Valley, Calif.; Priscilla Grew, former director, California Department of Conservation; James Davis, California State Geologist; Eric Carruthurs, alternate member, San Francisco Bay Conservation and Development Commission; and G. D. Robinson, Robert Page, and Robert Schuster, geologists, and Andrew Spieker, hydrologist (all of the U.S. Geological Survey).

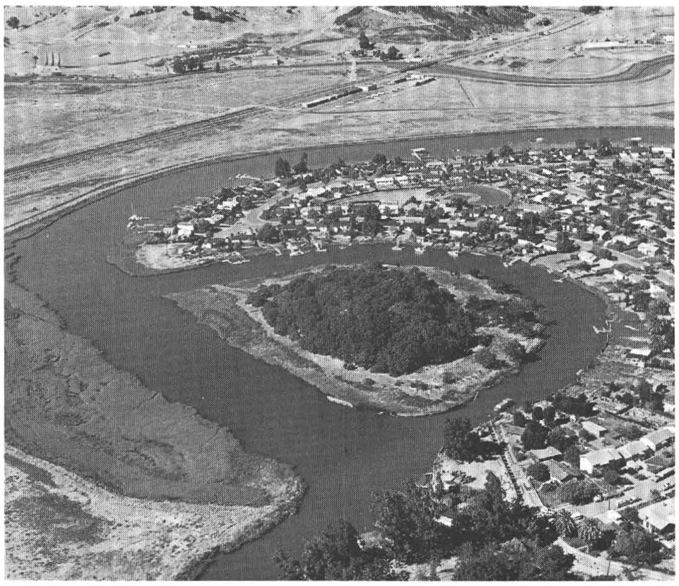
Substantial contributions, exceeding the normal scope of a review, were made by six people who had special knowledge of, or responsibility for, the six examples discussed in the final section of this report: Earl Hart, senior geologist, California Division of Mines and Geology; Jeanne Perkins, regional planner III, Association of Bay Area Governments; George Reed, senior planner, San Francisco Bay Conservation and Development Commission; James Berkland, Santa Clara County Geologist; Charles Gyselbrecht, former Chief Building Inspector, Redwood City; and John Freidlington, associate counsel, California Association of Realtors.

The concept for this report, and much of its scope and content, emerged from our many discussions with three people: James Balsley, former Assistant Director for Research, U.S. Geological Survey; Arthur Zeizel, former environmental scientist in the Office of the Assistant Secretary for Policy Development and Research, U.S. Department of Housing and Urban Development, and currently with the Office of Natural and Technological Hazards, Federal Emergency Management Agency; and Andrew Spieker, former Deputy Director of the San Francisco Bay Region Environment and Resources Planning Study.

THE PROVINCES OF LAND-USE CONCERN



Natural marshland and sloughs near Palo Alto yacht harbor, San Mateo County. The island and the channel margin (upper left) retain the intricate natural drainage systems and the cordgrass and pickleweed vegetation of the extensive marshlands that once fringed the bay. Bay mud, which underlies the marshland and tideflats, is water saturated and low in compressive and shear strength; at many sites it tends to amplify and prolong earthquake shaking. Where it contains saturated fine sand, it may liquefy during strong shaking, to create gaping fractures and cause lateral spreading of the ground surface. Photograph by Norman Prime, U.S. Geological Survey.



Reclaimed and natural marshlands along the South Fork of Gallinas Creek near Santa Venetia, Marin County. All of the valley floor is underlain by bay mud and was formerly marshland similar to that bordering the straight segment of the creek on the left. Though diked and drained, such sites are within a few feet of sea level and retain many of the natural characteristics of marshland, among which are near-surface ground water and susceptibility to tidal, stream, and local flooding. Successful development of reclaimed marshlands depends on recognizing and solving the problems that accompany construction on bay mud. Photograph by Norman Prime, U.S. Geological Survey.

THE ESTUARY

Open water, tidal marshlands, and saltponds now cover 611 mi^2, or about 8 percent, of the total surface area of the San Francisco bay region. Because of its size and central location, the estuary acts as a regional air conditioner, cooling the surrounding land areas in summer and moderating the chill in winter. Its waters provide harbors, shipping lanes, and a habitat for fish and shellfish; its marshlands are a source of salt and peat, and a hospitable environment for wildlife and waterfowl.

THE PROBLEM

The San Francisco Bay and its bordering marshlands (fig. 2) make up the estuarine system, in which freshwater from inland rivers mixes with seawater. The estuary tempers the climate, provides waterways, and supports a complex biologic system, but it can easily be degraded by pollution, by changes in the seasonal inflow of freshwater, or by filling, which reduces its size and impairs normal estuarine processes. The natural and reclaimed (historical) marshlands bordering the bay lie at or near sea level and are underlain by unconsolidated water-saturated organic mud. Thus, much bay-margin land is susceptible to flooding and saltwater corrosion, as well as to foundation failure or settlement due to liquefaction and strong ground motion during earthquakes.

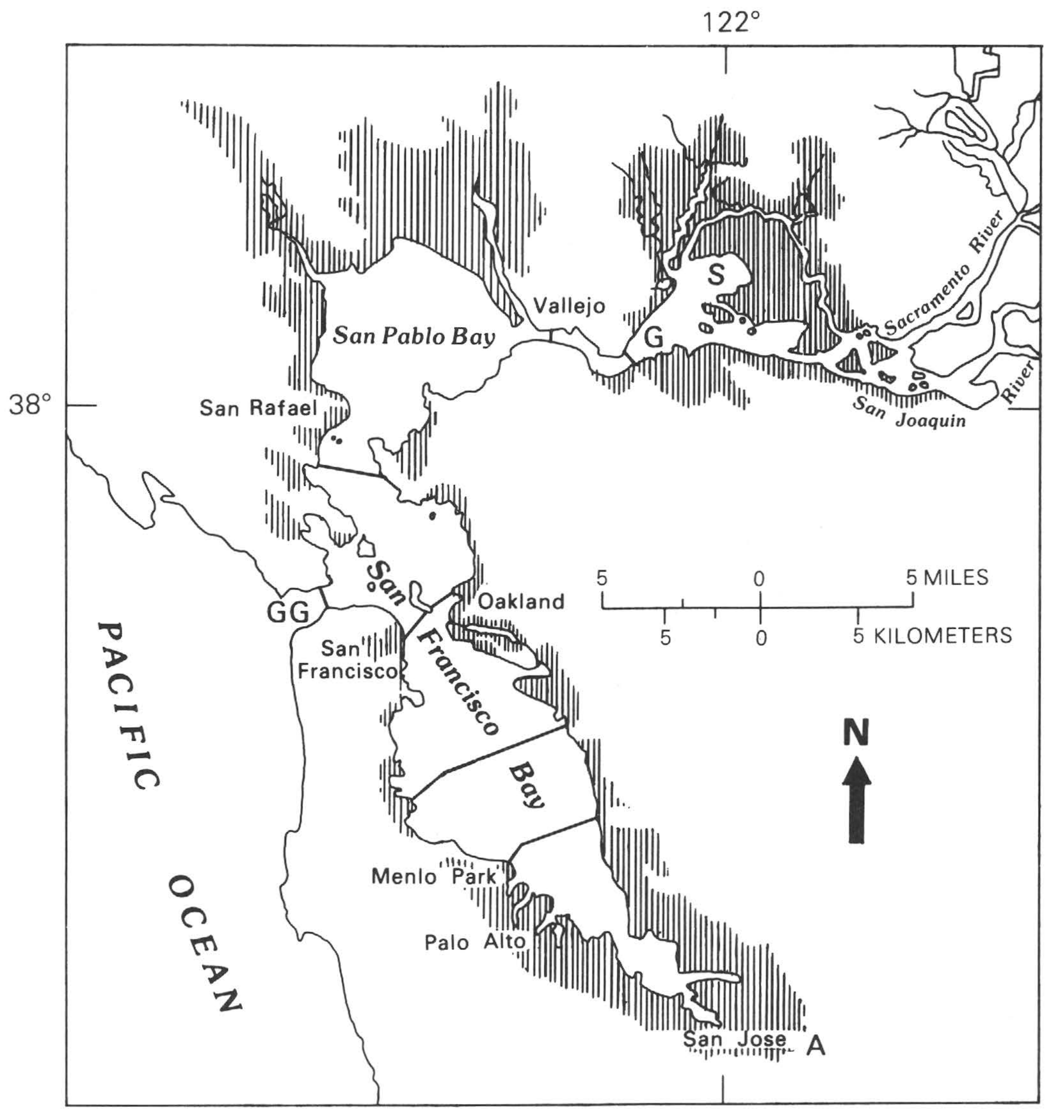


FIGURE 2.—Part of the San Francisco Bay discussed in this report; eastern part of estuary extends beyond map area into inland valleys that are outside bay region. Shaded areas are underlain by bay mud and approximate original extent of saltmarsh (now greatly reduced). A, Alviso; G, Grizzly Bay; GG, Golden Gate; S, Suisun Bay. Adapted from Schlocker (1970).

GEOLOGY AND PROCESSES

The estuary formed when melting ice from the last great glaciation caused a worldwide rise in sea level (Atwater and others, 1977; Atwater, 1979). Toward the end of the glacial period, about 15,000 years ago, sea level off the Golden Gate was more than 300 feet (ft) lower than today. The shoreline then lay 20 to 30 miles (mi) off the present coast and a few miles to the west of the Farallon Islands. As sea level rose, the shoreline moved landward. It reached the Golden Gate about 10,000 years ago, and seawater then invaded the branching valleys that now form the San Francisco, San Pablo, and Suisun Bays. The rate of marine incursion slowed about 6,000 years ago, but flooding of the estuary by seawater continued up to historical time.

As it grew in area and depth, the estuary formed a settling basin for fine sediment carried into it by streams and rivers. This sediment, chiefly clay and silty clay, was first deposited along the course of the primitive estuary as bottom mud. Later, as sea level stabilized near its present position, salt-marsh deposits accumulated between the level of high and low tides. These deposits grew outward from the shore until a belt of marshland, several miles wide, fringed much of the prehistoric bay (Atwater and others, 1979). Over time, as much as 120 ft of mud accumulated in some places (Helley and others, 1979, p. 21). Because it is geologically very young and has never been deeply buried or deformed, this mud is still unconsolidated and saturated with water; much of it is rich in organic material, and locally it contains lenses or beds of well-sorted silt and sand, as well as beds of peat.

Within the estuary, saltwater from the ocean mixes with freshwater from inland streams. Depending on salinity, tide, and streamflow, estuarine water may flow seaward or landward; surface water commonly moves in one direction, and the denser, more saline bottom water in another (Conomos, 1979). Seawater enters the estuary at the Golden Gate, driven by tides that have a maximum range there of about 8 ft. (Maximum tidal ranges elsewhere in the bay are greater; for example, at Alviso the range is about 14 ft.) Freshwater enters the bay from many streams, but by far the greatest volume comes from the Sacramento and San Joaquin Rivers, which enter the estuary together at its east end. Because saltwater is denser than freshwater, the water near the bottom of the bay is more saline than that near the surface. Thus, at any one time, the salinity of the water varies with both location and depth.

Salinity also varies over time. Minor changes result from the ebb and flow of the tide or from mixing by winds; major seasonal changes in salinity follow changes in the discharge of freshwater from the Sacramento and San Joaquin Rivers (fig. 3). The maximum discharge of these two rivers depends on rainfall

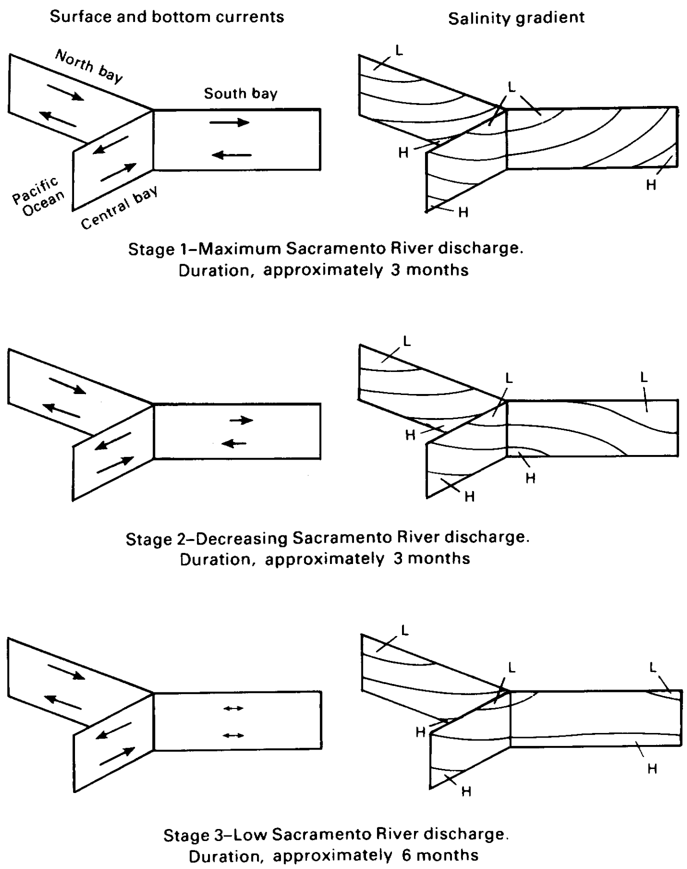


FIGURE 3.—Diagrammatic model of salinity gradients and net surface and bottom currents through annual seasonal stages in the San Francisco Bay. Lengths of arrows represent relative rates of flow. Curved lines on right-hand figures are salinity contours: H, high salinity; L, low salinity (from McCulloch and others, 1970, p. A12).

and snowmelt and comes during late winter or spring. It may be 5 to 7 times the minimum discharge, which commonly occurs in late summer or early fall. The annual inflow of freshwater reduces the salinity of estuarine water and alters the density layering within the estuary; this inflow is especially important in flushing the southern San Francisco Bay (McCulloch and others, 1970), which receives only a minor amount of freshwater from its own small drainage basin.

ACTIONS TO ENHANCE LAND USE

The estuary (fig. 2) is a unique and irreplaceable part of the San Francisco Bay region. However, this resource has not always been managed wisely. In the past 120 years, the area of open water has decreased from 476 to 423 mi^2, or by about 11 percent, and of the marshland from 313 to 125 mi^2, or by about 60 percent (Nichols and Wright, 1971, p. 6). These changes are mostly manmade; they result from landfill, disposal of dredge spoil, diking and reclamation of marshland, and accelerated rates of sedimentation due, for example, to hydraulic gold mining in the Sierra Nevada. Historically, the estuary has also served as a receptacle for sewage, industrial wastes, and other pollutants. As early as 1912, residents of the bay region recognized that a decline in the productivity of bay fisheries was caused by human activities and that the estuary needed protection (Nichols, 1973, p. 1).

Attempts to protect the estuary and to ensure consistent management of its resources were long hampered by the conflicting priorities and overlapping jurisdictions of the numerous counties, cities, and towns along its perimeter. Pollution and sewer discharges were gradually controlled and regulated under State and Federal law, but filling of the inlets and marshes remained a problem until 1969, when the San Francisco Bay Conservation and Development Commission (BCDC) was given permanent status by the California Legislature. This commission had been established as a temporary body in 1965 in response to citizen concern, and in its first 4 years it prepared the San Francisco Bay Plan, a management program based on detailed findings and explicit policies. The 27 commissioners represent the public (7), the State (5), the Federal Government (2), the counties around the bay (9), and selected cities (4). Under the law and the Bay Plan, the commission regulates filling, dredging, and other changes in existing land use in the San Francisco, San Pablo, and Suisun Bays, as well as in the sloughs that are part of the bay system. It has limited jurisdiction over land use within a 100-ft-wide strip inland from the bay and over any proposed filling of saltponds or managed wetlands. A 1977 law extended the commission's jurisdiction to protect the Suisun Marsh (San Francisco Bay Conservation and Development Commission, 1978).

The estuary and its bordering tidal lands confront planners and decisionmakers with two difficult problems: How to use the marshlands safely and prudently, and how to protect the quality of water. Both of these problems are related, and neither can be dealt with in isolation; for convenience, however, we discuss them here separately.

MARSHLANDS

Several characteristics of the marshlands make them difficult or costly to convert to intensive use. The marshland surface lies between high and low tide and is subject to periodic flooding, which can cause trouble when peak storm runoff from local streams coincides with high tides. This flooding can be partly controlled by dikes or landfills, but it cannot be completely eliminated because the land is flat, the dikes are vulnerable to failure, and, in most places, ground-water levels are within a foot or so of the surface. Near-surface ground water also creates other problems: It makes drainage difficult, it requires special foundation designs for certain structures, and, where it is saline, it is corrosive.

Bay mud underlies existing, reclaimed, and filled marshlands and ranges in thickness from a few inches to many tens of feet. Because this mud is unconsolidated, rich in organic matter, and saturated with water, its bearing strength is so low that it fails under even modest load; in some places, a foundation pile will sink into bay mud without being driven. The high water content and low strength of the mud, in its natural state, make it susceptible to settlement—gradual downward movement of an engineered structure as the unconsolidated material below the foundation compacts under load (fig. 4). It is somewhat firmer when drained, but draining reduces its volume and causes subsidence. The surfaces of many drained bay-region marshlands have already sunk several feet below their original levels. Subsidence and consolidation are even

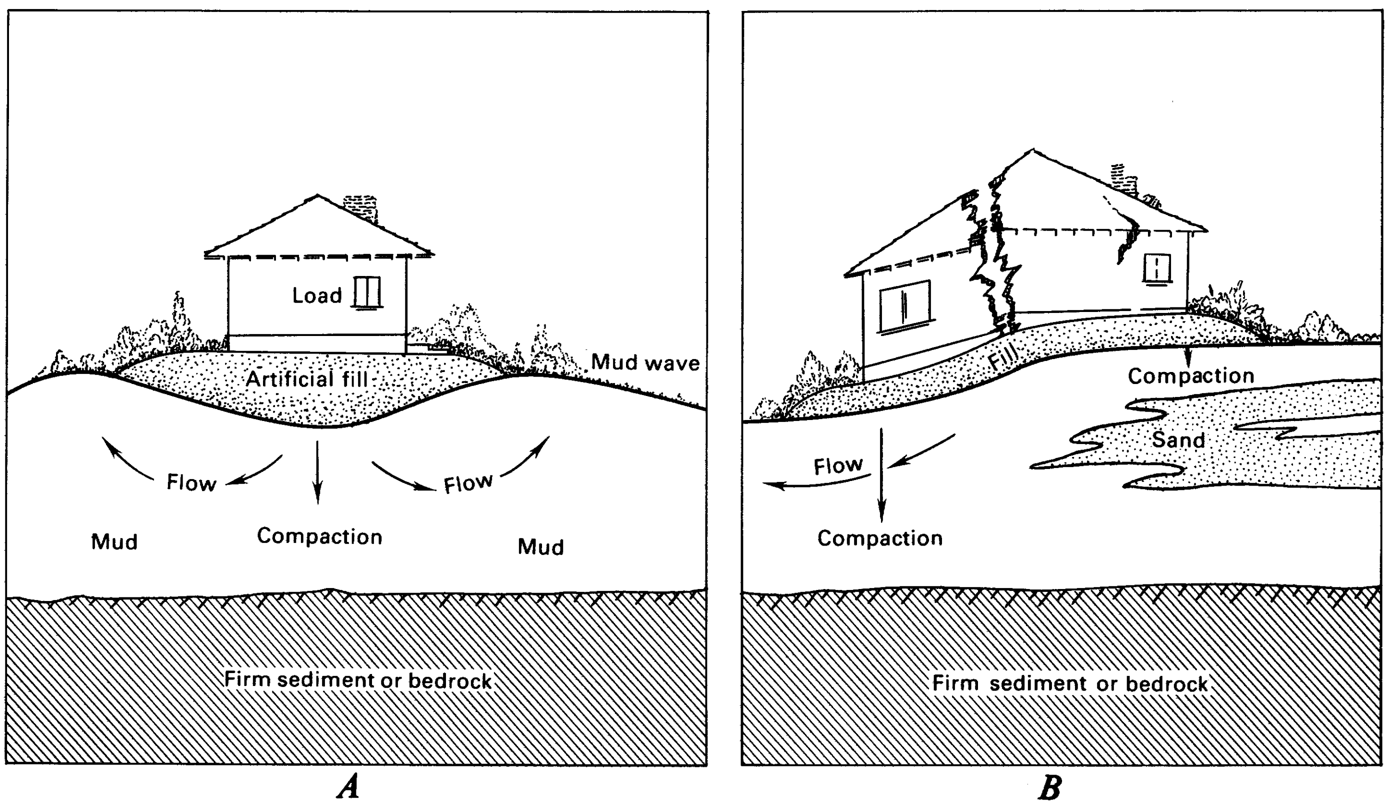


FIGURE 4.—Typical settlement of engineered structures placed on artificial fill over mud with a low shear strength. *A*, Uniform settlement over a homogeneous layer of mud. *B*, Differential settlement over mud containing a sand body with a relatively high shear strength. From Helley and others (1979, p. 50).

greater where peat, which is common in some marshes, is drained and exposed to the air (fig. 5).

Earthquakes cause other problems in sites underlain by bay mud. These sites shake longer and harder than those on bedrock, and where sand or silt beds in the mud are are saturated, the sediment may liquefy and cause ground failure. These problems are discussed further in the section below entitled "Faults and Earthquakes" (see also Youd, 1973; Youd and Hoose, 1978; Helley and others, 1979).

Some of the difficulties presented by the marshlands can be overcome by special engineering practices if geologic investigations have determined the thickness of the mud, its properties, and whether it contains lenses or beds of liquefiable sediment. Besides diking and filling, which are commonly used to mitigate flood hazards, some marshland sites have been drained and compacted before and during filling. Such attempts to control subsidence have succeeded in some places, but estimation of the total amount of subsidence and prediction of the rate at which it occurs are difficult. Many large or heavy structures on bay mud avoid these problems because they are built on pilings or piers that penetrate through the mud to bedrock.

Investigation of the geology of a site, preparation of the land, design and construction of special foundations, and installation of utility services add significantly to the costs of development on bay mud (Helley and others, 1979, p. 76-77, 82-83). Public costs are also high (Laird and others, 1979, p. 61-89) because roads, storm and sewer pipelines, and other public improvements require more maintenance and because the risk of loss from earthquake and flood damage is greater in the marshlands than elsewhere in the bay region.

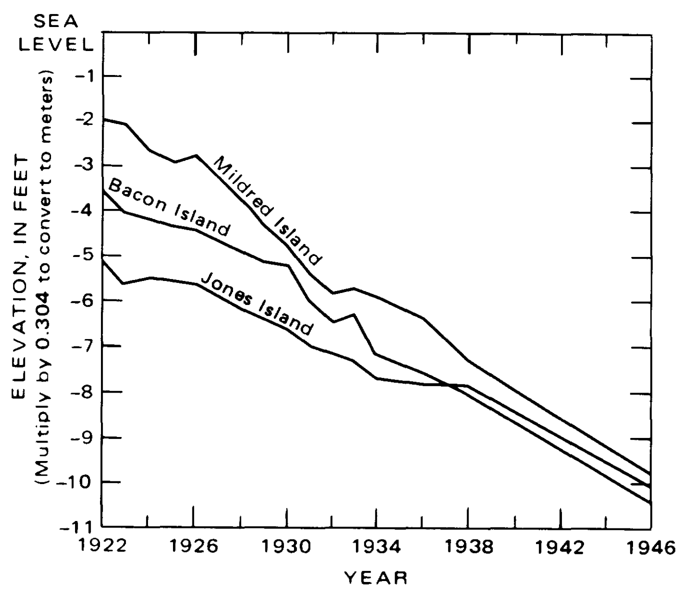


FIGURE 5.—Progressive subsidence of Mildred, Bacon, and Jones Islands in the Sacramento-San Joaquin delta, primarily owing to peat oxidation, between 1922 and 1946. These islands, diked to protect them from flooding, are in eastern part of estuary (not shown in fig. 2). From Weir (1950) and Helley and others (1979, p. 49).

BAY WATERS

Some land-use practices profoundly affect the quality of the estuarine water: Either they pollute it, or they interfere with such natural estuarine processes as the exchange of freshwater and saltwater or the production of oxygen.

The San Francisco Bay Plan (San Francisco Bay Conservation and Development Commission, 1969, p. 10) summarized the findings concerning water pollution as follows:

a. San Francisco Bay receives a variety of municipal, industrial, and agricultural wastes from sources throughout its tributary drainage area. Pollution occurs when waste discharges cause water quality conditions that damage or destroy varied uses of the Bay. Such conditions can result from toxic (poisonous) substances, from residues that unduly stimulate organic growth in the Bay, and from sewage that consumes oxygen in the water as it disintegrates. Polluted waters may be unsafe for human contact or use, offensive to the senses, damaging or lethal to marine life, and even unsuitable for industrial use.

b. Compared to rivers and estuaries in other parts of the country, San Francisco Bay is relatively unpolluted. In recent years, extensive improvements in the treatment of industrial and municipal wastes have greatly reduced the pollution that once existed in the Bay. But some parts, especially in the South Bay, are still polluted at certain times of the year. As long as the Bay continues to receive wastes from an expanding population and industry, there must be constant improvement in waste management to upgrade presently polluted areas and prevent pollution problems in the future.

c. While waste disposal poses a continuing threat to water quality in the Bay, this use of Bay waters will continue for some time. Pollution of Bay waters from these wastes can be prevented by: (1) transporting wastes directly to the ocean (but without allowing waste discharges to damage the ocean's marine life); (2) prohibiting the discharge into the Bay of toxic wastes (poisons) that do not break down; (3) adequate treatment of wastes before discharge into the Bay; and (4) natural breakdown of any biodegradable wastes placed in the Bay, which can be encouraged by maintaining adequate flushing action and an adequate supply of dissolved oxygen in the Bay.

The San Francisco Bay Plan (San Francisco Bay Conservation and Development Commission, 1969, p. 9-13, 27) also recognizes the importance of natural estuarine processes in maintaining the quality of the water in the estuary. Historically, these processes have been impaired by the loss of both estuarine volume and surface area; either loss modifies the circulation and mixing of freshwater and saltwater and causes significant and generally detrimental increases in salinity. Moreover, most of the lost area was marshlands and mudflats, where grasses and algae are important sources of oxygen; thus, the loss of these wetlands deprived the estuarine system not only of important biologic habitats but also of part of its natural oxygen supply. The laws and regulations that now control filling of the estuary are, in part, specifically aimed at maintaining its surface area and volume.

Also important to a biologically healthy estuary is the inflow of sufficient volumes of freshwater from the Sacramento and San Joaquin Rivers (San Francisco Bay Conservation and Development Commission, 1969, p. 10, 12; McCulloch and others, 1970). Recent plans to divert part of this flow from the Sacramento River drainage system to southern California and the San Joaquin Valley by way of a peripheral canal around the east side of the Sacramento River delta raise the difficult question of how much water can be diverted without degrading the estuary. The benefits of such diversion would accrue chiefly to water users in the San Joaquin Valley and in southern California; the most evident adverse effects—diminished flow, loss of circulation, and increased salinity—will be felt downstream and in the estuary. Although the scientific evidence needed to answer this question is beyond the scope of this report, this issue illustrates the important point that land uses and resources in the bay region can be seriously and permanently affected by decisions that are made outside the region.

California Highway 1 at the Devils Slide, San Mateo County. Hillslopes above and below the highway are mantled with landslide debris or detached landslide masses. The most active part of the slope is the debris-covered chute near the center, but the brushy hillside above the highway on the right also exhibits landslide topography and one well-defined landslide scarp. Bedded dark-gray shale and sandstone, the underlying bedrock here, dip to the left in the cliffs beyond the slide; granitic rock beneath the shale and sandstone crops out in the rugged cliffs at extreme right. This part of Highway 1 is frequently closed by slides, and because storm waves continue to erode the base of the cliff every winter, the stability of the slope diminishes over time. Ultimately this segment of the coastal highway may have to be abandoned. Vestiges of the Ocean Shore Railroad on the left below the highway mark an early, unsuccessful attempt to link San Francisco with coastal towns to the south. Constructed between 1905 and 1908, the railroad was severely damaged by landslides during the 1906 San Francisco earthquake and was abandoned in 1921. Photograph by Earl E. Brabb, U.S. Geological Survey.

Point Montara lighthouse, San Mateo County. Resistant granitic rocks in the surf zone defend the shoreline, but the sea erodes and gullies the marine deposits underlying the coastal terrace—the nearly flat land surface checkered with tilled fields. As they slowly retreat landward, the bluffs along the shore will eventually deliver buildings, roads, and other structures to the sea. Coastal erosion here averages less than a foot per year; only a few miles to the south, however, near Half Moon Bay, the average rate of coastal erosion is as much as 6.5 feet per year. Photograph by Earl E. Brabb, U.S. Geological Survey.

THE COASTAL STRIP

The Pacific Ocean bounds the San Francisco Bay region from the mouth of the Gualala River on the north to Point Año Nuevo on the south. No well-defined feature marks the landward extent of the coastal strip, and so, for the purposes of this discussion, we define it as extending inland 1 mi from the coast.

THE PROBLEM

The coastline, constantly under attack by the sea, retreats inland over time. Under natural conditions, some coastal bluffs retreat at rates of a few feet per year. These rates may increase rapidly where man interferes with coastal processes; for example, at Half Moon Bay, construction of a breakwater resulted in a nearly tenfold jump in local erosion rates to 20 ft per year. Cliff retreat and coastal landslides adversely affect development and are major problems along those parts of the coast that are underlain by sheared or poorly consolidated sedimentary rocks. Seacliffs of resistant rock, such as the bluffs of granite or ancient lava flows that defend most of the headlands, are more stable and enduring. Furthermore, because of its proximity to the San Gregorio and San Andreas faults, all the coastal strip is subject to severe earthquake hazards, of which strong ground shaking and earthquake-induced ground failure are the most prevalent.

GEOLOGY AND PROCESSES

The shape and trend of the Pacific coastline (fig. 6) provide important clues for planning because they show how various parts of the coast respond to attack by the sea. The general northwesterly trend of the coastline is interrupted by prominent headlands, by broad and gently concave embayments, and by narrower curving bays. Each of these features has resulted from the pounding of the sea against rock masses that differ in their resistance to marine erosion. Granite, one of the most resistant rocks in the bay region, defends Bodega Head, Point Reyes, and Point Montara; volcanic rocks defend Pigeon Point. Between these headlands the long reentrants in the coastline, such as those between Fort Ross and Bodega Head and between Point Reyes and Point Montara, are carved into less resistant sedimentary rocks.

Smaller embayments at Drakes Bay, Bolinas Bay, and Half Moon Bay have a more complex origin. Each of these bays occupies the south side of a headland, and each owes its shape and position to the processes exemplified at Half Moon Bay. There, waves driven by the prevailing northwesterly wind approach the coast from the northwest, but they slow and change course as they pass the headland at Pillar Point and meet south- or southeast-trending rocky shoals on the leeward side. These refracted waves approach the north shore of the bay from the west or southwest, attack the easily eroded rocks behind the headland, and carve out an arcuate bay.

Beach sand protects parts of the coastline from marine erosion. It accumulates in the beach and surf zones, moves to and fro with breaking waves and runoff from the beach, and consumes much of the energy directed toward the shore. Winter storm waves erode the beach and carry sand from it to the surf zone. Winter beaches are, therefore, narrower than summer beaches, but in winter the submerged sand deposits cause the waves to break farther out, so that they expend much of their energy in turbulence before they reach the shore.

The daily and seasonal to-and-fro movement of beach sand is superimposed on a broader pattern—the slow drift of sand for many miles along the coast. South- or southeast-flowing longshore currents form as waves from the northwest strike the shoreline at an oblique angle. These currents gradually move the sand that is brought to the sea by rivers or is eroded from the seacliffs. This littoral drift, combined with the refraction of waves on the leeward side of headlands, accounts for many of the beaches and bars rimming such south-facing bays as Drakes Bay and Bolinas Bay.

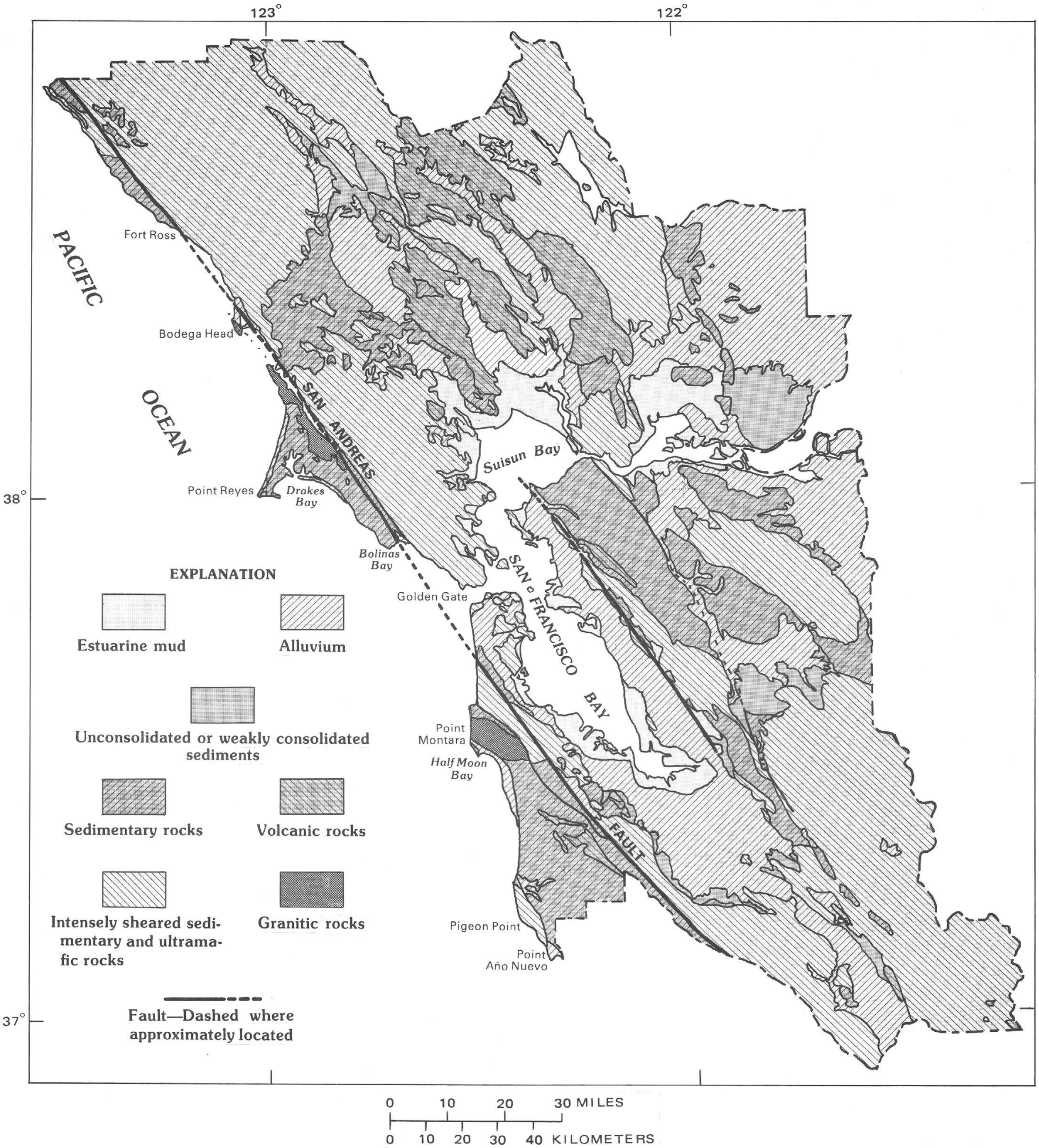


FIGURE 6.—Generalized geologic map of the San Francisco Bay region, showing prominent coastal landmarks. Nearly all irregularities in the coastline are related to the geology, but at this scale only large features and a few major rock types can be shown. Modified from Schlocker (1970).

ACTIONS TO ENHANCE LAND USE

The coastal strip is scenic and relatively unspoiled. It contains much of the Point Reyes National Seashore and nearly a score of State and county parks and beaches. It is intensively developed only on the west side of the San Francisco peninsula, where the land is relatively flat; elsewhere, development has been slowed by the rugged topography, the distance from inland cities, and the relatively inhospitable climate.

Fog shrouded and damp for much of the year, the coastal strip was long considered a less desirable place to live than the sunnier, drier areas east of the coastal mountains. Since about 1950-60, however, more and more coastal land has been subdivided or converted to commercial and industrial use. This trend, which has taken place along almost the entire California coast, has raised statewide concern that a valuable agricultural, recreational, and esthetic resource might be threatened.

Expressing this concern, California voters, in a 1972 referendum, mandated a comprehensive plan for the use of resources in the coastal zone. This plan was ratified by the State legislature as the California Coastal Act of 1976. Through mandatory implementation of its policies by local government, the act guarantees public access to the shore, insures that coastal developments serve the public as a whole, protects and restores coastal marshes, preserves coastal farmlands, and provides stringent environmental safeguards for coastal developments. The coastal plan is in part funded by the Federal Coastal Zone Management Act of 1972, and, like the San Francisco Bay Plan, it uses Earth-science knowledge and principles as a basis for decisions.

Our description of the coastal strip stresses chiefly those features and processes that are unique to the shoreline environment. We emphasize them because the shoreline changes so rapidly and because the forces of change—especially marine processes—are so great that they defy our attempts to control them. These forces are concentrated at the shore, and their effects diminish inland. The multitude of natural processes along the coastal strip, and the force and intensity of some of these processes, make decisions on coastal land use as challenging and as difficult as those in any other province of the bay region.

LANDSLIDING

Regardless of its local character, the coastal strip is geologically young, a result of the same postglacial rise in sea level that formed the San Francisco Bay. Thus, many coastal landforms are still being shaped by the sea, and some seacliffs are retreating at average rates of more than a foot per year (fig. 7). Past generations of planners, engineers, and developers, accustomed to the more moderate pace of inland geologic processes, seriously underestimated the erosive power of the sea. Many of the highways, streets, railroads, and private dwellings built along the coast in past years have been partly or wholly destroyed. For example, State Highway 1, the coastal route, crosses many landslides caused by marine erosion. Parts of this highway south of Fort Ross and at Devils Slide on the San Francisco peninsula require almost constant maintenance; at Thornton Beach, in northern San Mateo County, the original right-of-way has been abandoned, and the highway relocated.

Large landslides abound along exposed, precipitous stretches of coast, especially where the seacliffs have been cut into unconsolidated sediment or bedded, jointed, or sheared sedimentary rocks. Landslides here resemble those on the hillsides, but because they are under continuous attack by waves and surf, many coastal landslides are more unstable than their inland counterparts.

Identifying landslides is critical in coastal planning. Some large active slides are so obvious that they are easily recognized in the field; less obvious or inactive ones may be shown on published geologic maps. The stability of seacliffs can be evaluated either by site investigations or by study of detailed geologic maps that show the distribution of rock types and the orientation of potential failure surfaces, such as bedding, joints, or shears. These active and potentially active coastal landslides are far more difficult to stabilize than their inland counterparts, chiefly because they are triggered by

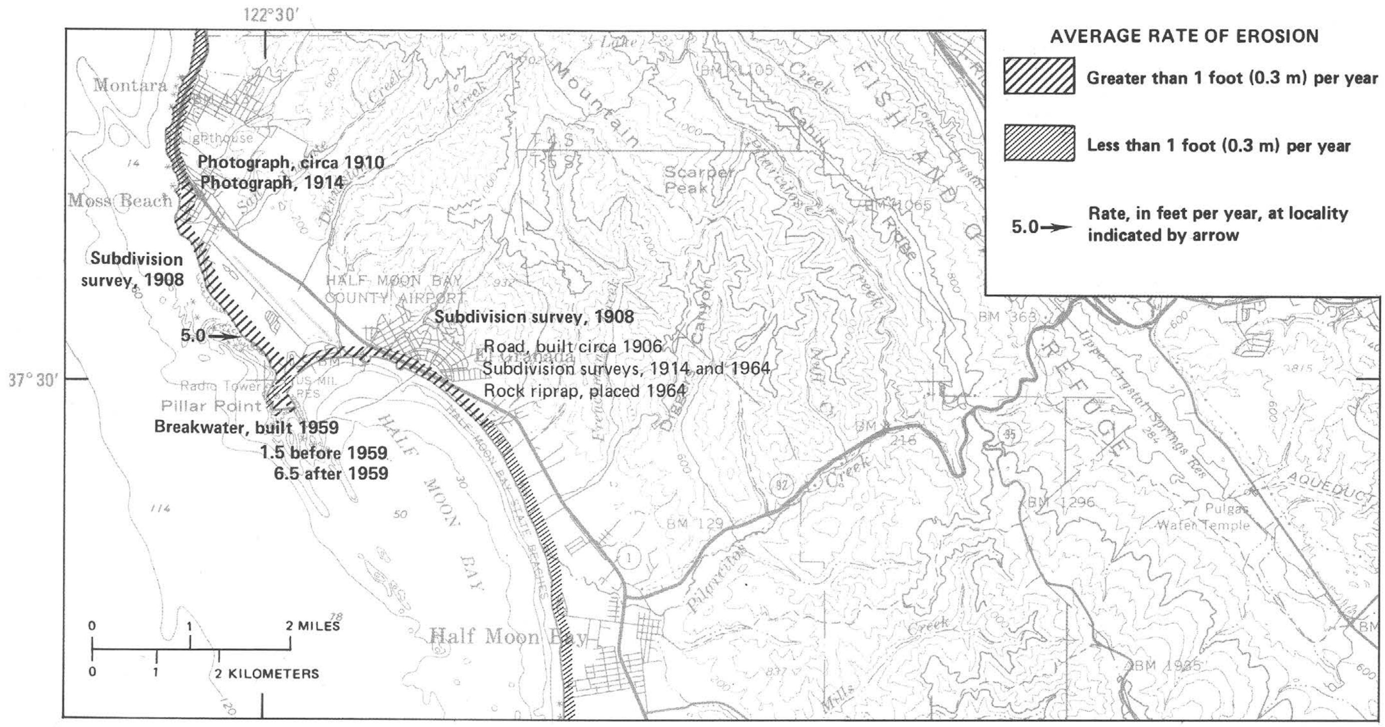


FIGURE 7.—How the rate of marine erosion during historical time can be determined by comparing the present coastline with its former position as shown on old maps and photographs. These rates depend on the resistance of the seacliffs and on the orientation of the shoreline with respect to the direction of prevailing swells. Modified from Atwater (1978, p. 15).

marine processes that are difficult or impossible to control. Moreover, where coastal landslides are part of a general, long-term retreat of the coast, stabilization is, at best, a temporary solution; in such places, the only practical way to reduce the hazard from landslides is to avoid building on or near them.

SEACLIFF RETREAT

Some massive, homogeneous rocks successfully resist large-scale failure by sliding but fail piecemeal as waves and rain wash them away grain by grain or remove small fragments of rock. The relatively steady retreat of seacliffs eroded in this way is less spectacular than a large landslide, but the long-term rate of retreat may be comparable. For example, at Moss Beach in northern San Mateo County, historical records and photographs covering the past 105 years document 165 feet of seacliff retreat (Tinsley, 1972, p. 63)—an average of 1½ ft per year. Both landsliding and gradual erosion contribute to this retreat, the rate of which has increased to more than 3 ft per year since 1965 (Leighton and Associates, 1971).

Partly as a result of experience at Moss Beach, San Mateo County now regulates bluff-top development in this and other coastal areas. Depending on the erosion resistance of the materials and the historical rate of erosion, the county may prohibit building, require that stability be demonstrated by a geotechnical study, or allow use only after a standard geotechnical report has been prepared (fig. 8).

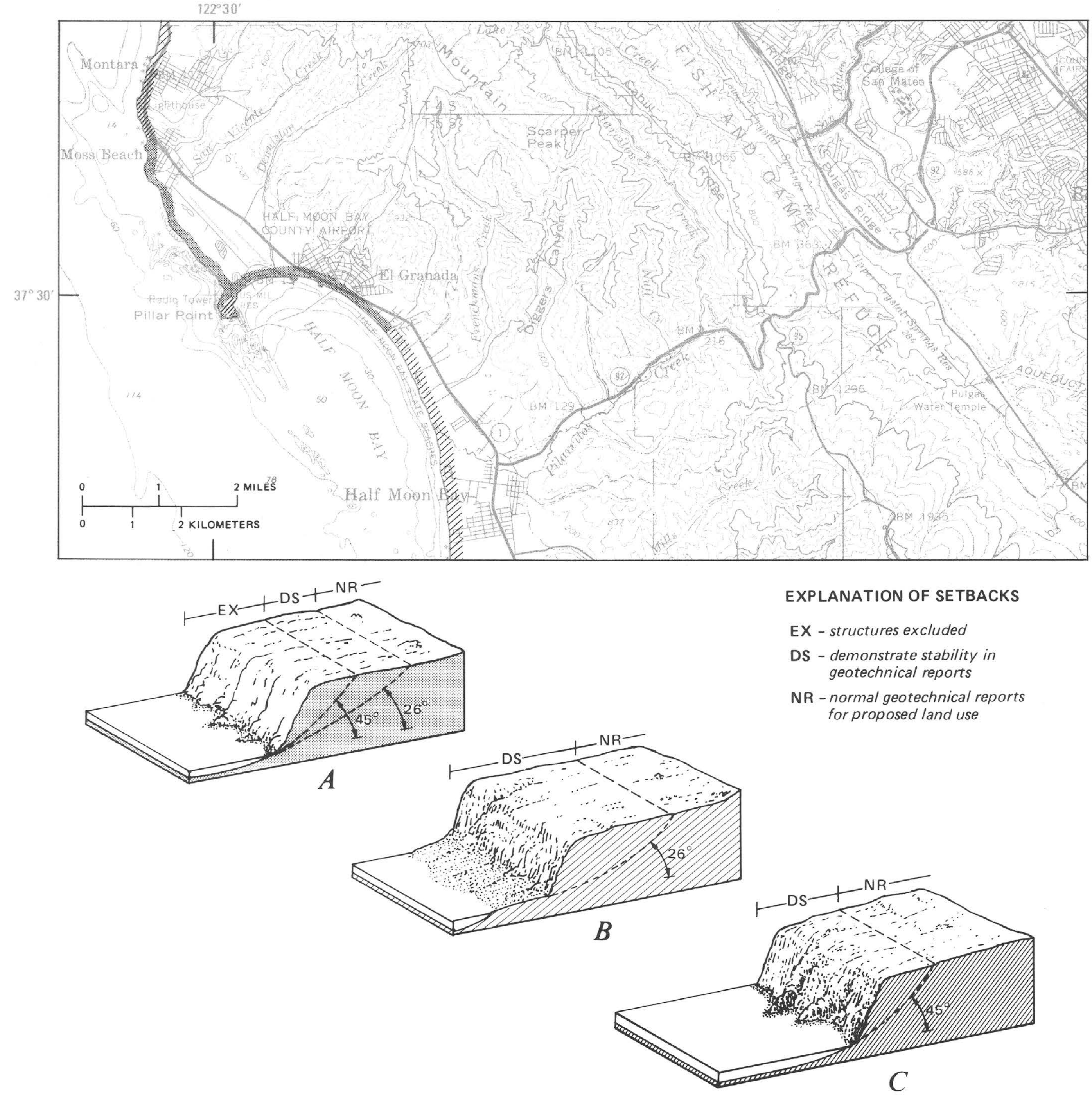
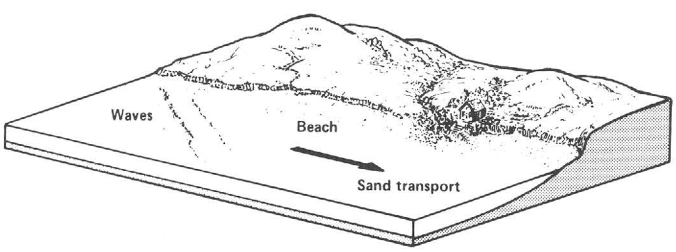


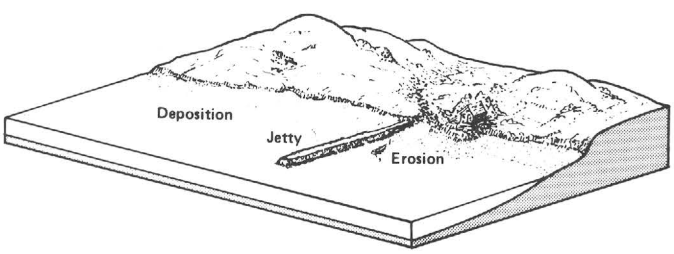
FIGURE 8.—How San Mateo County regulates coastal development according to the stability of seacliffs, from least stable and most closely regulated (*A*) to most stable and least development constrained (*C*). Stability of seacliffs can be interpreted from historical data (see fig. 7), from resistance of cliff materials to erosion, and from degree of natural protection from waves. Modified from Atwater (1978, p. 15).

BEACH EROSION

Beaches, like seacliffs, are easily eroded by the sea. Many beaches temporarily change their shape and size with the seasons, but they may change permanently if the natural equilibrium between sea and shore is disturbed. Manmade structures that reduce the supply of sand or obstruct its movement along the shore disturb this balance and may destroy the beaches. Both seawalls and inland dams reduce the supply of sand—seawalls by blocking the erosion of sand from seacliffs, and dams by preventing stream sediment from reaching the ocean. Jetties and breakwaters interfere with the longshore movement of sand (fig. 9) and may also divert wave energy toward vulnerable seacliffs or beaches.



Natural sand transport
Waves striking the shore obliquely cause beach sand to move parallel to the shore



Jetty-obstructed sand transport
Sand accumulates on one side of the jetty, starving the beach on the other side, and resulting erosion threatens the house

FIGURE 9.—Manmade obstructions, which interfere with natural marine processes, can cause permanent changes in beaches, seacliffs, and bottom conditions. From Atwater (1978, p. 14).

Tinsley (1979, p. 49-50) described how construction of a breakwater at Pillar Point in northern San Mateo County caused drastic and rapid changes in the shoreline. The breakwater, on the north side of Half Moon Bay (fig. 7), was built between 1959 and 1961 to shelter the harbor from the southwesterly swells that accompany some winter storms. During its construction, the nearby shoreline began to erode rapidly, and erosion rates, which formerly had ranged from 2 to 3 ft per year, increased to 20 ft per year between 1959 and 1964. The most rapid increase was within a few hundred feet southeast of the east end of the breakwater, but, in all, a strip of land nearly a mile long and about a 100 ft wide was lost to the sea.

Recent surveys show that this segment of the coast is still being eroded more rapidly than it was before 1959. Tinsley (1979) attributed the accelerated erosion to the impact of the breakwater on the following marine processes:

1. The wave energy that formerly was refracted into the north end of Half Moon Bay and dissipated there, now is reflected off the breakwater and is directed toward that part of the shoreline where erosion rates are the highest.
2. The southward longshore movement of sand by littoral currents has been stopped by the breakwater; the beach is deprived of its northern source of sand and is replenished only by sand eroded from the seacliff.
3. Because no protective beach shields the cliff from the waves, erosion of unconsolidated sediment in the seacliff is rapid.

Although the erosion caused by construction of the breakwater can be checked by engineering techniques, these techniques, too, will alter marine processes and introduce new imbalances into the shoreline regime.

OTHER PROCESSES

Although erosion and deposition may be the most evident coastal processes, for good planning other processes must also be recognized and provided for. For example, the strength and direction of ocean currents limit the choice of sites for offshore disposal of solid and liquid wastes and dredge spoils; they also limit the choice of areas for those tanker operations that may cause offshore oilspills. Moreover, because surface currents, driven by the wind, commonly flow in different directions from those on the bottom (Conomos and others, 1970, 1971), disposal sites that are acceptable for wastes which sink to the bottom may be unacceptable for wastes that float or remain suspended in the water.

Coastal planners must also recognize and provide for earthquake hazards. Except for the outer part of the Point Reyes peninsula, all of the bay-region shoreline is less than 5 mi from known active faults—the San Andreas fault in Sonoma, Marin, and northern San Mateo Counties; and the San Gregorio fault in southern and central San Mateo County. Both these faults have caused large, damaging earthquakes in the past, and both are capable of doing so again. Because of its proximity to these faults, the coastal strip is especially vulnerable to strong ground motion, and because so much of it is fringed with active or potentially active landslides, it also is vulnerable to earthquake-triggered landslides. These hazards, which are common to all the provinces of the bay region, are discussed more fully below in the section entitled "Faults and Earthquakes."

San Francisco, noted for its hills, grew chiefly on lowlands of gravel, sand, and silt deposited by the sea, the bay, and local streams. In this view, the westerly sun reflects brightly from buildings north of Market Street. Building facades south of Market are shaded and dark because of the different orientation of the streets there. The industrial area between Potrero Point (extreme left) and China Basin (extreme right) rests on reclaimed marshlands underlain by bay mud and on artificial fill. The more extensive and more distant lowland development, especially north of Market, is on beach sand, dune sand, or alluvium deposited from streams. The most evident bedrock areas are both north of Market Street: Russian Hill and Nob Hill on the right and Pacific Heights in the center, beneath the centerspan of the Golden Gate Bridge. The varied geology beneath the city demands special care in investigating and designing foundations for building, but it also permits us to forecast where earthquake damage will be most intense and the nature of the processes causing that damage. Photograph by Norman Prime, U.S. Geological Survey.

THE LOWLANDS

In this report, we consider the lowlands to be the terrain that is less than 1,000 ft above mean sea level, that has slopes of no more than 15 percent (15 ft of elevation change in 100 horizontal feet), and that is above the level of tidal effects. Most of this land is in stream valleys or in alluvial slopes near the bay; some is in the marine terraces of coastal San Mateo and Marin Counties.

THE PROBLEM

Although the lowlands occupy only about a third of the land area in the San Francisco Bay region, they are by far the most intensely developed and most heavily populated province. Underlain chiefly by compacted, porous, and permeable deposits of gravel, sand, and silt, they provide level building sites, good drainage, and stable foundations. Some lowland areas periodically flood, but these areas are easily identified, and many different measures can be taken to reduce flood losses. Because lowland sites are valued for agriculture, housing, construction materials (for example, sand and gravel), and waste-disposal facilities, the competition for them is keen, and, in some places, such essential resources as construction materials must be protected for future use.

GEOLOGY AND PROCESSES

The smooth, nearly level surface of the lowlands and the unconsolidated gravel, sand, and silt beneath this surface result from the deposition of sediment by running water. Most streams begin in the hills, follow steep gradients, and flow rapidly until they emerge from the hills onto inland valleys or alluvial plains. They erode and carry sediment derived from hill slopes, but their erosive and carrying capacities diminish in the lowlands, where stream gradients flatten and stream velocities decrease (fig. 10). These changes in erosive and carrying capacities are recorded by the composition of the sediment deposited along the stream course. Where streams emerge from the hills, they construct alluvial fans—sloping fan-shaped, deposits that contain lenses of poorly sorted gravel and coarse sand. Downstream, where streamflow further slackens, finer, better sorted, and more regularly bedded deposits of gravel, sand, and silt blanket valley floors and lowland plains. As outlined on a geologic map, these deposits of gravel, sand, and silt show where stream deposition is the dominant geologic process. Some of these deposits in the San Francisco Bay region are hundreds of feet thick and represent tens of thousands of years of stream deposition. From such evidence, we can conclude that stream deposition and flooding are established natural processes, and that they will continue to affect our use of the lowlands.

Stream flooding, deposition of sediment, and erosion are common and related geologic processes in the lowlands. Sediment is deposited, and banks and channels are eroded, during normal streamflow, but rates of deposition

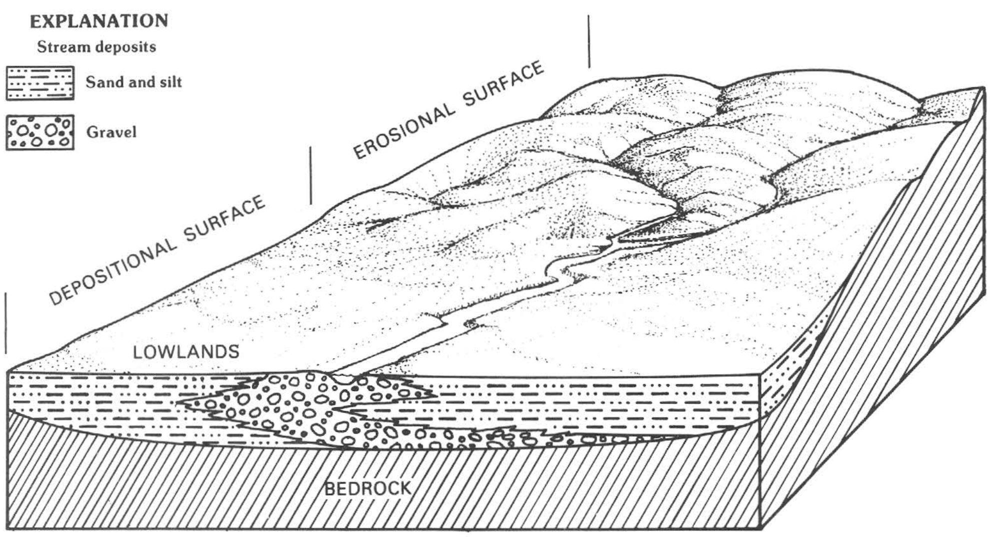


FIGURE 10.—The lowlands are underlain by deposits of stream sediment carried from the hills and deposited where stream gradients flatten and stream velocities decrease. Depositional processes predominate in the lowlands, and erosional processes in the hills.

and erosion increase greatly during floods. Thus, for convenience, all three processes are here discussed together. Other, sporadic lowland processes, including earthquake shaking, faulting, and liquefaction, are discussed elsewhere in this report.

Stream flooding is probably the most common and one of the most costly geologic processes in the lowlands. Its relative impact on various kinds of land use was shown (table 2) in a land-capability study, prepared by Laird and others (1979), to evaluate the costs of converting land to new, more intensive uses. The U.S. Water Resources Council (1978) estimated that annual flood damages in the California region—California plus Klamath County, Oregon—amount to $417 million and that $269 million, or 62 percent of this total, is in urban regions. The amount of flood losses has steadily increased as a result of increases in property values, in the size of floods, and in the number of buildings and other structures on flood-plain lands (Waananen and others, 1977, p. 6).

Most major floods in the San Francisco Bay region affect only parts of the region; they tend to be localized both by the effects of topography and by storm tracks. Floods occur during the wet season, generally from November through April; and because prolonged rainfall and saturated-soil conditions increase the possibility of flooding, they are most likely later in the season. Flooding results when streamflow exceeds the capacity of the stream channel. Because flooding

TABLE 2.—*Expected costs associated with stream flooding*

[Amounts shown are future costs due to flooding, discounted to their value in 1975 dollars. From Laird and others (1979, p. 39)]

Land use	Expected cost per acre
Rural or agricultural	$ 200
Semirural residential	700
Single-family residential	9,000
Multifamily residential	40,000
Regional shopping centers	40,000
Downtown commercial	50,000
Industrial	40,000

recurs so frequently, the lowland valleys are floored with the deposits of innumerable earlier floods. Where the surface of the land is relatively undisturbed, flood-prone areas can be recognized by a well-defined natural flood plain (fig. 11), by natural levees along streambanks, by alluvial fans at the mouths of major canyons, or by the distinctive soil types that are associated with flood plains.

Although these features may identify a potential flood hazard to an alert observer, accurate mapping of flood-prone areas depends on knowledge of the height and extent of past floods and of the normal patterns of streamflow. Detailed records of peak discharge (the highest rate of streamflow at a given point, measured in cubic feet per second) are used to estimate how

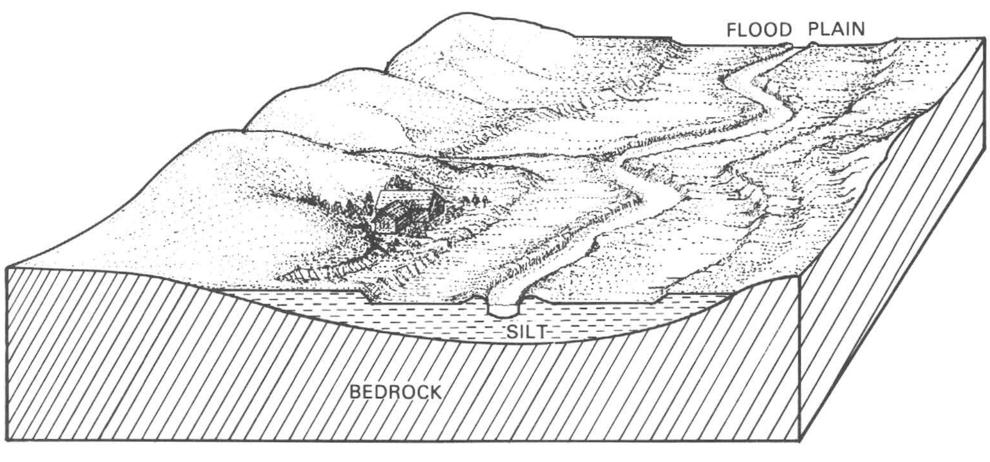


FIGURE 11.—Many flood-prone areas are easily recognized because they coincide with a well-defined natural flood plain.

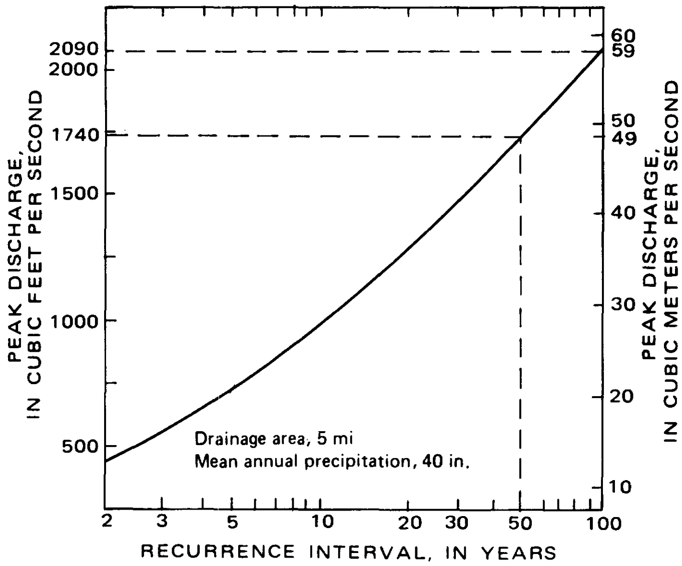


FIGURE 12.—Flood-frequency curve for a hypothetical basin in the San Francisco Bay region (from Waananen and others, 1977, p. 9).

often major floods are likely to recur (fig. 12) and how large an area will be inundated. From such estimates has come the useful concept of the 100-year flood: This flood will, on the average, happen once every 100 years; or, in a given year, the odds are 1 in 100 that this large a flood will occur. The areal extent, depth of water, and other characteristics of the 100-year flood are commonly used in river-basin planning, for regulatory purposes, and in administering the National Flood Insurance Program. Despite its wide acceptance as a planning tool, however, it is not always an appropriate or safe concept. Even larger floods are possible, and so dams and other major structures are commonly designed to accommodate larger and less frequent flooding. Moreover, the extent of the 100-year flood is estimated from records of historical events; its value as a reliable predictive tool diminishes where runoff and discharge characteristics have been modified by recent changes in land use or land cover.

ACTIONS TO ENHANCE LAND USE

Early settlers in the bay region chose to live in the lowlands because of convenience and accessibility. The level or gently sloping surface and the low relief provided good building sites, good farmland, and direct, nearly level routes for roads. Streams and, later, shallow wells provided a supply of freshwater. Lowland areas near the bay or along navigable streams provided access to transportation—an important added incentive for many enterprises. Thus, most early cities and towns were ports or agricultural centers, and from these early lowland communities, later growth and development has spread.

The premium value attached to lowland sites is greater now than ever. Together, the inland valleys and plains and the coastal terraces provide nearly all the prime agricultural soils in the region. The lowlands provide optimum sites for residences and for commercial and industrial facilities, provided that the land is outside flood plains and free from other stream-related problems, such as erosion and deposition. Extensive interior lowlands, such as the Santa Clara and Livermore Valleys, contain relatively permeable sand and gravel deposits with important supplies of ground water, some of which is developed for domestic and agricultural use. The same properties that permit ground water to accumulate in the rocks also permit the underground storage of other fluids, so that some stream deposits are favored sites for the storage of liquid wastes. And, finally, the sand and gravel beneath the lowlands are important sources of construction materials, critically needed both for new development and for renovation of older structures.

Our society demands level, accessible land for many critical needs, of which housing, industry, airports, mass-transit routes, and railroads are but a few. The intense competition for lowland sites brings change and conflict, as is evident where farms, ranches, or orchards give way to suburban housing, or where a major change in land use adversely affects the value of nearby property. The intensity of competition and the opportunities for change and conflict are unlikely to subside. They call for prudent and informed decisions by government, business, and individual citizens. These decisions are complex, but many of them depend critically on knowledge of the geologic processes operating in the lowlands and of the materials beneath the lowland surface.

FLOODING

Manmade changes in drainage basins profoundly alter flood characteristics. Logging, conversion of grass- or brush-covered land to agriculture, grading or paving for urban and suburban use, and similar actions all diminish the capacity of land to absorb and retain rainfall, increase the rate of runoff, and increase the probability and size of floods (fig. 13). Removal of vegetation and extensive grading may also increase local rates of erosion and thereby lead to downstream deposition of sediment, to reduced downstream channel capacity, and thus to further risk of flooding. Similarly, construction on flood plains and obstructions in stream channels impede the free flow of floodwaters, reduce stream velocities, and result in higher crests and more extensive flooding.

Changes in land use may be especially troublesome where they are upstream from established lowland communities. Storm drains, culverts, and regulatory flood plains that were adequate for floodflow from a natural watershed may be unable to carry an increased flow. Because much new development in the bay region is encroaching on the steeper slopes upstream from established communities, flood hazards in some areas may be greater now than ever before.

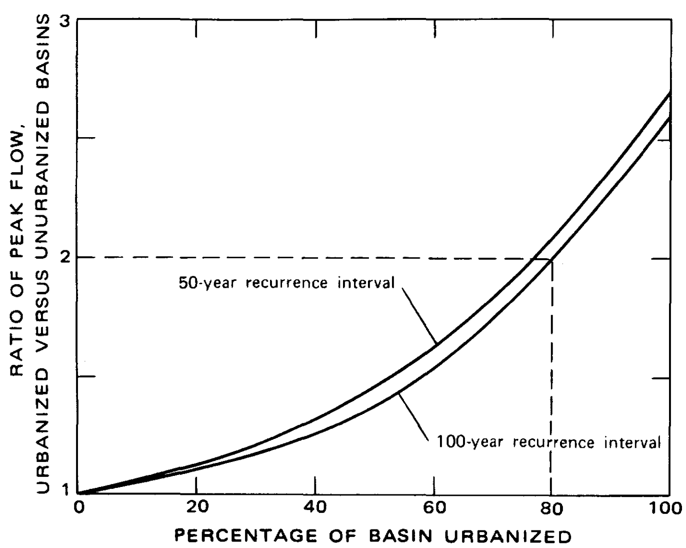


FIGURE 13.—Ratios of peak flows for 50- and 100-year floods in urbanized and unurbanized basins in the San Francisco Bay region (from Waananen and others, 1977, p. 12). For a basin that is 80 percent urbanized, peak flow for a 100-year flood is twice the peak flow in a similar but unurbanized basin.

Even attempts to reduce flood hazards may produce mixed results. Some methods of controlling floods utilize such structural measures as dams, levees, and channel improvements to impound floodwaters or to confine them. Although these measures may successfully achieve their immediate objective of protecting a designated section of a stream from flood losses, they alter the natural streamflow and cause new problems, such as silting, accelerated erosion, or flooding in areas that previously were free of floods. Structural measures are likely to be most effective and to create the fewest unanticipated problems where they are part of a comprehensive river-basin plan. Such plans consider the hydrology and projected land use of the entire basin, together with other water-related objectives, such as irrigation, erosion control, and water quality.

Despite the difficulties, flood losses can be greatly reduced. Floods obey fundamental physical laws that are well understood, and in most large streams, flood size and frequency can be predicted from data on streamflow. Where these data are unavailable, reliable estimates can be made by analogy with similar, well-measured drainage basins. All these predictions are probabilistic and nonspecific, but if their limitations are recognized, they can at least provide a rational basis for planning.

Planners employ several methods to control flood losses. Some of these methods (table 3) were discussed more fully elsewhere (Kockelman, 1977, p. 23). Such methods most effectively reduce losses where the possibility of flooding is recognized early and evaluated carefully.

Recognition and evaluation of flood hazards require careful review of land-use plans and development proposals, as well as knowledge of stream-basin characteristics. Such review must be tailored to specific plans or proposals, but some of the most common review questions are:

1. Is the plan or proposal for an area that is subject to flooding? (If not, see question 5). If the area is subject to flooding:

TABLE 3.—*Techniques to prevent flood losses*

[From W. J. Kockelman (in Waananen and others, 1977, p. 24)]

Purpose	Techniques
Protection of existing development.	Flood-control works: Reservoirs Channel improvements Diversions Flood warning and evacuation Floodproofing
Removal or conversion of existing development.	Public acquisition Urban redevelopment Public-nuisance abatement Nonconforming uses Conversion of use or occupancy Public-facility reconstruction
Discouragement of development.	Public information Warning signs Recordation of hazard Tax-assessment practices Financing policies Public-facility extensions Flood-insurance costs
Regulation of flood-plain uses.	Zoning ordinance districts Special flood-plain regulations Subdivision ordinances Building ordinances

A. On the basis of existing data, what is the degree of hazard to the proposed development?
B. How will the plan or proposed use affect flood characteristics and normal streamflow at the site; will it tend to increase or decrease flood crests and extent, or will these be unaffected?
C. How will the plan or proposal affect flood characteristics and normal streamflow upstream and downstream from the site?

2. Does the plan or proposal incorporate, as an essential component, structural measures for flood protection or control of streamflow?
   A. If so, are these measures a consistent part of a broader watershed-management plan?
   B. If they are not part of such a plan, how will they affect (i) streamflow above and below the site, (ii) erosion and sedimentation rates above and below the site, and (iii) other important uses of the water and the waterway?

3. Is the plan or proposal likely to lead to additional but as yet unplanned development in the area subject to flooding?
4. What liability does the community assume in permitting the planned or proposed use within an area of recognized flood hazard?
5. If the plan or proposal is in a flood-free area, will it require extensive changes in vegetation, slope, or surface permeability?
   A. How will these changes affect runoff and downstream flood characteristics?
   B. How will these changes affect local erosion rates and downstream sedimentation processes in the channels and flood plains that help determine flood characteristics?
6. Will the plan or proposal, through its effects on flood characteristics, make obsolete any measures that protect existing development?

LOWLAND SEDIMENT

The stream deposits of gravel, sand, and silt beneath the lowland surface possess several properties of importance in land-use decisions. These deposits, compacted but not yet turned to rock, are in beds or lenses, a few inches to tens of feet thick and hundreds to thousands of feet wide and long. The layers of sediment are nearly flat; at most, they dip a few degrees downstream or toward the bay. Their continuity and near-horizontal attitude are interrupted in some places by such active faults as the San Andreas or Hayward, and in others by buried bedrock ridges across which the layers of sediment are draped and mildly deformed. Most beds and lenses contain well-sorted sediment with a narrow range of grain sizes. Well-sorted sand or gravel contains voids or pore space, which may account for 25 percent or more of the total rock volume and which permit this sediment to store ground water or to serve as a conduit for flowing ground water.

These properties make the lowland surface and the underlying deposits attractive to many users. The flat surface, left when sediment was deposited from flowing water, is the most obvious advantage. But the land is also well drained. In most areas and during most seasons, the water table lies below the depths reached by human activities. Although the deposits of gravel, sand, and silt are firm and well compacted, most are uncemented to very weakly cemented. Land underlain by these deposits is stable, firm, and strong enough to support normal structural loads without failing, yet it is far more easily excavated than hillside sites that are underlain by bedrock.

Because the subsurface layers of gravel, sand, and silt were deposited by running water, most are sorted by particle size. Gravel is concentrated in some beds, sand in others, and even where mixing occurs, one grain size tends to dominate. The degree of sorting enhances the value of these deposits as commercial sources of sand and gravel, and because good sorting increases both the amount of void space and the ability to transmit fluids, many lowland beds of sand or gravel are important sources of freshwater. Porous and permeable layers also conduct subsurface drainage down the inclined surface, or dip, of the beds to the bay or to the ocean. Percolating water thus drains away to leave a zone of aerated, well-drained soil and sediment. Although fluids readily pass through most of the water-laid deposits, some natural barriers inhibit the flow of ground water and other fluids, and some water-bearing beds, or aquifers, are confined and will sustain artesian flow. For example, before the extensive development of ground-water resources in the Santa Clara Valley, many of the water wells there were artesian.

The properties of lowland sediment differ greatly from those of the rocks that underlie the hills, although these lowland deposits are by no means uniform. Wells drilled at one lowland site may penetrate scores of feet of gravel and coarse sand before entering bedrock; wells a few miles away may penetrate only a few feet of silt, clay, or fine sand, even though the sediment layers in both drill holes are of the same age and were deposited by the same stream. Such local variations in grain size and bed thickness are typical of stream deposits and show how stream processes varied during deposition.

In the bay region, however, the properties of stream-laid sediment also vary with the age of the deposits. The youngest, and most extensive, stream deposits are those near present stream courses and those which fringe the bay. These young deposits are less consolidated, weaker under load, more likely to have a shallower water table, and support younger and less mature soils than does older stream sediment. The older deposits of sediment are graded to an ice-age sea level that was more than 300 ft lower than the present stand of the sea (Atwater and others, 1977); they are exposed in narrow bands near the hills and underlie the younger deposits near the bay and in the valleys of most large streams.

Because such properties as rock strength, depth of weathering, and porosity change with geologic age, sediment size by itself is an incomplete measure of the adequacy of a site for a specific use. Stated another way, the suitability of a site for a given land use depends on the geologic age of the underlying material as well as on its grain size. The extent of lowland deposits, their significant properties, and how these properties may affect major land-use decisions were discussed more fully by Helley and others (1979).

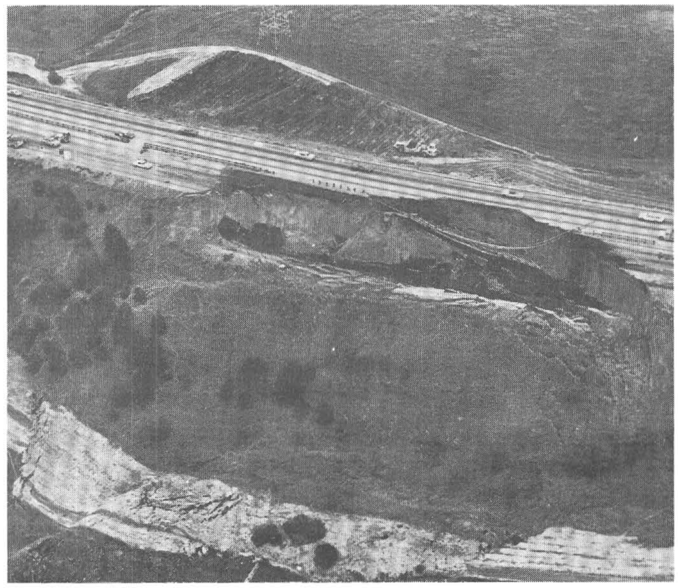
Competition for space in the lowlands intensifies the need for informed and thoughtful decisions on land use. In the past, land-use decisions were strongly influenced by short-term economics; that is, those options that most quickly produced the greatest economic gain were favored. This strategy commonly encouraged land development for residences, commerce, and industry at the expense of agriculture, construction materials, ground-water resources, and potential waste-disposal sites. But as more and more lowland is converted to urban and suburban use, it becomes prudent to plan carefully for future needs: To conserve ground water, to reserve sites that are adaptable to the disposal of liquid or solid wastes, and to protect sources of essential construction materials. Such planning demands specific knowledge of the lowlands, of the materials beneath the surface, and of the changes in those materials from place to place. An example of how geologic and hydrologic knowledge is used to select waste-disposal sites is given below in the section entitled "Identifying Potential Waste-Disposal Sites."

Landslide on Van Cleave Way in Oakland, March 1958. This slope, less than half a mile northeast of the Hayward fault, is underlain by sheared bedrock of diverse origin; much of the rock exposed nearby is serpentinite, which is commonly unstable in steep slopes or where it is intensely sheared and altered. Slides such as this have a major lasting impact beyond their immediate limits: They diminish the stability of slopes above and alongside the failure scar; the displaced slide mass is potentially unstable and may threaten downslope structures; the changes in topography caused by the slide alter drainage and runoff, which may accelerate local erosion; and the unstable debris in the slide mass may choke downstream drainage systems with sediment and cause flooding. Most bay-region cities and counties now require professional geologic studies of proposed hillside developments to identify potentially unstable slopes before grading and construction. Photograph by the Oakland Tribune.

Coalescing active landslides at Lomerias Muertas, 5 miles north of San Juan Bautista and near the boundary between San Benito and Santa Clara Counties. Scarps, ponds, hummocky topography, and primitive drainage record recent movement and instability in the central and youngest lobe, but nearly all of the land surface in this view has failed in the past and is very likely to do so again. In such terrain, grading, filling, or other construction is likely to trigger or accelerate slope failure. Even untrained observers would probably recognize the problems with this slope, but many unstable hillslopes are much more difficult to evaluate and require modern methods of geologic and geotechnical analysis as well as skill and experience in applying those methods. Photograph by Earl E. Brabb, U.S. Geological Survey.

U.S. Interstate Highway 80 near El Sobrante, Contra Costa County. Although only embankment fill is visible in the scarp and the slide mass below, the failure extended into and probably began in the underlying bedrock. The initial failure, on May 11, 1969, followed a wet winter, and later exploratory drilling disclosed that the slip surfaces beneath the slide were saturated with water. Successive failures at the head of the slide caused all lanes of the highway to be closed by May 15 and thus cut the main highway link from the bay region to the east. Slip during the first stages of sliding also severed an aviation gasoline pipeline; leakage from this pipeline triggered emergency procedures because of the threat of fire or explosion to nearby residential areas in El Sobrante.

This fill was constructed in 1958 at a cost of $7.1 million. Today, relatively modest geologic and geotechnical investigation, using modern knowledge and techniques, would probably identify potential site problems before construction and thus lead to appropriate mitigative measures. Photograph by Norman Prime, U.S. Geological Survey.



THE HILLSIDES AND UPLANDS

The hillsides and uplands occupy more than half the land area in the San Francisco Bay region. Nearly all of the hillsides and uplands were used for timber, orchards, and grazing until the 1950's, when residential hillside developments began to grow in number and size. Today, residential growth continues unabated in the hills. People move to the hills for both economic and esthetic reasons. Economic incentives include the scarcity and high cost of lowland sites relative to the lower cost of undeveloped hillside land, and the ease and economy with which modern heavy equipment can excavate and grade the slopes. Esthetic incentives include unusual or unique homesites, opportunities for views, and proximity to open space. Moreover, some hillside sites are high enough to be above the inversion layer and in relatively clean, smog-free air.

THE PROBLEM

Although the hillsides offer many advantages, developers face more numerous and different problems in the hillsides than in the lowlands—problems that, if unrecognized, can cause substantial loss of property and spell financial ruin for builders or homeowners. Among the most common of these problems are:

—high costs for grading or excavating because of the unanticipated properties of near-surface rock;

—failure of natural slopes due either to natural processes or to manmade changes in drainage, vegetative cover, or load.

—failure of manmade slopes or fills;

—poor drainage because of a shallow water table or impermeable rock at or very near the surface;

—erosion, deposition, or flooding caused by removal of vegetative or soil cover, or by modification of the natural drainage system;

—unstable foundation conditions caused by swelling clays, which change volume seasonally as they absorb or lose moisture.

Some of these problems appear as rural land is cleared or graded for suburban use; where recognized early, many of them can be remedied. Other problems, such as slope failure, poor drainage, and swelling clay, commonly remain unrecognized or underestimated until much later; they may not be discovered until years after a development is completed and occupied. Thus, in spite of the low initial cost of undeveloped hillside land, long-term costs due to geologic problems can make hillside land much more costly to develop than the alluviated nontidal lowlands (Laird and others, 1979, p. 51-54).

In this report, we consider the hillsides and uplands to include all slopes steeper than 15 percent and those gentler slopes that are at least 1,000 ft above sea level. This terrain differs from the lowlands in three special ways: (1) It is underlain by bedrock and the weathered products of bedrock, (2) its surface slopes moderately to steeply, and (3) it is shaped and modified by erosional processes.

GEOLOGY AND PROCESSES

As we have seen, the lowlands are covered with gravel, sand, and silt—unconsolidated deposits that record stream processes during the past 20,000 to 40,000 years. By contrast, the hills and uplands are underlain by harder, consolidated rocks. These rocks have a longer geologic history spanning more than 200 million years. The rocks we find in the hills today represent ancient beaches, fans, and oozes of the deep ocean; submarine lava flows; terrestrial flows of lava and ash; gravel and sand from ancient rivers and streams; and crystalline bodies that formed deep within the Earth's crust. Many of these rocks were deeply buried, folded, and faulted. These differences in origin and in degree and style of deformation yield an assortment of bedrock types that vary widely in strength, in chemical composition, and in the spacing and orientation of fractures.

Bedrock near the surface decays, is leached, and breaks down into a mantle of weathered rock and soil. In most places, this mantle is no more than a few feet thick, although it may be several times thicker at the foot of some slopes. The mantle is weaker and more permeable than the bedrock beneath it; it is more easily excavated than bedrock, and some of it is permeable enough to be suitable for septic-tank drainfields.

ACTIONS TO ENHANCE LAND USE

BEDROCK AND MANTLE

The heterogeneity of bedrock and mantle defies simple rules for safe, economical hillside development. Despite impressive advances in geologic knowledge and engineering technology, satisfactory development still depends on careful geologic site investigations and effective communication between geologists and engineers. Although many of the problems caused by the diversity of bedrock and mantle characteristics are technically complex (Wentworth and others, 1983), we describe a few representative examples below.

MATERIAL STRENGTH

The strength of rock or soil determines whether a slope will stand or fail under the load of overlying material. Most rocks are stronger than soils, and some can stand in nearly vertical faces hundreds of feet high; however, such rocks are found in only a few parts of the bay region.

The strength of rock or soil may be described in various ways. Although shear strength most directly limits the height of cut slopes and the load imposed on foundations by structures, we commonly refer to unconfined compressive strength because it is more easily measured by simple laboratory tests and because it is applicable to the many routine problems that arise in hillside development: It measures the maximum load that can be supported without failure under unconfined conditions. Worldwide, unconfined compressive strengths for soils range from less than 3.5 to about 50 lb of force per square inch (lbf/in^2), and for rocks from about 50 to more than 32,000 lbf/in^2. Although little information on this subject is available for the bay region, empirical evidence and approximate field tests suggest that unconfined compressive strengths for rocks and soil here range from about 5 to about 15,000 lbf/in^2.

Differences in rock and soil strengths depend on many variables, including parent bedrock, degree of weathering, and depth beneath the surface of the land. Where deep cuts intersect fresh hard rock, excavation becomes difficult. On the other hand, even shallow cuts in mantle materials of low strength require special care to ensure stability. Highway and freeway cuts are good places to compare rock strengths. Some near-vertical cuts in the volcanic rocks of eastern Sonoma County are stable, but more gently inclined cuts are needed for stability in most roadside materials. Although other factors also affect stability, rock or soil strength can be critical.

FRACTURES

Also important for stability, especially in hard, unweathered rock and in some soils, are the spacing and orientation of fractures, joints, and bedding. Many of these planar discontinuities in rock or soil form potential failure surfaces; whether they contribute to the actual failure of slopes or cuts depends on their dimensions and orientation. Thus, joints that are vertical or dip into a slope are less likely to fail than those that dip outward (fig. 14).

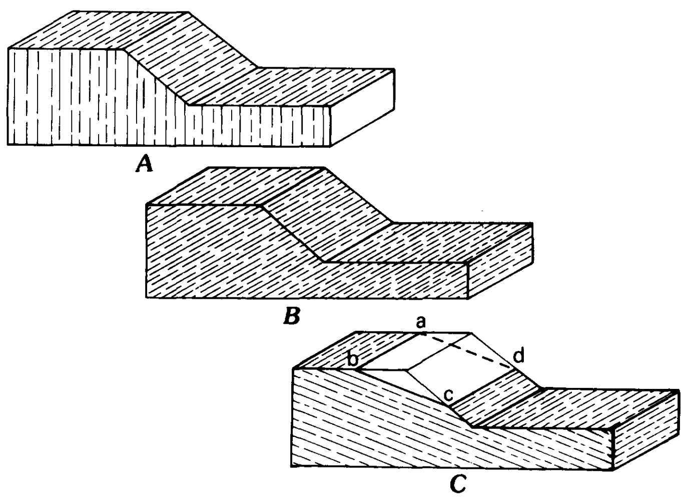


FIGURE 14.—The orientation of joints or other breaks may affect the stability of a slope. Vertical joints in block A and inclined joints that dip into the slope in block B do not significantly reduce stability. Outward-dipping joints in block C define planar failure surfaces, one of which (abcd) is outlined. Most jointed or fractured rocks exhibit more than one set of breaks; intersection of fracture sets having different orientations can cause other, nonplanar types of failures.

EXPANSIVITY

Many soils and weathered rocks swell when wet and shrink when dry. They do so because they contain swelling clays, which expand as they absorb moisture. If small cracks in plaster and wallboard open and close seasonally, as they do in many homes in the bay region, this may mean that the soil beneath the foundation contains some swelling clay. In most such homes, patches and paint will repair the damage. However, serious damage results if structures or facilities rest on clay with a high expansivity or if they straddle the contact between nonexpansive rock or soil and beds with a high content of swelling clay. Claystone beds can cause swelling pressures and volume changes that are capable of breaking sewers, streets, and foundations as well as causing unsightly damage to interiors.

Although simple tests help to identify and evaluate problems with swelling clays, engineering solutions are costly and not always completely successful. In 1975, engineering measures to mitigate a major problem of swelling clay in one community on the San Francisco peninsula added about 5 percent to the cost of new residences (Meehan and others, 1975, p. 946).

GROUND-WATER LEVEL

Water, too, affects stability, as is shown almost annually by the rash of landslides and slope failures that follow heavy storms (Nilsen and Turner, 1975; Nilsen and others, 1976). Most of these failures are on slopes underlain by permeable, water-saturated rocks or mantle in which the pore spaces or fractures and joints are filled with ground water (fig. 15). Many slopes fail simply because the weight of rock or soil, plus the added load imposed by pore water, exceeds the bearing strength. Others fail because the pressure of pore water reduces the effective strength across joints, fractures, or bedding surfaces. If they are anticipated and correctly evaluated, many potential water-induced slope failures can be avoided by corrective engineering measures. Successful engineering measures depend on knowledge of the permeability of rock or soil, of seasonal fluctuations in ground-water levels, and of the mechanisms of failure.

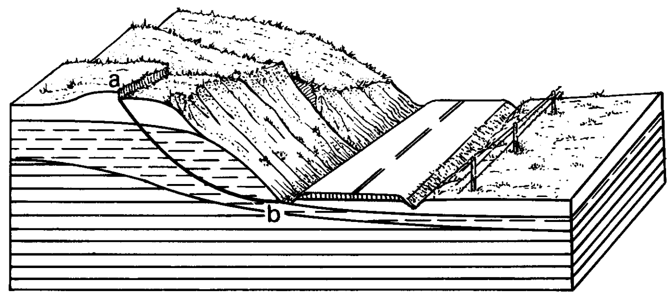


FIGURE 15.—Slopes, whether cut or natural, may be stable at normal ground-water levels (n, ruled) but unstable during wet seasons when water levels are higher (s, dashed). Failure on such a surface as a-b may be caused by the added weight of pore water, by the loss of effective strength due to pore-water pressure along the failure surface, or by both.

The bedrock and mantle properties we have just discussed—material strength, fractures, expansivity, and ground-water level—are among the most important if hillside land is to be developed successfully. They are, or should be, carefully evaluated on site. For preliminary planning and for evaluating larger areas, these properties can be estimated from information available on modern geologic maps that are prepared with land-use issues in mind. These maps depict major rock masses, or formations, that are distinguished by their geologic characteristics. Many of these geologic characteristics determine the properties that are critical in hillside development. Methods of recognizing these properties from conventional geologic maps have been discussed by Wentworth and others (1983).

SLOPES

The slope of the land surface is easily seen and measured. Measurement of slope is expressed as an angle, as the ratio of horizontal distance to elevation change, or as the percentage of elevation change per unit of distance (fig. 16) Slope can be read directly from slope maps, such as those released by the U.S. Geological Survey; it can be calculated from distances and elevations measured on contour maps; or, where precise slope measurements are needed, it can be determined accurately by surveying methods. Site planning usually demands surveying methods, but slope information derived from maps is useful for more general city and county planning.

Steep slopes significantly increase the cost and difficulty of land use because they require more extensive grading for roads, utilities, and construction sites. Grading on steep slopes generates large volumes of earth or rock and leaves cuts, which must be carefully engineered if they are to remain intact. Manmade fills on steep slopes utilize the waste rock from nearby cuts, but, for lasting stability, deep fills must consist of carefully selected materials and be well engineered. Figure 17, which illustrates the relation between slope, height of cut, and volume of earth removed, shows vertical cuts. Such cuts minimize the height of the cut and the volume of earth or rock to be moved, but they are practical only in strong, unjointed rock.

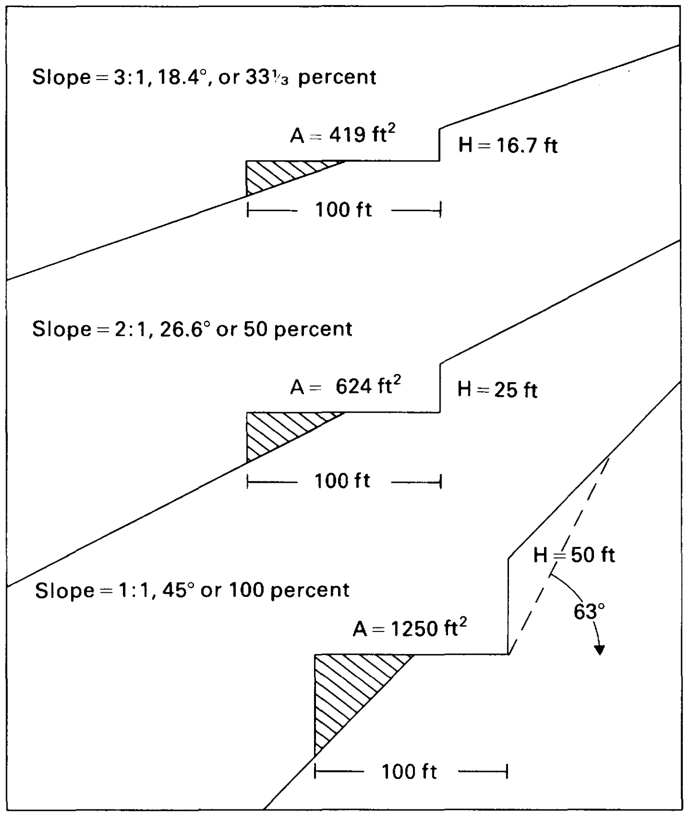


FIGURE 17.—Heights of cuts (H) and cross-sectional areas (A) of cut or fill (shaded) increase on steeper slopes. Horizontal graded surface, 100 ft wide, is shown as half cut and half fill. Volume of earth or rock removed is a product of the length of the cut and its average cross-sectional area. Vertical cut slopes and fill margins are diagrammatic. In the San Francisco Bay region, most surface rocks and all unretained fills are unstable in vertical faces. Inclination of the cut face to achieve stability, as indicated by dashed line where the slope is 1:1, significantly increases both the height of the cut and the volume of earth or rock to be removed.

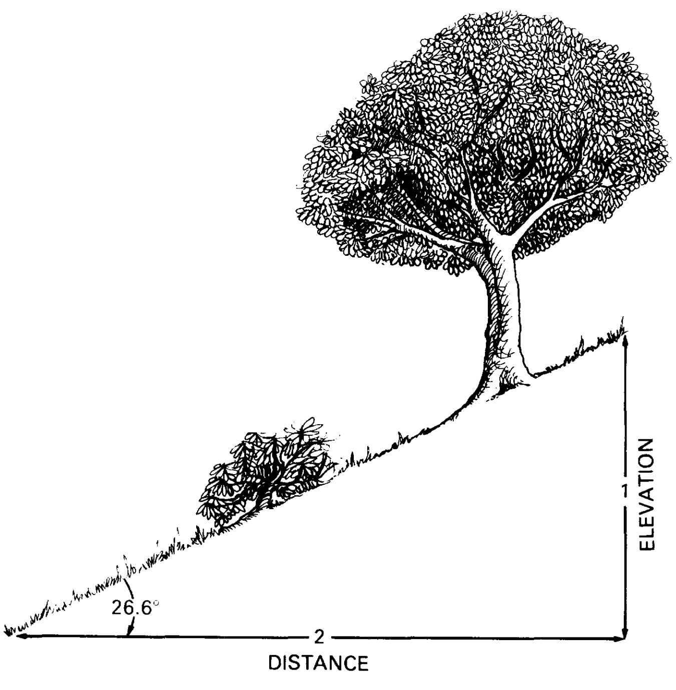


FIGURE 16.—Slope can be expressed as (1) a vertical angle, measured in degrees from the horizontal (26.6°); (2) a ratio of horizontal distance to elevation change (2:1); or (3) a percentage, measured by dividing elevation change by horizontal distance (50 percent).

Most cuts in the San Francisco Bay region must be inclined from the vertical to minimize the possibility of cut-slope failure. Greater departure from the vertical is needed in strongly jointed rocks or those with unusually low bearing or shear strength. For the 1:1 slope shown in figure 17, reduction of the angle of the cut from vertical to about 63° doubles its height and more than doubles the volume of material that must be removed. Fills, too, must be designed for the slope, the rock or soil on which they rest, and the properties of the material used as fill. To insure stability, fills commonly employ gently sloping outer surfaces, retaining walls, and engineered drainage systems.

Although steep slopes require more excavation than do gentle ones, slope alone is an unreliable measure of stability. Some natural slopes of 20° or less fail; others much steeper than 45° are stable. Manmade cut slopes have similar ranges in stability. Some vertical cuts stand without engineered retaining walls, but some gently inclined cuts fail. Clearly, properties other than slope control the stability; these properties include: The shear strength of the rock or earth; the number and orientation of joints, bedding planes, and faults; the load imposed by the mass of earth or rock above the potential failure surface; and the degree to which pore spaces and fractures are filled with water. All these factors, together with the slope of the land surface, must be considered in analyzing slope stability.

EROSION

Erosion constantly shapes and modifies the hills and uplands, and gradually wears away the land surface and reduces the steepness of slopes. Gravity and runoff from storms carry rock and soil debris downslope and deliver it to streams, which ultimately deposit it in the lowlands or in the bay. The importance of erosional processes is commonly underestimated because, except for large landslides and flood deposits, evidence of erosion is not obvious. Nonetheless, streams that drain upland areas carry immense loads of eroded debris both as suspended sediment and as sediment that moves along the bottom. Brown and Jackson (1973) showed that, over the 7-year period from 1965 to 1971, the Russian River at Guerneville, Calif., carried a mean annual load of nearly 4 million tons of suspended sediment, equivalent to more than 2,800 tons of sediment per square mile of drainage area, which indicates a basinwide lowering of the land surface of about 0.02 in. per year.

Rates of erosion vary in other drainage basins within the bay region. High rates can be found in areas with heavy rainfall, high relief, a paucity of vegetation, and weak, intensely fractured, or unconsolidated rock or soil, although the relation among these variables is complex and not fully known. Abnormally high rates of erosion may also be caused by urbanization, as was noted for the Colma Creek basin, south of San Francisco (Knott, 1973). Accelerated erosion during urbanization can be attributed chiefly to the removal of vegetation, to extensive grading, and to increased runoff, which also is caused by urbanization. Lightly developed or pristine hillslopes are constantly eroded by such processes as rillwash, surface creep of rock or soil, gullying, downcutting by streams, streambank erosion, and landsliding.

RILLWASH

Rillwash attacks barren slopes of loose sand or silt. It erodes furrows on debris slopes, cut banks, and newly graded surfaces, but it is not a major problem in hillside development.

CREEP

Downslope creep of rock or soil on steep slopes (fig. 18) is due to gravity and to wetting and drying of the slope debris. Creep moves large volumes of soil and surface rock. On most slopes, the zone of creep is only a few feet thick, and rates of movement are so slow that creep is not an important problem for hillside development. Locally, however, creep rates of 0.5 in. per year are observed on slopes as low as 8° (Fleming, 1972); such rates may require attention in site planning.

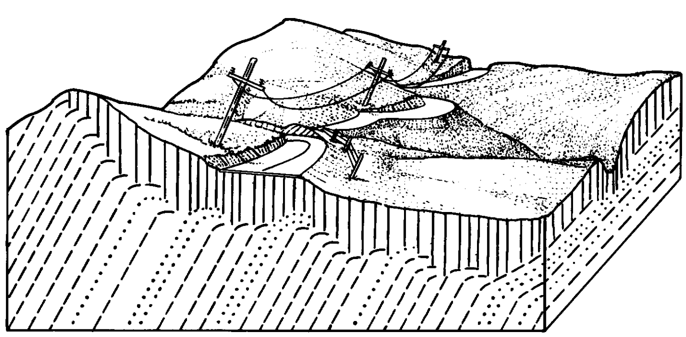


FIGURE 18.—Creep of rock or soil, caused by gravity, slowly moves material downhill. Creep deforms the bedding near the surface and tilts or displaces fenceposts, power poles, and other manmade structures.

GULLYING

Gullies (fig. 19) are steep-walled ravines that result from abnormally rapid downcutting of weak, easily eroded rock or soil by running water. Gullying signifies an increase in the erosive power of a stream; it may be induced by increased runoff, by lowering of the base level of the stream, or by deprivation of the stream of its normal load of sediment. Common causes of gullying are: (1) Overgrazing, which increases runoff; (2) addition to runoff by diversion of nearby drainages or storm sewers into the gully; (3) grading below the normal gradient of the stream, which lowers the local base level and induces downcutting upstream; and (4) damming of the stream, which traps sediment and increases the erosiveness of water discharged from the reservoir. Unless it is controlled, gullying moves upstream into tributaries as the base level of the main stream is lowered.

Gullying is a minor problem in some parts of the bay region, but it can ordinarily be controlled when its cause is known.

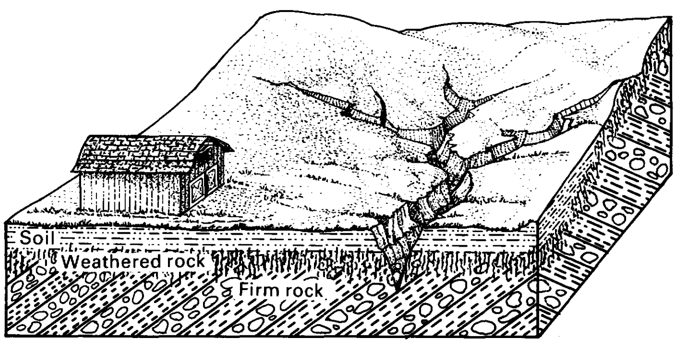


FIGURE 19.—A gullied slope. Rapid downcutting of soil and weathered rock has incised a small drainage below its normal course. Gullying moves upstream along small tributaries, but erosion slows where firm rock is encountered.

DOWNCUTTING

Most perennial streams in the hills gradually erode their channels and slowly lower the streambed; they are in equilibrium, automatically adjusting to changes in flow and sediment load. For these streams the rate of downcutting is low, and their gradient from source to mouth is relatively stable.

The rate of downcutting by streams may be changed by dams or major diversions of streamflow. Such changes, which result from large engineering projects, are beyond the scope of this report, but most of these projects include, as an essential part of their design, an analysis of their effect on normal streamflow and provisions to minimize those effects.

STREAMBANK EROSION

Bank erosion by streams is a common and, in some places, serious problem. Streams erode their banks where they impinge on natural slopes or artificial fill, especially at the outer margins of curves or meanders (fig. 20), where water velocity and erosive power are greatest. During floods, high water levels and increased velocity accelerate bank erosion, and at these times the effects are most easily visible: Fills fail, roads are undermined, utility and service systems are lost or damaged, and, less frequently, dwellings and other structures are lost or damaged owing to undermining of their foundations. Roads are common victims of streambank erosion because many roads in the hills follow narrow stream valleys. Where a stream flows at the

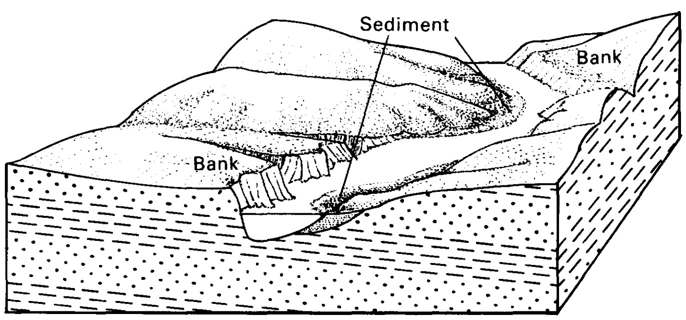


FIGURE 20.—Streams erode laterally on the outer margins of curves and meanders, leaving steep cut banks that are subject to failure. Sediment is deposited on the inner margins of curves.

base of a landslide, bank erosion can remove support at the toe of the slide and cause failure and renewed sliding that may extend hundreds of feet upslope from the eroded bank.

Many bank-erosion problems stem from a failure to recognize that rare or infrequent floods can greatly increase the volume of water and its velocity. Other problems appear when people or Nature diverts the flow against a bank that was previously stable. Such diversions are commonly caused by dumped fill, landslide deposits, or bridge piers. Most bank-erosion problems can be avoided or reduced to manageable proportions if streamflow data and basic hydrologic principles are taken into account in the design of structures or facilities located near the streamcourse.

LANDSLIDING

Historically, landslides are the most costly and pervasive geologic problem in the San Francisco Bay region; annual losses can exceed $25 million (Nilsen and others, 1979, p. 7) and are likely to increase in the future as more hillside land is developed.

Landsliding carves distinctive hillside landforms throughout the bay region. Landslides commonly move as debris slides, slumps, earth flows, and rock falls; rock slides and rock topples are less common in the bay region. Each of these terms describes a different mechanism of slope failure (Varnes, 1978, p. 11). Although each of these mechanisms is separately important to geologists and engineers, here we discuss them all together as landslides.

Recent landslides provide clues to slope failure. Headwall scarps, bulging toes, and jumbled and poorly drained terrain (fig. 21) delineate slide deposits and leave telltale signs of internal disorder. Also, small ponds, springs, or wet areas—the results of interrupted drainage—are associated with many landslide deposits. Over time, erosion modifies and eventually destroys all these features, but landslide deposits as old as 10,000 to 20,000 years still retain traces of their origin. Geologists use such clues to detect and map landslide deposits. Landslide-inventory maps, prepared in this way, show that landslide deposits can cover hundreds of square miles of hillside terrain (Nilsen and others, 1979).

If we compare landslide-inventory maps with geologic maps of the same area, we note that some geologic units host more or larger landslides than others and are, therefore, relatively unstable. A comparison of landslide-inventory maps with slope maps shows a similar relation between the number and size of landslides and the steepness of the land surface. Combining information on slope, landslide distribution, and geology, Brabb and others (1972) mapped the varying degrees of landslide susceptibility in San Mateo County. Nilsen and others (1979) modified this method and applied it to the entire bay region. These landslide-susceptibility maps, which were designed chiefly for preliminary planning or for the evaluation of large areas, also indicate possible problem areas for site planners and developers.

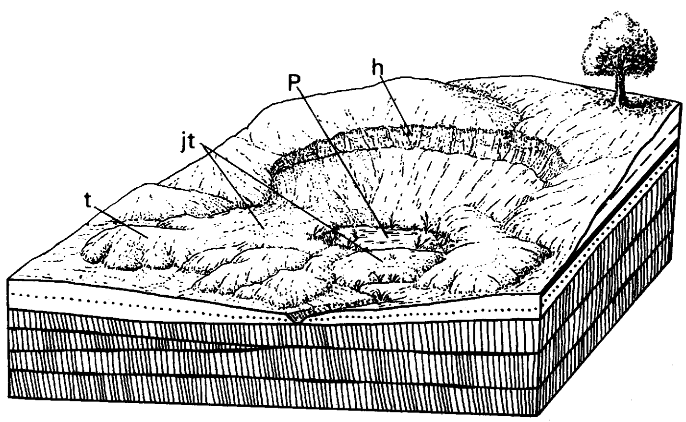
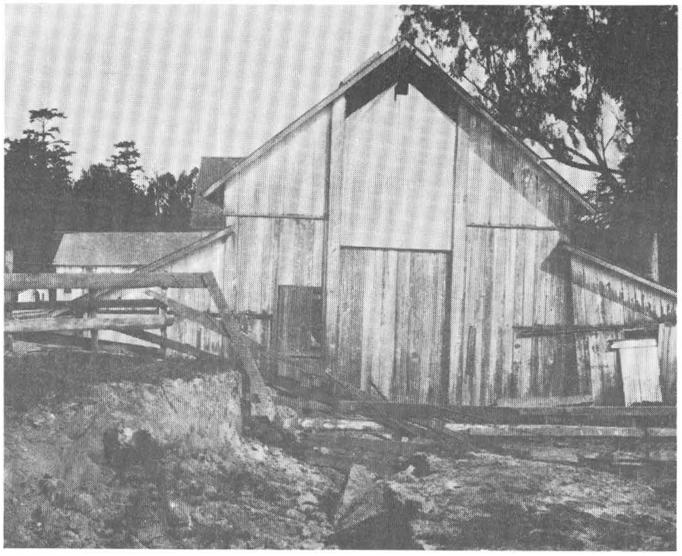


FIGURE 21.—Landslides exhibit headwall scarps (h), bulging toes (t), and jumbled, poorly drained terrain (jt); ponds (p), springs, and wet areas on the surface of a landslide deposit indicate a shallow water table, poor drainage, or both. Slides are most abundant in weak rock or soil and where bedding or other potential failure surfaces dip outward.

The possibility of a landslide at a specific site can best be judged by investigating the surface materials, the bedrock and structure beneath the surface, and the ground water. Sites on or near recent or ancient landslide deposits, those in areas of high landslide susceptibility, and those on geologic units of known low stability warrant careful investigation by an experienced engineering geologist. Such investigations should precede site planning and continue as grading provides additional geologic information.

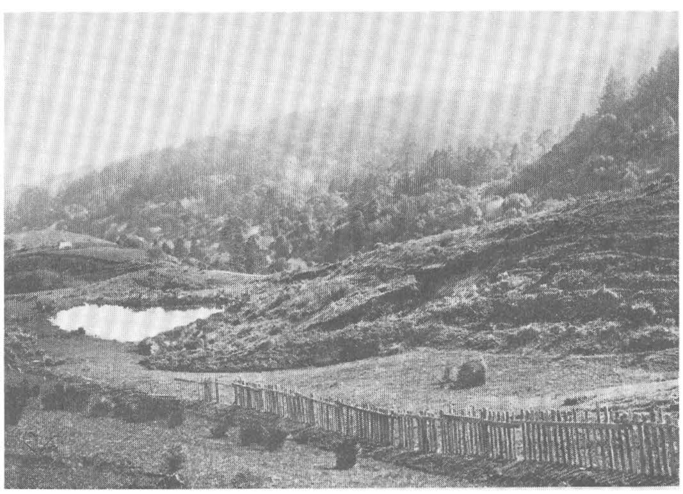
The importance of competent geologic guidance can be illustrated by examining two common misconceptions. The first concerns soil tests, which measure the strength of surface materials and their ability to support structures without failing. Favorable tests of surface soil are commonly, though erroneously, cited as evidence that a site is free of landslide problems. Although some slides are shallow, many result from failure on surfaces that lie many feet or tens of feet beneath the surface—far deeper than standard soil tests. Thus, tests of surface materials, though useful in estimating foundation stability, do not necessarily assure us that a slope is stable.

The second misconception concerns ancient landslide deposits, especially those showing no evidence of movement in historical time. Because the slope has already failed and because the landslide debris is in seeming equilibrium with its surroundings, the deposit appears to be stable and thus as suitable for development as are other areas. This view is invalid because it neglects two important principles: (1) Any landslide deposit is, at best, only temporarily stable, and relatively minor changes in load, slope, or ground-water level may generate renewed sliding; and (2) development on a landslide deposit necessarily alters many of the site characteristics that control stability. Although some ancient landslide deposits can be modified and developed safely, they should be viewed as potentially sensitive sites until thorough geologic investigation has proved them to be otherwise.



This barn on the old Skinner Ranch, 0.5 miles northwest of Olema in Marin County, straddled 15 ft of horizontal displacement during the 1906 San Francisco earthquake; although it remained standing, its utility as a cowbarn was clearly reduced. The site of the Skinner Ranch is now the headquarters for Point Reyes National Seashore, and a modern version of the Skinner cowbarn still sits on the fault trace. Elsewhere along the fault, near Olema, several well-built wood-frame houses within a few feet of the fault break survived the earthquake with substantial damage; repaired, some of these remained in use for more than half a century. The impact of this earthquake in rural parts of Marin, San Mateo, Santa Clara, and Santa Cruz Counties contrasted sharply with its devastating effect in nearby towns and cities. Photograph by G. K. Gilbert, U.S. Geological Survey.

A water tank on the Hayward fault sits above a hillside residential district in the eastern part of Hayward. The fault scarp, formed by repeated episodes of horizontal slip, interrupts the regular slope of the hills and is most evident below the fence to the right of the water tank. This segment of the Hayward fault broke during the magnitude 6.7 earthquake of October 21, 1868, which caused major damage throughout the East Bay. This view also shows how cut-and-fill grading is used to modify natural slopes and provide flat surfaces for housing and streets. Photograph by Norman Prime, U.S, Geological Survey.



Landslide on the San Andreas fault about 4 miles northwest of Bolinas Lagoon, Marin County. This small mass of earth and soil failed in March 1907, nearly a year after major faulting along this segment of the San Andreas fault. Many similar slides moved during the winter and spring after the 1906 San Francisco earthquake. These failures, scattered along the fault zone, occurred where rainfall and runoff from winter storms saturated cracked and broken ground formed during fault displacement.

Throughout northern California, many other slopes failed during the April 18, 1906, earthquake. That earthquake followed several months of heavy rainfall, and even for north-coastal California, March 1906 was unusually wet, with rainfall amounts from 50 to 200 percent above normal. The coincidence of strong ground shaking and water-saturated hillslopes created hundreds of massive slides and earth flows, but because most of northern California was still sparsely settled, the damage caused by slope failure was less apparent than that due to shaking. A repeat of this scenario today would result in major damage and financial loss because of widespread development on the hillslopes and uplands. Photograph by G. K. Gilbert, U.S. Geological Survey.

Ground failure on Bluxome Street near Sixth Street in San Francisco after the 1906 earthquake. This and many other parts of San Francisco near the waterfront were formerly part of the bay and, after the Gold Rush, were reclaimed by artificial fill. These early fills, consisting of garbage, debris, and the hulks of abandoned wooden ships, were notoriously unstable and exhibited local compaction and subsidence even before the earthquake. Some of the most spectacular ground failures during the earthquake were in such filled areas, and in many places, liquefaction in the fill or in the underlying bay mud contributed to surface damage. These arcuate fractures may be due to compaction during ground shaking or to liquefaction. The two high points on the skyline to the right of the power pole are the Twin Peaks. Photograph by G. K. Gilbert, U.S. Geological Survey.

FAULTS AND EARTHQUAKES

THE PROBLEM

Every community in the San Francisco Bay region is subject to earthquake damage, and many have experienced one or more destructive shocks. Surface faulting, the tearing apart of adjoining blocks of land at the Earth's surface, accompanies earthquakes of magnitude 6 and greater. Because the style of faulting is comparable throughout the bay region, the effects of surface fault displacement are comparable from place to place. In contrast, the severity of ground motion varies with distance from the fault and with local geologic conditions. Thick deposits of unconsolidated sediment, such as bay mud or alluvial gravel, sand, or silt, may amplify and prolong the shaking; thus, the hazard from shaking is greater around the margins of the bay and in some alluviated valleys than on hillside land that may be closer to the earthquake source. Whereas earthquake-induced landslides are a significant hazard in the hillsides and uplands, ground failure caused by liquefaction in soft, water-saturated sediment is more important in natural or reclaimed marshlands or in alluviated valleys.

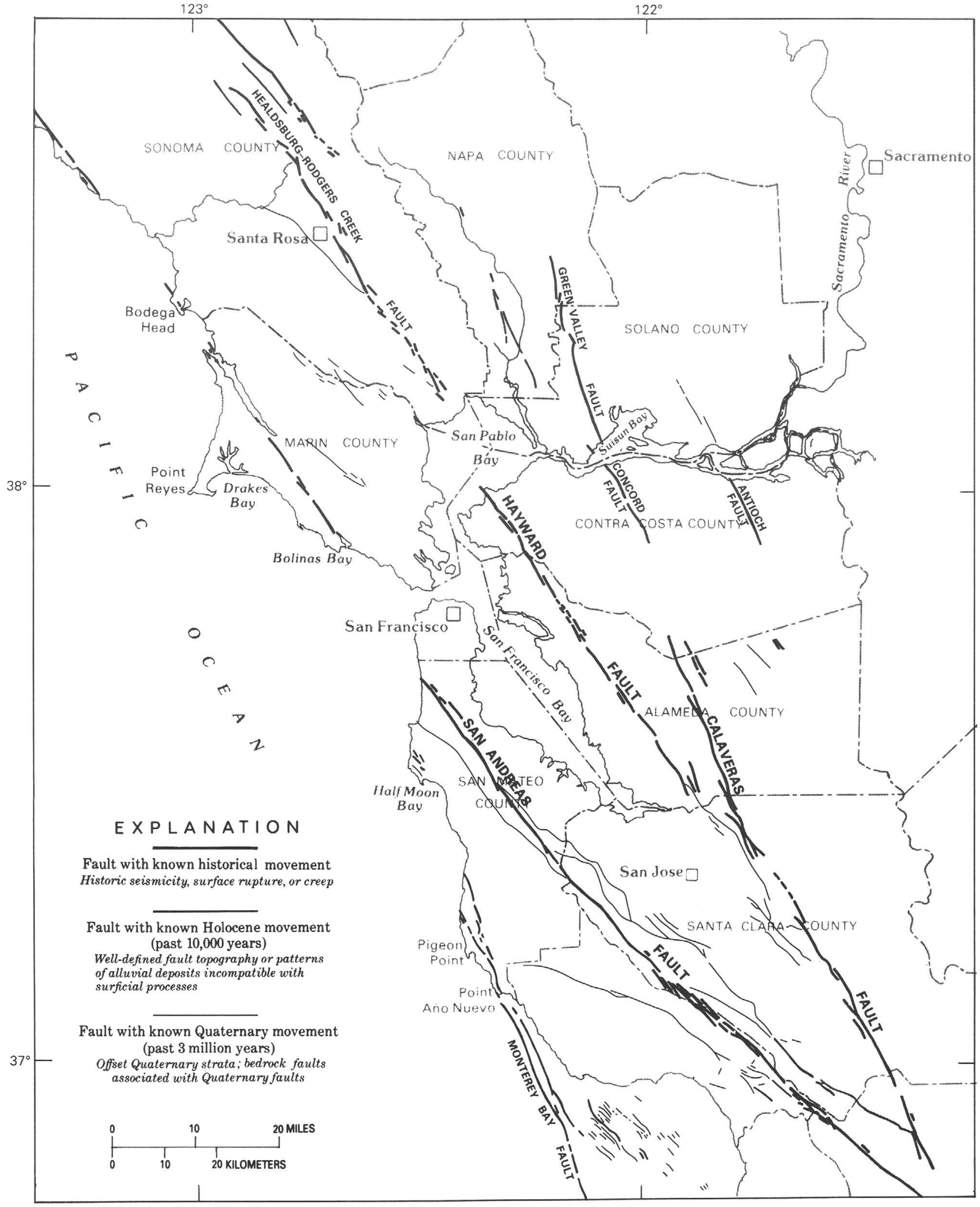


FIGURE 22.—Faults in the San Francisco Bay region that may cause damaging earthquakes or surface displacement, or both. Some of these faults have slipped during historical time (past 150 years), some during Holocene time (past 10,000 years), and some during Quaternary time (past 3 million years). Most are members of the San Andreas fault system. Adapted from Borcherdt (1975, p. A7, fig. 3).

GEOLOGY AND PROCESSES

Enormous amounts of rock waste are continually being eroded from the hills and deposited in the lowlands of the San Francisco Bay region. Were no other processes acting, this continual erosion and deposition would eventually bring the hills and the lowlands to a common, nearly flat surface. No such regional surface is evident because the Earth's crust warps and deforms at rates that equal or exceed the rates of erosion and deposition. Some deforming mechanisms, such as tilting and folding, are gradual or intermittent, and in the bay region their effects, if any, are almost imperceptible. Faulting and earthquakes, however, are frequent, readily perceived, and potentially catastrophic.

Nearly all destructive earthquakes in the San Francisco Bay region originate on faults in the San Andreas system (fig. 22), a set of northwest-trending fractures that extends more than 800 mi from the Gulf of California to Cape Mendocino. The nine bay counties straddle this fault system. Movement along faults of the San Andreas system juxtaposes strikingly dissimilar rock masses in the upper 10 mi of the Earth's crust, separating the North American continental plate from the Pacific oceanic plate and accommodating much of the motion as the continental plate episodically slips southeastward, past the oceanic plate. The long-term average rate of movement across the San Andreas fault system is about 2 in. per year. The forces that drive the plates elastically deform the Earth's crust near the plate boundary until the frictional forces resisting fault slippage are overcome. When this happens, the energy stored in the deformed crust is converted into seismic energy and radiates from the fault as seismic waves, which we feel as ground motion and record as wavy lines on a seismogram. We can see the fault—the failure surface or break between displaced rock masses—only if it extends to the surface and offsets the ground or disrupts manmade structures.

Earthquakes come in all sizes, or magnitudes. The presently used method of measuring magnitude is that of C. F. Richter (fig. 23).

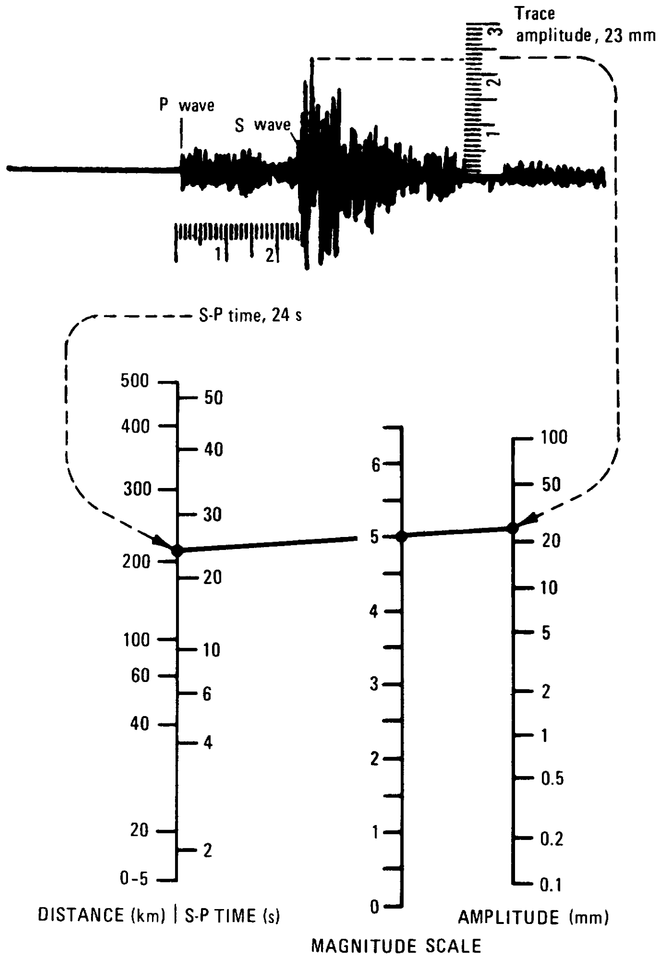


FIGURE 23.—Determination of Richter magnitude. Using the maximum amplitude of the seismogram and the difference in arrival times of the *P* and *S* waves, the value of magnitude can be read from this nomogram (from Hays, 1980, p. 28, fig. 24).

The amplitude, or height, of a seismic wave recorded by a seismograph is measured and adjusted to compensate for differences in the sensitivity of individual seismographs and for the distance from the earthquake to the recording instrument. The magnitude determined in this way is a measure of the ground motion at a standard distance from the earthquake source; it is a single value for each earthquake. Because magnitude varies logarithmically, each step in the magnitude scale—for example, from 5 to 6—represents a thirtyfold increase in the energy released and a substantial increase in the potential for damage.

In the San Francisco Bay region, most earthquakes smaller than about magnitude 3 are detected only by seismographs, those greater than magnitude 3 are generally felt, and those greater than magnitude 5 can cause damage in urban or developed areas. Table 4 lists the magnitudes and dates of occurrence of historical earthquakes in the bay region. The largest, of magnitude 8.3, was the great San Francisco earthquake of April 18, 1906. Worldwide, the largest earthquakes attain magnitudes of about 8.9; larger ones are unlikely because the breaking strength of the strongest rocks limits the amount of strain energy that can be stored in the Earth's crust.

TABLE 4.—*Historical earthquakes of magnitude greater than 5.0 in the San Francisco Bay region*

[Magnitude data before 1945 are incomplete, and some earthquakes of magnitude greater than 5.0 may have gone unreported. Data from Bolt and Miller (1975), Borcherdt (1975), Lester and Meagher (1978), and Toppozada and others (1981)]

Date	Locality	Magnitude
Jan. 1980	Livermore	5.8
Aug. 1979	Gilroy	5.7
Nov. 1974	Hollister	5.1
Oct. 1969	Santa Rosa	5.6
Dec. 1967	Watsonville	5.3
Sept. 1963	do	5.4
Apr. 1961	Hollister	5.6
Mar. 1959	Gilroy	5.3
Mar. 1957	San Francisco	5.3
Sept. 1955	San Jose	5.5
Oct. 1955	Concord-Walnut Creek	5.4
Apr. 1954	Watsonville	5.3
Mar. 1949	Hollister	5.2
June 1938	do	5.5
July 1911	Coyote	6.6
Apr. 1906	San Francisco	8.3
June 1899	do	5.5
Apr. 1899	Watsonville	5.7
Mar. 1898	Vallejo	6.3
Apr. 1892	Winters	6.6
Apr. 1892	Vacaville	6.4
Oct. 1891	Napa	5.6
Jan. 1891	San Jose	5.1
Apr. 1890	San Juan Bautista	5.9
July 1889	Oakland	5.1
May 1889	Antioch	5.6
Mar. 1884	Santa Cruz	5.3
Mar. 1883	Gilroy	5.7
Apr. 1870	Oakland	5.1
Oct. 1868	Hayward	6.7
Oct. 1865	Watsonville	6.2
Mar. 1865	Santa Rosa	5.3
July 1864	Fremont	5.4
Mar. 1864	Milpitas	5.3
July 1861	Dublin	5.3
Nov. 1858	Fremont	5.9
Feb. 1856	San Mateo	5.9
Jan. 1856	San Francisco	5.3
Aug. 1855	Sonoma	5.1
June 1838	Woodside	7.0
June 1836	Hayward	6.7

Earthquake damage results (1) from faulting, (2) from ground motion or shaking, and (3) from ground failure induced by strong shaking; ground failure includes both landslides and failures caused by liquefaction of soft, water-saturated sediment. Borcherdt (1975), Borcherdt and others (1979), and Archuleta and others (1979) described methods of identifying damage-prone areas in the bay region, and Youd and Hoose (1978) discussed various earthquake-induced ground failures in northern California. Here, we discuss only briefly these three sources of earthquake damage and refer the interested reader to the above-mentioned reports for more complete information.

FAULTING

Geologic maps show hundreds of faults crisscrossing the San Francisco Bay region. Most of these faults, locked and immobile for millions of years, are unlikely to cause a major earthquake. Others, however, exhibit historical slip, currently generate small earthquakes, or show other evidence (such as offset soils or offset topographic features) of movement within the recent geologic past. These faults may suddenly shift several inches or feet and cause a damaging earthquake, or they may creep gradually, a fraction of an inch at a time, without any perceptible earthquake shocks. Such faults are considered active if their history, as determined by geologic and seismologic evidence, indicates that they are likely to move again during the lifetime of manmade structures.

Criteria for defining an active fault differ with the kind of structure and with the Federal or State agency responsible for its safety. For city and county planning, the State of California defines as active those faults that have moved during the past 11,000 years. (State regulations regarding development on active faults are discussed on p. 58-62 of this report.) For dams, nuclear powerplants, and other critical facilities, less frequent—hence, older—movement is accepted as evidence that a fault is active. In this report, because we are concerned chiefly with city and county planning, our usage of the term "active fault" is closest to that of the State of California, although the latest movement on some faults that we consider active may not yet be accurately determined.

Most active faults in the bay region belong to the northwest-trending San Andreas fault system and move in accordance with the plate-boundary mechanism discussed above. The Hayward, Calaveras, and San Andreas faults are familiar active members of the San Andreas system; less well known, but also active, are the San Gregorio, Rodgers Creek, and Green Valley faults; all are nearly vertical, and all are right-lateral strike-slip faults. As we look along the fault trace of a right-lateral strike-slip fault, the block to our right moves toward us, and the slip is almost wholly in the horizontal plane, parallel to the strike, or surface trace, of the fault (fig. 24).

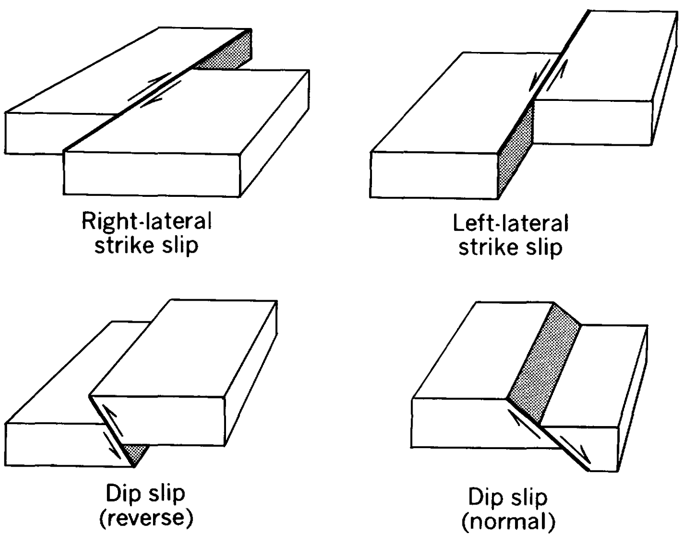


FIGURE 24.—Four types of fault movement, characterized by movement relative to the fault and to the horizontal. Most faults in the San Francisco Bay region show right-lateral strike slip—the characteristic movement for the San Andreas fault (from Wesson and others, 1975, p. A12, fig. 4).

Most of these faults have generated one or more damaging earthquakes. In those places where surface displacement has accompanied an earthquake, the sense of the displacement indicates right-lateral strike slip. Surface displacements accompanied the earthquakes of 1861, 1868, and 1906 (see table 4); it was also reported for the earthquakes near Hayward in 1836 and near Woodside in 1838.

A few bay-region active faults depart as much as 45° from vertical, and many have a large component of vertical slip (fig. 24). These, too, are part of the San Andreas system. Because they are more difficult to identify and map than vertical strike-slip faults, more of these dip-slip faults may still be undiscovered.

Most active faults display clear evidence of repeated past movements (fig. 25), and because they consist of zones of crushed and broken rock, they are weak and likely to fail again. Hazards from surface faulting exist where buildings or other structures straddle the fault. Folklore and movie scripts commonly depict faults as gaping chasms that indiscriminately swallow both people and buildings. Such effects are unrealistic; nevertheless, fault displacement within the foundation of a building or major structure, such as a dam or powerplant, can cause appalling damage. Strike-slip displacements at the surface of as much as 16 ft accompanied the 1906 San Francisco earthquake, and even several inches of displacement can seriously damage many buildings.

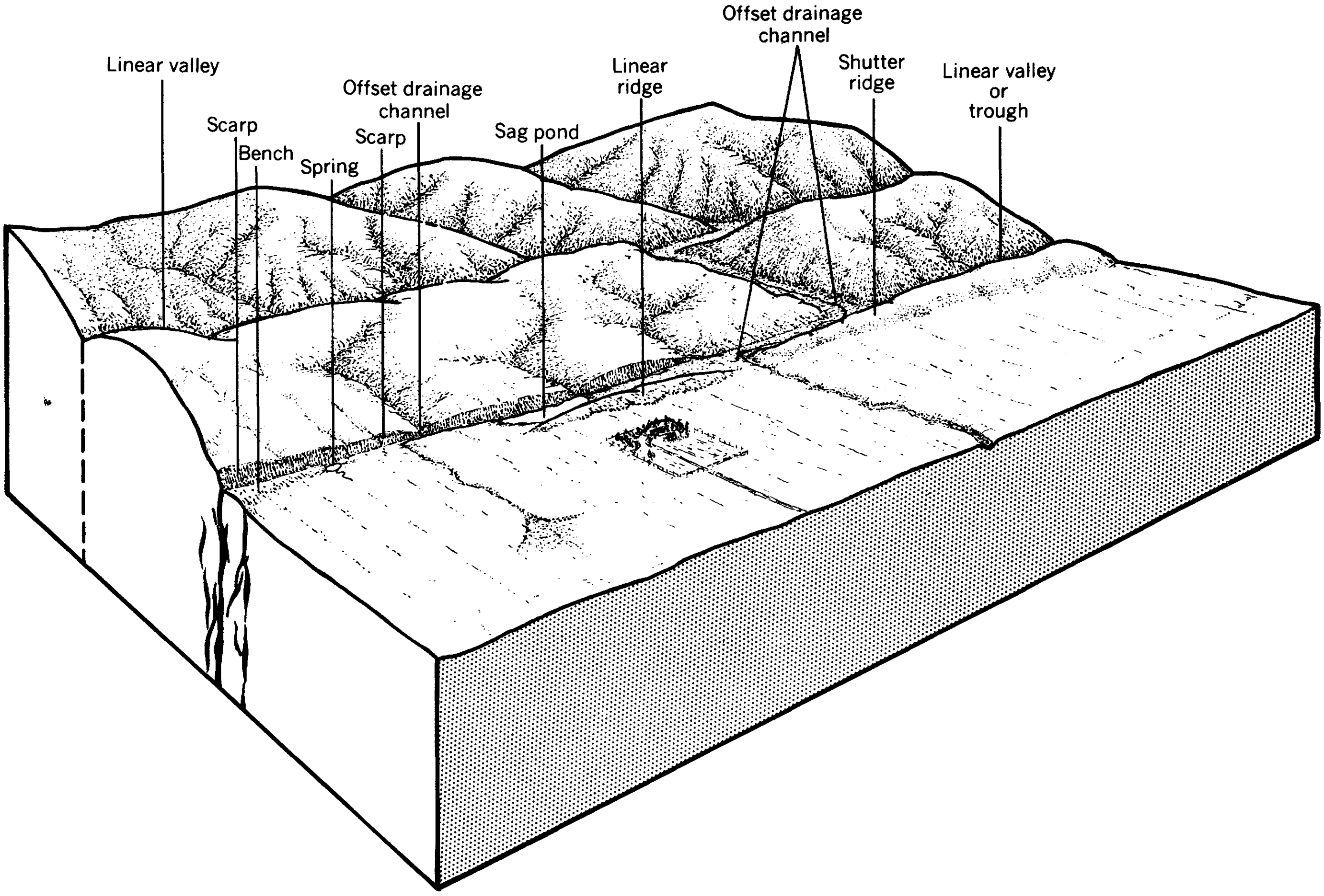


FIGURE 25.—Distinctive landforms and drainage patterns alined along strike-slip fault are visible evidence that fault movement is recent enough to have interrupted the more gradual processes of erosion and deposition.

GROUND MOTION

Shaking, due to the passage of seismic waves through the Earth, causes most of the damage in earthquakes. Several different waves propagate from the rupture surface and are reflected and refracted by layers with varying physical properties in the Earth's crust and deeper interior. Compressional, or *P*, waves and shear, or *S*, waves traverse the Earth's interior; surface waves travel along the Earth's surface layers. Each of these waves travels at a different velocity (compressional waves are fastest, surface waves slowest), possesses typical amplitude and frequency patterns, and attenuates at varying rates with distance from the fault, or earthquake source.

The most accurate and detailed information on ground motion comes from the records written by strong-motion seismographs (fig. 26). These instruments record ground motion when they are triggered by a shock above a predetermined threshold level of acceleration, generally about 0.01 g (1 g=32 ft/s^2). Estimates of the expected peak acceleration of the ground at a distance of 3 mi from a magnitude 6.5 earthquake range from about 0.3 to more than 1.0 g (Boore and others, 1978). The records obtained provide precise information about the amplitude, frequency, and duration of shaking. Unfortunately, very few instrumental recordings of damaging levels of ground motion are available, and nearly all the strong-motion data from earthquakes larger than magnitude 6 come from instruments

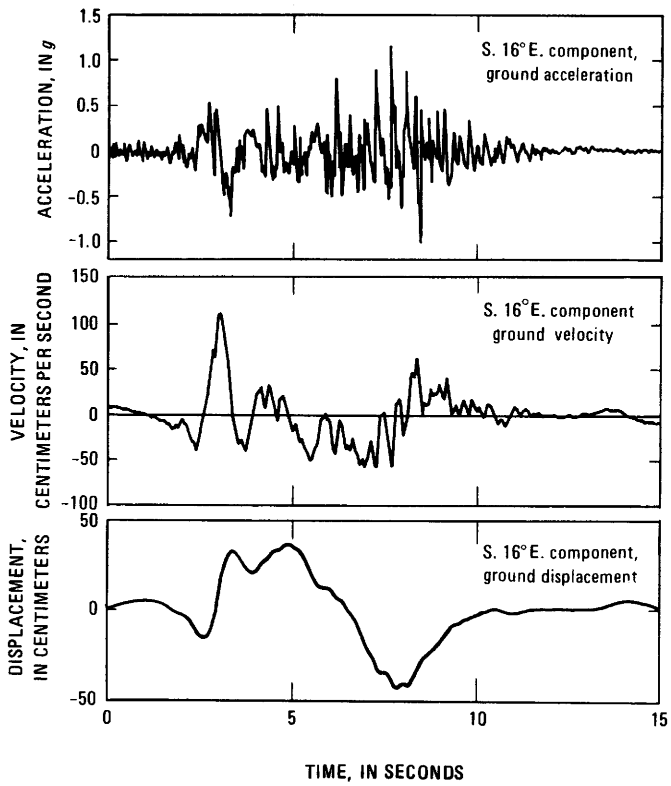


FIGURE 26.—Strong-motion seismograph records of horizontal ground motion at Pacoima damsite during the San Fernando, Calif., earthquake of February 9, 1971 (after Trifunac and Hudson, 1971, p. 1406, fig. 13). Velocity (middle) and displacement (bottom) records were obtained by integrating the acceleration record (top) once and twice, respectively. This record is one of very few from an instrument less than 5 mi from a fault break.

that are more than 5 mi away from the fault break. No records have been obtained from within 50 mi of a magnitude 8 or greater earthquake. Because of the absence of instrumental data, much uncertainty accompanies estimates of the severity and dynamics of shaking close to the fault, where damage is greatest.

The severity of ground motion diminishes with distance from the earthquake source, and, where this source is a vertical fault and the surrounding geology is uniform, the pattern of shaking is simple and regular. In the absence of instrumental data, earthquake intensity is commonly used as a measure of shaking. *Earthquake intensity* is a number describing the effects of an earthquake on people, structures, and the Earth's surface. Though expressed quantitatively, intensity is actually a subjective measure (table 5). Intensity maps—that is, maps that show the severity of shaking in terms of observed earthquake effects—typically display nearly circular or elliptical bands of equal intensity of shaking surrounding the fault. On most of these maps, the strongest effects are nearest the fault, and intensities are progressively lower outward from the fault (fig. 27). This simple distance-intensity relation is complicated where the earthquake fault dips at a low angle or where the geology is complex and nonuniform.

The effect of local geology on ground motion appears on many intensity maps as pockets and irregular areas of severe damage that closely match the surface extent of certain geologic units. Areas underlain by thick deposits of uncompacted artificial fill, by soft, water-saturated mud, or by unconsolidated stream sediment shake longer and harder than areas underlain by bedrock, especially where these unconsolidated deposits are more than 50 ft thick and overlie firm bedrock (Borcherdt, 1975). Thus, some lowland areas 5 to 10 mi from an active fault may undergo as much shaking damage as bedrock sites much closer to it. Fortunately, most lowland areas in the bay region are underlain by well-compacted, well-drained sediment that behaves much like bedrock. The areas in which local geology is most likely to amplify the shaking are those underlain by bay mud, by old artificial fill resting on bay mud, and by stream sediment within a mile or two of the original landward boundary of the bay marshlands. Because of the possibility of dike failures during strong shaking, reclaimed marshlands underlain by these geologic units are especially vulnerable.

TABLE 5.—*Modified Mercalli scale of earthquake intensity*

[Modified from Richter (1958, p. 137-138). See Uniform Building Code for specifications on the quality of masonry construction (International Conference of Building Officials, 1976)]

Intensity	Description
I	Not felt.
II	Felt by persons at rest, on upper floors, or favorably placed.
III	Felt indoors. Hanging objects swing. Vibration like passing of light trucks. Duration estimated. May not be recognized as an earthquake.
IV	Hanging objects swing. Vibration like passing of heavy trucks, or sensation of jolt like a heavy ball striking the walls. Standing automobiles rock. Windows, dishes, doors rattle. Wooden walls and frame may creak.
V	Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors swing. Shutters, pictures move. Pendulum clocks stop, start, change rate.
VI	Felt by all. Many frightened and run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knickknacks, books, and so on knocked off shelves. Pictures fall off walls. Furniture moved or overturned. Weak plaster and masonry D cracked.
VII	Difficult to stand. Noticed by drivers of automobiles. Hanging objects quiver. Furniture broken. Weak chimneys broken at roofline. Damage to masonry D, including cracks; fall of plaster, loose bricks, stones, titles, and unbraced parapets. Small slides and cave-ins along sand or gravel banks. Large bells ring.
VIII	Steering of automobiles affected. Damage to masonry C; partial collapse. Some damage to masonry B, none to masonry A. Fall of stucco and some masonry walls. Twisting, fall of chimneys, factory stacks, monuments, towers, elevated tanks. Frame houses moved on foundations if not bolted down; loose panel walls thrown out. Decayed pilings broken off. Branches broken from trees. Changes in flow or temperature of springs and wells. Cracks in wet ground and on steep slopes.
IX	General panic. Masonry D destroyed; masonry C heavily damaged, sometimes with complete collapse; masonry B seriously damaged. General damage to foundations. Frame structures, if not bolted, shifted off foundations. Frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous cracks in ground and liquefaction.
X	Most masonry and frame structures destroyed with their foundations. Some well-built wooden structures and bridges destroyed. Serious damage to dams, dikes, and embankments. Large landslides. Water thrown onto banks of canals, rivers, lakes, and so on. Sand and mud shifted horizontally on beaches and flatland. Rails bent slightly.
XI	Rails bent greatly. Underground pipelines completely out of service.
XII	Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

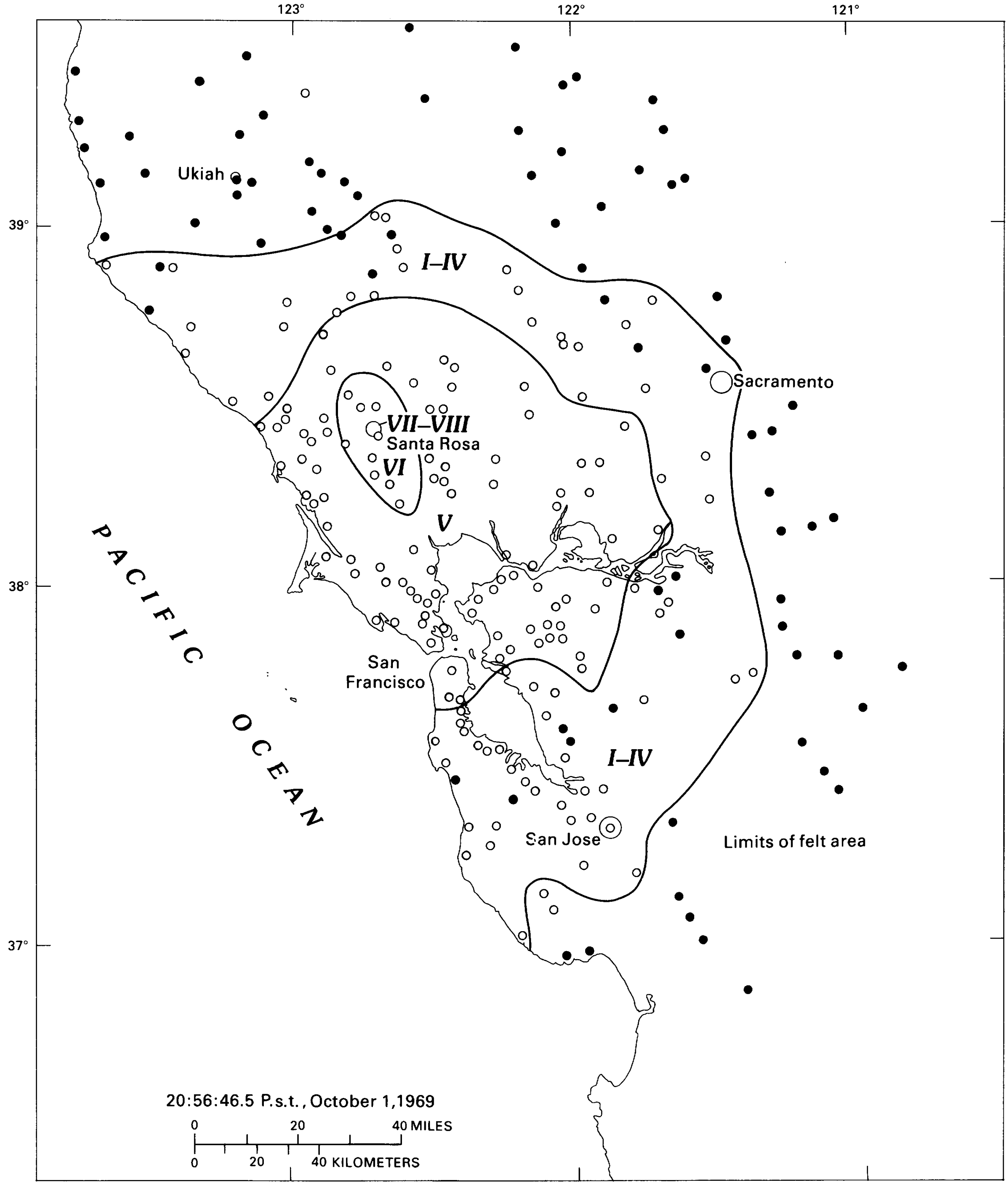


FIGURE 27.—Modified Mercalli intensity map of the Santa Rosa, Calif., earthquake of October 1, 1969. Small circles denote where intensity observations (table 5) were reported; solid dots denote where earthquake was not felt. This magnitude 5.6 earthquake, which lasted 10 to 15 seconds, caused building damage of $6 million and damage to dwelling contents of $1.25 million (Steinbrugge and others, 1970, p. 94). Adapted from Steinbrugge and others (1970, p. 95).

GROUND FAILURE

Earthquake shaking also imposes cyclic vertical and horizontal forces on both rock and soil. Most California earthquakes larger than about magnitude 5 shake the ground long enough to trigger at least a few small landslides, and still larger earthquakes may trigger hundreds. During the great 1906 San Francisco earthquake, landslides and other kinds of ground failure were reported from Salinas northward to Eureka and across nearly the entire width of the Coast Ranges. Earth flows, debris slides, and slumps blocked roads and railroads, damaged dwellings and other structures, overrode agricultural land, and dammed flowing streams. After the earthquake, the slide scars and deposits remained as the most obvious evidence of violent shaking. Still visible today, they remind us that earthquake-induced landslides are a major hazard throughout the bay region.

LANDSLIDING

The pervasive landsliding in 1906 is attributed to three main causes: Abundant unstable slopes, high ground-water levels, and unusually strong shaking. Hillslopes in the northern California Coast Ranges, which make up most of the bay region, are covered with both ancient and active landslide deposits; and even slopes that appear stable can be reactivated if they are shaken or overloaded with ground water. At the time of the great San Francisco earthquake, most potential landslide areas were heavily charged with ground water because of a period of unusually heavy rainfall during the preceding March (Youd and Hoose, 1978). Ground motion during this magnitude 8.3 earthquake was both severe and of long duration, so that the forces resisting ground failure were overcome.

Although we cannot predict the magnitude of the next bay-region earthquake or tell whether it will come during a period of excess ground moisture, potential landslides are presently at least as numerous now as they were in 1906. The risk to life and property, of course, is much greater now. Hillsides where cattle and sheep grazed in 1906 are today completely built over. Streams that drain unstable or marginally stable slopes now contain reservoirs; other streams, which earthquake-induced landslides may temporarily and insecurely dam, flow downstream through urbanized lowlands. And at countless points, complex networks of roads, railroads, and utility and communication lines cross terrain of doubtful stability.

LIQUEFACTION

Although earthquake-induced landsliding is chiefly a hillside process, earthquakes also cause ground failures in the lowlands. Some lowland ground failures resemble hillside landslides and result from the failure of steep slopes along streambanks or in manmade cuts. Others, however, occur on nearly flat ground and are accompanied by lateral spreading, by settlement, or by the ejection of fine sand from beneath the surface. Many of these flat-ground failures are caused by liquefaction—a process that Youd (1973, p. 3; Youd and others, 1975) defined as "the transformation of a granular material from a solid state into a liquefied state as a consequence of increased pore-water pressures." Saturated sediment may also liquefy and change its shape under static loading, but liquefaction is most apt to take place during earthquake shaking.

Lateral spreads, the most common evidence of liquefaction, cause arcuate or linear ground fractures. These fractures are typically tens or hundreds of feet long, a few feet deep, and a few inches to a few feet wide at the surface. They separate masses of earth or soil that are slightly tilted or that have shifted horizontally as though they were pulled apart. Water may be visible in the deeper fractures, and even where it is not, sand boils—small inverted cones of clean sand 1 or 2 ft in diameter—may remain as evidence that subsurface sediment has flowed to the surface.

Settlement due to liquefaction is indicated by relative downward movement of the land surface adjacent to such fixed objects as well casings and pilings. It may amount to several feet if large volumes of subsurface sediment liquefy and flow laterally.

During earthquakes, sediment liquefies and causes significant ground failures only if all four of the following geologic conditions are present:

(1) A potentially liquefiable bed or lens of porous well-sorted sand, (2) saturation of the intergranular pore spaces in the bed or lens by water, (3) confinement of pore water by impermeable layers above and below the liquefiable bed, and (4) proximity of the liquefiable bed to the surface (50 ft or less).

In the bay region, few geologic settings meet all four of these conditions. Those that do, occur locally where sand layers are interbedded either with bay mud or with flood-plain silt and clay along stream valleys (fig. 28). Some landslides on hillslopes also move at least partially by liquefaction, but in this report we do not differentiate these from other landslides.

Although the possibility of damage from liquefaction is more localized than that from ground shaking or landsliding, it is a hazard at some sites on the reclaimed marshlands fringing the bay, especially where land at or below mean sea level is protected by dikes. In such places, lateral spreading or settlement may contribute to dike failure and lead to extensive flooding. Even without dike failures, the ground failures that result from liquefaction can damage structures and roads and interrupt sewer, water, and utility service.

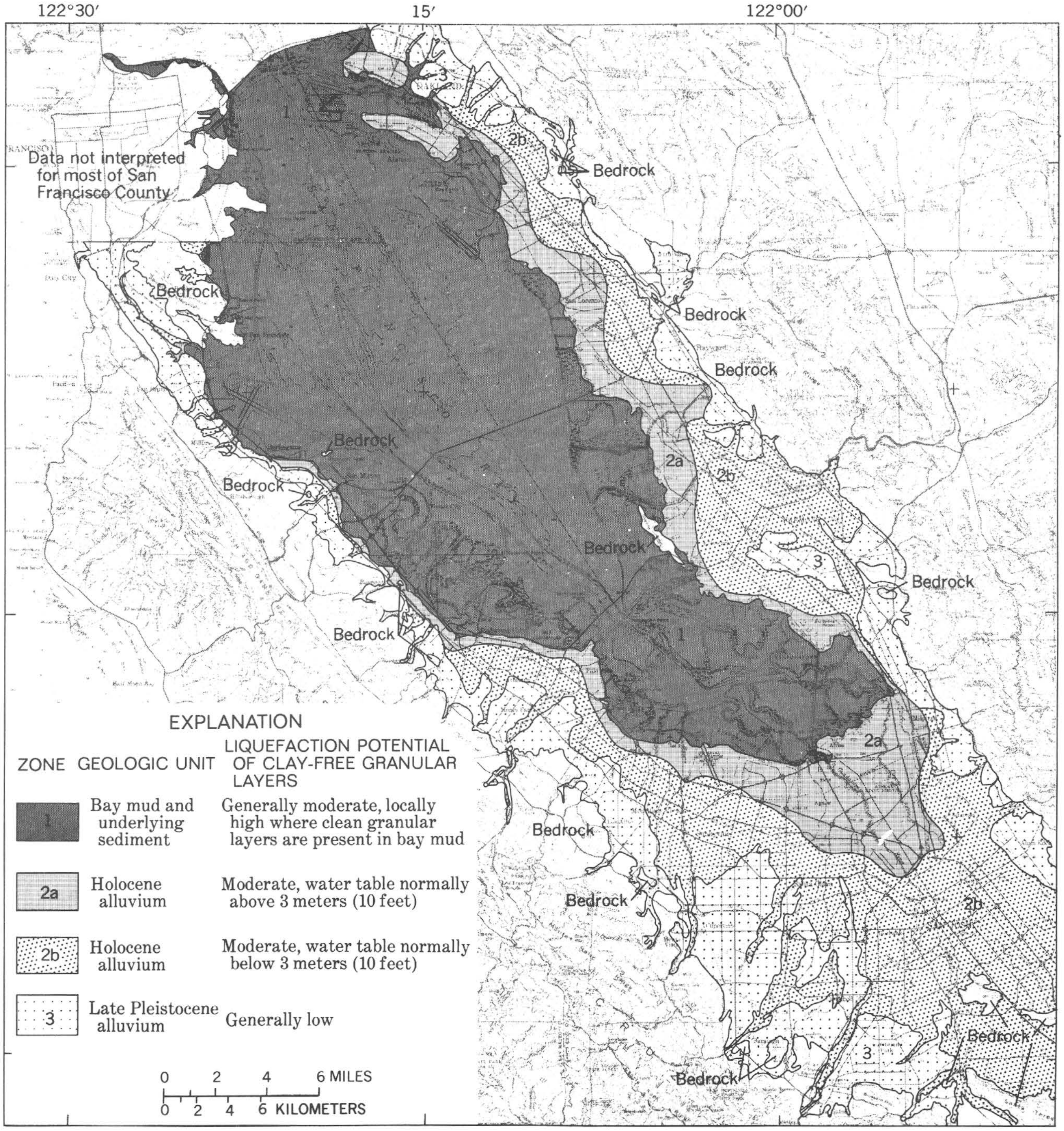


FIGURE 28.—Preliminary map showing liquefaction potential in the southern San Francisco Bay region. The map shows the generalized liquefaction potential of granular layers in each map zone but does not delineate the locations of these layers. Thus, the map is useful for designating zones where special consideration should be given to the possibility of liquefaction, but is not valid for assessing a given site (from Youd and others, 1975, p. A73, fig. 50).

ACTIONS TO ENHANCE LAND USE

FAULTING

State law now regulates new building for human occupancy along active faults. To the extent that this regulation has slowed the pace of development in active fault zones, it will undoubtedly save lives and minimize damage during future earthquakes. Fair and consistent administration of these regulations, however, is difficult because few faults exhibit the unity and simple continuity that their names imply. Most, like the San Andreas, form a series of sharp, well-defined breaks a few inches to a few feet wide and from 1 to 3 mi long. Individual breaks vary somewhat in trend, in length, and in their relation to neighboring breaks; some overlap, some split into branches, and others die out into broad, ill-defined fracture zones (fig. 29). Collectively these breaks define a zone that ranges from about 100 to more than 1,000 ft in width. It is the continuity of this zone that warrants naming a fault as a single continuous feature.

Evaluation of the possibilities for surface faulting at sites within this zone requires careful geologic appraisal. In most places, trenches or test pits must be dug or holes drilled to confirm known or suspected fault breaks, to locate branch faults, and to identify relatively safe sites in unbroken rock.

GROUND MOTION

Most conventional dwellings and low-rise buildings possess natural periods of vibration in the range from 0.1 to 1 s. *S* waves typically induce horizontal shaking of the ground in this period range. When ground shaking is in tune with the natural period of structures and is prolonged, buildings begin to sway and vibrate. Unless structures are designed and built to withstand the horizontal forces imposed by this shaking, as well as the vertical forces that result from the weight of the structure and its contents, they will fail. Inexpensive methods of protecting conventional houses include plywood sheathing and diagonal bracing of frames (Yanev, 1974); variations on these methods, described in the Uniform Building Code (International Conference of Building Officials, 1976), protect most modern residences in the bay region. Tall buildings, dams, and other massive or unusually large structures are most sensitive to longer period ground motion. Because of their cost and the consequences of failure, such structures require more sophisticated analysis, as well as more care in siting and in the engineering design and choice of building materials.

Design of structures to survive earthquakes requires knowledge of ground shaking over a critical range of frequencies or periods. This information may be obtained from the analysis of strong-motion records or, where such analysis is impractical, from records of earthquake intensities. Intensity data exist for historical earthquakes that occurred before the deployment of strong-motion seismographs and thus constitute a valuable data base for setting design criteria for earthquake-resistant construction.

GROUND FAILURE

Earthquake-induced landslides resemble those caused by other processes and the same strategies for reducing their impact apply. These strategies were briefly discussed in the preceding section entitled "The Hillsides and Uplands." Of the many hazards related to earthquake-induced landslides, the most serious are those that cause the sudden release of impounded water. Slides may undermine or weaken the foundation of a dam and cause sudden failure. Large volumes of debris may slide into a reservoir and generate giant waves; where such waves overtop earthfill dams, they may trigger catastrophic failure of the dam. Slide debris may temporarily block natural stream courses, cause rapid impoundment, and threaten sudden and unpredictable flooding. Examples of such catastrophes and near-catastrophes are well documented from various parts of the United States and from other countries as well. None has thus far occurred in the bay region, but our future safety depends on knowledge of the degree of hazard and on exercising vigilance and caution in developing our hillside lands.

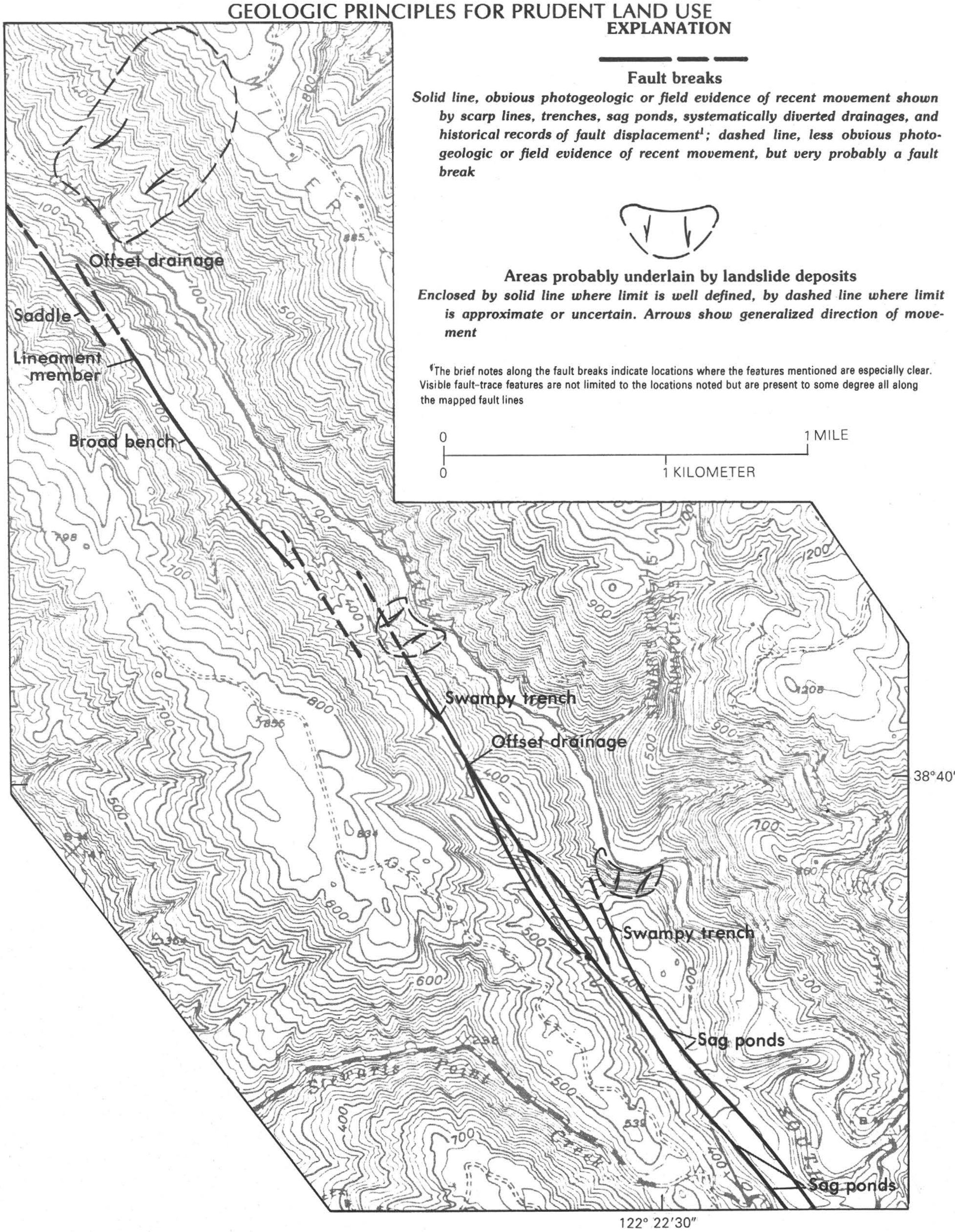
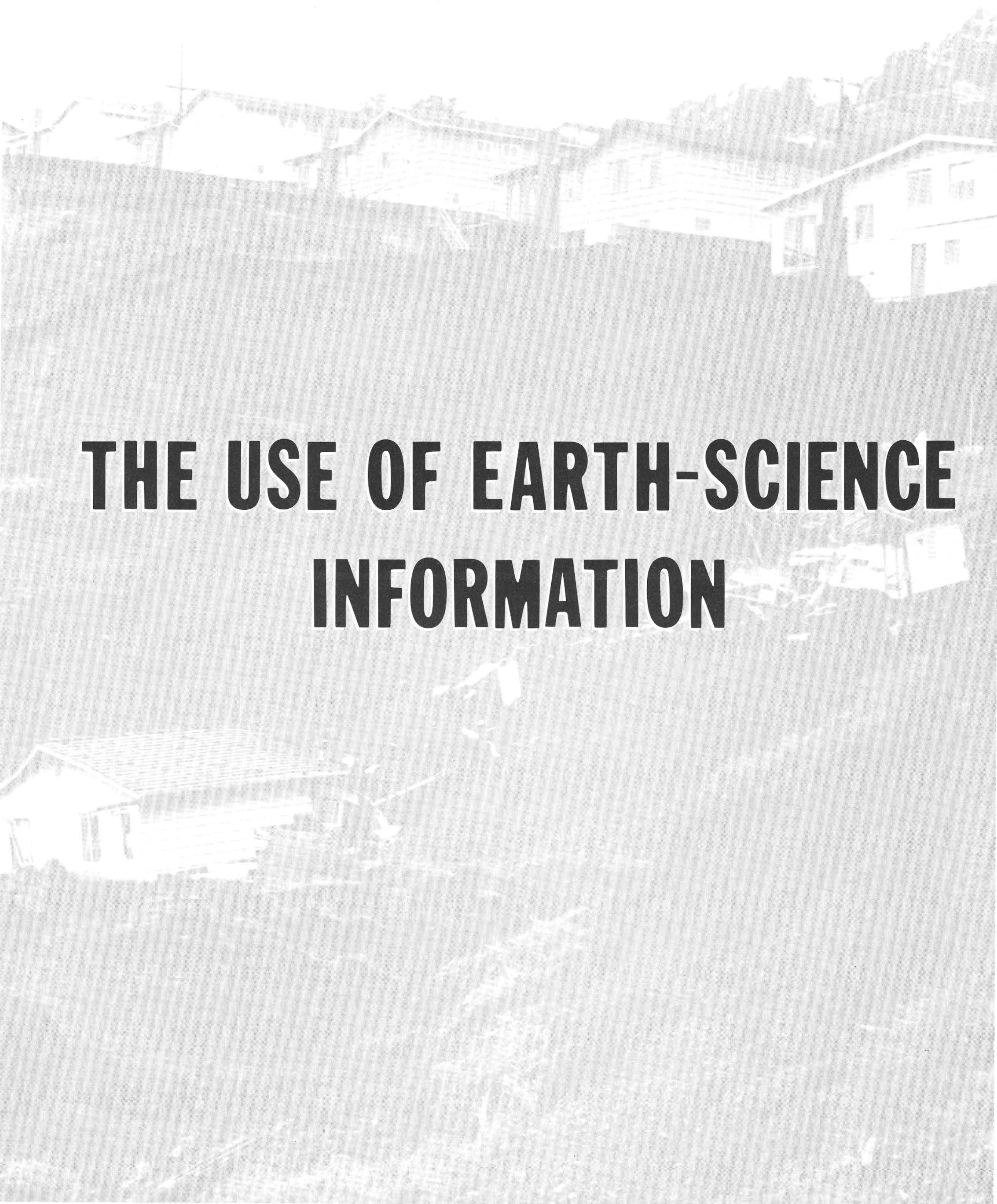


FIGURE 29.—The individual breaks that make up an active fault zone branch, overlap, and die out, as on this map of the San Andreas fault in northwestern Sonoma County. Adapted from Brown and Wolfe (1972).

LIQUEFACTION

Geologists and geotechnical engineers employ drilling and other subsurface geologic and geophysical methods to determine whether potentially liquefiable sand underlies a site. A well-designed, well-executed geologic exploration program distinguishes hazardous areas from those that are relatively safe and provides a basis for prudent site development. However, such programs have come into use only in the past 15 years, after liquefaction began to be recognized as a separate earthquake hazard. Until about 1965, few if any, geologic site studies in the reclaimed marshlands around the bay employed specific testing to determine whether earthquake-induced liquefaction was possible; thus, older developments near the bay may still be susceptible to this kind of damage.

THE USE OF EARTH-SCIENCE INFORMATION



The following six examples illustrate some of the range and types of uses of Earth-science information by decisionmakers in the San Francisco Bay region. Included among these decisionmakers are State legislators, State agencies, regional commissioners, county board supervisors, mayors, councilpersons, municipal engineers, building inspectors, and real-estate sellers. The examples affect an entire State, a nine-county metropolitan area, a bay-and-shoreline district, a 1,312-mi^2 county, a city of 55,000 people, and individual lots and acreages offered for sale. Similar examples from the bay region have been reported elsewhere (Kockelman, 1975, 1976, 1979; Robinson and Spieker, 1978; Kockelman and Brabb, 1979). Each example contains: A summary of the problems or needs faced by the decisionmakers, the Earth-science information needed and available, the specific decisions or actions taken, the methods and procedures used to carry out each decision, and brief comments on the impact of each decision and its adaptation to other problems faced by other decisionmakers. Illustrations have been modified from the decisionmakers' original documents to show their actual use of Earth-science information.

Example 1. An entire State

REGULATING DEVELOPMENT IN ACTIVE FAULT ZONES

The trace of an active fault cannot always be seen at the surface. It may be concealed, and a geologist may have to approximate its location. Displacements do not always occur along a single fault trace; branching segments, braided, and echelon faults may result in wide areas of disturbance (fig. 30). Therefore, regulatory measures for avoiding or reducing the hazards of fault rupture commonly require detailed geologic investigations to accurately identify and evaluate all the strands of the faults. Once these fault strands are located, specific regulations—prohibiting certain uses or requiring specific buildings to be set back from the active strands—can be applied.

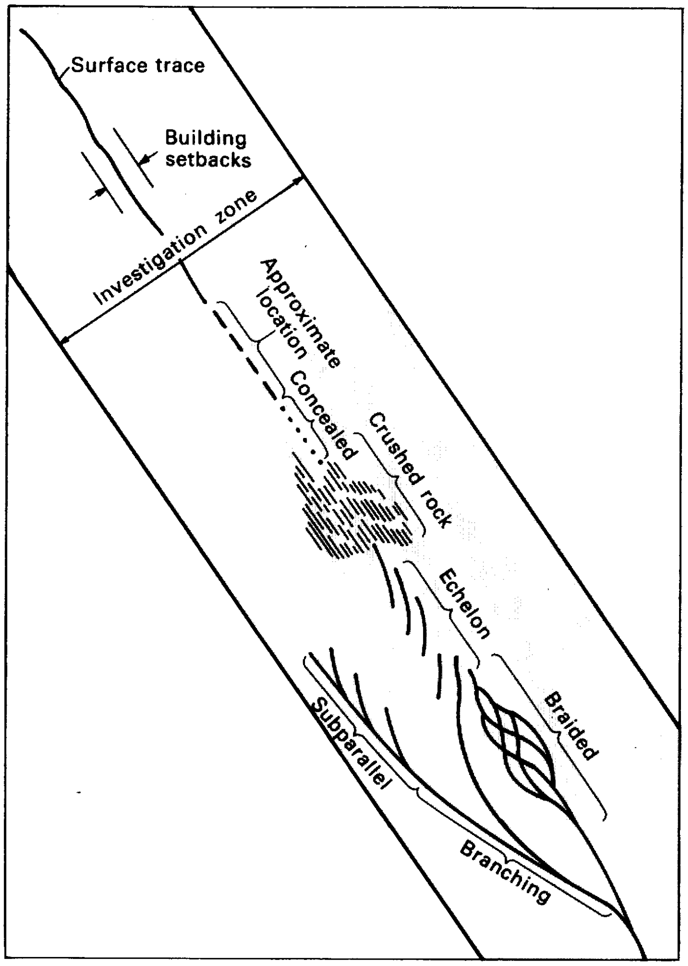


FIGURE 30.—Diagram of hypothetical fault traces, showing possible complexities of faulting that demonstrate the necessity for detailed geologic investigations within a broad zone astride a known fault-rupture trace.

Much of the damage associated with fault rupture can be limited by regulating construction on active faults. Utility lines and transportation facilities can be located, designed, and operated in such a way as to reduce outages and other disruptions.

INFORMATION AVAILABLE

In California, many potentially active and recently active faults have been identified and mapped at various scales; fault maps by the U.S. Geological Survey and the California Division of Mines and Geology are available at a scale of 1:24,000 (1 in. = 2,000 ft) or larger. Evidence for surface fault displacement, magnitudes of the largest historical earthquakes, and estimated recurrence intervals for maximum earthquakes were summarized for 25 faults in a report on seismic zonation edited by Borcherdt (1975) that included discussions of patterns of surface faulting, fault-zone widths, and amounts of displacement. Some of the methods for using Earth-science information and hazard mapping in land-use planning and regulations were discussed by Blair and Spangle (1979).

DECISION

In response to public concern and because of the availability of scientific information, the California Legislature (1972a) enacted the Alquist-Priolo Special Studies Zones Act. This act provides for public safety in areas subject to fault rupture. In addition, the act provides for: Geologic reports, project approval by cities and counties, exemptions for altering or adding to existing structures, disclosure of hazards by real-estate sellers and their agents, and the charging of reasonable application fees.

To assist the various cities and counties, the act requires the State Geologist of the California Division of Mines and Geology to delineate Special Studies Zones that include all "potentially and recently active" traces of the San Andreas, Calaveras, Hayward, and San Jacinto faults and other faults he deems "sufficiently active and well-defined" to constitute a potential hazard. For the purposes of the act, a fault is deemed "sufficiently active" if there is evidence of surface displacement along one or more of its segments or branches during the past 11,000 years, and a fault is considered "well-defined" if its trace is clearly detectable by a trained geologist as a physical feature at or just below the ground surface (Hart, 1980, p. 5-6).

The State Geologist initially delineated zones about a quarter-mile wide; currently, the zones delineated are about 400 to 600 ft wide. Surface traces of all faults are shown on topographic maps, on the basis of the best information available (fig. 31). Zones are established by

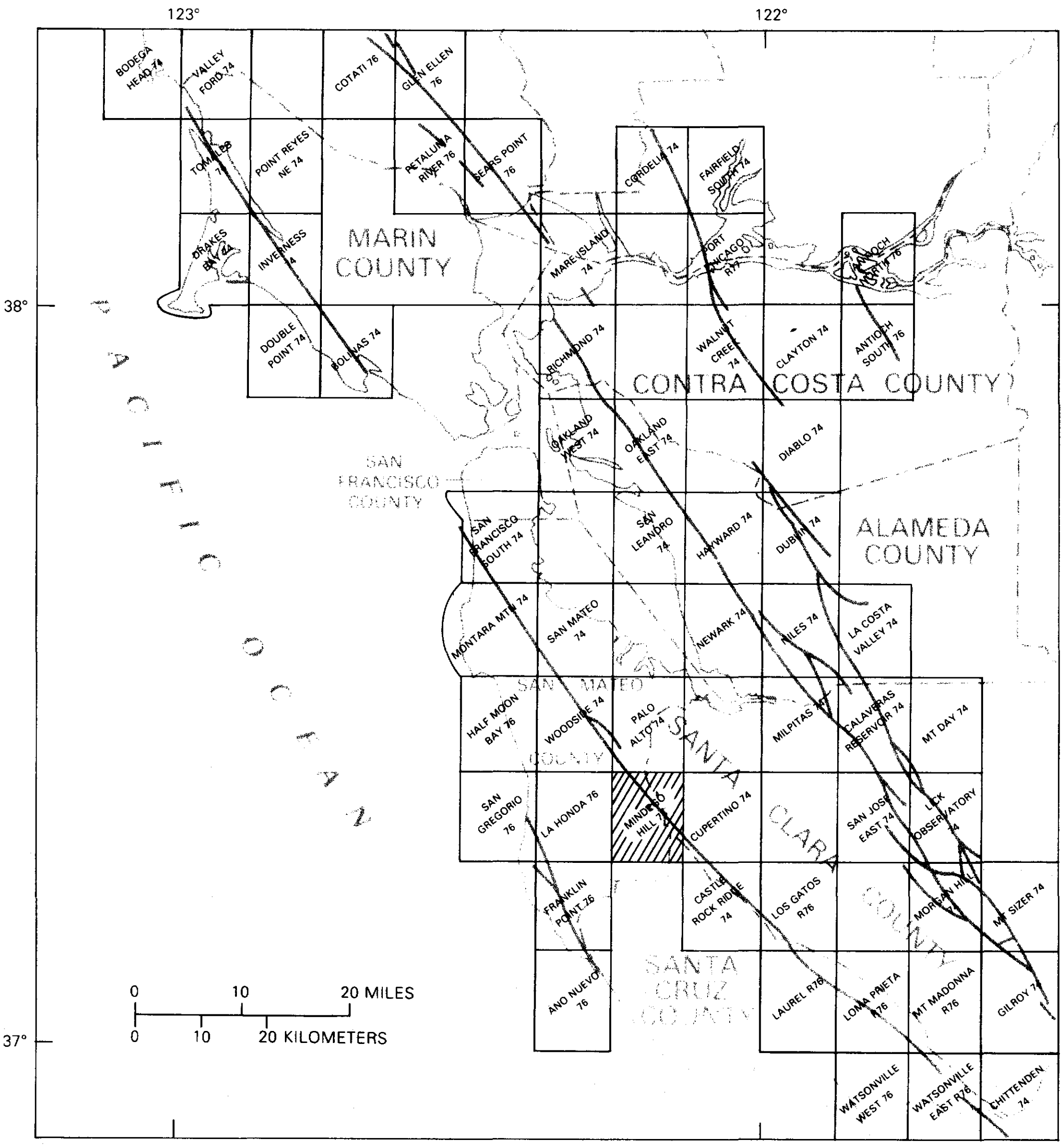


FIGURE 31.—Part of Special Studies Zones index map (Hart, 1980), showing faults zoned for special geologic studies by the State Geologist. The quadrangle name of the State official map and the year issued or revised are indicated. Part of shaded quadrangle is shown in figure 32. Surface traces of well-known faults have been delineated on about 300 topographic maps at a scale of 1:24,000 (1 in. = 2,000 ft). Information about the availability of these maps can be obtained from the Office of the State Geologist, California Division of Mines and Geology, Room 1341, 1416 Ninth Street, Sacramento, CA 95814.

selecting turning points located at obvious features about an eighth-mile or less on either side of the fault trace (fig. 32); the zone boundaries are drafted as straight lines connecting these points. Because fault traces vary—some have branching segments, curved or discontinuous traces, and wide areas of crushed rock (fig. 30)—the zones are irregular and may exceed a quarter-mile in width. Maps similar to figure 32 show faults, historical offsets (indicated by year), displacements caused by creep, and lineaments seen on aerial photographs, as well as the boundaries of zones.

In addition, the California Division of Mines and Geology staff is presently conducting a 10-year fault-evaluation program. This program has as its objective the evaluation of potentially active faults relative to the potential hazard of surface fault rupturing. The results, methods of evaluation, recommended zoning and zone revisions, and some of the problems discovered were summarized by Hart and others (1977, 1978, 1979).

APPLICATION

The State Geologist uses U.S. Geological Survey 7½-minute quadrangles (topographic series), at a scale of 1:24,000 (1 in. = 2,000 ft), as the base for delineating the Special Studies Zones. Information from fault and geologic maps is transferred to these quadrangle maps. Each Special Studies Zones quadrangle map contains specific references to the sources of the scientific information.

The Special Studies Zones Act provides that cities and counties shall require, before the approval of a project in a Special Studies Zone, "a geologic report defining and delineating any hazard of surface fault rupture," and that approval shall be in accordance with the policies and criteria established by the California Mining and Geology Board (California Legislature, 1972a, sec. 2623). The California Mining and Geology Board (in Hart, 1980, app. B) has prepared and adopted specific and detailed criteria. In addition, the California Division of Mines and Geology provides information on the availability of: Waiver forms, guidelines for evaluating surface fault ruptures, maps showing Special Studies Zones, indexes to the zone maps, and indexes to geologic reports within the zones.

The board's criteria prohibit specific development within Special Studies Zones until a registered geologist retained by each city and county has evaluated geologic reports prepared by another registered geologist. The fault information shown on a quadrangle map (fig. 32) is not sufficient to meet the requirement for a "geologic report." In addition, the cities and counties must require that developers evaluate sites within Special Studies Zones to determine whether potential hazards from any faults exist. If a city or county finds that no undue hazard exists for a specific site, the required geologic report may be waived with the approval of the State Geologist. The act and the criteria provide that cities and counties may establish more restrictive policies and criteria if they so desire.

One criterion initially adopted by the board provided that "No structure for human occupancy * * * shall be * * * placed across the trace of an active fault" or within 50 ft of it. The area within 50 ft is assumed to be underlain by active branches until proved otherwise by a geologic investigation by a registered geologist.

In 1976, the California Legislature (1972a, sec. 2621.6(a)) subsequently amended the original Special Studies Zones Act to exclude developments consisting of as many as three "single-family wood-frame dwellings" and, therefore, removed such buildings from the board's criteria. However, many cities and counties retain the 50-ft setback for all structures for human occupancy; others require even greater setbacks (fig. 33).

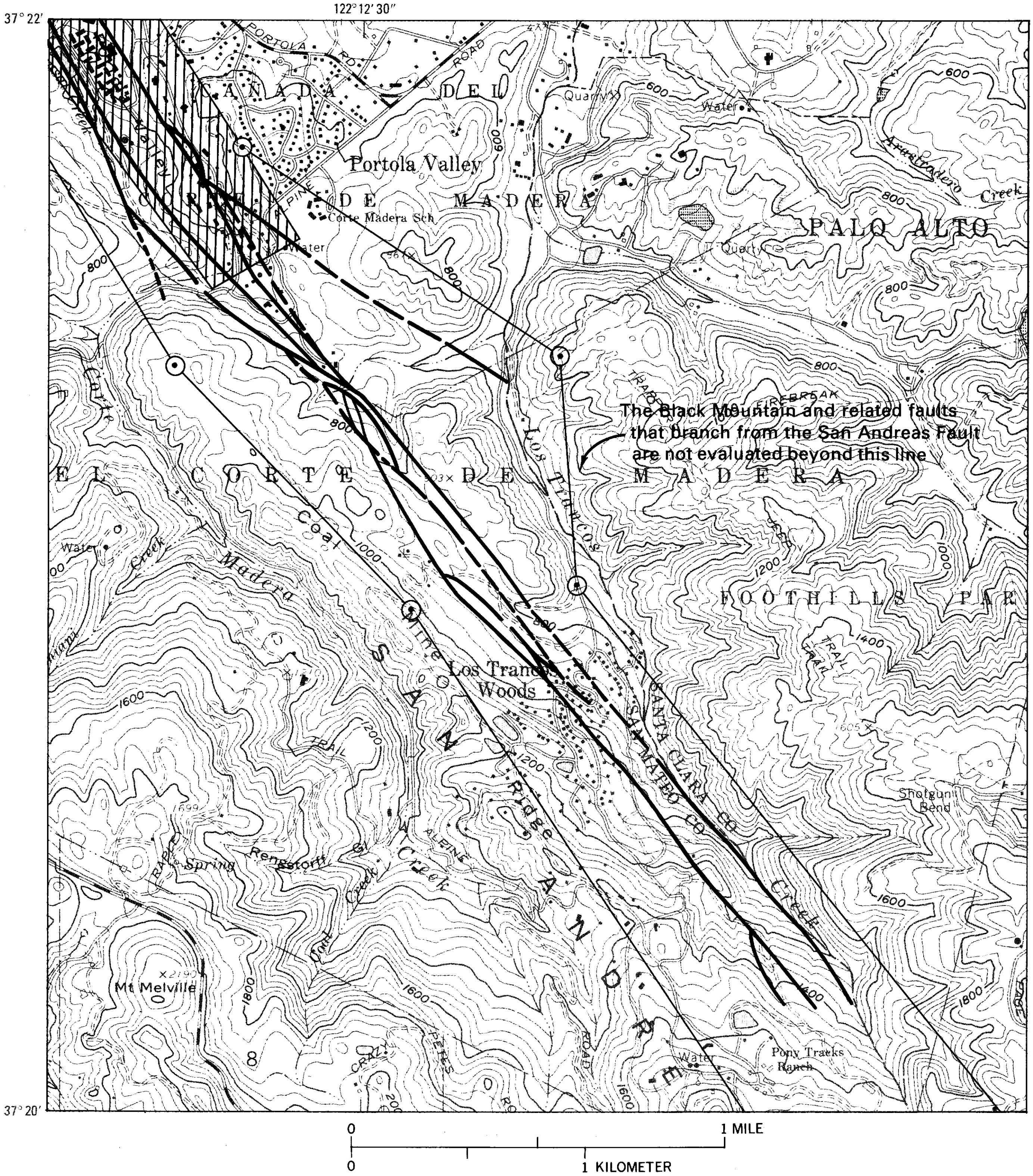


FIGURE 32.—Part of the Mindego Hill quadrangle, originally mapped at a scale of 1:24,000 (1 in. = 2,000 ft) by the California Division of Mines and Geology (1974), showing a Special Studies Zone along a section of the San Andreas fault. Faults are indicated by a solid line where accurately located, by a long dash where approximately located, by a short dash where inferred, and by dots where concealed. The map also shows zone boundaries with turning points. Part of the shaded area is shown in figure 33 at a large scale. As of January 1, 1982, Special Studies Zones affect 25 counties and more than 70 cities in California. Reproducible masters have been provided for each city and county.

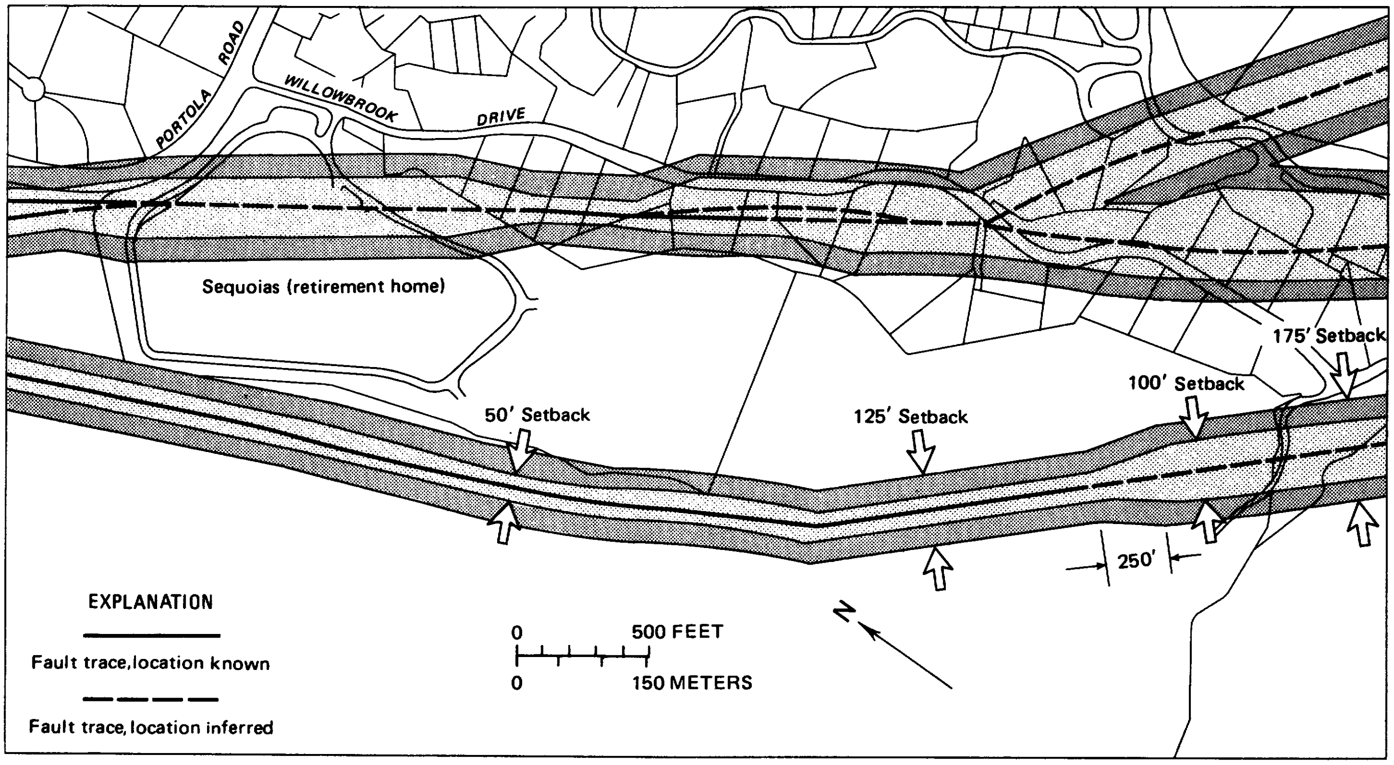


FIGURE 33.—Example of minimum easements required for building setbacks from active fault traces, as mandated by the Portola Valley Town Council (1973). All new building construction is prohibited within the 100-ft-wide lightly shaded zone (50 ft on each side of the accurately located section of the San Andreas fault); structures housing more than a single family are required to be 125 ft from the fault trace (dark shading). Where the location of the fault trace is less well known, more conservative setbacks of 100 ft for single-family residences and of 175 ft for structures with larger occupancies are required (modified from Mader and others, 1972, fig. 5).

COMMENTS

This example illustrates how geologic and seismic information is used by State legislators, State geologists, city and county officials, and consulting geologists to avoid fault-rupture areas throughout California. The act's provisions, the board's criteria, and local ordinances deter the placement of public and private buildings over faults that may creep, or move suddenly during a major earthquake. This method of providing for public safety can be adapted to other types of potential ground failures, including landslides and liquefaction, and to other States where similar hazards exist and where adequate scientific information can be obtained.

Example 2. A nine-county metropolitan area

IDENTIFYING POTENTIAL WASTE-DISPOSAL SITES

According to the Association of Bay Area Governments (ABAG) (1978b, p. V-17), about 11.5 million tons of solid waste was produced in the San Francisco Bay region in 1975, of which about 820,000 tons was hazardous industrial waste. According to Perkins and others (1977), these figures will probably increase by about 5 percent annually, and existing techniques of landfill and waste disposal may be the only effective methods of dealing with the problem.

Many wastes are long lived and chemically complex and, when mixed, may form new compounds whose effects on health are largely unknown. Ground water contaminated by such wastes may remain in an unusable or hazardous condition for decades or even centuries. Pettyjohn (1979) reported that such contamination has occurred at Keizer, Oreg., Niagara Falls, N.Y., Barstow, Calif., Bellevue, Ohio, and in many other areas. Waste-disposal impacts on the San Francisco Bay have been discussed by Russell and others, Luoma and Cloern, and Hall (in Kockelman and others, 1982, p. 127-162).

The four most common types of solid-waste disposal—open dumps, sanitary landfills, incineration, and onsite storage—carry an inherent potential for pollution. Seepage of rainwater through the wastes leaches out constituents that can reach the ground water; this leachate is generally contaminated both biologically and chemically. The extent of pollution from the leachate depends on the hydrogeology of the disposal site. The possibility of pollution is greatest where waste-disposal sites are located in flood-prone areas, near fault traces, in landslide areas, on permeable soil and rocks, on steep slopes, in areas of high precipitation, in areas where the water table is high, or in recharge areas.

INFORMATION AVAILABLE

Most of the basic information needed to make wise decisions concerning safe locations for waste-disposal sites in the bay region is currently available—information on flood-prone areas, geology, relative intensities of ground shaking, surface traces of faults, landslide deposits, areas susceptible to landsliding, slopes, annual precipitation, maximum probable well yield, areas with high water table, and historical marshlands.

Sources of pollution, critical resources, critical geologic and hydrologic conditions, and suitability ratings for the various types of waste-disposal sites were discussed by Hines (1973). The development costs associated with geologic and hydrologic constraints and resources for several land uses were demonstrated in a quantitative land-capability analysis by Laird and others (1979).

A wide range of hydrologic and geologic information is needed to identify safe waste-disposal sites. Although large-scale and detailed information is necessary for identifying specific sites, smaller scale and less detailed information, if accurate and clear, can help identify acceptable areas. The use of a wide range of information requires the selection and systematic application of specific criteria relating to surface- and ground-water quality. These criteria and their application can assist decisionmakers in understanding and using the results to identify and regulate specific sites.

DECISION

Hazardous-waste management was identified as a regional concern in seven of the nine bay-area county plans and by the nine-county group charged with solid-waste-plan coordination (Perkins and others, 1977). Because of this concern, ABAG identified potential Class I sites (Perkins, 1978) as part of a regional solid-waste-management plan. Class I sites are disposal areas for such hazardous wastes as toxic chemicals, soluble industrial wastes, saline brines, and unquenched incineration ashes. The California

Hazardous Waste Control Law (California Legislature, 1978a) defines "hazardous waste" as:

> * * * a waste, or combination of wastes, which because of its quantity, concentration, or physical, chemical, or infectious characteristics may either: (a) Cause, or significantly contribute to, an increase in mortality or an increase in serious irreversible, or incapacitating reversible, illness. (b) Pose a substantial present or potential hazard to human health or environment when improperly treated, stored, transported, disposed of, or otherwise managed.

The ABAG study identifies areas that warrant further study for use as disposal sites for toxic and hazardous wastes, and recommends that these disposal sites and facilities be located so as not to adversely affect human health and safety, air and water quality, wildlife, critical environmental resources, and urbanized areas (Perkins and others, 1977).

APPLICATION

The hydrogeologic criteria used by ABAG for evaluating waste-disposal sites have been adapted from those of the California Water Resources Control Board (1976) and those suggested by Hines (1973). The board also requires all Class I sites to have a natural barrier to prevent downward movement of the wastes to usable ground water. Sites that may be subject to inundation, washout, faulting, liquefaction, landsliding, or accelerated erosion are not acceptable. The criteria used by ABAG have been divided into the three groups listed in table 6.

TABLE 6.—*List of criteria used to select Class I waste-disposal sites*

[Modified from Perkins (1978, table 2). The factors have been divided into three classes: Strict, graded, and acceptability. The strict factors eliminate those areas that are hydrologically and geologically unsuitable for sites; the graded factors identify the remaining areas as most likely, moderately likely, or unlikely to be found suitable; and the acceptability factors attempt to identify site limitations that are unrelated to hydrology or geology, or those that require onsite investigation]

Factors	Source
Strict	
Out of flood-prone areas	Areas on 100-year flood plains (Limerinos and others, 1973).
Not in areas that average more than 30-in. of rain.	Areas within 30-in. isohyet (Rantz, 1971).
Not in active earthquake area	Areas within 0.2 km of a fault capable of producing ground shaking (Association of Bay Area Governments, 1978a).
Not on unconsolidated materials	Areas shown as Quaternary or Quaternary/Tertiary on maps by Schlocker (1970) and California Division of Mines and Geology.
Not on unstable materials or on slopes greater than 15 percent.	Areas shown as categories 1 or 2 on map by Nilsen and others (1979).
Graded	
Amount of precipitation	Assign "3" to 0 to 20 in. and "2" to 20 to 30 in., as shown on map by Rantz (1971).
Yield from wells	Assign "3" to category A, "1" to category B, and "0" to categories C and D, as shown on map by Webster (1972).
Rock types	Assign "1" to the Franciscan Complex and granitic rocks, and "3" to other Tertiary or older rocks, as shown on maps by Schlocker (1970) (1970) and California Division of Mines and Geology.
Soil permeability	Assign "3" to extremely impermeable soils, "2" to very impermeable soils, "1" to moderately permeable soils, and "0" to permeable soils, as shown on U.S. Soil Conservation Service map of soil associations.
Relative slope stability and soil erosion.	Assign "3" to category 1 and "1" to category 2, as shown on map by Nilsen and others (1979).
Acceptability	
Not in or adjacent to developed areas or areas with development potential.	Developed lands and lands with development potential, as shown on ABAG's Local Policy Survey Summary Map.
Not publicly owned for parks, recreation, and so on.	Road maps (various scales); local plans when applicable.
Not in ecologically sensitive areas.	USGS topographic quadrangles (scale, 1:24,000) and ABAG's Areas of Critical Environmental Concern (Association of Bay Area Governments, 1976).
Not affecting significant agricultural crops.	No available maps; general information from ABAG's San Mateo Coast Corridor Evaluation (Association of Bay Area Governments, 1975) and Areas of Critical Environmental Concern (Association of Bay Area Governments, 1976).
Reasonably accessible by truck	Road maps (various scales) and ABAG base map.
Acceptable to the public and the Government (to the extent possible before public workshops).	Based on discussions with selected county staff.
Located on shale or sandstone, not on highly sheared materials.	Various geologic maps.
Away from waters used for drinking or recreation.	ABAG base map.

Map information from the sources listed in table 6 was digitized and converted into grid cells (¼ km^2, or approx 62 acres) to create eight computer files. These computer files were then combined so that a shaded map including both the "strict" and "graded" factors could be drawn by the printer-plotter (fig. 34). Cells with similar characteristics in each county were grouped, and the "acceptability" factors manually applied (table 7). As a result, several cells located in several counties were identified as possibly acceptable for use as Class I waste-disposal sites (fig. 35). More than 350 mi^2 of the San Francisco Bay region meets the strict hydrologic and geologic factors. Of this area, more than 85 mi^2 is only marginally acceptable, and more than 54 mi^2 possibly acceptable. The other areas are in or near urbanized areas, or fail to meet one or more of the other "acceptability" factors. The general areas shown in figure 35 as possibly acceptable would be the focus of any site investigation (Perkins, 1978).

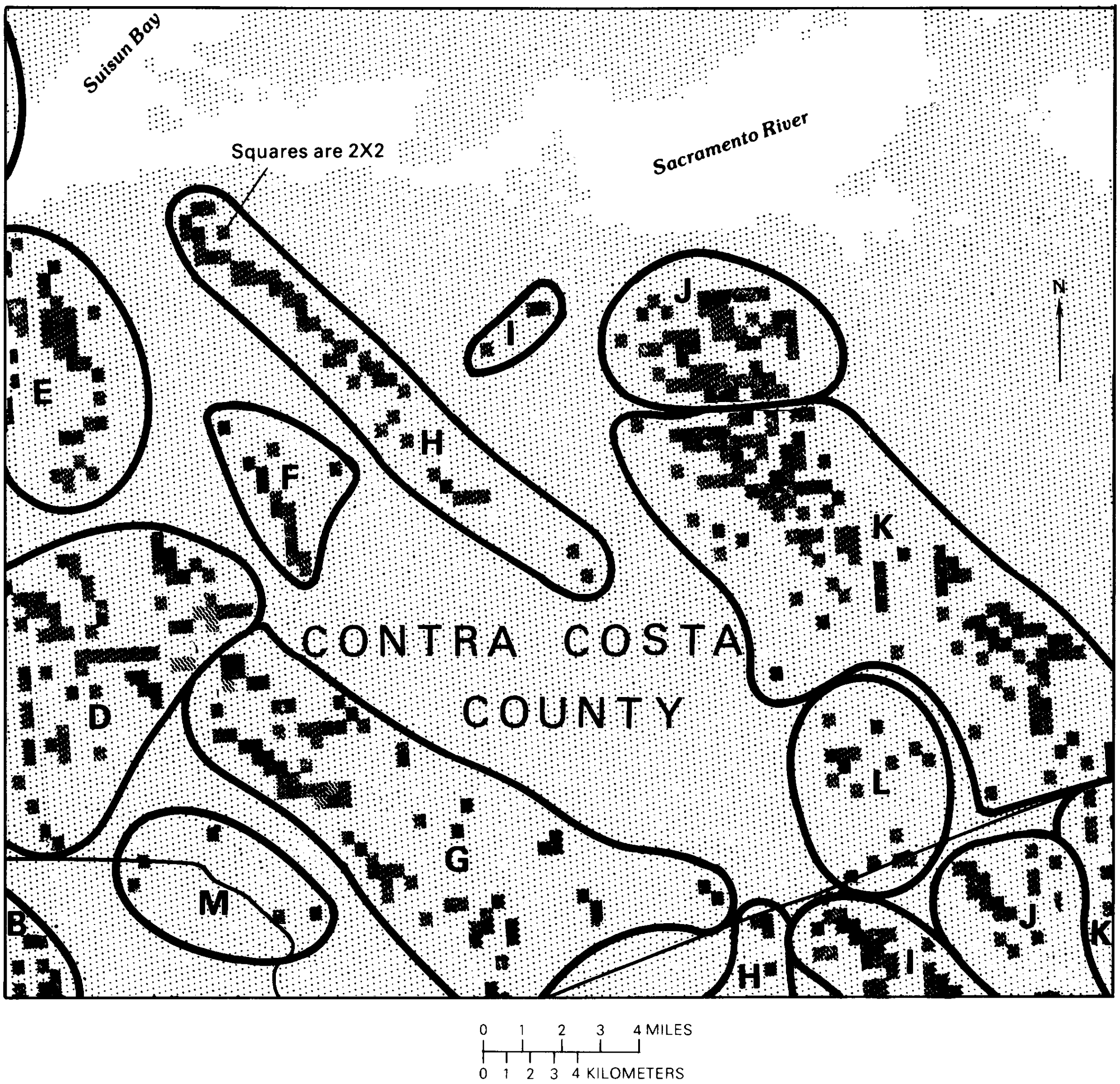


FIGURE 34.—Part of a map from Perkins (1978) produced by a printer-plotter after a minicomputer was used to combine individual digitized maps and apply strict and graded factors. Shaded grid cells indicate areas that meet strict and graded factors (table 6) for waste-disposal sites. Letters designate areas (table 7) having similar social and environmental characteristics to which the acceptability factors were applied manually.

COMMENTS

This example shows how a wide range of hydrologic and geologic information, as well as physical, social, and political data, can be digitized and evaluated together through the use of a computer. The study, by a nine-county regional planning agency, covered a 7,000-mi^2 area. Selection of future sites for the disposal of hazardous wastes on the basis of the study's criteria will substantially reduce the likelihood of adverse effects on surface- and ground-water supplies.

These criteria and this method of protecting water quality (and public health) also can be adapted where similar wastes must be disposed of on land and where adequate hydrologic and geologic information is available. The value to other counties and regions is increased because the California Legislature (1972b) requires solid-waste management plans, and section 208 of the Federal Water Pollution Control Act (U.S. Congress, 1977) requires waste-treatment-management plans.

TABLE 7.—*Application of waste-disposal-site factors to several areas in Contra Costa County*

[From Perkins (1978, app. B). Codes refer to some of the circled areas in figure 34. Acceptability tables for each designated area in each county within the San Francisco Bay region are available from: Association of Bay Area Governments, Hotel Claremont, Berkeley, CA 94705]

Code	Size (cells)	Location	Present use (cells)	Adjacent uses(s)	Transportation access	Geologic materials	Nearest surface water	Other issues	Overall areal acceptability
F	15	Lime Ridge and Concord Hills.	Undeveloped (15).	Urban, undeveloped, and open space.	Interstate Highway 680; Ygnacio Valley Road through residential areas.	Cretaceous and Tertiary sandstone and shale.	Drainage through Walnut Creek and Concord to Carquinez Straits.	Probably not politically acceptable; one cell is scattered.	Probably unacceptable for all but one scattered cell that is unacceptable.
G	77	East of San Ramon Valley.	Undeveloped (77).	Urban and undeveloped, grazing.	Interstate Highway 680; poor to outlying areas.	Cretaceous and Tertiary sandstone and shale, largely unconsolidated.	Drainage to San Ramon Creek.	....	Probably unacceptable for all but five scattered cells that are unacceptable.
I	3	Hills south of Pittsburg.	Development potential (1), undeveloped (2), grazing.	Urban and undeveloped.	State Highway 4; Buchanan and Kirker Pass Roads.	Cretaceous and Tertiary sandstone and shale.	Drainage through Pittsburg; Kirker Creek to delta.	Scattered cells.	Unacceptable.
J	56	Northern Central Valley foothills.	Urban (1), development potential (28), undeveloped (27).	Urban and undeveloped, grazing and crop rows.	State Highways 4 and 160.	Tertiary sandstone and shale.	Drainage through Contra Costa; Sand and Marsh Creeks to Suisun Marsh.	....	Probably unacceptable for undeveloped cells.
K	127	Southern Central Valley foothills.	Undeveloped (127).	Undeveloped, grazing and crop rows.	State Highway 4 and Byron Highway; to outlying areas.	Cretaceous and Tertiary sandstone and shale.	Drainage through Marsh and Kellogg Creeks to San Joaquin River.	....	Possibly acceptable.
L	16	North of Altamont Pass.	Undeveloped (16).	Undeveloped, grazing.	State Highway 4 and Vasco Road; poor to outlying areas.	Largely Cretaceous sandstone and shale.	Drainage through Kellogg Creek to San Joaquin River.	....	Do.

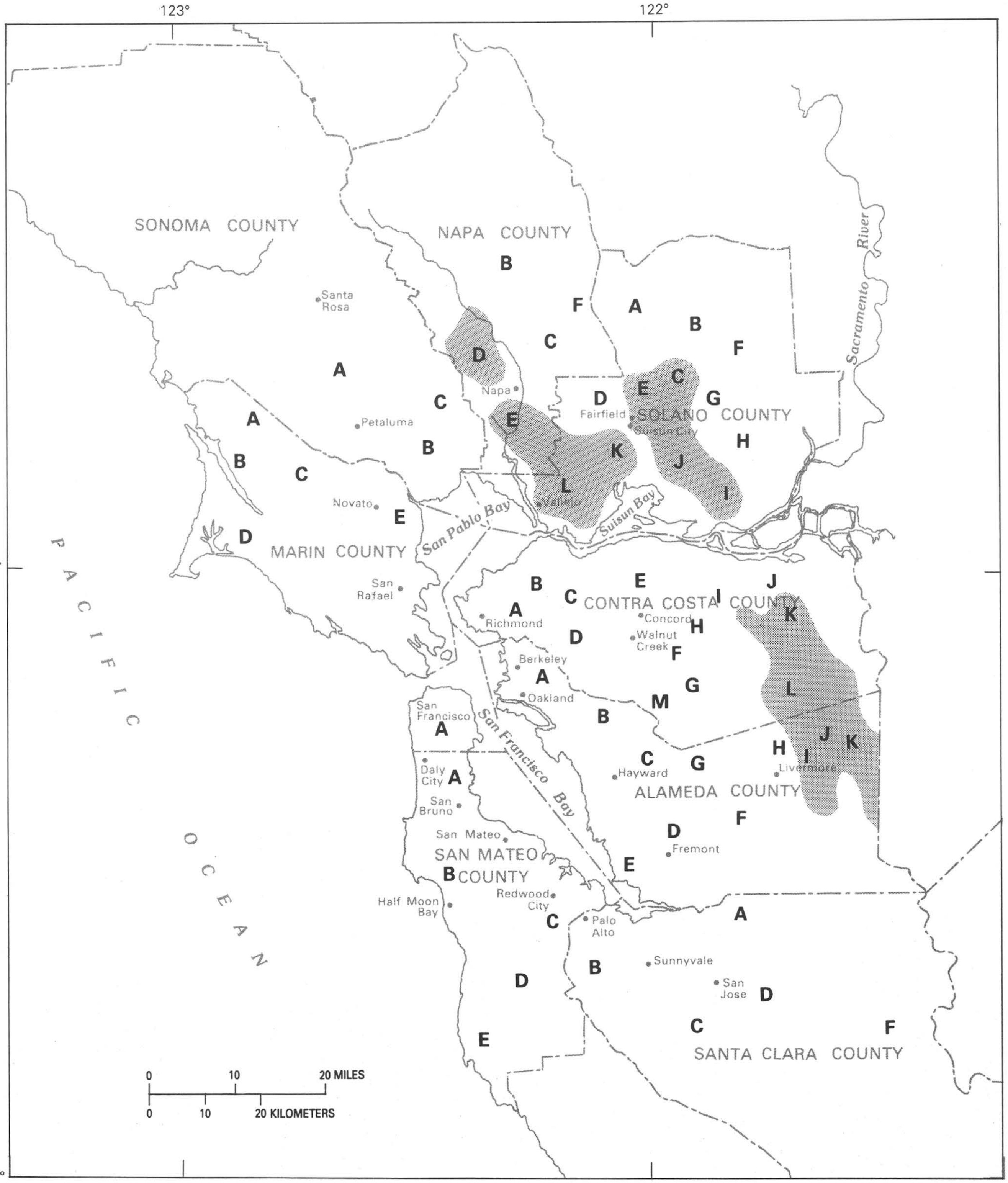


FIGURE 35.—Part of an index map from Perkins (1978, pl. 1) showing areas (letters) evaluated in the acceptability tables (table 7) and areas (shaded) found to be possibly acceptable for hazardous-waste disposal (Class I sites). The possibly acceptable areas in Alameda County are in the vicinity of Altamont Pass; those in Contra Costa County are in the eastern part of the county on the edge of the Central Valley; those in Napa County border the hills in the southern part of the county; and those in Solano County are in the hills south of Vacaville, in the hills northwest of Fairfield, in the western Montezuma Hills, in the hills near Suisun and Denverton, and in the hills north of Benicia and Vallejo.

Example 3. A bay-and-shoreline district

PROTECTING AN AQUATIC AND WILDLIFE HABITAT

The Suisun Marsh (fig. 36), the largest remaining wetland area near San Francisco, encompasses approximately 85,000 acres of tidal marsh, managed wetland, and waterways—more than 10 percent of California's remaining wetlands. It is a wildlife habitat of international as well as national importance and provides an important resting place for waterfowl on the Pacific flyway from Canada to Mexico.

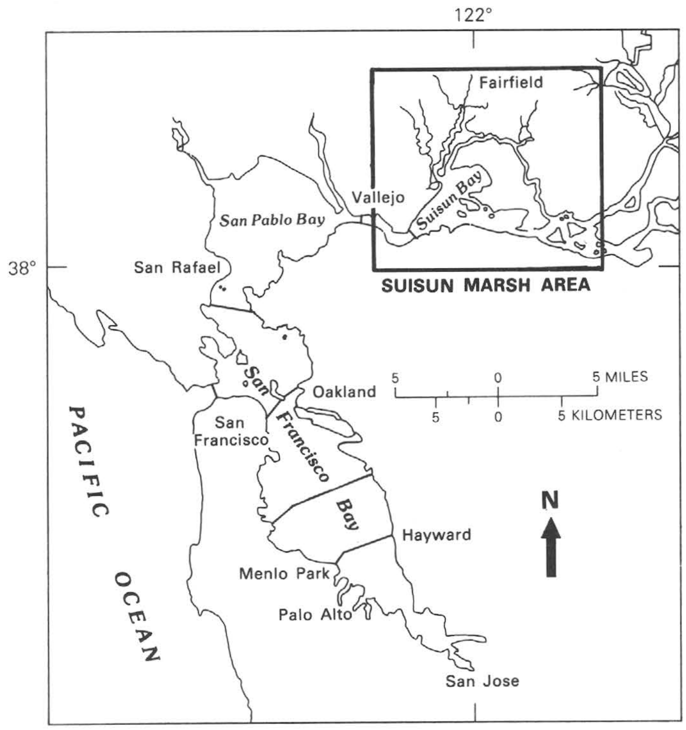


FIGURE 36.—The San Francisco Bay Conservation and Development Commission has jurisdiction over the San Francisco Bay system, including San Pablo Bay and Suisun Bay; all sloughs, marshlands, tidelands, and submerged lands; a 100-ft-wide shoreline strip inland from the bay system; diked saltponds; managed wetlands; and certain tributary waterways.

INFORMATION AVAILABLE

Most of the Earth-science information necessary for preparing and implementing a protection plan for the Suisun Marsh is currently available, much of it at relatively large scales (1:24,000 [1 in. = 2,000 ft]). This information includes topography, the distribution of—and potential for—landslides, the locations of active faults, the extent of historical marshlands, and data on land use, flooding, and slope. The geologic and seismic history, physical and engineering properties, development problems, and general land-use capabilities of bay mud were discussed in the reports on flatland deposits by Helley and others (1979), on flood-prone areas by Waananen and others (1977), and on relative slope stability by Nilsen and others (1979).

Aquatic and wildlife habitats can be preserved and enlarged by acquiring marshlands, regulating the surrounding uplands, and proper management. Information regarding the location and character of the marshlands, geologic hazards, existing land uses, and natural resources is necessary to secure public and legislative support before preparing a protection plan. Furthermore, accurate, clear, and large-scale maps showing the boundaries of the lands to be acquired or regulated are prerequisite to effective and legal implementation of such a plan.

DECISION

The California Legislature in 1974 required the San Francisco Bay Conservation and Development Commission (BCDC) to submit a protection plan for the Suisun Marsh to the Governor and the California Legislature (1974). In response, the BCDC (San Francisco Bay Conservation and Development Commission, 1976) prepared a proposal for the preservation and enhancement of the large aquatic and wildlife habitat, entitled the Suisun Marsh Protection Plan (figs. 37, 38). This plan calls for the creation of a primary management area that

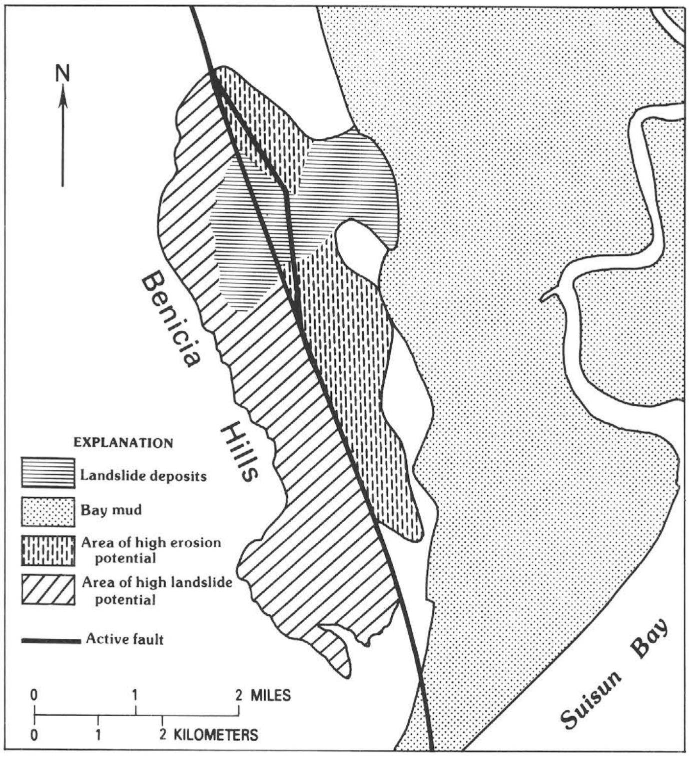


FIGURE 37.—Part of the Natural Factors Map used in preparing the Suisun Marsh Protection Plan. The San Francisco Bay Conservation and Development Commission (1976) derived the locations of the primary and secondary management areas (shown in part in fig. 38) from the natural factors indicated here.

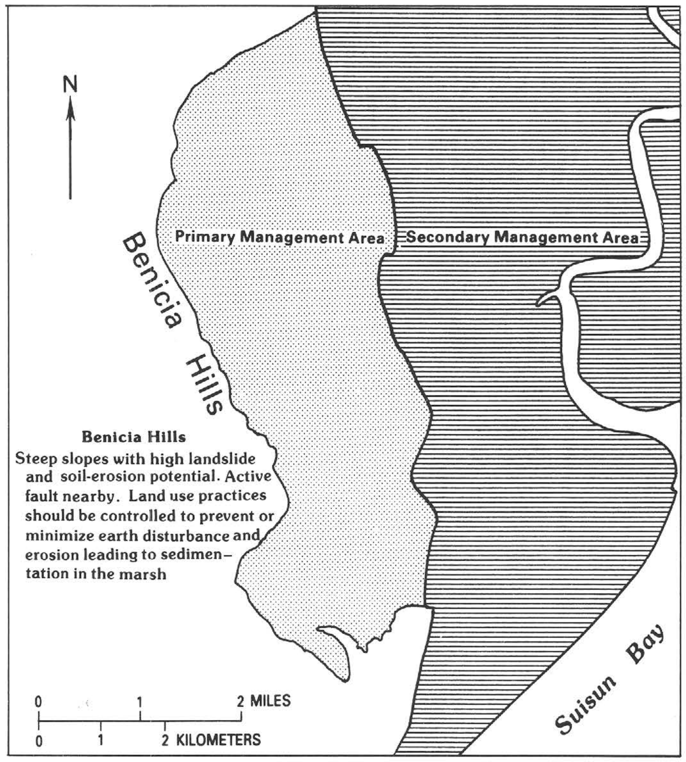


FIGURE 38.—Part of the Suisun Marsh Protection Plan map prepared by the San Francisco Bay Conservation and Development Commission (1976), showing parts of the management areas.

encompasses 89,000 acres within which existing uses—generally duck hunting, limited grain production, and cattle grazing—will continue. The BCDC has the major regulatory responsibility in the primary management area. To insulate this primary management area from incompatible upland land uses and agriculture, the plan also calls for the creation of a secondary management area encompassing 22,500 acres surrounding the primary management area and consisting of upland grasslands and cultivated land. In this area, where the major regulatory responsibility rests with local government, such existing agricultural uses as grain production and grazing also would continue.

The plan includes a statement of the policies designed to preserve and enhance the quality and diversity of the marsh's aquatic and wildlife habitat and to ensure that upland areas adjacent to the marsh will be retained in uses compatible with its protection. Specific findings and recommendations concerning marsh environment, water supply and quality, natural-gas resources, utilities, transportation, recreation, public access, industry, land use, assessment practices, marsh acquisition, and marsh management are included in the plan.

The San Francisco Bay segment of the coastal zone, including the Suisun Marsh, was placed under BCDC jurisdiction by the California Legislature (1977, sec. 29205). The BCDC management program for the bay system (San Francisco Bay Conservation and Development Commission, 1969), including the marsh-protection plan, was approved by the U.S. Secretary of Commerce in February 1977, pursuant to the Federal Coastal Zone Management Act (U.S. Congress, 1972).

APPLICATION

Information on landslide deposits, historical marshlands, landslide susceptibility, land use, flood-prone areas, steep slopes, and active faults was obtained from published and unpublished sources, transferred to regional topographic workmaps, and then summarized on a Natural Factors Map (fig. 37). From this map, the marsh-protection-plan map (fig. 38) was prepared. Recommendations for land-use practices in the Benicia Hills are also based on Earth-science information, as were some of the legal boundaries and areas of jurisdiction (fig. 36) for the BCDC's planning and regulatory functions (Kockelman, 1979, p. 102).

The California Legislature (1977) declared the Suisun Marsh a unique and irreplaceable resource, approved most of the marsh-protection-plan recommendations, provided for implementation of the plan, and assigned to the BCDC the primary State responsibility for carrying out the plan. The implementation process includes: (1) Requiring local governments—Solano County, the cities of Benicia, Fairfield, and Suisun City, and special districts—to develop a local protection program and controls consistent with the plan; (2) acquiring lands for public use or resource management through the California Wildlife Conservation Board; (3) regulating development within the primary management area through permits issued by the BCDC; (4) regulating development within the secondary management area through permits issued by the local governments; (5) managing fish and wildlife through the California Department of Fish and Game; (6) creating the Suisun Resource Conservation District, and requiring it to regulate and improve water-management practices on privately owned lands; (7) requiring preferential tax-assessment practices; (8) providing for cease-and-desist orders; and (9) appealing the issuance of marsh-development permits by local governments to the BCDC.

The development to be regulated in both the primary and secondary management areas includes: Placement of any material or erection of any structure, discharge or disposal of any material, grading or removal of any material, change in the density or intensity of land use, land division, alteration or demolition of any structure, and removal or harvesting of vegetation other than for agricultural purposes.

A detailed map, prepared by the BCDC at a scale of 1:24,000 (1 in. = 2,000 ft), shows both the primary and secondary management areas. Guidelines (San Francisco Bay Conservation and Development Commission, 1978) define the local protection program that the county, cities, and special districts are preparing for commission review and certification.

About $4 million was made available to the California Wildlife Conservation Board for acquiring and improving lands in the marsh. Almost 1,400 acres has already been acquired, and additional acreage is being considered for acquisition.

The BCDC has authority to grant, deny, or grant subject to conditions, permits to place fill, extract materials, or make any substantial change in the use of any water, land, or structure within its area of jurisdiction (California Legislature, 1965, sec. 66632). Pursuant to this authority, the BCDC has adopted an application and permit system and has prescribed the content and the procedures required for obtaining permits. It has integrated the marsh-development-permit system (a system which required that any proposed development be consistent with the BCDC's plan or local protection programs) into the existing bay-development-permit system. Under its enforcement powers, the BCDC monitors development in its area of jurisdiction (fig. 36) and has issued orders to cease and desist filling and other work in the marsh area. In addition, it reviews and comments on environmental-impact reports for actions affecting the marsh and has filed lawsuits where reports were believed to be inadequate.

COMMENTS

This example shows how both basic and interpretative scientific information can be employed to protect an irreplaceable aquatic and wildlife habitat encompassing an area of more than 110,000 acres. The combination of regulations, land acquisition, local controls, fish and wildlife management, water management, and preferential tax assessments has preserved specific resources.

Scientific information can be applied similarly to resource-protection planning and plan implementation in other estuarine environments, including those in the coastal areas of the United States affected by the Federal Coastal Zone Management Act (U.S. Congress, 1972).

Example 4. A 1,312-mi^2 county

REQUIRING SITE INVESTIGATIONS IN HAZARDOUS AREAS

Santa Clara County is subject to numerous earthquake hazards, including ground displacement, landslides, liquefaction of bay mud and other materials, and flooding (fig. 39). The county is traversed by several major active faults, and it has been shaken by many earthquakes, some of which caused severe damage.

Santa Clara County has more than 1¼ million people and is one of the fastest growing counties in the United States. Some urban development, involving major gas and electric lines, transportation facilities, major water conduits, and some emergency-service facilities, has taken place in areas now known to be geologically hazardous (figs. 40, 41). However, the county is still predominately rural, and most of the potentially hazardous areas are undeveloped.

In many parts of the county, landslides are caused by such factors as weak rock or soil conditions, high moisture content, and steep slopes (fig. 39). Landslides also commonly accompany earthquakes, as occurred during the great 1906 San Francisco earthquake. In addition, slides are triggered by such human activities as steepening of slopes, removal of vegetation and downslope support, increase of upslope weight, disruption of surface drainage, and addition of fluids by watering of lawns and discharge of septic tanks. Landslides have made it necessary for the county to relocate roads, repair houses and lots, replace utility services, remove reservoir sediment, and lower property assessments (Taylor and Brabb, 1972).

Natural and filled marshlands in Santa Clara County are underlain by soft bay mud that in places contains water-saturated fine silt and sand (fig. 39). The areas of clay-free alluvium below the water table are subject to seismically induced ground failure by liquefaction, lurching, lateral spreading, or differential settlement. In 1906, such ground failures were observed to result in displacements of more than 6 ft, with cracks as much as 5 ft wide, 6 ft deep, and 100 ft long (Youd and Hoose, 1978, p. 114).

In addition, if the dike system that borders the bay were to fail during strong earthquake shaking, storm waves, high tides, and, possibly seismic seawaves could cause extensive saltwater flooding. The area inundated would depend on the tidal level.

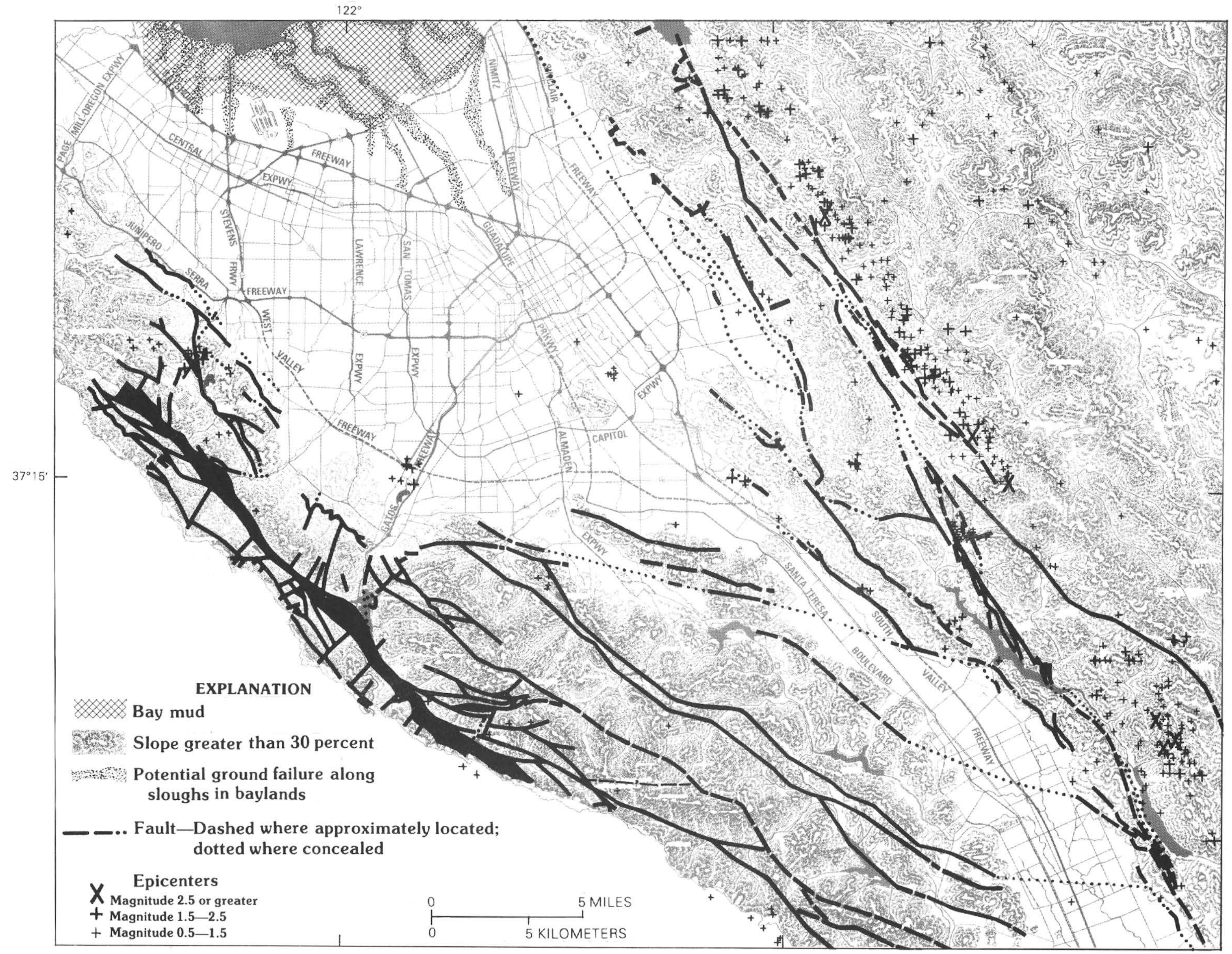


FIGURE 39.—Part of a map showing some of the earthquake hazards in Santa Clara County. The map was prepared and used by the Santa Clara County Planning Department (1973) for public-information purposes. Preparation and distribution of the map took place before adoption of the county's seismic safety plan and ordinance enforcing onsite geologic investigations. Its wide distribution made the general public more aware of earthquake hazards and partly contributed to the unanimous adoption of both the plan and ordinance (Eleanor Young, former senior planner, Santa Clara County Planning Department, oral commun., Oct. 3, 1979).

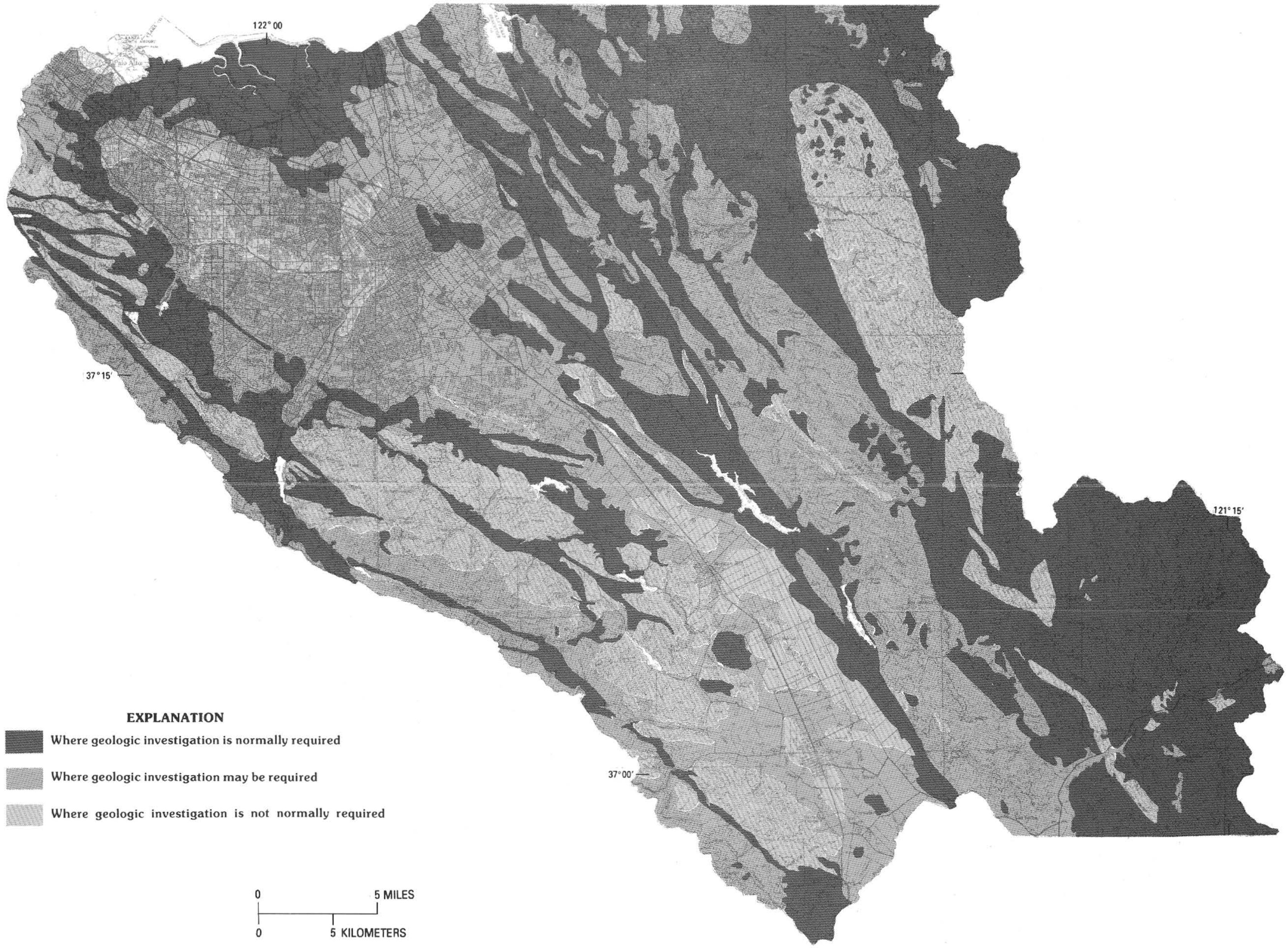


FIGURE 40.—Part of the San Clara County Relative Seismic Stability Map prepared by the Williams and Rogers (1974) and revised by the county in 1978. Shaded patterns indicate degrees of hazards and areas in which site investigations may be required. Larger scale maps of the county showing hazard areas and property boundaries are also available (see fig. 41).

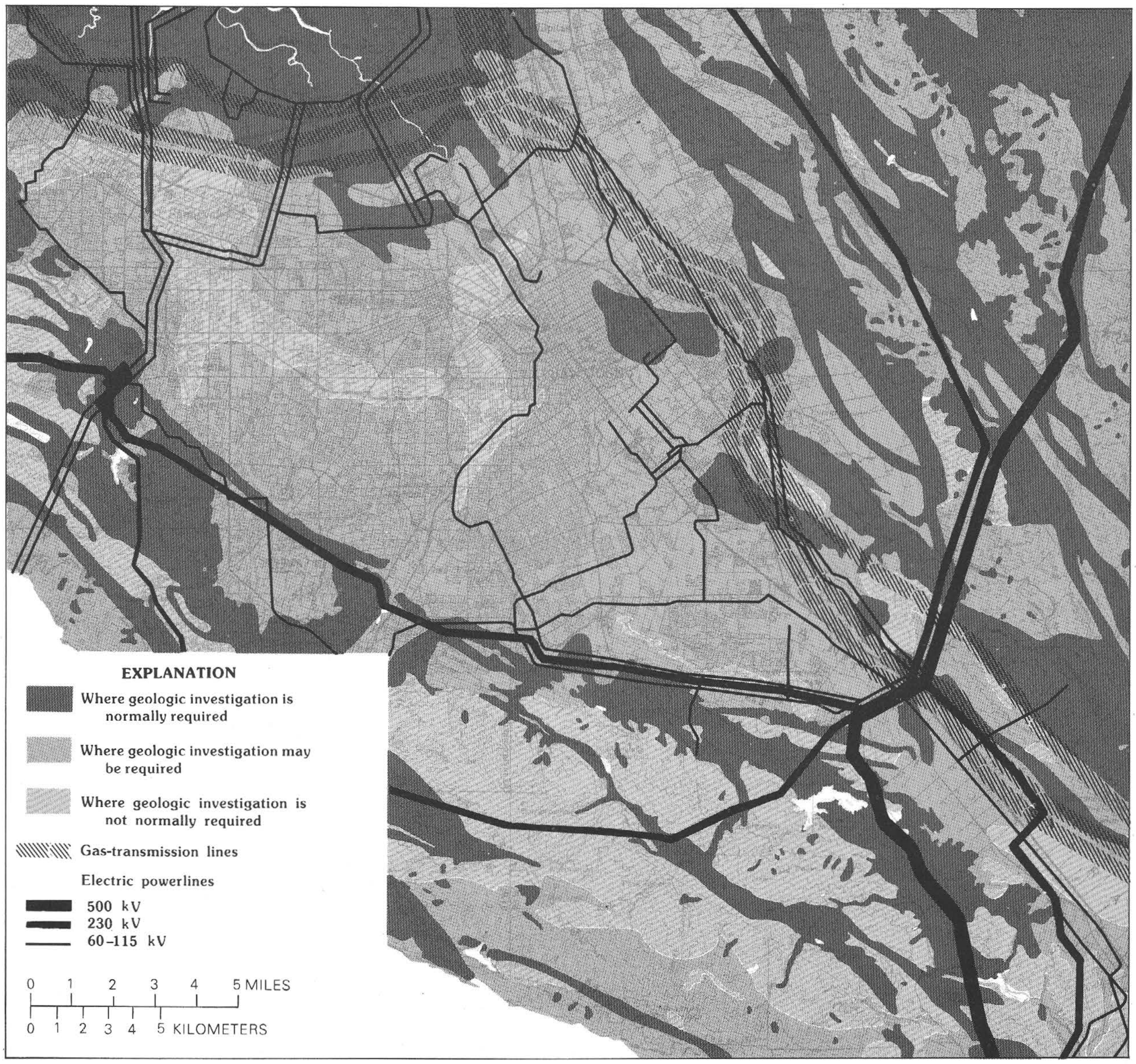


FIGURE 41.—Part of a map prepared by the Santa Clara County Planning Department (1975), showing major gas and electric lines located in potentially hazardous areas. The Planning Department observes that the capability of such lines to withstand ground failures caused by earthquakes needs to be evaluated. Similar maps show freeways, railroads, bridges, hospitals, and fire stations located in potentially hazardous areas. Repair or replacement of some of these facilities is recommended by the planning department only if the hazards can be reduced.

INFORMATION AVAILABLE

Most of the seismic, geologic, and other information that is needed in preparing safety plans for counties in the San Francisco Bay region is currently available—topographic maps, land-use maps, and maps showing the locations of active fault breaks, landslide deposits and susceptibility, historical marshlands, liquefaction potential, relative intensities of ground shaking, geology, and steepness of slopes. Some of this information is available at a scale of 1:24,000 (1 in. = 2,000 ft).

The geologic and seismic histories, physical and engineering properties, development problems, and general land-use capabilities of areas involving bay mud, landslides, and active faults were discussed in the reports on seismic zonation edited by Borcherdt (1975), on relative slope stability by Nilsen and others (1979), on flatlands by Helley and others (1979), and on hillsides by Wentworth and others (1983). This information, however, is not commonly available at the scale or degree of detail needed for the administration of local land-development ordinances that would affect individual building sites. Detailed information, ordinarily at scales of 1:2,400 to 1:6,000 (1 in. = 200-500 ft), must be gathered for individual sites as part of carefully designed geologic investigations.

Large-scale hazard maps of the entire community, at a scale of 1:24,000 (1 in. = 2,000 ft), are a prerequisite to requiring site investigations. More detailed maps, at scales of 1:6,000 to 1:12,000 (1 in. = 500-1,000 ft), that show hazards related to property boundaries are desirable. Once the site investigation and geologic report are completed, development can be guided to safe, stable parts of the site, or remedial measures can be required. All such maps should be readable and readily available to land developers, homebuilders, real-estate salespersons, appraisers, assessors, lot purchasers, lending institutions, and insurance companies.

DECISION

In compliance with the State law requiring all cities and counties to prepare and adopt a seismic-safety element as part of their general plan for physical development (California Legislature, 1978b, sec. 65302(f)), the Santa Clara County Planning Department (1975) prepared such a plan. This plan includes two major recommendations to the county: Retain the services of an engineering geologist, and require onsite geologic investigations before construction.

The County Planning Department combined all the potential earthquake hazards—liquefaction, lurching, lateral spreading, differential settlement, ground displacement, landslides, and flooding due to dike failure—on a seismic-stability map. Three zones, shown in red, yellow, and green on the map, were then delineated to indicate three different degrees of need for detailed site investigations, as determined by the level of hazards (fig. 40). Large-scale maps (fig. 42) show potential hazards in relation to property boundaries.

The seismic-safety plan, unanimously adopted by the County Planning Commission and Board of Supervisors, is now implemented under the county geologic ordinance (Santa Clara County Board of Supervisors, 1978). This ordinance affects the county's other land-development ordinances—building, subdivision, grading, and zoning. The ordinance cites the seismic-stability map as one of the county's official hazard maps and includes the statement "Development within a known geologic hazard area will be discouraged."

APPLICATION

Existing land uses, such as urban development and major gas and electric lines, were superimposed on the seismic-stability map (fig. 41). Citizens, planners, and decisionmakers are

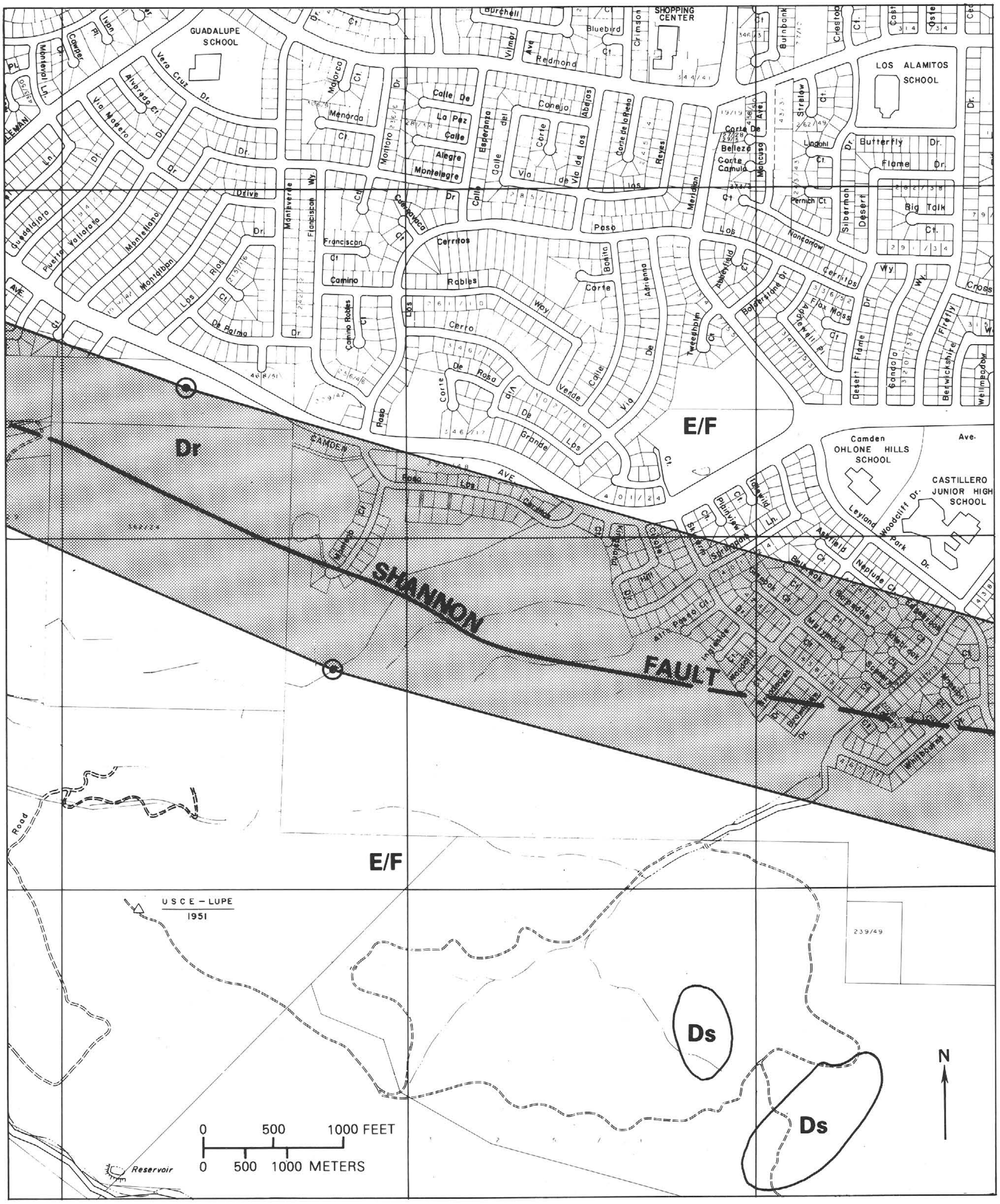


FIGURE 42.—Part of one of Santa Clara County's cadastral (property boundary) maps, showing geologic hazards. Shaded area indicates a zone where site investigations are required because of an active or potentially active fault. Letters indicate specific hazards that need to be investigated and evaluated: Dr, area of high potential for ground displacement; Ds, area of high potential for earthquake-induced landslides; E/F, areas of low to moderate potential for any geologic hazard. Information on the availability of these maps can be obtained from the Office of the County Geologist, Department of Land Development Engineering and Surveying, County of Santa Clara, 70 West Hedding Street, San Jose, CA 95110.

made aware of potential damage when they can see homes, freeways, railroads, bridges, pipelines, powerlines, hospitals, and fire stations located in the red hazard zones on the map. Recommendations on how to minimize possible losses of life and property are made for each element of the general plan.

The county established a position for a State-certified engineering geologist within its Department of Land Development Engineering and Surveying. He helped prepare the seismic-safety plan and the geologic ordinance, and has major responsibility for administering the ordinance. The seismic-safety plan and seismic-stability map were prepared with the assistance of, or contributions from, consultants and members of the California Division of Mines and Geology, and from many other sources.

The county geologist uses the seismic-stability map, along with other geologic information, when he reviews land-development and land-use proposals to determine whether a site investigation and detailed geologic report should be required. The geologic report, based partly on site investigations, describes the geology of the site and its surroundings, identifies specific problems of the site, and specifies remedial measures necessary to make the proposed development reasonably safe. Review and approval of the geologic report by the county geologist must precede any final action on applications for building sites and mobile homes, final approval of subdivisions, issuance of grading permits, and approval of use permits and rezonings. The geologic report and the county geologist's recommendations serve as the basis for approval or disapproval of specific land-use and land-development proposals or for any special conditions that may be imposed.

If the geologic report indicates unusually severe geologic constraints, development may proceed only after the property owner signs a statement which acknowledges that he or she has been informed of the existence of the specific hazards, accepts the risks, and relieves the county of liability. This statement is recorded in the county recorder's office but may be expunged if subsequent information—approved by the county geologist—indicates that the hazard no longer exists or has been reduced. Generally, however, no new structures for human occupancy can be located on active fault traces or on active landslides that have not been stabilized by acceptable engineering procedures.

The county geologic ordinance provides for a waiver of the site investigation and geologic report in rare situations. This waiver must be signed by the property owner, acknowledged and recorded in the office of the county recorder, and state that the property owner accepts all risks and consequences; the waiver can be expunged upon approval of a favorable geologic report by the county geologist. The ordinance also provides that a seller of real property located within a major hazard zone shall disclose to the buyer— by a written statement—the existence of the geologic risk. These statements, waivers, and acknowledgments serve to inform all parties to a real-estate transaction—the buyer, seller, agents, builder, lender, and insurer, as well as local building and zoning officials—that the property is subject to earthquake hazards.

COMMENTS

This example illustrates how earthquake-hazard information can be used by a county before development to determine where site investigations and detailed geologic reports are necessary. The public understanding and buyer awareness that derive from the county's seismic-safety plan, seismic-stability map, and geologic ordinance will help guide development toward less hazardous areas, encourage remedial measures in other areas, and generally promote reasonably safe development in one of the United States' most populous and seismically active counties.

These methods for avoiding earthquake hazards and reducing potential damage can also be adapted to other natural hazards and to other counties where hazard information is available and where seismic-safety plans are required by the California Legislature (1978b).

Example 5. A city of 55,000 people

SUPPLEMENTING BUILDING STANDARDS ON UNSTABLE BAYLANDS

Recent estuarine deposits, called bay mud, underlie the San Francisco Bay and the present and former tidal marshes. The physical properties of bay mud are described above in the section of this report entitled "The Estuary." These properties, together with the high water table and location at or below mean sea level, result in several potential problems for urban development, such as flooding, ponding, foundation shifting, uneven settlement, liquefaction, and amplification of seismically induced ground shaking (Helley and others, 1979, p. 72). Therefore, retention of the natural estuarine environment—as has been recommended by the BCDC and by several cities—is generally the more economical and practical alternative.

Nonetheless, the levelness of these lands, their proximity to freeways, and their position near a scenic and recreational estuarine environment has resulted in intense development pressures on many of the communities that border the San Francisco Bay. Development proposals include plans for single-family and multifamily dwellings, office buildings, shopping centers, hotels, airport and seaport facilities, industries, and amusement parks. More than 30 cities in the bay region have existing or historical tidal marshes underlain by bay mud within their jurisdiction.

Some bay-region cities have planned and provided for urban development of these lands by dewatering and demulching the bay mud and by reconditioning diked land. For example, more than half of Redwood City (population, about 55,000; located 25 mi south of San Francisco) lies on bay mud. At present, less than 10 percent of the more than 6,000 acres underlain by bay mud is developed. The comprehensive general plan prepared by the Redwood City Planning Department (1975) proposes residential, commercial, institutional, industrial, public-facility, open-space, and unclassified uses for these undeveloped lands. Although the land-use plan being implemented by a recent zoning ordinance (Redwood City Council, 1978) permits urban use in some areas, most of the undeveloped baylands are presently zoned for tidal-plain uses.

Even where dikes and fills reduce the risk from flooding, a major earthquake could cause severe damage to certain types of urban development as a result of liquefaction and subsequent ground failure. Youd and Hoose (1978) reported that ground failures in San Francisco have been limited mainly to areas underlain by filled-over marsh and bay-mud deposits, filled-in ravines, loose-sand deposits, sand dunes, and steep slopes.

The effects of ground shaking are likely to be especially severe in areas underlain by bay mud and alluvium. In historical earthquakes, building damage from liquefaction and ground shaking included failure of foundations or footings, collapse of unreinforced-masonry walls and chimneys, movement of houses off their foundations, and toppling of unanchored machinery, storage tanks, and electrical equipment along with rupture of the lines.

INFORMATION AVAILABLE

Information on the location and general seismic response of bay mud, necessary for supplementing the building standards, is currently available, including information on historical marshlands, liquefaction potential, and the relative intensities of ground shaking. In addition, more detailed maps, at a scale of 1:24,000 (1 in. = 2,000 ft), of the historical marshlands are available at the U.S. Geological Survey Western Region library in Menlo Park.

The responses of bay mud to ground shaking, to ground failure associated with liquefaction, and to the predicted geologic effects of a postulated earthquake were discussed in the report on seismic zonation edited by Borcherdt

(1975). In addition, the geologic and seismic histories, physical and engineering properties, development problems, and general land-use capabilities of bay mud were discussed in the report on flatland deposits by Helley and others (1979), which includes maps of flatland deposits useful to public and private decisionmakers.

Damage due to ground failure can be mitigated by first investigating and then designing for recognized site problems. Properly engineered fills, carefully designed foundations and structures, reinforced masonry, anchored machinery and equipment, and well-supervised construction are some of the supplemental measures that can be incorporated into building regulations to reduce damage from earthquake shaking.

Information as to seismic response, examples of damage to be expected, and the locations of the unstable lands are necessary for public information before the adoption of supplemental building standards. An accurate, clear, and large-scale map showing the boundaries of the unstable lands is essential for effective and legal administration of such standards.

DECISION

To ensure community safety and welfare, the Redwood City Council (1974, 1977a) adopted an ordinance that provides for special seismic requirements relating to design and construction standards. These standards supplement those recommended by the International Conference of Building Officials (1976, secs. 1807(k), 2313, 3704(c)) for structures in seismic zone 4 under the Uniform Building Code—the code adopted by the city as its own building code. The adoption of this ordinance was accompanied by a resolution by the Redwood City Council (1977b) expressly determining the necessity of the additional requirements because

> * * * local seismic and geologic conditions, experience, and comprehensive engineering, geological, seismic and soils analyses have shown that implementation of these detailed requirements in the specified areas can greatly minimize differential settlement of structures and provide increased structural integrity with respect to seismic safety.

This ordinance is consistent with the city's initial Seismic Safety Element (Redwood City Planning Department, 1974), which had placed the bay mud in a moderately high risk zone and recommended that the Uniform Building Code be reviewed and amended as "frequently as may be prudent." The ordinance also follows the recommendations of the Redwood City Seismic Advisory Board (1972) with respect to foundation design, building design, and equipment anchorage.

The ordinance was unanimously adopted and is presently being administered by the city's building department. The supplemental structural-design and construction standards (fig. 43) called for in the ordinance relate to special foundation-design criteria, design provisions for greater lateral force, foundation systems to resist settlement, wood-frame sheathing, moment-resisting frames, response spectrum, reinforced-masonry construction, elements of structural redundancy, and reinforcement of structural members. These standards apply only to those lands within the city that are underlain by bay mud, as shown on a map adopted by reference in the ordinance (fig. 44). The last part of the ordinance provides that within any structure that would be subject to earthquake hazard, all equipment shall be securely anchored. This part of the ordinance affects new installations throughout the entire city, including those on bay mud, alluvium, or hillside materials.

DIVISION 2. AREAS OF REDWOOD CITY UNDERLAIN BY YOUNGER BAY MUD

Sec. 9.121. Applicability of provisions.

The provisions of this division shall be applicable to that portion of the City of Redwood City underlain by younger bay mud as indicated on that map prepared by the building department of the City of Redwood City entitled "Area of Redwood City Underlain by Younger Bay Mud," and on file in the office of the city clerk .(Ord. No. 1727, § 2, 11-28-77)

Sec. 9.122. One and two story structures.

For one and two story residential buildings or structures only, all lot grading, soils design, foundation design, and construction design including lateral force analysis, shall be in accordance with the recommendations of the "Recommended Foundation Design Criteria for One and Two Story Residences" (dated April 15, 1974) as prepared by Rutherford and Chekene, Consulting Structural Engineers and as approved by the Redwood City Building Department, which document is on file in the office of the city clerk. (Ord. No. 1727, § 2, 11-28-77)

Sec. 9.123. Structural design.

All structural design shall be in accordance with the building code including lateral force provisions for earthquakes. Structural design for major structures in the longer range period (three-fourths (¾) of a second or more) shall use the "Recommended Base Shear Coefficient 'CS' for Lateral Force Design," as shown on Plate V-1, as revised, October 6, 1977,

Sec. 9.124. Foundation systems.

Foundation systems shall consist of mat, grill, piles or a similar system with a demonstrated ability to resist differential settlement and for tying the foundation elements together. The minimum tie strength shall be at least ten (10) per cent of the greatest load imposed on a foundation or foundation element. (Ord. No. 1727, § 2, 11-28-77)

Sec. 9.125. Sheathing on exterior frame of wood frame buildings.

All wood frame buildings shall be provided with five-sixteenths (5/16) inch plywood sheathing on the exterior frame in accordance with the "Design Criteria" prescribed by section 9.122 herein unless structural design and calculations prescribe lateral force parameters equal to or greater than the "Design Criteria Recommendations" of section 9.122. (Ord. No. 1727, § 2, 11-28-77)

Sec. 9.126. Walls or frames to resist lateral loads.

"Frame only" (space frame-ductile moment resisting and space frame-moment resisting as per the building code) structures where K = 0.67 are not permitted. Shear walls or braced frames are required to resist the entire lateral load. In buildings of more than one hundred sixty (160) feet in height a moment-resisting ductible frame is required; this frame shall be capable of resisting twenty-five (25) per cent of the required lateral load. (Ord. No. 1727, § 2, 11-28-77)

Sec. 9.127. Unit masonry structures.

Unit masonry structures (concrete block, brick, unitized precast, prestressed concrete) are not permitted unless the project design engineer can demonstrate, by thorough analysis and/or tests, that the strength and ductility (including the effects of temperature, foundation settlement, shrinkage and creep) are equal to that of monolithic construction. (Ord. No. 1727, § 2, 11-28-77)

Sec. 9.128. Design of certain structures to incorporate sufficient elements of redunancy.

For all structures more than four (4) stories irrespective of height or which contain more than twenty thousand (20,000) square feet of floor area, the design shall incorporate sufficient elements of redundancy such that complete failure of any one bracing element will not reduce the bracing capacity of the structures by more than seventy-five (75) per cent. (Ord. No. 1727, § 2, 11-28-77)

Sec. 9.129. Design of structures based on response spectrums.

The design of buildings or structures more than six (6) stories must, irrespective of height, be based on a response spectrum computed for the site. This response spectrum shall be compared with the average spectrum in accordance with Plate V-1 "Recommended Base Shear Coefficients 'CS' for Lateral Force Design," as revised October 6, 1977, following page 75A, 1972 Seismic Advisory Board Report (on file in the office of the city clerk) and the higher valued spectrum incorporated in the design. (Ord. No. 1727, § 2, 11-28-77)

DIVISION 3. REDWOOD CITY GENERALLY

Sec. 9.135. Provisions cumulative; applicability.

The provisions of this division shall be applicable throughout Redwood City and shall be in addition to all other applicable provisions of the building code. (Ord. No. 1727, § 2, 11-28-77)

Sec. 9.136. Anchoring of machinery or equipment.

Whenever connected to, part of, or housed within a building or structure, towers, tanks, storage-type water heaters, lighting fixtures, power transformers, machinery or other equipment that would constitute or contribute to earthquake hazards shall be securely anchored in accordance with Table 23J, item 4 of the building code. Exception: Domestic storage-type water heaters installed in one and two story residential buildings shall be anchored as recommended in the "Design Criteria" referenced in section 9.122. (Ord. No. 1727, § 2, 11-28-77)

FIGURE 43.—Part of the Redwood City Council (1977a) building code supplementing the design and construction standards for lands underlain by bay mud. Distribution of bay mud is shown in figure 44.

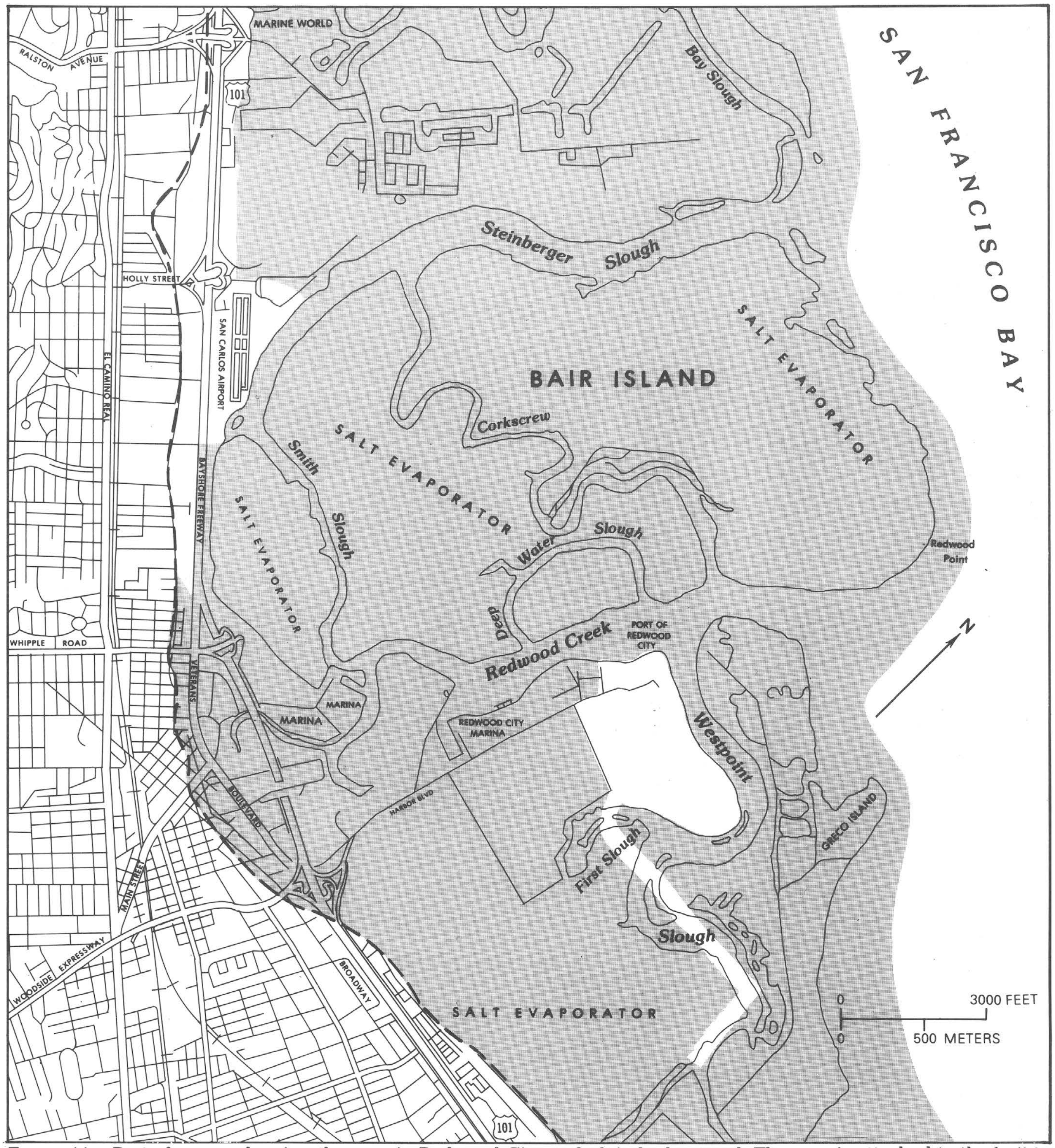


FIGURE 44.—Part of a map showing the area in Redwood City underlain by bay mud. The map is attached to the building code (Redwood City Council, 1977a), which requires supplemental structural-design and construction standards for all new development. Bay mud is indicated by shading, and its southwest boundary by a dashed line. Unshaded area along the Bayshore Freeway (U.S. Highway 101) lies outside the city's jurisdiction.

APPLICATION

Redwood City's map showing bay mud (fig. 44) was based on the published map by Nichols and Wright (1971) that shows the historical margins of marshlands, but more detailed information from their unpublished materials was also incorporated (Robert Bruce, former building official, Redwood City, oral commun., July 13, 1979).

During preconstruction conferences with developers and builders, the city building-department staff ascertains the location of the proposed development, advises on any additional seismic requirement for development on bay mud, recommends foundation-design criteria (Rutherford and Chekene, 1974a, b) for one- and two-story residences, and, in some cases, provides visual guides similar to that shown in figure 45. A site investigation and soils report by a registered geologist or soils engineer, and the retention of an architect, civil engineer, or structural engineer, are required for any development on bay mud (Charles Gyselbrecht, former chief building official, Redwood City, oral commun., July 18, 1979).

Before issuing a building permit, the city staff verifies that the plans and specifications contain the appropriate structural-design and construction standards. The staff inspects the work during construction to ensure that the standards are complied with before their final approval of the completed work.

In addition, the city's Public Works Department requires supplemental design and construction standards on bay mud for public works, such as storm drains, streets, sanitary sewers, and water supply (Charles Csicsman, project engineer, Redwood City, oral commun., July 12, 1979). These standards include: Preparation of sites by dredging, demucking, excavation, filling, and compaction; determination of construction grades to obtain the "ultimate" grades needed for hydraulic flows after settlement; use of drainpipes made of noncorrosive materials; requirement of gates at outfalls to tidal waterways; and reduction of underground pipe lengths and increase of underground pipe grades over old slough crossings to reduce pipe damage during settlement.

COMMENTS

This example illustrates how knowledge of the locations of geologic units, their engineering properties, and their response to earthquake shaking can be used by a city to supplement building-design and construction standards. Buildings designed, erected, and equipped under this type of ordinance should have fewer foundation problems, withstand greater seismic shaking, and sustain less damage from earthquakes.

The supplemental design and construction standards required for development on bay mud can be adapted for other types of unstable lands and can be applied in other cities where development on estuarine deposits or unstable lands may result in a threat to the public safety and welfare.

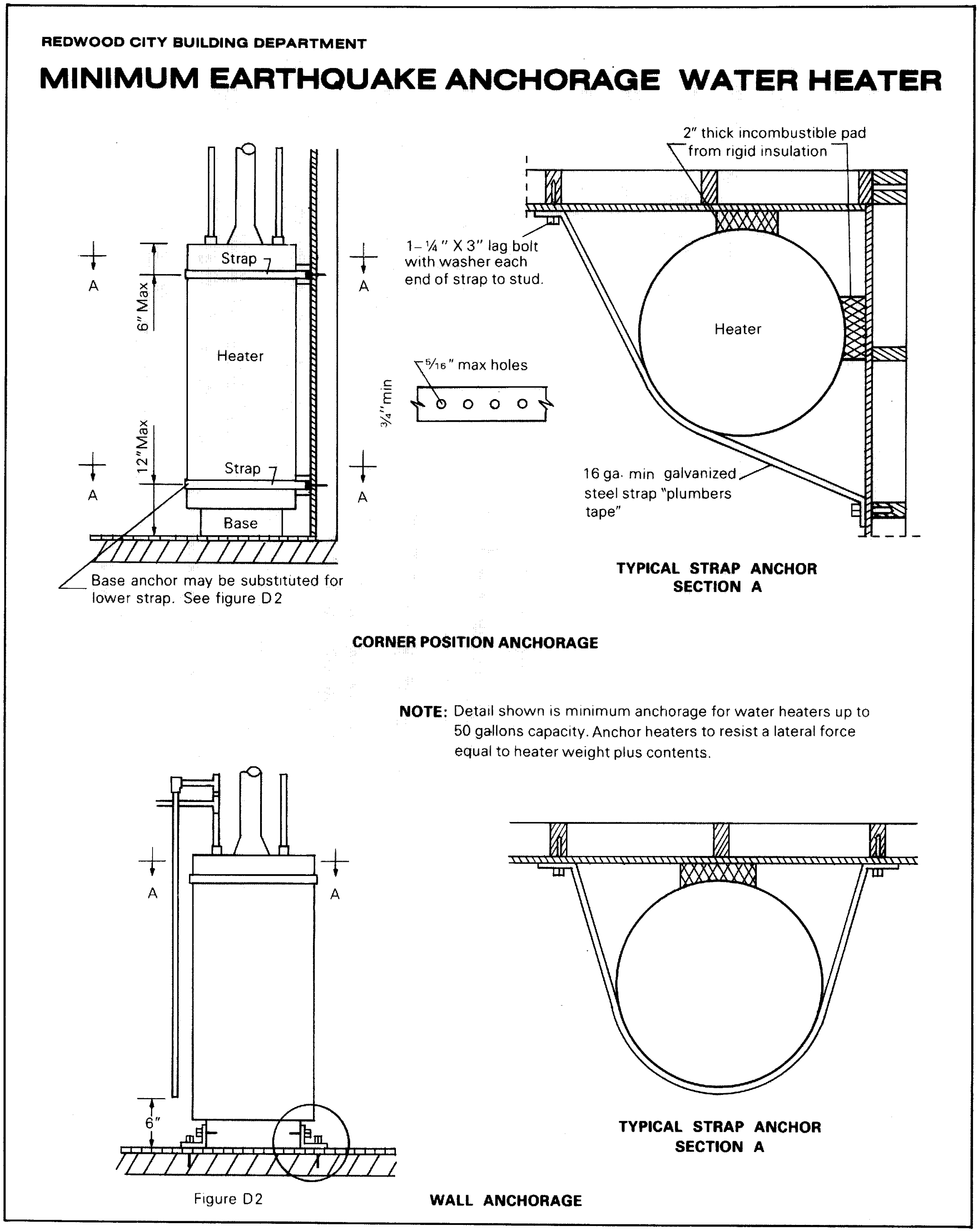


FIGURE 45.—Part of the earthquake anchorage guide prepared and distributed by the Redwood City Building Department (1974) to applicants for water-heater installations. Use of the guide ensures compliance with section 9.136 of the building code, shown in figure 43.

Example 6. Individual lots and acreages offered for sale

DISCLOSING POTENTIAL HAZARDS TO REAL-ESTATE BUYERS

The population of the nine-county San Francisco Bay region was more than 3.6 million in 1960 and surpassed 4.5 million in 1970. The California Department of Finances' Population Research Unit (1979) estimated the population to be almost 5 million on January 1, 1979, and the Association of Bay Area Governments (ABAG) (1980) projected about 5.2, 5.7, and 6.2 million people in the years 1980, 1990, and 2000, respectively. In 1975, these people lived in an estimated 1,770,000 dwelling units (Association of Bay Area Governments, 1980).

The construction of dwellings and other development continues in the bay region. Subdivision activity during the 4-year period ended June 1979 shows a rising trend in residential construction. The Real Estate Research Council of Northern California (1979) reported that the number of lots cleared for building in the bay region during two 12-month periods increased from 19,787 in 1975 to 32,356 in 1978. In addition, the total building valuation for the nine-county bay region increased from $1.71 billion in 1975 to $3.37 billion in 1978 (Security Pacific National Bank Research Department, 1978). The California Association of Realtors[1] advised that about 140,000 residential transactions (sales, exchanges, and other transfers) occur annually in the bay region (Joel Singer, California Association of Realtors, oral commun., Sept. 11, 1979).

Some of these new lots, dwellings, and other developments have been located or constructed in areas subject to flooding, slope failure, or fault rupture. Many of the lots and dwellings have been purchased or repurchased without the sellers, buyers, or their agents even being aware of the potential hazards that may affect the use or value of the property.

[1]The term "Realtors" denotes members of the National Association of Real Estate Boards.

INFORMATION AVAILABLE

Much information on hydrologic, seismic, and other geologic hazards is currently available for the San Francisco Bay region. Flood-prone-area, landslide-susceptibility, and fault-rupture maps have been prepared in a form understandable to, and at relatively large scales usable by, buyers who have no education or training in science or engineering.

Flood-plain characteristics, maps of flood-prone areas, measures to prevent and reduce flood loss, and the National Flood-Insurance Program were discussed in the report on flood-prone areas and land-use planning by Waananen and others (1977); indexes to flood-plain maps and other flood information were included. Types of landslides, the factors causing landslides, and landslide mapping were discussed in the report on relative slope stability and land-use planning by Nilsen and others (1979); a regional map showing six categories of susceptibility to slope failure was included. Evidence for surface fault displacement, magnitude of the largest historical earthquake, and the estimated recurrence interval for a maximum earthquake were presented for 25 faults in the report on seismic zonation edited by Borcherdt (1975); discussions of patterns of surface faulting, fault-zone width, and amount of displacement were included.

In addition, the Federal Insurance Administrator has identified communities in the bay region subject to flood hazards and has prepared maps showing the flood-hazard boundaries or the flood-insurance rates for many of these communities at scales ranging from 1:4,800 to 1:24,000 (1 in.=400-2,000 ft). The State Geologist has prepared Special Studies Zones maps showing fault-rupture traces at the relatively large scale of 1:24,000 (1 in. = 2,000 ft). At least one county in the bay region has transferred flood-prone, landslide, and fault-rupture areas onto cadastral (property boundary) maps at the large scale of 1:12,000 (1 in. = 1,000 ft) (see fig. 42).

General information about hazards can be obtained by buyers of lots, dwellings, or other real estate through school classes, briefings, university courses, adult-education programs, special workshops, field trips, displays, regional conferences, lectures, and publications. More specific information can be obtained by contacting local building and zoning officials, local, State, and Federal geologists, or geotechnical consultants. However, an awareness that hydrologic, seismic, and other geologic hazards exist and may endanger the property being purchased is prerequisite to obtaining such information. One way to make property owners aware that their property may be affected by floods, landslides, or fault rupture is to disclose such hazards at the time of purchase.

DECISION

To provide for protection against flood losses through a Federally subsidized flood-insurance program, the U.S. Congress (1974) requires lenders to notify prospective borrowers that the real estate being mortgaged is located in a flood-hazard area, as identified by the Federal Insurance Administrator.

To provide for the public safety from fault rupture through the Special Studies Zones Act, the California Legislature (1972a) requires a seller or his agent to inform the prospective buyer that the real estate is located within a fault-rupture zone, as delineated by the State Geologist.

In an ordinance enforcing onsite geologic investigations before construction, the Santa Clara County Board of Supervisors (1978) also requires all sellers of real estate lying partly or wholly within the county's flood, landslide, and fault-rupture zones to provide the buyer with a written statement of the geologic risk.

To assist them in complying with these Federal, State, and county laws, five local boards of Realtors in the bay region prepared colored street-index maps showing some or all of the designated flood, landslide, and fault-rupture zones. These five maps together cover one entire county and parts of three others, and include more than 50 cities; the maps show the flood-hazard and fault-rupture zones (fig. 46) designated and mapped by the Federal Insurance Administrator and the California State Geologist, respectively. In addition, two maps show a county-designated fault-rupture zone; one of these maps (San Jose Board of Realtors, 1977) delineates areas of possible differential settlement of compressible soils, landslides, and salt-water flooding due to seismically induced dike failure. Another map delineates the locations of landslide deposits and faults in the Livermore Valley. The Federal, State, and county disclosure laws and the use of the map by Realtors directly affect buyers, sellers, and their agents and help interconnect the work of lenders, appraisers, builders, developers, insurance firms, local building and zoning officials, and geotechnical consulting firms.

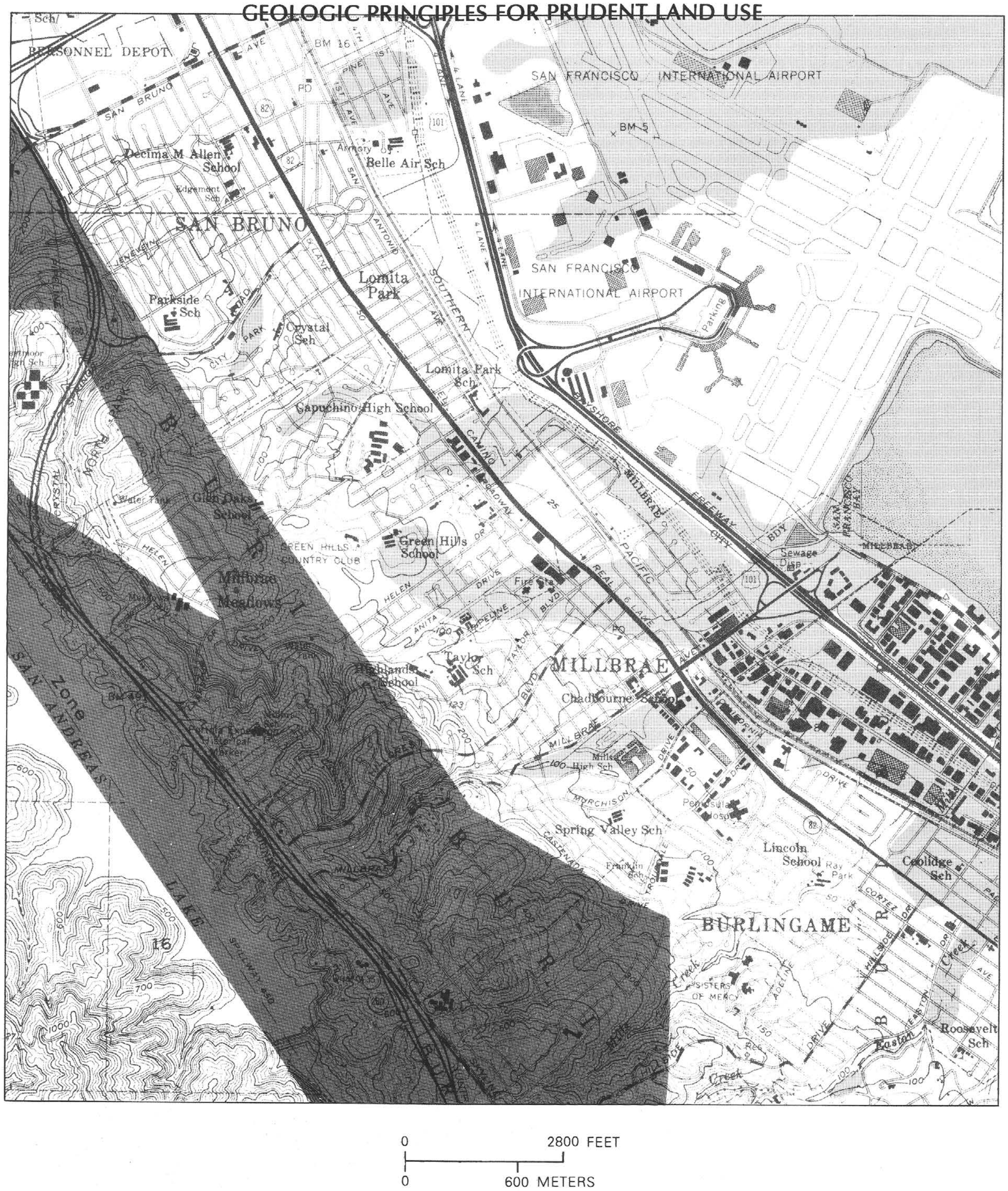


FIGURE 46.—Part of the Mid-Peninsula Cities streets index map prepared for the San Mateo-Burlingame Board of Realtors (1979), showing hazard zones. Lightly shaded areas denote flood-prone areas; darker shaded areas denote fault-rupture zones. Color maps are available from the publisher: Barclay Maps, 1206 Panoche Avenue, San Jose, CA 95122.

APPLICATION

The publisher of the street-index maps used U.S. Geological Survey topographic maps, at a scale of 1:24,000 (1 in. = 2,000 ft), as the base for all of these five maps. The fault-rupture zones were taken directly from the State Geologist's Special Studies Zones maps, the flood-hazard areas from Federal Insurance Administration publications, and the county fault-rupture zone from the county geologist. All the potential hazards mapped, including differential settlement, landslides, saltwater flooding, landslide frequency, and Livermore Valley faults, were based on information from various Federal, State, and local agencies.

Individual members of the five boards of Realtors have either received notice of and have access to, or have received free copies of, the maps for their particular jurisdiction; for example, almost all the 20,000 maps for the Menlo Park-Atherton area were distributed free. These maps may be used by Realtors to indicate, on the form that lists or offers it for sale, that the real estate is located in a flood-hazard or fault-rupture zone. (A listing form is one of the primary techniques used by a seller's agent to make other Realtors aware of real property that is being offered for sale.) Also, the maps may be used by Realtors as a general reference for advising prospective buyers on the presence of officially recognized hazards, as required by State and county disclosure laws.

Because these types and scales of maps are not lot and site specific, the Realtors either merely alert buyers to the potential hazards or request supplemental advice from consulting geologists, county geologists, or local building officials. The publisher has placed a caveat on each of the maps, one of which reads:

> The primary purpose of this map is to provide a ready reference for quick identification of areas within officially adopted hazard zones. The zone boundaries were compiled from official maps available at the time of preparation and cannot be guaranteed as to accuracy due to changes in map scale. Also, periodic revisions of the official maps are made by responsible agencies * * *. Therefore, questions involving specific parcels at or near zone boundaries should be answered by consulting the appropriate official maps or contacting local firms offering determination services.

In Santa Clara County, Realtors have begun to use new cadastral maps, at a scale of 1:12,000 (1 in. = 1,000 ft), on which the County Geologist shows fault-rupture zones, flood-hazard zones, and areas of possible ground failure (fig. 42). The California Association of Realtors (1977) published an instruction booklet on the legal obligations of Realtors to disclose the geologic hazards that relate to the use of real estate. The California Association of Realtors (1981) provides, in its real-estate purchase contract form (fig. 47), space for attaching information about flood (hazard) insurance and Special Studies (fault rupture) Zones. The California Association of Realtors (1978) also prepared a disclosure form for Special Studies Zones (fig. 48) that can be attached to the contract. The last paragraph of this form provides space for entering the number of days a prospective buyer has, from the time of the seller's acceptance, within which to make further inquiries concerning the use of the property under the Special Studies Zones Act and provides that where inquiry discloses conditions unsatisfactory to the buyer, the buyer may cancel the contract. In addition, some Realtors in the bay region use other forms that can be attached to the contract and which disclose to prospective buyers that the property is located in areas subject to floods, fault rupture, or other geologic hazards (fig. 49).

CALIFORNIA ASSOCIATION OF REALTORS® STANDARD FORM

REAL ESTATE PURCHASE CONTRACT AND RECEIPT FOR DEPOSIT

THIS IS MORE THAN A RECEIPT FOR MONEY. IT IS INTENDED TO BE A LEGALLY BINDING CONTRACT. READ IT CAREFULLY.

______________________, California. ______________, 19____

Received from ______________________

herein called Buyer, the sum of ______________________ Dollars $ ________

evidenced by cash ☐, cashier's check ☐, or ____________ ☐, personal check ☐ payable to ____________

____________ to be held uncashed until acceptance of this offer, as deposit on account of purchase price of

______________________ Dollars $ ________

for the purchase of property, situated in ____________ County of ____________, California, described as follows:

1. Buyer will deposit in escrow with ____________ the balance of purchase price as follows:

____

Set forth above any terms and conditions of a factual nature applicable to this sale, such as financing, prior sale of other property, the matter of structural pest control inspection, repairs and personal property to be included in the sale.

2. Deposit will ☐ will not ☐ be increased by $ ________ to $ ________ within ________ days of acceptance of this offer.
3. Buyer does ☐ does not ☐ intend to occupy subject property as his residence.
4. The supplements initialed below are incorporated as part of this agreement.

		Other
___ Structural Pest Control Certification Agreement	___ Occupancy Agreement	________ ____________
___ Special Studies Zone Disclosure	___ VA Amendment	________ ____________
___ Flood Insurance Disclosure	___ FHA Amendment	________ ____________

5. Buyer and Seller acknowledge receipt of a copy of this page, which constitutes Page 1 of ___ Pages.

X ____________ BUYER   X ____________ SELLER

FIGURE 47.—Part of a real-estate purchase-contract form prepared by the California Association of Realtors (1981) and approved by the State Bar of California. This form or a similar one is used by many Realtors in the bay region to legally bind the buyer to his offer and the seller to his acceptance. Item 4 provides for supplemental disclosure forms (see fig. 48). These forms are available from the California Association of Realtors, 525 South Virgil Avenue, Los Angeles, CA 90020. Reprinted by permission; endorsement not implied.

This Addendum is attached as Page ________ of ________ Pages to the Real Estate Purchase Contract and Receipt for Deposit dated ________________ 19______ in which ____

____

is referred to as Buyer and ____

____ **is referred to as Seller.**

The property which is the subject of the contract is situated in a Special Study Zone as designated under Sections 2621-2625, inclusive, of the California Public Resources Code; and, as such, the construction or development on this property of any structure for human occupancy may be subject to the findings of a geologic report prepared by a geologist registered in the State of California, unless such report is waived by the city or county under the terms of that act. No representations on the subject are made by Seller or Agent, and the Buyer should make his/her own inquiry or investigation.

Note: California Public Resources Code #2621.5 excludes structures in existence prior to May 4, 1975;

California Public Resources Code #2621.6 excludes wood frame dwellings not exceeding two (2) stories in height and mobilhomes over eight (8) feet in width;

California Public Resources Code #2621.7 excludes conversion of existing apartment houses into condominiums;

California Public Resources Code #2621.8 excludes alterations and additions under 50% of value of structure from the Special Studies Zone Act.

Buyer is allowed ____________ days from date of Seller's acceptance to make further inquiries at appropriate governmental agencies concerning the use of the subject property under the terms of the Special Study Zone Act and local building, zoning, fire, health and safety codes. When such inquiries disclose conditions or information unsatisfactory to the Buyer, Buyer may cancel this agreement. If notice in writing has not been delivered within such time, this condition shall be deemed waived.

Receipt of a copy is hereby acknowledged.

DATED: ____________________________, 19________ BUYER: ________________________________

FIGURE 48.—Part of a Special Studies (fault rupture) Zone disclosure form prepared by the California Association of Realtors (1978). This form is designed to be attached to a real-estate purchase contract, as shown in figure 47, and is used by many Realtors in the bay region to comply with the disclosure provisions of the California Legislature (1972a). The form is available from the California Association of Realtors, 525 South Virgil Avenue, Los Angeles, CA 90020. Reprinted by permission; endorsement not implied.

2. NATIONAL FLOOD CONTROL ACT DISCLOSURE: The property which is the subject of this contract may be located in an area which has been identified as having special flood and/or mudslide hazards by the Secretary of Housing and Urban Development pursuant to Title 42 of the United States Code Annotated, Sections 400 and following.

In the event said property is situated within such an area, the Buyer of said property will be required to purchase, in addition to other insurance, flood insurance as a condition to obtaining financing through a federally backed mortgage or through federally supervised, regulated or insured agencies or institutions.

3. SPECIAL STUDIES ZONE ACT DISCLOSURE: The property which is the subject of the contract is or may be situated in a Special Studies Zone as designated under the Alquist-Priolo Special Studies Zone Act, Sections 2621-2625, inclusive, of the California Public Resources Code; and, as such the construction or development on this property of any structure for human occupancy may be subject to the findings of a geologic report prepared by a geologist registered in the State of California, unless such report is waived by the city or county under the terms of that act. No representations on the subject are made by Seller or Agent, and the Buyer should make his own inquiry or investigation. This act provides certain exemptions from the necessity of obtaining a geologic report. These exemptions are set out as follows:

California Public Resources Code § 2621.5 provides in part as follows: "This chapter is applicable to any project, as defined in § 2621.6...."

California Public Resources Code §2621.6 excludes from the definition of "project"

1) Uses which do not contemplate the eventual construction of structures for human occupancy subject to the Subdivision Map Act;

2) Single family woodrame dwellings not exceeding two stories in height (which is further defined to include mobilehomes whose body width exceeds eight feet), unless located as part of a development of four or more such dwellings constructed by a single person, individual partnership or other organization;

California Public Resources Code § 2621.7 excludes from the definition of "project" the conversion of an existing apartment complex to a condominium;

California Public Resources Code § 2621.8 excludes from the definition of "project" the alteration or addition to any structure within a Special Studies Zone, the value of which does not exceed 50% of the value of the structure;

California Public Resources Code § 2621.8 excludes from the definition of "project" properties in which a previous geologic report has been approved or waiver granted provided such new geological data warranting further investigation is not 'recorded';

California Public Resources Code § 2621.5 provides that the provisions of the act do not apply to any development or structures in existence prior to May 4, 1975.

The above is a summary of exemptions available under the California Public Resources Code. In the event further information is desired, you are directed to Chapter 7.5 of Division 2 of the California Public Resources Code (§§ 2621 et seq.).

For Further Information Contact Appropriate City or County Agencies

4. OTHER MAJOR GEOTECHNICAL HAZARD ZONES DISCLOSURE (REQUIRED BY SANTA CLARA COUNTY) — Other than Alquist-Priolo Special Studies Zones: The property which is the subject of this contract is or may be situated in a zone of high geologic hazard (other than Alquist-Priolo Special Studies Zones) as shown on the Santa Clara County Relative Seismic Stability Map, as revised. Such zones are designated on the described map, as follows: (Place a check mark in the appropriate box indicating the zone or zones in which the subject property is or may be situated.)

- ☐ DC — areas of high potential for liquefaction and differential settlement.
- ☐ DR — areas of high potential for ground displacement along fault traces believed to be possibly active, but not presently in an Alquist-Priolo Special Studies Zone.
- ☐ DS — areas of high potential for earthquake-induced landslides.
- ☐ DF — areas of high potential for salt water flooding from failure of dikes.

For further information, contact County Geologist, telephone No. 299-2871.

____________________ Seller ____________________ Buyer

FIGURE 49.—Part of a form prepared for the San Jose Board of Realtors (1978). This form is designed to be attached to a real-estate contract, as shown in figure 47, and is used by many local Realtors in the board's jurisdiction to comply with the disclosure provisions of the California State Legislature (1972a) and the Santa Clara County Board of Supervisors (1978). Items 2 through 4 provide for disclosure of flood, fault-rupture, and other geologic hazards. Reprinted by permission; endorsement not implied.

COMMENTS

This example shows that complex hydrologic, seismic, and other geologic information can be conveyed to real-estate buyers before the sale. The five maps of single-line indexed streets with color overlays showing hazard zones provide easy reference and quick identification. Furthermore, they have unusually wide distribution throughout four counties in one of the most seismically active regions in the United States.

Presenting scientific information in the form of relative degrees of hazard; passing Federal, State, and local disclosure laws; providing real-estate-contract disclosure forms; and preparing and distributing hazard maps have resulted in making some buyers at least aware of, if not actually knowledgeable about, floods, fault rupture, and other geologic hazards. Prerequisites for effective disclosure of potential hazards by real-estate sellers include the sellers' or real-estate agents' knowledge and objectivity, the buyers' realization of the possible danger or financial loss *before* making the commitment to purchase, and the buyers' concern about hazards in relation to their other priorities. Palm's (1981) study of the disclosures of fault-rupture hazards by real-estate agents in Berkeley and Contra Costa County, indicates that these prerequisites are not always met.

The method of conveying scientific information on these geologic hazards to real-estate buyers can be applied to other areas within the bay region and to other geologic hazards in areas where interpretative information exists. Because of the uniqueness of each real-estate transaction, however, decisionmakers cannot rely solely on sellers for effective disclosure of potential hazards or on buyers for a proper response to such hazards.

CONCLUDING COMMENTS

The six examples presented at the end of this report illustrate typical problems faced by planners and decisionmakers, along with innovative responses that were based on Earth-science information and designed to avoid geologic hazards, protect natural resources, and reduce property damage. Each decision was influenced by many of the same factors—a geologically hazardous environment, general public awareness, strong community interest, Federal or State enabling legislation, availability of scientific information, and the ability of geologists, engineers, planners, and lawyers to incorporate this information into a plan, program, or regulation. The collective effect of their decisions is to provide for greater public safety and the health and welfare of their constituents and their communities.

Many other examples of hazard avoidance and resource protection could be cited in addition to the six examples presented above. The California Legislature (1975) enacted the Surface Mining and Reclamation Act to assure mineral-resource conservation in areas subject to irreversible land uses incompatible with mining. In accord with California Mining and Geology Board (1979) guidelines, the State Geologist is currently classifying lands and gravel-resource areas in the San Francisco Bay region; the final classification will resemble the sand and gravel classification by the California Division of Mines and Geology (1979) for the Los Angeles area.

Decisionmakers—both public and private—live and work in a complex geologic environment. This geologic environment, however, is just one aspect of the surroundings that affect a decisionmaker's life and work; other aspects are social, economic, political, and esthetic, some of which are more apparent or more important than others to individual decisionmakers or their constituents. The crises faced by decisionmakers who fail to accommodate to a geologic environment affected by urban growth include: (1) The danger and trauma that accompany major earthquakes, landslides, and floods; (2) the contamination or loss of natural resources caused by pollution or incompatible land uses; and (3) the economic loss caused by damage or disruption to public facilities, utilities, and private property that are located in potentially hazardous areas. Many adverse geologic processes can be triggered by human activities simply because people lack an awareness or an appreciation of the specific hazard or resource. For example, watering landslide areas or draining septic systems into aquifers can cause property damage and resource contamination.

Much of the scientific information needed for prudent land use in the San Francisco Bay region is currently available to decisionmakers and their staffs. Some of this information has been published at the detail and scale (1:24,000 [1 in. = 2,000 ft]) needed for general decisionmaking. However, greater detail and larger scales, ranging from 1:1,200 to 1:12,000 (1 in. = 100-1,000 ft), are needed for detailed development planning, site investigations, ordinance administration, project review, and permit issuance. Public staffs, private consultants, and applicants for permits generally can provide decisionmakers with information in the greater detail and at the larger scales needed.

Decisionmakers, however, cannot be expected to have the requisite training or experience to understand and use scientific information. Therefore, to enable nonscientists to use the information available, it must be interpreted and placed on readable maps that display such information as: Recurrence intervals for maximum earthquakes and specific floods, relative intensities of ground shaking, susceptibility to landsliding, suitability ratings for waste-disposal sites, general land-use capabilities of bay mud, locations of landslides or active faults, potential for liquefaction, and predicted geologic effects of postulated earthquakes.

The Earth-science information and decisions described here for the San Francisco Bay region are applicable to areas outside the region where similar geologic hazards and land developments exist. Of course, any such use of this report would depend on the level of public awareness, enabling legislation, hazard and resource issues, order of priorities, community interest, innovativeness of decisionmakers, and staff abilities. Usually, additional scientific information related to each area would be needed to provide a sound basis for decisionmaking. In the end, however, the lasting effectiveness of any such decisions depends on many other factors, including:

—continued awareness and interest by the public and their decisionmakers,
—meticulous updating of hazard information and maps by geologists or geotechnical engineers,
—careful revision of enabling legislation (if needed) by legislative bodies,
—accurate site investigations by registered geologists or geotechnical engineers,
—conscientious administration of regulations by inspectors and effective disclosure by real-estate sellers,
—consistent enforcement by government attorneys,
—sustained support of inspection and enforcement officials by political leaders,
—judicious adjustment of regulations by administrative appeal bodies,
—skillful advocacy (if challenged) and informed interpretation by the courts, and
—concern for individual, family, and community health, safety, and welfare by real-estate buyers and developers.

REFERENCES CITED

Archuleta, R. J., Joyner, W. B., and Boore, D. M., 1979, A methodology for predicting ground motion at specific sites, *in* Brabb, E. E., ed., Progress on seismic zonation in the San Francisco Bay region: U.S. Geological Survey Circular 807, p. 26-36.

Association of Bay Area Governments, 1975, San Mateo coast corridor evaluation: Berkeley, Calif., 10 p.

———1976, Areas of critical environmental concern: Report to the Regional Planning Committee by the Regional Open Space Task Force: Berkeley, Calif., 88 p.

———1978a, Earthquake intensity and related costs in the San Francisco Bay area: Earthquake preparedness program: Berkeley, Calif., 12 p.

———1978b, San Francisco Bay area environmental management plan, volume I: Berkeley, Calif., 563 p.

———1980, Projections 79—Population, employment, housing, 1980-2000: Berkeley, Calif., 111 p.

Atwater, Brian, 1978, Central San Mateo County, California—land-use controls arising from erosion of seacliffs, landsliding, and fault movement, *in* Robinson, G. D., and Spieker, A. M., eds., "Nature to be commanded...": Earth-science maps applied to land and water management: U.S. Geological Survey Professional Paper 950, p. 11-21.

———1979, Ancient processes at the site of southern San Francisco Bay: Movement of crust and changes in sea level, *in* Conomos, T. J., ed., San Francisco Bay: The urbanized estuary: San Francisco, California Academy of Sciences, p. 31-45.

Atwater, Brian, Conard, S. G., Dowden, J. N., Hedel, C. W., MacDonald, R. L., and Savage, Wayne, 1979, History, landforms, and vegetation of the estuary's tidal marshes, *in* Conomos, T. J., ed., San Francisco Bay: The urbanized estuary: San Francisco, California Academy of Sciences, p. 347-385.

Atwater, Brian, Hedel, C. W., and Helley, E. J., 1977, Late Quaternary depositional history, Holocene sea-level changes, and vertical crustal movement, southern San Francisco Bay, California: U.S. Geological Survey Professional Paper 1014, 15 p.

Blair, M. L., and Spangle, W. E., 1979, Seismic safety and land-use planning—selected examples from California: U.S. Geological Survey Professional Paper 941-B, p. B1-B82.

Bolt, B. A., and Miller, R. D., 1975, Catalogue of earthquakes in northern California and adjoining areas, January 1910-31 December 1972: Berkeley, University of California, Seismographic Station, 567 p.

Boore, D. M., Joyner, W. B., Oliver, A. A., III, and Page, R. A., 1978, Estimation of ground motion parameters: U.S. Geological Survey Circular 795, 43 p.

Borcherdt, R. D., ed., 1975, Studies for seismic zonation of the San Francisco Bay region: U.S. Geological Survey Professional Paper 941-A, p. A1-A102.

Borcherdt, R. D., Gibbs, J. F., and Fumal, T. E., 1979, Progress on ground motion predictions for the San Francisco Bay region, California, *in* Brabb, E. E., ed., Progress on seismic zonation in the San Francisco Bay Region: U.S. Geological Survey Circular 807, p. 26-36.

Brabb, E. E., Pampeyan, E. H., and Bonilla, M. G., 1972, Landslide susceptibility in San Mateo County, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-360, scale 1:62,500.

Brown, R. D., Jr., and Wolfe, E. W., 1972, Map showing recently active breaks along the San Andreas fault between Point Delgada and Bolinas Bay, California: U.S. Geological Survey Miscellaneous Geologic Investigations Map I-692, scale 1:24,000, 2 sheets.

Brown, W. M., III, and Jackson, L. E., Jr., 1973, Erosional and depositional provinces and sediment transport in the south and central part of the San Francisco Bay region, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-515, 21 p., scale 1:125,000.

California Association of Realtors, 1977, Disclosure of geologic hazards: Los Angeles, 43 p.

———1978, Special studies zone disclosure: Standard Form SSD-FHD 11: Los Angeles.

———1981, Real estate purchase contract and receipt for deposit: Standard form D-11-1 NCR: Los Angeles, 2 p.

California Department of Finance, Population Research Unit, 1979, Population estimates of California, cities and counties: Report 79-E-1, 5 p.

California Division of Mines and Geology, 1974, State of California Special studies zones, Mindego Hill quadrangle: Sacramento, scale 1:24,000.

———1979, Mineral land classification of the greater Los Angeles area: Special Report 143, 79 p.

California Legislature, 1965, McAteer-Petris Act, as amended: California Government Code, secs. 66600 ff.

———1972a, Alquist-Priolo Special Studies Zones Act, as amended: California Public Resources Code, secs. 2621 ff.

———1972b, Nejedly-Z'berg-Dills Solid Waste Management and Resource Recovery Act, as amended: California Government Code, secs. 66780 ff.

———1974, Nejedly-Bagley-Z'berg Suisun Marsh Preservation Act of 1974, as amended: California Fish and Game Code, secs. 1850 ff.

———1975, Surface Mining and Reclamation Act of 1975: California Public Resources Code, secs. 2710 ff.

———1977, Suisun Marsh Preservation Act of 1977: California Public Resources Code, secs. 29000 ff.

———1978a, Hazardous Waste Control Law: California Health and Safety Code sec. 25117.

———1978b, Planning and Zoning Law: California Government Code, secs. 65300 ff.

California Mining and Geology Board, 1979, Guidelines for classification and designation of mineral lands, pt. 2 *of* California surface mining and reclamation policies and procedures (revised ed.): Special Publication 51, p. 21-36.

California Water Resources Control Board, 1976, Waste discharge requirements for nonsewerable waste disposal to land; disposal site design and operation information: Sacramento, 60 p.

Conomos, T. J., 1979, Properties and circulation of San Francisco Bay waters, *in* Conomos, T. J., ed., San Francisco Bay: The urbanized estuary: San Francisco, California Academy of Sciences, p. 47-84.

Conomos, T. J., McCulloch, D. S., Peterson, D. H., and Carlson, P. R., 1971, Drift of surface and near-bottom waters of the San Francisco Bay system—March 1970 through April 1971: U.S. Geological Survey open-file map, scale 1:625,000, 2 sheets.

Conomos, T. J., Peterson, D. H., Carlson, P. R., and McCulloch, D. S., 1970, Movement of seabed drifters in the San Francisco Bay estuary and the adjacent Pacific Ocean: U.S. Geological Survey Circular 637-B, p. B1-B8.

Fleming, R. W., 1972, Soil creep in the vicinity of Stanford University: Stanford, Calif., Stanford University, Ph. D. thesis, 148 p.

Hart, E. W., 1980, Fault-rupture hazard zones in California (revised ed.): California Division of Mines and Geology Special Publication 42, 25 p.

Hart, E. W., Bortugno, E. J., and Smith, T. C., 1977, Summary report: Fault evaluation program, 1976 area (western Transverse Ranges): California Division of Mines and Geology Open-File Report 77-8 SF, 8 p.

Hart, E. W., Smith, D. P., and Saul, R. B., 1979, Summary report: Fault evaluation program, 1978 area (Peninsular Ranges-Salton Trough region): California Division of Mines and Geology Open-File Report 79-10 SF, 10 p.

Hart, E. W., Smith, D. P., and Smith, T. C., 1978, Summary report: Fault evaluation program, 1977 area (Los Angeles basin region): California Division of Mines and Geology Open-File Report 78-10 SF, 8 p.

Hays, W. W., 1980, Procedures for estimating ground motions: U.S. Geological Survey Professional Paper 1114, 77 p.

Helley, E. J., LaJoie, K. R., Spangle, W. E., and Blair, M. L., 1979, Flatlands deposits of the San Francisco Bay region, California—their geology and engineering properties, and their importance to comprehensive planning: U.S. Geological Survey Professional Paper 943, 88 p.

Hines, W. G., 1973, Evaluating pollution potential of land-based waste disposal, Santa Clara County, California: An application of earth-science data for planning: U.S. Geological Survey Water Resources Investigations 31-73 (San Francisco Bay Region Environment and Resources Planning Study Interpretive Report 6), 21 p.

International Conference of Building Officials, 1976, Uniform building code: Whittier, Calif., 728 p.

Knott, J. M., 1973, Effects of urbanization on sedimentation and floodflows in Colma Creek basin, California: U.S. Geological Survey Open-File Report, 54 p.

Kockelman, W. J., 1975, Use of USGS earth science products by city planning agencies in the San Francisco Bay region, California: U.S. Geological Survey Open-File Report 75-276, 110 p.

———1976, Use of USGS earth-science products by county planning agencies in the San Francisco Bay region, California: U.S. Geological Survey Open-File Report 76-547, 186 p.

———1977, Flood-loss prevention and reduction measures, *in* Waananen, A. O., Limerinos, J. T., Kockelman, W. J., Spangle, W. E., and Blair, M. L., Flood-prone areas and land-use planning—selected examples from the San Francisco Bay region, California: U.S. Geological Survey Professional Paper 942, p. 23-30.

———1979, Use of USGS earth-science products by selected regional agencies in the San Francisco Bay region, California: U.S. Geological Survey Open-File Report 79-221, 173 p.

Kockelman, W. J., and Brabb, E. E., 1979, Examples of seismic zonation in the San Francisco Bay region, *in* Brabb, E. E., ed., Progress on seismic zonation in the San Francisco Bay region: U.S. Geological Survey Circular 807, 91 p.

Kockelman, W. J., Conomos, T. J., and Leviton, A. E., eds., 1982, San Francisco Bay; use and protection: San Francisco, American Association for the Advancement of Science, Pacific Division, 310 p.

Laird, R. T., Perkins, J. B., Bainbridge, D. A., Baker, J. B., Boyd, R. T., Huntsman, Daniel, Staub, P. E., and Zucker, M. B., 1979, Quantitative land-capability analysis: U.S. Geological Survey Professional Paper 945, 115 p.

Leighton, F. B., and Associates, 1971, Geologic report of Seal Cove-Moss Beach area, County of San Mateo: Irvine, Calif., 78 p.

Lester, F. W., and Meagher, K. L., 1978, Catalog of earthquakes along the San Andreas fault system in central California for the year 1974: U.S. Geological Survey Open-File Report 78-1010, 89 p.

Limerinos, J. T., Lee, K. W., and Lugo, P. E., 1973, Flood-prone areas in the San Francisco Bay region: U.S. Geological Survey Water Resources Investigations 3-73 (San Francisco Bay Region Environment and Resources Planning Study Interpretive Report 4), scale 1:125,000, 3 sheets.

Little, A. D., Inc., 1975, An evaluation of the San Francisco Bay Region Environment and Resources Planning Study: Report to U.S. Department of Housing and Urban Development, Office of Policy Development and Research, 93 p.

Mader, G. G., Danehy, E. A., Cummings, J. C., and Dickinson, W. R., 1972, Land use restrictions along the

San Andreas fault in Portola Valley, California: International Conference on Microzonation for Safer Construction Research and Application, Seattle, Wash., 1972, Proceedings, v. 2, p. 845-857.

McCulloch, D. S., Peterson, D. H., Carlson, P. R., and Conomos, T. J., 1970, A preliminary study of the effects of water circulation in the San Francisco Bay estuary: U.S. Geological Survey Circular 637.

Meehan, R. L., Dukes, M. T., and Shires, P. O., 1975, A case history of expansive claystone damage: American Society of Civil Engineers Proceedings, Geotechnical Engineering Division Journal, v. 101, no. GT9, p. 933-948.

Nichols, D. R., and Wright, N. A., 1971, Preliminary map of historic margins of marshlands, San Francisco Bay, California: U.S. Geological Survey Open-File Map, scale 1:125,000, 29 sheets.

Nichols, F. H., 1973, A review of benthic faunal surveys in San Francisco Bay: U.S. Geological Survey Circlar 677, 20 p.

Nilsen, T. H., Taylor, F. A., and Brabb, E. E., 1976, Recent landslides in Alameda County, California (1940-71): An estimate of economic losses and correlations with slope, rainfall, and ancient landslide deposits: U.S. Geological Survey Bulletin 1398, 21 p.

Nilsen, T. H., and Turner, B. L., 1975, Influence of rainfall and ancient landslide deposits on recent landslides (1950-71) in urban areas of Contra Costa County, California: U.S. Geological Survey Bulletin 1388, 18 p.

Nilsen, T. H., Wright, R. H., Vlasic, T. C., and Spangle, W. E., 1979, Relative slope stability and land-use planning in the San Francisco Bay region, California: U.S. Geological Survey Professional Paper 944, 96 p.

Palm, R., 1981, Real estate agents and the dissemination of natural hazards information in the urban area: Valuation (American Society of Appraisers Journal), v. 26, p. 172-182.

Perkins, J. B., 1978, Identification of possible class I site areas, solid waste management plan: Berkeley, Calif., Association of Bay Area Governments Technical Memorandum 7, 36 p.

Perkins, J. B., San Jule, Y. C., Chiu, P. Y., 1977, Environmentally dangerous waste in the San Francisco Bay; land disposal and its alternatives: Berkeley, Calif., Association of Bay Area Governments final project report for California Solid Waste Management Board, 92 p.

Pettyjohn, W. A., 1979, Ground-water pollution, an imminent disaster, in National Ground Water Quality Symposium, 4th, Minneapolis, 1979, Proceedings: National Water Well Association, Ground-Water Technology Division Journal, v. 17, no. 1, p. 18-24.

Portola Valley Town Council, 1973, Zoning regulations: Portola Valley, Calif., Ordinance No. 1967-80, sec. 6209.2.

Rantz, S. E., 1971, Mean annual precipitation and precipitation depth-duration-frequency data for the San Francisco Bay region, California: U.S. Geological Survey Open-File Report, 23 p.

Real Estate Research Council of Northern California, 1979, Real estate and mortgage finance trends: San Francisco, no. 97, 2 p.

Redwood City Building Department, 1974, Minimum earthquake anchorage—water heater: Redwood City, Calif., 2 p.

Redwood City Council, 1974, Ordinance No.1613: Building code, secs. 9.120 ff.: Redwood City, Calif., 12 p.

———1977a, Ordinance No. 1727: Building code, secs. 9.120 ff.: Redwood City, Calif., 15 p.

———1977b, Resolution No. 7933: Redwood City, Calif., 3 p.

———1978, Zoning ordinance: Ordinance No. 1130 with revisions to Dec. 31, 1978: Redwood City, Calif., 120 p.

Redwood City Planning Department, 1974, Seismic safety element: Redwood City, Calif., 26 p.

———1975, Comprehensive general plan, *including* A land-use plan map: Redwood City, Calif., 195 p.

Redwood City Seismic Advisory Board, 1972, Supplementary report on Redwood City General Improvement District No. 1-64: Redwood City, Calif., 85 p.

Richter, C. F., 1958, Elementary seismology: San Francisco, W. F. Freeman, 768 p.

Robinson, G. D., and Spieker, A. M., eds., 1978, "Nature to be commanded...": Earth-science maps applied to land and water management: U.S. Geological Survey Professional Paper 950, 95 p.

Rutherford & Chekene, 1974a, Recommended foundation design criteria—one and two story residences—lots having a predicted differential settlement less than 2 inches vertical in 50 feet horizontal: San Francisco, 31 p.

———1974b, Recommended foundation design criteria—one and two story residence—lots having a predicted differential settlement less than 4 inches vertical in 50 feet horizontal: San Francisco, 31 p.

San Francisco Bay Conservation and Development Commission, 1969 (revised 1979), San Francisco Bay Plan: Sacramento, California Documents and Publications Branch, 41 p.

———1976, Suisun Marsh protection plan: San Francisco Bay Plan: 48 p. (supplement volume, 496 p.).

———1978, Suisun Marsh local protection program guidelines: San Francisco, 85 p.

San Jose Board of Realtors, 1977, Map of Santa Clara County, California, special studies zones and flood hazard areas: San Jose, Calif., Barclay Maps.

———1978, San Jose real estate board standard form: Addenda A: San Jose, Calif.

San Mateo-Burlingame Board of Realtors, 1979, Midpeninsula cities map; special studies zones and flood hazard maps: San Jose, Calif., Barclay Maps.

Santa Clara County Board of Supervisors, 1978, Geological ordinance No. NS-1205.35: Santa Clara County Code, secs. C-12-600 ff.

Santa Clara County Planning Department, 1973, Public safety map No. 1: San Jose, Calif.

———1975, Seismic safety plan—an element of the general plan: San Jose, Calif., 119 p.

Schlocker, Julius, 1970, Generalized geologic map of the San Francisco Bay region, California: U.S. Geological Survey open-file map, scale 1:500,000.

———1974, Geology of the San Francisco North quadrangle, California: U.S. Geological Survey Professional Paper 782, 109 p.

Security Pacific National Bank, Research Department, 1978, California trends: Los Angeles, 84 p.

Steinbrugge, K. V., Cloud, W. K., and Scott, N. H., 1970, The Santa Rosa, California, earthquakes of October 1, 1969: Rockville, Md., U.S. Department of Commerce, Coast and Geodetic Survey, 99 p.

Taylor, F. A., and Brabb, E. E., 1972, Maps showing distribution and cost by counties of structurally damaging landslides in the San Francisco Bay region, California, winter of 1968-69: U.S. Geological Survey Miscellaneous Field Studies Map MF-327, scale 1:500,000.

Tinsley, J. C., 1972, Sea cliff retreat as a measure of coastal erosion, San Mateo County, California, *in* Frizzell, V. A., ed., Progress report on the USGS Quaternary studies in the San Francisco Bay area: An informal collection of preliminary papers: Friends of the Pleistocene Guidebook, p. 56-83a.

Toppozada, T. R., Real, C. R., and Parke, D. L., 1981, Preparation of isoseismal maps and summaries of reported effects for pre-1900 California earthquakes—annual report to U.S. Geological Survey: California Division of Mines and Geology Open File Report 81-11 182 p.

Trifunac, N. D., and Hudson, D. E., 1971, Analysis of the Pacoima Dam accelerogram—San Fernando, California, earthquake of 1971: Seismological Society of America Bulletin, v. 61, no. 5, p. 1393-1411.

U.S. Congress, 1972, Coastal Zone Management Act of 1972, as amended: Public Law 92-583, 86 Stat. 1280, 16 U.S.C. 1451 ff.

———1974, National flood insurance act of 1968, as amended: Public Law 93-383, 88 Stat. 739, 42 U.S.C. 4104a.

———1977, Federal Water Pollution Control Act amendments of 1972: Public Law 92-500, 86 Stat. 839, U.S.C. 1251 ff.

U.S. Water Resources Council, 1978, The Nation's water resources, 1975-2000, volume 4: California region: Second national water assessment: Washington, U.S. Government Printing Office, 73 p.

Varnes, D. J., 1978, Slope movement types and processes, *in* Schuster, R. L., and Krizek, R. J., eds., Landslides: Analysis and control: U.S. National Academy of Sciences, National Research Council, Transportation Research Board Special Report 176, 234 p.

Waananen, A. O., Limerinos, J. T., Kockelman, W. J., Spangle, W. E., and Blair, M. L., 1977, Flood-prone areas and land-use planning—selected examples from the San Francisco Bay region, California, U.S. Geological Survey Professional Paper 942, 75 p.

Webster, D. A., 1972, Map showing ranges in probable maximum well yield from water-bearing rocks in the San Francisco Bay region, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-431, scale 1:250,000.

Weir, W. W., 1950, Subsidence of peat lands of the Sacramento-San Joaquin Delta, California: Hilgardia, v. 20, no. 3, p. 37-55.

Wentworth, C. M., Ellen, Stephen, Meehan, R. L., Mader, G. G., and Vlasic, T. C., 1983, Hillside materials and their significance for land-use planning in the San Francisco Bay region, California: U.S. Geological Survey Professional Paper 947 [in press].

Wesson, R. L., Helley, E. J., Lajoie, K. R., and Wentworth, C. M., 1975, Faults and future earthquakes, *in* Borcherdt, R. D., ed., Studies for seismic zonation of the San Francisco Bay region: U.S. Geological Survey Professional Paper 941-A, p. A5-A30.

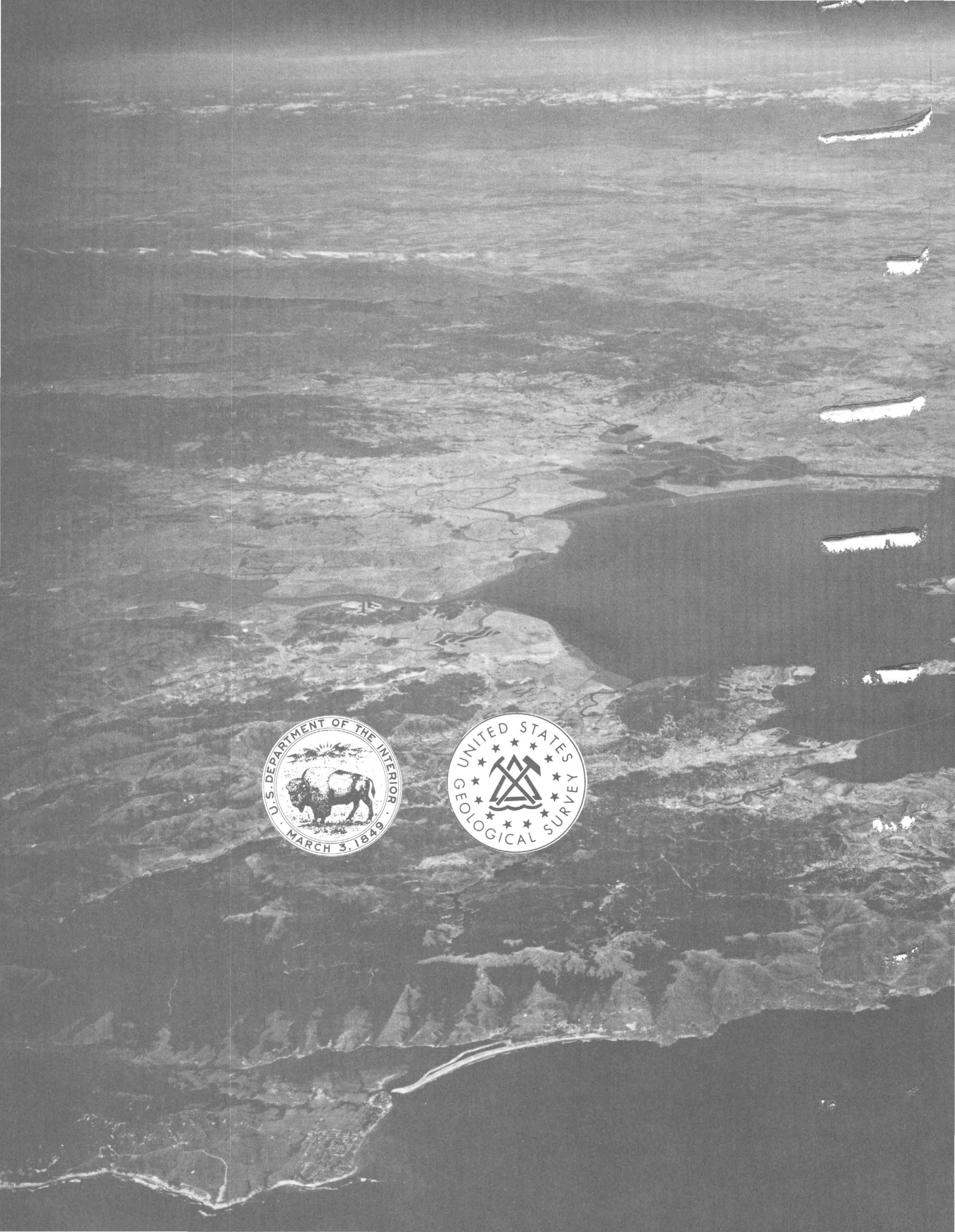
Williams, J. W., and Rogers, T. H., 1978, Relative seismic stabililty map, Santa Clara County, California (revised ed.): San Jose, Calif., Santa Clara County Environmental Management Agency, scale 1:250,000.

Yanev, Peter, 1974, Peace of mind in earthquake country; how to save your home and life: San Francisco, Chronicle Books, 304 p.

Youd, T. L., 1973, Liquefaction, flow, and associated ground failure: U.S. Geological Survey Circular 688, 12 p.

Youd, T. L., and Hoose, S. N., 1978, Historic ground failures in northern California triggered by earthquakes: U.S. Geological Survey Professional Paper 993, 177 p.

Youd, T. L., Nichols, D. R., Helley, E. J., and Lajoie, K. R., 1975, Liquefaction potential, *in* Borcherdt, R. D., ed., Studies for seismic zonation of the San Francisco Bay region: U.S. Geological Survey Professional Paper 941-A, p. A68-A74.


U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849
UNITED STATES
GEOLOGICAL SURVEY