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PRELIMINARY MAP OF HISTORIC MARGINS OF MARSHLAND, SAN FRANCISCO BAY, CALIFORNIA

by Donald R. Nichols and Nancy A. Wright

INTRODUCTION

The changes in the margins, size, and depth of San Francisco Bay in historic time have been the subject of much controversy. Estimates of the area that has been filled have been cited as evidence that one of the Nation's most scenic estuaries is rapidly being destroyed. Widespread concern has been voiced on the possible disastrous effects of a great earthquake on structures built on fill overlying soft saturated sediments in the Bay. Legal questions have arisen over the boundaries of original land grants bordering the Bay and the blocking of navigable channels by filling or diking. Data bearing on these and related problems, however, have not been readily accessible or easily compiled.

The location of former margins of salt marshes and old sloughs [1/] and channels have been determined for small areas of the Bay (Bonilla, 1965; Bonilla and Gates, 1961; and Radbruch, 1957, and 1959) or for specific sites. The character of sediments in and between old channels and sloughs may vary markedly and may greatly affect the stability of fill and structures placed over them. However, the location of many of these relic features may be masked from detailed site exploration by fill and evaporation ponds. A detailed synthesis of early surveys for the entire Bay area has long been needed for regional and local planning efforts and for engineering projects. The accompanying map was prepared from the earliest available U. S. Coast and Geodetic Survey (C&GS) topographic surveys (see tabulation of dates and index map) to satisfy these needs. In this compilation "the Bay" is used to refer collectively to all areas marginal to the San Francisco Bay (west to the Golden Gate Bridge), including Carquinez Strait and San Pablo, Grizzly, Suisun, and Honker Bays (east to Pittsburg on the Sacramento River).

SOURCES AND METHOD OF COMPILATION

The preliminary map of historic margins of marshlands was compiled through a series of reductions and interpretation of 32 C&GS topo-

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[1/] For ease of reference and to distinguish them from other channels, sloughs are defined here as sluggish or quiet-water channels that are now open at both ends to the Bay or to a tidal channel tributary to the Bay.

graphic sheets and part of the U. S. Geological Survey 15-minute Mare Island quadrangle (1916 edition). Stable-base film positives were obtained from the C&GS at 1:24, 000 by photographic reduction of 25 sheets surveyed between 1850 and 1897 and presently stored in archives in Rockville, Maryland. In seven areas, data was compiled by reduction of paper prints at the original scale of 1:10, 000 in a Saltzman overhead projector. The sheet numbers and dates surveyed are tabulated and the area covered by each are shown on the inset. Sloughs, channels, and marsh limits on these early surveys were traced on paper prints of modern USGS 7 1/2-minute quadrangles. Because of some geodetic inaccuracies in the early surveys, in the paper used for the surveys, and possibly in the photographic reduction process, a direct tracing would be grossly misleading. Consequently, data were transferred from the film positives, and adjusted from local control points in small portions of the early map to similar points on modern maps. The control points include topographic highs, intricate stream-meander patterns, cultural features, and geodetic control. In some places, one or more control points within a given area were askew, and arbitrary decisions, based on interpretations of local morphology, were made on how the data were to be adjusted. Compilations made by others would very likely differ in these areas.

The limits of the marshland, the sloughs, and all but a few of the smallest channels shown on the 1:24, 000-scale compilation, were reduced in a Saltzman projector and transferred by hand to a single scale-stable base at 1:62, 500. This base was compiled from a controlled mosaic of the 1968 edition, 1:24, 000-scale USGS maps. The 1:62, 500 compilation was photographically reduced and superimposed on an enlargement to 1:125, 000 of the 1:250, 000 USGS map prepared as a planning base for the Association of Bay Area Governments.

DEFINITION OF MAP LINES

1. Inner (landward) edge of marsh

The significance of lines shown on the early C&GS maps and on this map varies from place to place. Shalowitz (1964, p. 181), in discussing early surveys, writes that, in general, the inner, or landward line, of marsh areas, "has always been interpreted (by C&GS)... as indicating the dividing line between the marsh land and the fast or upland, and not as representing any particular tidal elevation other than that inshore of this line and land if bare (of water) at all stages of the tide. Generally, it may be considered as the limit of penetration of the highest tides, but... in certain stages of marsh development (and in nonmarsh areas) it may coincide with the high-water line."

"The detail with which the line was surveyed depended largely upon its accessibility. Not being a feature readily seen by the mariner, the tendency was toward generalization..."

In some areas surrounding the Bay, marsh symbols extend inland from the inner edge of the marsh line shown on the early maps. Such marshes are continuous with the salt-water marshes and probably represent areas of high water table during the winter rainy season and may be underlain by young bay mud although they are not shown on this compilation.

The location of the inner marsh line appears quite accurate in many areas but is in obvious error locally. In the few places where good drainage or topographic control is common to both modern and early maps, the landward limit, if traceddirectly, would fall well up on natural hillslopes. In such areas of obviously gross error, the inner marsh line was accomodated to the present topography. Examples of such areas occur locally in Suisun Bay and Carquinez Strait. Parts of several early surveys did not extend inland to the inner edge of the marsh. Where more recent C&GS survey sheets were not readily available at the time of compilation, the approximate location of the inner marsh line is shown as a dashed line. This line is based on thegeneral coincidence of the inner marsh line with the modern 5-foot contour and with bayward land-grant boundaries, which appear as a red dash-dotted line on modern 7 1/2-minute quadrangles.

Today, relatively limited areas of original marshland surround the Bay. Comparison of modern C&GS hydrographic charts (5531, 5532, 5533, and 5534) with the mid-1800 surveys indicates that "true" marshland remains only in a large area north of Grizzly Bay; in smaller areas east of Napa Slough and north of San Pablo Bay, east of Dumbarton Bridge, and parts of Bair Island; and in small areas elsewhere. Most of the marshland shown on early surveys has been filled or diked off for various uses, principally as salt evaporation ponds.

2. Outer (bayward) edge of marsh

The bayward line, which corresponds to the shoreline on modern maps, normally is defined as mean high water. In practice, however, it represents the outer edge of vegetation--the visible line between marsh grass and mud flat exposed at low tide. This same practice seems to have prevailed in the preparation of early maps with the added note by Shalowitz (1964, p. 177) that, "to the navigator (it) would be the dividing line between land and water. On most early surveys, no distinction was made between this line and the line of high water on fast ground..."

"Where the (early) topographic or hydrologic surveys show a low-water line outside the marsh line (as they do on most topographic survey sheets in the San Francisco Bay area) it would be a safe indication that the marsh at its outer edge was above low water, but it would still be no indication as to the conditions of the marsh with respect to high water unless determined by other evidence."

In many parts of the Bay, extensive mud flats--45,000 acres according to Harvey (1966, p. 17)--are exposed bayward of the outer marsh line during low water. Actually, the large size of this area results from the shallowness of much of the Bay rather than the great tidal range. The maximum tidal range in the Bay varies from only 8.5 feet to 14.0 feet, being least at the confluence of the Sacramento and San Joaquin Rivers and greatest at Alviso in the southern part of the Bay.

3. Channels and Sloughs

Most small channels shown on maps of the 1850's are remarkably accurate in detail and relative spacing when compared to the same channels on modern maps. Channels in a few areas, however, evidently were depicted schematically or without close planimetric control. Both accuracy and detail suffered where the surveys did not extend inland to the inner marsh line, such as in parts of Suisun Bay and the Sonoma River drainage. In the upper Sonoma River drainage, major channels were traced from the 1916 edition of the 1:62,500 Mare Island USGS map. A few of the smallest channels are not shown on the map where their density was so great that they couldn't be represented easily at 1:24,000. The configuration of many of these very small channels were generalized where required by the reduction from 1:10,000 to 1:24,000.

Man has modified the shoreline and many of the larger sloughs and channels; these changes are obvious in some areas and less apparent in others. Migration or modification of meander patterns in many large sloughs and channels, however, probably result from natural processes. Currents, either from stream flow or from in-going and out-going tides, erode the outside curve of a meander and deposition occurs on the slip-off slope, or inside curve. Modification of small sloughs is perhaps less likely because they are generally protected from the direct effects of the full tidal reach. Similarly, small- and intermediatesized channels exhibit little change, probably because they have only minor intermittent fresh-water flow and are protected from tidal currents.

GENERAL GEOLOGY OF MARSHLANDS

A number of authors (Louderback, 1939; Trask and Ralston, 1951; Treasher, 1963; Goldman, 1968; Schlocker, 1968, and in press; and others) have described the general geologic framework of San Francisco Bay, its prism of unconsolidated sediments, and, in varying detail, the lithologic and engineering character of the young bay mud. For the purpose of this discussion, a brief, generalized description of the distribution and character of unconsolidated sediments will suffice.

The area encompassed within the lines on the accompanying map is virtually everywhere immediately underlain by "young bay mud." Schlocker (1968, p. 24-25), in a summary description, states:

> "...The youngest deposits are mostly soft clay and silt (mud) and minor amounts of sand and gravel. In the north-central part of the Bay, sediments are generally coarser in the tidal channels than near the shore, probably because the finer particles are carried out of the Bay by swift tidal currents or are deposited in shallow tidal marshes. Bedrock or sand and gravel are found in the main trunk channel of the Golden Gate and as far north as San Pablo Strait; soft mud or clay are common along and near the shoreline. Local exceptions are the shores of rock headlands where boulders, gravel, and sand are mixed with mud. Scattered sand deposits are also found near locations where ebb tides are concentrated into narrow powerful currents by shoreline projections. North-south sand ridges as much as 6 to 8 feet high, are common between San Francisco and Angel Island, and may be related to the interaction of ebb and flood tidal currents.
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> "The soft muds, the most common modern sediment, vary considerably in thickness. They are generally less than 10 feet thick near the shore, but are more than 100 feet thick offshore--for example between San Francisco and Yerba Buena Island and in Richardson Bay. In the Redwood Shores-Bair Island area, soft muds are about 10 feet thick near Bayshore Freeway, but about 60 feet thick near the eastern shore of Bair Island, 3 miles to the

northeast. At many places mud is more than 60 feet thick only 1/2 to 1 mile from the landward edge of the marshlands. In many parts of Suisun Bay mud often lies on stiff older clay or on sand deposits. Near the mouths of such streams as San Mateo, San Francisquito, and Alameda Creeks, mud interfingers with sand, gravel, and silt brought into the Bay by the streams."

In addition to sand layers and lenses, significant peat and shell beds occur within the young bay mud in many areas. Virtually all of these sediments have been deposited in Holocene time (the last 10,000 years).

The historic extent of the inner marsh line may be used as a rough guide to the landward extent of young bay mud at the surface. Although young bay mud may be present at the surface inland from this line, such as in adjoining fresh-water marshes, it is likely to be quite thin (less than 5 feet). In the subsurface, young bay mud locally may extend well inland of the inner marsh line where the mud interfingers with alluvial deposits of the principal drainages such as the Alameda Creek fan in Fremont.

Sediments beneath the young bay mud consist of a sequence of estuarine dense stiff clay and silty clay deposits alternating with alluvial sand and gravel beds. These deposits of middle to late Pleistocene age (10,000 to 2,000,000 years) vary greatly in continuity and thickness; locally they are probably as much as 1,000 feet thick or more in the Santa Clara Valley. Except in areas of rock headlands, older bay sediments probably extend well inland from the marshland limits in the subsurface.

ENGINEERING SIGNIFICANCE OF FORMER MARSHLANDS AND BAY MUD DEPOSITS

In recognition of the engineering and environmental significance of San Francisco Bay, the State of California established the San Francisco Bay Conservation and Development Commission (BCDC) with broad regulatory authority over development within the Bay and its bordering mudflats and marshlands. Extensive studies have been made for a broad variety of structures placed on Bay sediments. The results of many of these studies are reviewed in a series of background reports prepared for BCDC and republished as Special Report 97 of the California Division of Mines and Geology, edited by Harold Goldman and titled "Geologic and Engineering Aspects of San Francisco Bay Fill." Suffice it to say that the high water content (generally more than 50 percent by weight); the low bearing strength; the high compressibility (especially where containing peat deposits); the moderately high sensitivity (Mitchell, 1963, p. 29); and, in some localities, a high shrink-swell ratio, constitute factors that must be considered in the exploration, testing design, and construction of engineering projects on younger bay mud. These properties, along with the varying thickness and grain size (and possibly mineralogy) over relatively short distances, can result in marked local differential and regional settlement and in slope instability when loads are imposed on the sediments.

An added concern in relation to large developments is their potential effect in producing significant amounts of settlement in areas of regional delta area. In the San Jose area a maximum of 13 feet of subsidence took place between 1912 and 1967, because of ground-water withdrawal (Poland, 1970, p. 288). Much of the subsidence in the delta area apparently is due to desiccation of low-lying peat lands that have been diked off for farming operations and exposed to subaerial weathering. Local surface settlement when combined with regional subsidence can create a severe potential for flooding of large areas, especially where protective dikes rest on low-strength young bay mud. Studies by Raymond Pestrong (1965, 1969, and undated) show measurable differences in engineering properties of young bay mud between channels, marshes, and mudflats; such differences are of course minor relative to those between these environments and alluvial soils marginal to the Bay. For example the moisture content may be 2 to 5 times greater; the density only about half; and the shear strength less than one-tenth as great in the mud as in alluvial soils. However, in areas above high-tide level or that have been diked off and drained, young bay mud slowly desiccates to a depth of 3 or 4 feet and achieves a moderate strength.

During earthquake shocks, sand and silt"...layers have a tendency to lurch, subside, and slide. Earthquake vibrations in thick soft bay mud are believed to be larger in amplitude and tend to have longer periods of vibration than those in firm soil or rock. Because these longer periods might be in the same range as the natural periods of vibration of some high-rise structures, it is necessary to pay special attention to their design." (Schlocker, 1968, p. 25.)

The potential hazard of liquefaction of sand is difficult to assess and even more difficult to design around. The geologic occurrence of sand in young bay sediments is not well known. However, sand is known to be present locally near the surface in sand bars (e.g. in the vicinity of San Francisco airport) and interbedded with the young mud at shallow depth (e.g. at the Palo Alto marina). Sand is most likely to occur within the mud near the mouth of major channels and sloughs. Because sloughs and channels may migrate considerably through geologic time, particularly near the toe of large alluvial fans, buried channel deposits containing sand and (or) organic clay may occur nearly anywhere beneath the surface in young bay mud. Consequently, extremely detailed subsurface investigations are required to locate these potentially troublesome foundation conditions.

REGIONAL PLANNING SIGNIFICANCE OF FORMER MARSHLANDS

In the past 120 years the Bay and its margins have undergone many significant changes. In the mid-1800's the Bay to the outer marsh edge covered 476 square miles. Today, the Bay covers only 423 square miles--a reduction of 53 square miles or 11 percent. Historically, marshlands (including sloughs and channels less than 1/2 mile wide) have covered as much as 313 square miles marginal to the Bay. Modern (1968) tidal marshland consists of 125 square miles--a reduction of 188 square miles or 60 percent. Salt evaporation ponds cover 63 square miles (40,000 acres) of former marshland, sloughs, and channels. Deposition, either natural or man-induced (Gilbert, G. K., 1917), and disposal of dredged waste have added 52 square miles of land to the Bay; erosion and dredging have removed 3 square miles of former marshland or fast land.

In addition to providing a detailed analysis of the extent of urban and industrial encroachment into San Francisco Bay, the accompanying map can be applied effectively to a variety of planning problems, some of which are suggested below:

1. The features depicted on this and additional maps (e. g., those showing bedrock and thickness of young bay mud) directly affect the capability of the land (and Bay) to support a variety of uses and therefore, when evaluated from a regional planning point of view, should provide some basic parameters on which to base land-use decisions.
2. Disaster planning must assess the potential extent of disruption during a strong earthquake of urban structures built on fill over young bay mud. Rupture of gas lines, for example, could create a severe fire threat that would be difficult to meet if water lines also were broken and streets were damaged and made impassable to fire-fighting equipment.
3. In order to eliminate damaging differential settlement under structures in areas of thick, highly compressible or potentially liquefiable materials (major sloughs and possibly elsewhere), extensive excavation and backfilling or costly engineering design would be required. Where these conditions prevail, retention of the original estuarine environment may be an alternative worth considering.
4. The ground-motion response of young bay mud during earthquakes is a subject of current controversy. Although the map delineates the areal distribution of the mud, only general conclusions can be drawn as to its thickness--a critical factor in ground response. Until the engineering properties of the mud are better known and the state-of-the-art in earthquake engineering is greatly advanced, it will be difficult to devise explicit planning guidelines for marshland development. Interim alternatives include retaining the marshlands in their current state or requiring extremely detailed (and costly) site investigations to demonstrate clearly that the risk to structures from potential ground failure and from damage due to shaking can be reduced to acceptable levels.
5. Marshland areas that have been filled and developed can be located by study of the map. Since the fill that preceded early development on marshland and bay deposits was often haphazard, the present stability in such areas is unknown. Consequently, policy-makers may wish to consider restricting development or redevelopment in filled areas until building officials can be assured that the fill was placed in accordance with modern engineering standards or that the fill, through time, has achieved acceptable levels of static and dynamic stability.
6. The C&GS sources used in this report provide an excellent reference bearing on certain historical and legal questions. Original land-grant boundaries were established in part from the location of the inner (landward) marsh line; the C&GS surveys provide one means of assessing the accuracy of these boundary lines. Descriptive reports that accompany topographic and hydrologic surveys issued after 1887 often cite small communities that were served by boat commerce, indicating that waterways leading to them were navigable.

7. Areas of bay-shore erosion (retreat) and deposition (advance) during the last 120 years that have planning, engineering, and scientific implications are evident from the map.
8. The map also indicates pre-existing surface forms that would serve as excellent sites for special topical studies: for example, studies on depositional environments of large versus small sloughs and channels; on grain size, shear strength, and other physical properties of natural-levee materials versus those in marshes and mudflats; or on the hydrologic effects of filled channels that were once covered by evaporation ponds.

SUPPLEMENTAL NOTE

Many of the original film positives at 1:24,000 scale and paper prints of modern maps on which the original data have been interpreted and compiled are available for inspection and reproduction at cost through the USGS library in Menlo Park, California. The intermediate compilation at 1:62,500 on scale-stable mylar is undergoing refinement and revision and is not available.

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