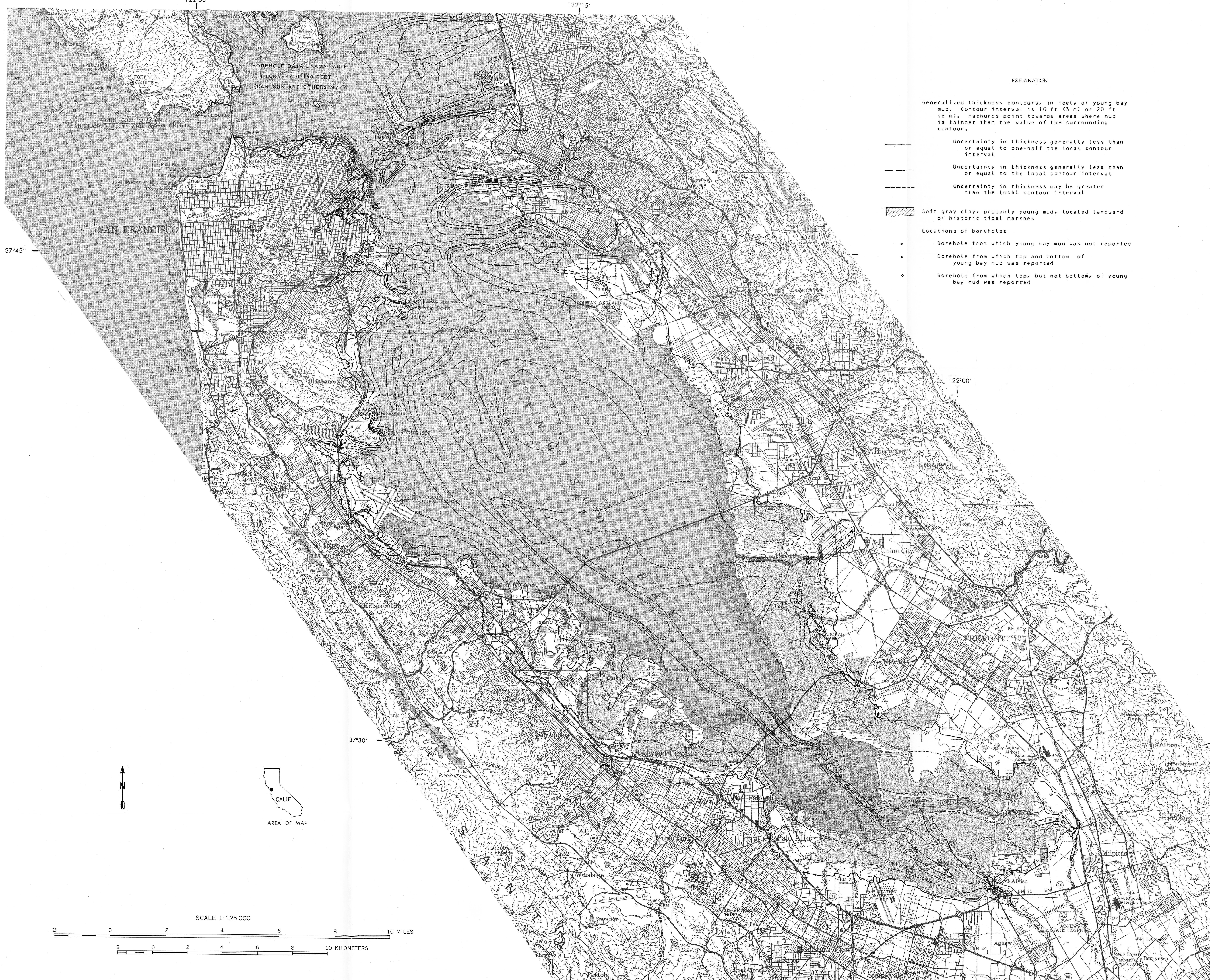

SCALE 1:125 000

2 0 2 4 6 8 10 MILES

2 0 2 4 6 8 10 KILOMETERS

BASE FROM U.S. GEOLOGICAL SURVEY, SAN FRANCISCO BAY REGION, SHEET 3 OF 3, 1970

EXPLANATION

Generalized thickness contours, in feet, of young bay mud. Contour interval is 10 ft (3 m) or 20 ft (6 m). Hachures point towards areas where mud is thinner than the value of the surrounding contour.

- Uncertainty in thickness generally less than or equal to one-half the local contour interval
- Uncertainty in thickness generally less than or equal to the local contour interval
- Uncertainty in thickness may be greater than the local contour interval

Soft gray clay, probably young mud, located landward of historic tidal marshes

Locations of boreholes

- Borehole from which young bay mud was not reported
- Borehole from which top and bottom of young bay mud was reported
- Borehole from which top, but not bottom, of young bay mud was reported

INTRODUCTION

Soft water-saturated estuarine deposits less than 10,000 years old underlie the southern part of San Francisco bay and the present and former marshlands that border the bay. Known locally as bay mud or as young bay mud, these deposits, and the estuarine environment that produces them, are of major importance in making decisions on land use and development in the San Francisco Bay area.

Knowledge of the distribution, thickness, and physical properties of young bay mud is critical to the feasibility, design, and maintenance of structures built on it. For this reason, numerous attempts have been made in the past to map or describe these characteristics (Mitchell, 1963; Goldman, 1969; McDonald and Nichols, 1974). The accompanying map of bay-mud thickness significantly revises part of an earlier compilation by Kahle and Goldman (1969) and includes new data from approximately 2400 boreholes, most of which have been drilled during the past 15 years. It also incorporates information on historic margins of San Francisco Bay and its tidal marshes (Nichols and Wright, 1971).

Although this map was compiled mostly from data gathered during foundation investigations and construction projects, it is not a substitute for such studies. Rather, the map provides regional information for land-use planning, seismic zonation, and design of foundation investigations.

ENGINEERING AND PLANNING SIGNIFICANCE OF MUD THICKNESS

Regional and local decisions on development and land use in areas underlain by young bay mud are based, in large part, on the expected response of proposed land fills and structures to compaction, flow, or earthquake-induced shaking of young bay mud (San Francisco Bay Conservation and Development Commission, 1969; City of Redwood City, 1974). This response is controlled mostly by the type, design, and weight of the structure and by the thickness and engineering properties of the fill materials, young bay mud, and underlying sediments.

Young bay mud consists of light-gray to black silty clay with subordinate beds and lenses of sand, shell, and peaty mud. Except for desiccated surficial mud behind dikes, most of these sediments have a high water content (generally more than 50 percent by weight), low bearing strength, high compressibility, moderately high sensitivity, and, in many localities, a high shrink-swell ratio (Trask and Rolston, 1951; Treasher, 1963; Pestrong, 1972). These properties can result in settlement and ground failure where static or seismic loads are placed on young bay mud, the severity of these effects generally increasing with the thickness of young bay mud and with local variations in mud thickness. Data on mud thickness have been used to predict the amounts, and thereby minimize the effects, of settlement under static loads (U.S. Corps of Engineers, 1963, fig. 23; Lee and Praszker, 1969, p. 45-48).

Young bay mud tends to flow laterally, particularly toward channels, sloughs, into excavations, and even toward gentle slopes if loads are placed unevenly. Although cohesive mud does not liquefy during earthquakes, thin, discontinuous, clay-free granular layers within young bay mud do have a generally high potential for liquefaction (Youd and others, 1975, p. 7).

The presence of young bay mud may increase the amplitude of low-frequency, earthquake-generated ground motion (Borcherdt and others, 1975, p. 90-93). Recent foundation studies have applied mud-thickness data to predict the nature of seismic ground shaking (for example, Garbe and Donovan, 1971, p. 10), thereby assisting engineers in the design of fills, levees, and buildings.

Information about bay-mud thickness is useful to planners and developers in determining the types of land use most compatible with site conditions. For example, partly on the basis of a geologic and structural engineering study (Woodward-Clyde and Associates and McClure, 1969), the Planning Policy Committee of Santa Clara County (1972) adopted a policy to preserve and enhance the "bay, marshlands, wetlands, salt ponds, sloughs, and creeks", which are underlain by young bay mud. Similarly, maps showing thickness of young bay mud and location of potentially liquefiable granular layers near Hayward (McDonald and Nichols, 1974) contributed to a map of "General Land-Use Capacities" (Goldman, 1973). Recommendations accompanying this map suggested that undeveloped areas underlain by more than 5 feet (1.5 m) of bay mud be "considered as unsuitable for development because of the engineering problems associated with building structures on the unstable bay muds, including the stability of fills; and [because of] the potential seismic effects on any fill or attendant developments on it and the existing levee system that would lead to earthquake damage and/or flooding." On the other hand, "The land areas between the seven foot [2.1 m] elevation contour and the contour delineating the thickness of the underlying bay mud as five feet [1.5 m] is considered to be developable with proper engineering controls and adequate inspection" (Goldman, 1973, pl. 5 and p. 35).

METHODS AND UNCERTAINTIES

Borehole records

Records from approximately 4,000 boreholes were used to prepare this map (table 1). Borehole locations were plotted initially by hand or by computer on 1:24,000-scale maps. These compilations were then reduced photographically to 1:125,000 and combined in a mosaic.

Variations in drilling equipment, discontinuous sampling, poor-quality logs, and ambiguous stratigraphy contribute to uncertainties in bay-mud thickness. Average drilling and logging procedures allow determination of the thickness of bay mud to within 5 to 10 ft (1.5 to 3 m). Greater precision is possible in localities where bay mud overlies more consolidated alluvial, eolian, or older estuarine sediments and where bay mud overlies bedrock. Physical properties of young bay mud and these older materials differ sharply beneath most of the southern part of San Francisco Bay, thus allowing easy recognition of the base of the bay mud (Trask and Rolston, 1951, p. 1087; Treasher, 1963, p. 23; Atwater and others, 1977, p. 5). Uncertainties greater than 10 ft (3 m) are likely where bay mud includes abundant sand (as in the axial channel of San Francisco Bay and the shoals west of San Lorenzo), has been covered or mixed with artificial fill (San Francisco and Treasure Island), has been removed by dredging (Alameda and Oakland Shipping Channels), and where sediments resembling young bay mud except for their slightly greater firmness directly underlie young bay mud (near South San Francisco).

Construction of contours

Accuracy of the thickness contours depends mostly on the density of borehole data. In areas with abundant borehole data, such as parts of San Mateo County, uncertainties in the thickness contours are generally less than one-half of the local contour interval. On the other hand, uncertainties equal or exceed the local contour interval where borehole data are sparse or absent, such as the subtidal areas south of Yerba Buena Island, northeast of the San Francisco International Airport, and northwest and southeast of the San Mateo Bridge. No attempt was made to assess local variations in mud thickness in the vicinity of channels and sloughs less than 0.3 mi (0.5 km) wide.

Dotted-line contours in areas having few boreholes are based mostly on the difference in elevation between the bay bottom, as depicted on modern bathymetric charts, and the land surface on which young bay mud was deposited, as shown on a preliminary topographic map of this ancient valley (Brian Atwater, unpub. data). Although contoured from the same borehole data as the thickness map, the map of buried landforms provides the best available means of extrapolating the thickness of young bay mud because the buried landforms should have simpler, more predictable contours than bay-mud thickness, which reflects the irregular shape of the bay bottom as well as the topography of the buried land surface.

Ambiguities in the interpretation of buried landforms, however, may locally invalidate dotted-line contours. For example, near the mouth of Alameda Creek, the land surface that existed before deposition of young bay mud, as indicated by scanty borehole data, could be either concave, planar, or convex. In showing a wedge of thick bay mud in this area, we have assumed the original surface to have been a stream valley draining toward the west. Others, however, might plausibly assume an alluvial fan, which would lead to a generally thinner section of bay mud.

The zero-thickness contour is generally equivalent to the landward edge of salt marshes existing between 1851 and 1897 (Nichols and Wright, 1971) or, in areas where no marsh was present, to the high-water line during that period. However, borehole records suggest that young bay mud underlies alluvium landward of the nineteenth-century shorelines at the mouths of all the major creeks tributary to the southern part of San Francisco Bay (Coyote Creek, Guadalupe River, San Francisquito Creek, Alameda Creek, and Colma Creek), and that mud locally underlies windblown sand in San Francisco (Schlocker and others, 1958). Although the zero-thickness contour is never shown bayward of the landward edge of a historic salt marsh, young bay mud appears to be missing beneath some marshes in Santa Clara County that have been plowed, graded, diked, or filled. These activities probably caused desiccation, consolidation, and mixing of a thin layer of bay sediments.

PATTERNS OF MUD THICKNESS

Bay mud is thickest where it has filled the valleys of ancient streams. For example, over 120 ft (35 m) of mud has accumulated east of South San Francisco along the probable course of the trunk stream that drained the site of southern San Francisco Bay 10,000-15,000 years ago, and as much as 100 ft (30 m) of mud has filled the narrow valleys that separated late Pleistocene sand dunes west of the sites of Alameda and Oakland.

Bay mud is commonly thin where tidal currents scour the bay bottom, such as in the channel that passes beneath the San Mateo and Dumbarton Bridges. It is also thin over the submerged crests of sand dunes west of Alameda and Oakland (Atwater and others, 1977, pl. 1).

VOLUME OF BAY MUD

Approximately 1.0±0.2 mi^3 (7±1 km^3) of young bay mud underlies the floor and margins of San Francisco Bay south and east of the San Francisco-Oakland Bay Bridge. This estimate is 0.3-0.5 mi^3 (2-3 km^3) larger than that of Smith (1965, p. 690), which was based on a thickness map that incorporated about 25 percent of the data from which our map was compiled.

We determined the approximate volume V of young bay mud beneath the floor and margins of southern San Francisco Bay from the summation

$$V = \Sigma A \cdot t,$$

where A is the area between adjoining thickness contours and t is the average thickness between the contours. The areas were measured with a digital planimeter for roughly concentric bands bounded by the following interpolated contours: 5 and 15 ft (1.5 and 4.5 m), 15 and 25 ft (4.5 and 7.5 m), 25 and 35 ft (7.5 and 10.5 m), 35 and 50 ft (10.5 and 15 m), 50 and 70 ft (15 and 21.5 m), 70 and 90 ft (21.5 and 27.5 m), 90 and 110 ft (27.5 and 33.5 m), and 110 and 130 ft (33.5 and 39.5 m). Bay mud thinner than 5 ft or thicker than 130 ft makes a negligible contribution to the mud volume and was ignored. The average thickness beneath each band, t, was equated with the thickness contour that approximately bisects the band: 10, 20, 30, 40, 60, 80, 100, and 120 ft (3, 6, 9, 12, 18, 24, 30, and 36 m), respectively. This procedure resembles the approximation of the area under a curve as the sum of the areas of rectangles.

ACKNOWLEDGMENTS

We appreciate the invaluable contributions of hundreds of drillers and loggers responsible for the borehole records on which the map is based, and the generous cooperation and assistance of the following firms: Cooper, Clark and Assoc., Gribaldo, Jones and Assoc., Harding-Lawson and Assoc., Lee and Praszker, Lowney Kaldveer Assoc., and Woodward-Lundgren and Assoc. John McMurdie, Erik Eliasen, and James Browning assisted in designing and maintaining the storage, retrieval, and plotting of computerized data. Sandra A. Stansbury, Krystyna Durön, and Zondra Kilpatrick contributed to preliminary versions of this map.

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Table 1.--Principal sources of borehole data used in compiling map of the thickness of young bay mud

Number of logs and thickness records[1/]		Principal compilers	Principal contributing firms and agencies
Entered into computer storage	Original data		
2200	2200	Sandra Chamberlin Sandra McDonald D. R. Nichols Sandra Stansbury Barbara Turner N. A. Wright	California Division of Bay toll Crossings California Division of Highways Cooper Clark and Assoc. Gribaldo, Jones & Assoc. Harding-Lawson & Assoc. Lee & Praszker Lowney Kaldveer Assoc. U.S. Crops of Engineers
400	~1000	R. C. Treasher and others, U.S. Corps of Engineers Dames & Moore	California Division of Bay Toll Crossings California Division of Highways Dames & Moore Portland Cement Company U.S. Corps of Engineers U.S. Navy
125	275	Julius Schlocker M. G. Bonilla	Numerous private firms and governmental agencies in San Francisco
50	400	F. C. Carraro B. F. Atwater	California Division of Bay Toll Crossings (contract 82-032 and 86-041)
10	10	A. Sarna-Wojcicki	Santa Clara County

[1/] All data held by the U.S. Geological Survey in Menlo Park, California.

MAP SHOWING THICKNESS OF YOUNG BAY MUD, SOUTHERN SAN FRANCISCO BAY, CALIFORNIA

BY

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