WILLIAM LETTIS & ASSOCIATES, INC.

Final Technical Report

Characterization of Subsurface Sediments, Northern San Francisco Bay Area

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FINAL TECHNICAL REPORT

CHARACTERIZATION OF SUBSURFACE SEDIMENTS, NORTHERN SAN FRANCISCO BAY AREA

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ABSTRACT

Our study provides an initial evaluation of the subsurface distribution of potentially liquefiable sediments in the northern San Francisco Bay area. The purpose of our mapping is to provide the preliminary geologic and geotechnical framework required to prepare three-dimensional liquefaction hazard maps in the northern San Francisco Bay area. Based on interpretation of compiled subsurface data, we have evaluated the subsurface distribution of the following for the northern San Francisco Bay:

- Elevation of the buried top of Pleistocene deposits, and,
- Distribution, and ages of artificial fills along the Bay margins.

Over half of all documented historical occurrences of liquefaction in the San Francisco Bay area have occurred within artificial fill placed over bay margins (Knudsen et al., 2000). During the past century, following the 1906 earthquake, tens of millions of cubic meters of fills have been placed along bay margins including infilling of the Marina District, creation of Treasure Island and Alameda Naval Air Station, and expansion of San Francisco and Oakland airports. Many of these artificial fills, emplaced prior to regulation in 1969, lack soil improvement to increase their liquefaction resistance and have yet to be shaken strongly during a major earthquake (Holzer et al, 2006). The relatively poor performance of post-1906 fills during the 1989 Loma Prieta earthquake, along with localized liquefaction-related damage in fill overlying deltaic deposits during the 1995 Kobe (Great Hanshin), 2001 Nisqually, and 2003 San Simeon earthquakes, demonstrate the unique vulnerability of artificial fills emplaced along Bay margins to strong ground shaking during future large earthquakes.

Our derivative maps contribute toward the ultimate goal of isopach maps depicting the cumulative thicknesses of poorly consolidated artificial fill and Holocene sandy sediments (i.e. potentially liquefiable sediments). Our research addresses Element I, Products for Earthquake Loss Reduction, and Element II, Research on Earthquake Occurrence and Effects, of the National Earthquake Hazard Reduction Program.

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1.0 PURPOSE

The focus of liquefaction hazard mapping is shifting from an assessment of the surficial distribution of liquefiable deposits to an understanding of the three-dimensional distribution of liquefiable deposits. A complete assessment of liquefaction hazard requires not only an understanding of the areal distribution of susceptible deposits, but also a characterization of the thickness, depth, and geometry of these potentially liquefiable units. In this study, we explore the preliminary three-dimensional geologic framework required for quantitative assessment of liquefaction hazard for the margins of the northern San Francisco Bay, California (Figure 1). Our research addresses Element I, Products for Earthquake Loss Reduction, and Element II, Research on Earthquake Occurrence and Effects, of the National Earthquake Hazard Reduction Program.

Much of the urban development within the broad flatlands bordering the San Francisco Bay is underlain by Holocene sediments deposited during the last interglacial rise in sea level. These largely unconsolidated to semi-consolidated sediments are vulnerable to liquefaction and amplification of strong ground motions. However, the subsurface distribution, thickness, seismic response, and geotechnical properties of these young sediments and overlying artificial fill within the Bay basin are poorly characterized.

Historically, localized liquefaction-induced ground failure and ground motion site amplification have been a major cause of damage to property and lifeline facilities during large-magnitude earthquakes in the San Francisco Bay area. For example, liquefaction produced by the October 17, 1989 Loma Prieta earthquake resulted in significant damage to bayshore areas on the borders of the bay. The distribution and thicknesses of soft sediment exerted a strong influence on both the occurrence of liquefaction and the severity of ground shaking throughout the affected region (EERC, 1990). As a result, major structural damage and corresponding loss of life was concentrated at a few sites along the Bay margin underlain by young sediments and artificial fill which failed during liquefaction and/or amplification of strong ground motions at the ground surface.

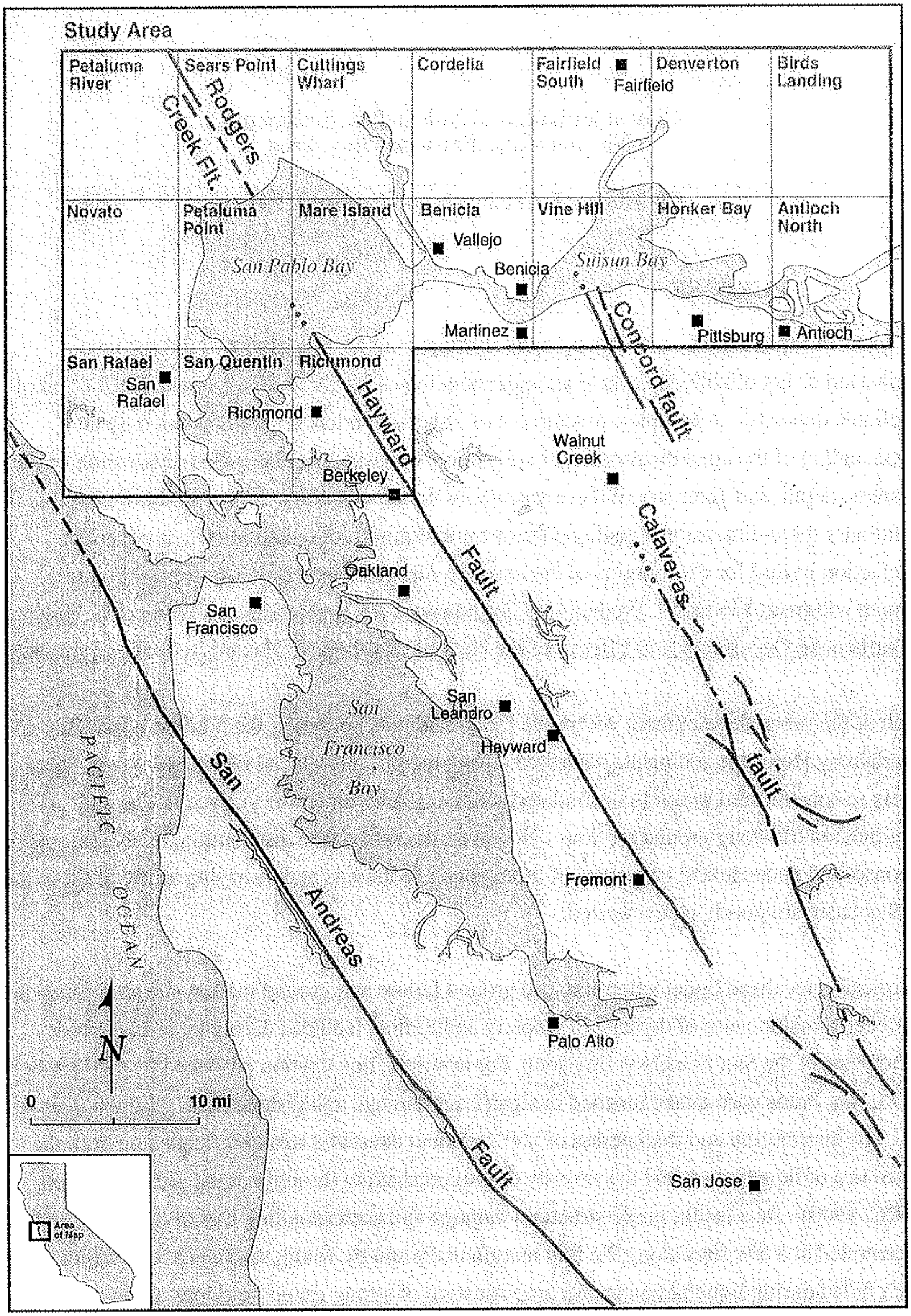

Figure 1. Map showing the northern San Francisco Bay study area.

Our research builds on the approach employed by Helley (1990) to delineate the top of Pleistocene deposits in the Santa Clara Valley, within the southern part of the San Francisco Bay area (Figure 1). Helley (1990) initially contoured the top of Pleistocene deposits within Santa Clara Valley using CALTRANS geotechnical borings. Helley's map contributed to the understanding of the subsurface structure of the Santa Clara Valley and has been used to estimate the thickness of liquefiable sediments for liquefaction hazard evaluation in San Jose (e.g. Power et al, 1992).

The top of the Pleistocene deposits typically is accompanied by a notable increase in borehole penetration resistance (i.e. blow counts) that coincides with a marked reduction in liquefaction susceptibility with depth (Power et al, 1992; Hitchcock and Helley, 2000). In general, the 'top of Pleistocene' represents the probable base of potentially liquefiable deposits within the Bay area. Based on this observation, first applied by Power et al (1992), we produced derivative maps showing the thickness of the overlying Holocene deposits for the south Bay area. These maps were constructed by contouring thicknesses of these deposits, as identified in boring logs, and by subtracting the elevation of top of the Pleistocene from the elevation of Holocene and/or artificial fill deposits mapped at the surface. Our maps contribute toward the ultimate goal of isopach maps showing the cumulative thickness of sandy sediments (i.e. potentially liquefiable sediments), within the Holocene deposits. Insufficient subsurface data and the very different, more discontinuous nature of Holocene deposits in the North Bay area precluded production of similar maps. However, we have examined the likely subsurface distribution of the buried top of Pleistocene deposits within the region. We also have delineated the distribution and ages of overlying artificial fills for the study area.

Although not the primary objective of this study, our results contribute indirectly to the characterization of the subsurface structure and stratigraphy of basins in the San Francisco Bay region. The 'top of Pleistocene' represents a former land surface that existed prior to the rise of seawater through the Golden Gate at the beginning of the Holocene (Helley and Lajoie, 1979; Atwater and others, 1977). Reconstructing the buried Pleistocene landscape to the degree possible, therefore, provides a unique and important strain gauge for evaluating the location and style of Holocene deformation along the Bay margins.

2.0 STUDY AREA

The study area extends from Berkeley on the northern San Francisco bay margin, to Vallejo on San Pablo Bay, and Antioch on Suisan Bay (Figure 1). The area has been mapped by William Lettis & Associates, Inc., as part of NEHRP-funded regional liquefaction susceptibility studies (Knudsen et al., 2000; Witter et al., 2006). San Francisco Bay is a northwest-trending basin bounded on the west by the San Andreas fault and on the east by the Hayward and Calaveras fault systems. The Bay basin is filled with up to 1000 m of sedimentary strata. However, poorly consolidated Holocene sediments deposited during the most recent sea level rise and intrusion into the Bay are generally less than 50 m thick. Of these young sediments, typically only the upper 15 m are susceptible to liquefaction where saturated.

3.0 BACKGROUND

During the last glacial period, when sea levels were significantly lower (up to 130 m elevation below the current sea level), fluvial and eolian sediments covered valleys that occupied the San Francisco Bay basin. These non-marine Pleistocene deposits experienced a sustained period of sub-aerial exposure and weathering and consolidation during this period of lower sea level (Helley and Lajoie, 1979). Melting and retreat of glacial ice at the end of the Pleistocene caused sea level to rise and invade the valleys now occupied by the San Francisco and San Pablo Bays (Helley and Lajoie, 1979). Holocene sea levels in San Francisco Bay documented by Atwater and others (1977) suggest that water re-entered the Golden Gate about 10,000 years ago and that water levels in the Bay rose to their present level about 5,000 years ago.

Holocene sea level rise has caused San Francisco Bay to fill and spread eastward through San Pablo and Suisan Bays into the Great Valley. In the Delta area, intertidal peat began to accumulate about 7,000 years ago (Schlemon and Begg, 1975). Holocene deposits principally formed in wetlands and consist of peat, peaty mud, and mud. These deposits usually are softer than underlying alluvial basin, eolian, and floodplain deposits. No well-documented estuarine deposits of Pleistocene age have been reported in the Delta (Atwater, 1980). In the northern Bay area, unlike in the southern Bay area, the Pleistocene surface also is preserved as isolated terrace remnants and coquina along Carquinez Strait (Atwater, 1980). During the Pleistocene, westerly winds likely carried glacial-age flood plains or river deposits, forming dune fields atop the exposed landscape. Thus the Pleistocene alluvial landscape, mantled in part by eolian sand, extends under the Holocene estuarine deposits. It is this abrupt contrast in stratigraphy between Holocene and Pleistocene deposits that marks the Pleistocene unconformity buried beneath the northeastern Bay Area, including San Pablo Bay.

3.1 Buried Top of Pleistocene Deposits

The primary basis for identification of the Pleistocene unconformity, now buried beneath Holocene sediments, is derived from the consolidation of Pleistocene deposits during subaerial exposure following lowering of water levels in the Bay during the last sea level drop. This period of subaerial exposure is distinguished by the development of a distinct pedogenic horizon identified in subsurface borings and excavations. The presence of this horizon typically is accompanied by a notable increase in density, and changes in color and texture that are identifiable in standard geotechnical boring logs.

The pedogenic horizon coincides with a marked increase in density, and, thus, reduction in liquefaction susceptibility with depth. Therefore the top of Pleistocene deposits represents the probable base of potentially liquefiable deposits within the Bay area. Where Pleistocene deposits are not preserved, the unconformity is often distinguished by the presence of Holocene Bay Mud atop older bedrock. This depositional contrast (i.e., Holocene deposits on bedrock) represents the most significant subsurface seismic impedance known in the southern San Francisco Bay area (Lajoie and Helley, 1975).

Identifying the buried top of Pleistocene deposits, based on the above criteria, provides a basis for delineating the thicknesses of overlying Holocene deposits. Our ongoing research builds on the approach first employed by Helley (1990) in the Santa Clara Valley to delineate the top of Pleistocene deposits. We have completed a preliminary evaluation of the subsurface location of the top of Pleistocene along northern Bay margins by incorporating geotechnical data collected by CALTRANS during earthquake retrofitting and other major road improvement projects.

3.2 Distribution and Ages of Artificial Fills

Over half of all documented historical occurrences of liquefaction in the San Francisco Bay area have occurred within artificial fill placed over bay margins (Knudsen et al., 2000). Artificial fill over Bay Mud has hosted about 50 percent of all historical liquefaction occurrences in the San Francisco Bay area. However, about 83 percent of liquefaction occurrences from the 1989 Loma Prieta earthquake occurred in artificial fill whereas only about 30 percent of liquefaction failures in earlier earthquakes, including 1906, occurred in fill emplaced on Bay margins. Holzer et al (2006) note that laterally extensive fills emplaced along the East Bay margins since 1906 performed badly when subjected to the relatively moderate ground shaking generated by the distant 1989 Loma Prieta earthquake, and have yet to be tested by intense ground shaking generated by a large, nearby earthquake.

During the past century, following the 1906 earthquake, tens of millions of cubic meters of fills have been placed along bay margins including infilling of the Marina District, creation of Treasure Island and Alameda Naval Air Station, and expansion of San Francisco and Oakland airports. Many of these artificial fills, emplaced prior to regulation in 1969, lack soil improvement to increase their liquefaction resistance and have yet to be shaken strongly during a major earthquake (Holzer et al, 2006). The relatively poor performance of post-1906 fills during the 1989 Loma Prieta earthquake, along with localized liquefaction-related damage in fill overlying deltaic deposits during the 1995 Kobe (Great Hanshin), 2001 Nisqually, and 2003 San Simeon earthquakes, demonstrate the unique vulnerability of artificial fills emplaced along Bay margins to strong ground shaking during future large earthquakes.

The behavior of artificial fills within reclaimed land along bay margins subject to strong ground shaking became a major source of concern following the catastrophic effects in bayfront fills during the 1995 Kobe (Great Hanshin) Japan earthquake. More recently, localized liquefaction produced by the 2001 Nisqually earthquake and 2003 San Simeon earthquake in artificial fills covering former tidal flats has confirmed the vulnerability of non-engineered, man-made fills emplaced along bay margins to failure during seismic shaking, even under relatively low ground motions (Troost et al., 2001; Holzer et al., 2005).

Based on our research to date, the age of the fills can be used as a proxy for fill composition (based on method of emplacement and source of material). During the 1989 Loma Prieta earthquake, there was a strong correlation between the age and type of fill (hydraulic versus dumped) and type of underlying deposit (sand shoals versus Bay Mud) with the prevalence of localized sand boils and ground failure (Holzer et al., 1993). Areas of the greatest settlement and number of sand boils coincided with hydraulically emplaced sand fills (mostly emplaced in the 1930s and 1940s). For example, there is a close correspondence between the occurrence of sand boils observed in 1989 at the Alameda Naval Air Station and location of hydraulic fills. In addition, few failures occurred in post-1965 fills suggesting that fill type, roughly correlative to fill age because of the evolution in fill emplacement practices over the past century, does have a direct correlation with potential liquefaction-induced failure.

Methods of fill emplacement and types of material used over the past century are directly correlative to the progressive bayward growth of the Bay shoreline. The historical progression of fills into the Bay has been accompanied by changes in how fill is placed (evolving from dumping to hydraulic filling using sand from the Bay to modern engineered fill) and what sources of fill have been used (ranging from local soil and quarry rock during early reclamation efforts, dumping of building debris after the 1906 earthquake, and massive reclamation efforts using sand dredged from the Bay during construction of much of Treasure Island and Alameda). The age of fills, verified against historical records and vintage aerial photographs, can be determined by analyzing progressive filling of the Bay based on shorelines derived from historic topographic maps.

Fills emplaced since 1965 along the Bay margins have been required to be engineered. However, engineered fill and subsequent Bay margin development in many instances overlies older, potentially liquefiable uncompacted artificial fill. These older Bay fills were placed directly on top of Holocene estuarine sediments, including sand shoals, tidal mud flats, and tidal and fluvial channels. Trask and Rolston (1951) noted that historic settlement rates of fill are, in part, directly related to both the thickness of the fill, and underlying Bay Mud, and the sand content within the fill and underlying Bay Mud. Fill settlement is not uniform because permeable sand layers within the estuarine sediments (e.g., within Bay Mud) enable migration of water during loading and thus influence the behavior of the overlying fills. Fill settlement is more pronounced and rapid in sandy fill and fill overlying sand shoals or sand bodies within Bay Mud, relative to areas where the fill is either well compacted, clayey, or the underlying estuarine sediment contains no sand (Trask and Rolston, 1951). It is likely that similar, although more rapid, localized liquefaction-related fill settlement and failure will occur at these locations during earthquake loading.

4.0 METHODS

Our methodology emphasizes delineating the thickness and lateral continuity of liquefiable sediments. We have collected subsurface boring logs representative of surface and subsurface deposits within the northern San Francisco Bay Area. We interpreted these subsurface data to produce a series of interpretative maps for the northern San Francisco Bay that delineate; (1) elevation of the top of Pleistocene deposits, and (2) the distribution and ages of artificial fills.

Our research builds on the approach employed by Helley (1990) to delineate the top of Pleistocene deposits in the Santa Clara Valley, within the southern part of our proposed San Francisco Bay study area (Figure 1). Helley (1990) contoured the top of Pleistocene deposits within Santa Clara

Valley using geotechnical borings from the California Department of Transportation (CALTRANS). We employ similar techniques for the northern Bay area by incorporating recent CALTRANS geotechnical data. The top of Pleistocene deposits typically is accompanied by a notable increase in penetrometer resistance, and changes in color and texture that are identifiable in standard geotechnical boring logs. Identifying the buried top of Pleistocene deposits provides a basis for delineating the thicknesses of overlying Holocene deposits and artificial fills. Below we provide more information on our approach and the mapping techniques we used.

4.1 Borehole Compilation

Geologic and geotechnical data compiled during the course of the study has been entered into our in-house ArcGIS system and formatted to meet requirements of CGS's Seismic Hazards Mapping Program (Real, 1993). Each borehole location was digitized into the computer via on-screen digitization. Selected data have been entered for each boring log, including depth to groundwater, elevation, total borehole depth, depth to Pleistocene deposits, thickness of Holocene deposits, thickness of artificial fill, thickness of Holocene Bay Mud, and depth to bedrock (where appropriate). These data were entered in Microsoft Excel format and converted into GIS format by linking the table data with ARCVIEW tables that contain the borehole location.

We collected borehole data from the California Department of Transportation (CALTRANS). CALTRANS data for right-of-ways, earthquake retrofits, and bridge crossings are especially valuable because CALTRANS collects the data using standardized procedures and equipment. CALTRANS borehole data typically include blow count information, lithologic soil descriptions, and depth to groundwater. We spent a week at CALTRANS in Sacramento copying Logs of Test Borings (LOTB) for the major highway intersections along the Bay margins. These LOTBs include borings completed for highway undercrossings, overcrossings, bridges, and soundwall investigations for highways. We also collected LOTBs for major bridges.

4.2 Identification of 'Top of Pleistocene'

As part of our mapping, compiled borehole logs were examined for information that might indicate the buried 'top of Pleistocene'. The primary basis for identifying the 'top of Pleistocene' is the consolidation of Pleistocene deposits during subaerial exposure following lowering of water levels in the Bay during the last sea level low stand. This period of exposure and consolidation typically is distinguished by the development of a distinct pedogenic soil horizon. The 'top of Pleistocene' is identified by a typically marked increase in density, changes in soil color, and changes in texture associated with: (1) development of this soil horizon and/or, (2) distinct stratigraphic changes associated with the unconformity between the top of Pleistocene deposits and Holocene deposits.

We have identified, and quantified in the selection and description within our borehole database, two main areas of uncertainty in interpretation of the "top of Pleistocene". Uncertainties in the subsurface location of the "top of Pleistocene" include those; (1) derived from the drilling method, logging procedure, and documentation for each borehole and, (2) derived from variations in subsurface stratigraphy and in the development of the buried soil horizon(s) associated with "Top of Pleistocene. We addressed the first source of uncertainty in our selection of representative boreholes for inclusion in our borehole database. The second source of uncertainty is directly dependent upon our interpretation of the buried "top of Pleistocene" surface. We have addressed this source of uncertainty by listing the criteria upon which our interpretation is based and by assigning a numeric value for each interpreted boring that expresses our degree of confidence in the interpretation.

Uncertainties associated with the physical process of drilling boreholes include the varying accuracy of borehole locations (borehole coordinates and elevation), quality of data derived from drilling method used (e.g. mud rotary, hollow-stem auger, etc.), and type and quality of geologic data recorded for each boring (i.e. detail and relevance of borehole descriptions). Additional information that, if missing, might reduce the utility of a boring include the presence or absence of in-situ density data (e.g. SPT-compatible blowcounts, CPT penetration data, etc.), and presence or absence of laboratory data (e.g. dry density tests, grain-size distribution data, etc.).

We have reduced the initial uncertainty associated with the variable quality of the available borehole dataset by sorting through available boreholes and selecting only those representative boreholes in which we have a reasonable degree of confidence. Typically in the environmental and geotechnical borings we have examined, samples are taken and described every five feet. We therefore only use those boreholes that contain positive evidence for the presence of the "top of Pleistocene". We do not include in our subsurface mapping borings that are not well located, lack adequate descriptions, or may be too 'shallow' to penetrate "top of Pleistocene".

In our opinion, the non-linear nature of drilling means that absence of evidence for the "top of Pleistocene" within a boring can not be used to preclude the presence of "top of Pleistocene". This assumption is based on our repeated examination of multiple adjacent borings in the same locations around the Bay. Some borings of similar depth contain clear evidence for the location "top of Pleistocene" while others contain no evidence for the presence of the buried horizon.

Second, there is considerable uncertainty associated with the spatially and temporally variable nature of the "top of Pleistocene" beneath the southern San Francisco Bay. In our borehole database, we list the various criteria used to identify the "top of Pleistocene". Where preserved, soils developed within the 'top' of Pleistocene deposits may be associated with a weak- to well-developed argillic or, more rarely, calcic B horizon exhibiting ped development, clay coatings around grains and peds, minor color changes, presence of rootlets and/or root casts, and increased density relative to overlying deposits. Less well-developed soils coincident with the 'top of Pleistocene' include those with thin soil profiles that may have developed during shorter periods of subaerial exposure or those from which the A- and upper B- soil horizons were possibly eroded before deposition of overlying Holocene sediment. Thinner soils may have similar characteristics to well developed soils but typically these are more subtle, less identifiable in the subsurface, and more likely to be missing within most borings that sample every five feet. Horizons interpreted to be associated with soil development, whether well developed or not, typically are moderately denser than overlying sediment and coincide with an abrupt increase in bulk density decreasing gradually downward into less dense material.

We rejected logs of borings that are not well located, not deep enough, or contain inadequate descriptions. We set aside for interpretation logs that contained density information (typically blow count data) with accompanying lithologic descriptions required for identification of changes in soil density, texture and stratigraphy associated with the buried "top of Pleistocene". In locations with multiple boreholes, we typically selected a representative borehole with the best available data. For each borehole, we listed the criteria used to identify "top of Pleistocene". We assign three levels of confidence in our interpretation of "top of Pleistocene": (1) definite, (2) probable, and (3) possible. Our confidence is based on the accompanying identification criteria that we list but our degree of confidence is not necessarily dependent upon the number of criteria seen.

4.3 Delineation of Artificial Fills

We subdivide Bay fills by age (approximate date of emplacement) by updating existing digital mapping of fill boundaries (polygons) published at 1:24,000-scale by Witter et al. (2006). Age of fill is important as: (1) a proxy for fill composition, based on method of emplacement and source of material, and (2) because uncompacted, nonengineered fills may densify sufficiently with time to reduce potential liquefaction-related settlement during strong ground shaking. We are using historical records to check our mapping of artificial fills emplaced along the margins of the northern San Francisco Bay after methods of O'Rourke and Roth (1990) and Bonilla (1992).

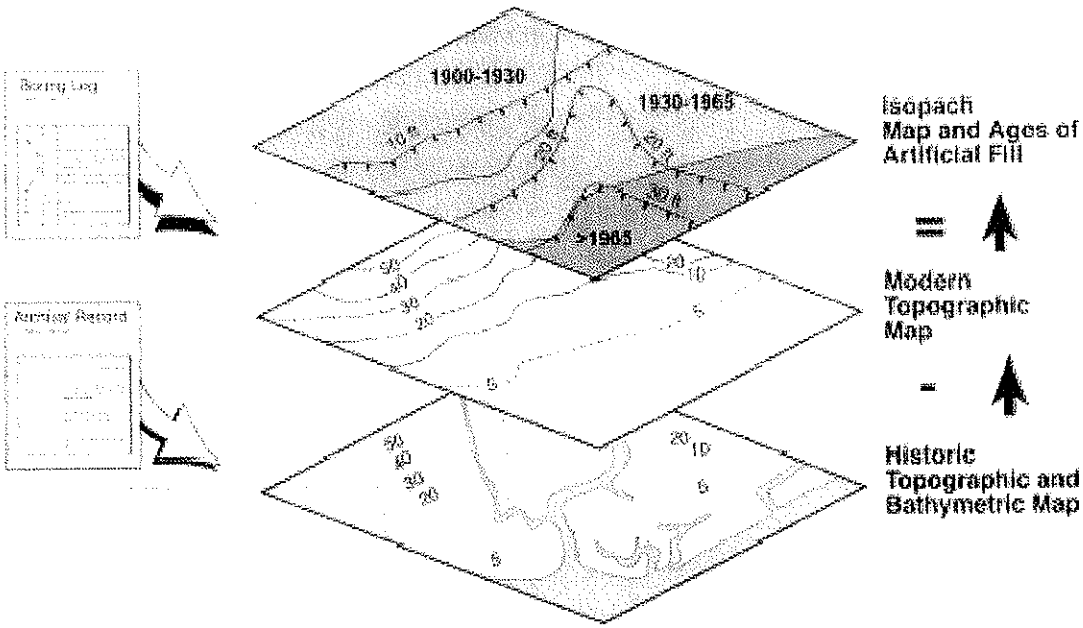

Figure 2. Conceptual diagram showing GIS-based method for mapping ages and thicknesses of artificial fill.

5.0 RESULTS

We completed data collection for twelve 7.5-minute topographic quadrangles, including quadrangles containing Santa Clara Valley and the East Bay plains (Figure 1). Over 400 boring logs have been compiled and interpreted for the north San Francisco Bay region (Figure 3).

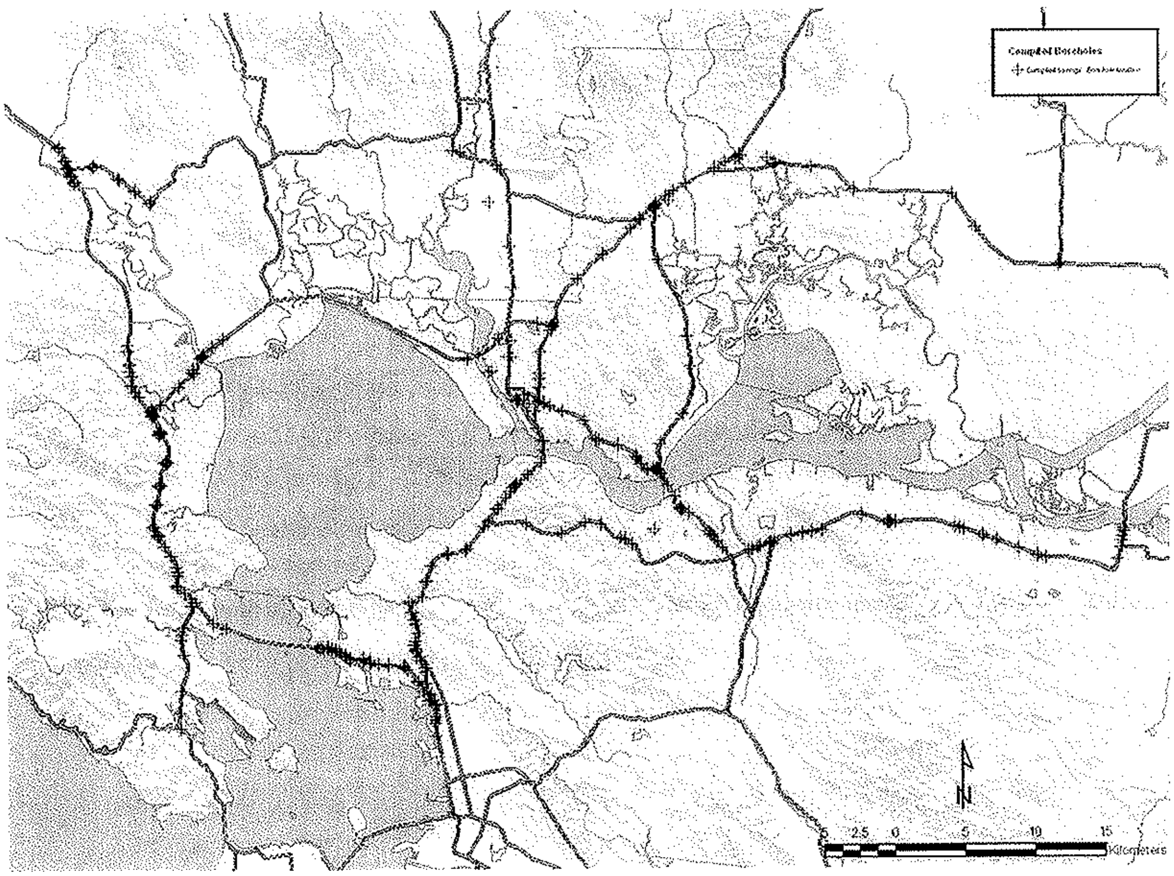

Figure 3. Locations of compiled CALTRANS borings in study area.

The uneven distribution of currently available subsurface data requires substantial interpretation in the depth of Pleistocene deposits. The absence of data has led us to retain several key borehole data points that, as contoured, remain anomalous. We believe that these data are accurate and that collection of additional data is required to fully resolve the apparent contouring anomalies. These data likely are representative of locally buried features (e.g. stream channels in buried 'top of Pleistocene) that currently can not be fully characterized (i.e. contoured) due to gaps in the available subsurface data.

Our interpretation of available borehole data suggests that the buried top of Pleistocene surface is highly variable in the northern Bay Area, where preserved within local depressions and indentations. It is likely that the Pleistocene landscape consisted of hillsides incised by stream and river channels, flooded or exposed within the modern landscape. Current wetlands and reclaimed marshes consist of Holocene deposits underlain by bedrock and, locally, remnants of Pleistocene fluvial deposits. The Pleistocene landscape thus is difficult to reconstruct, unlike the buried landscape in the southern Bay Area. Local erosion, Holocene deposition, and, possibly, uplift has removed or obscured much of the Pleistocene landscape and associated deposits

The distribution and age of overlying artificial fills, verified against historical records and vintage aerial photographs, was determined by analyzing progressive Bay shorelines derived from historic topographic maps. Historic 15- and 7.5-minute USGS topographic quadrangles, spanning more than 100 years of mapping (1885-1999), were obtained from the USGS's National Mapping Division and have been used previously for urban growth analyses (Kirtland et al, 1994; Acevedo et al, 1994).

We compared the outlines of the Bay on historic maps and aerial photography to the 1850 margin of marshlands mapped by Nichols and Wright (1971). The resulting maps show the progression of reclaimed marsh lands and artificial fills into the Bay (Figure 4). Fills primarily were placed during the expansion of the Mare Island Naval shipyard and along Highway 101 in the northwest Bay area, although development of Richmond and Berkeley also resulted in substantial fill placement onto and into the Bay margins.

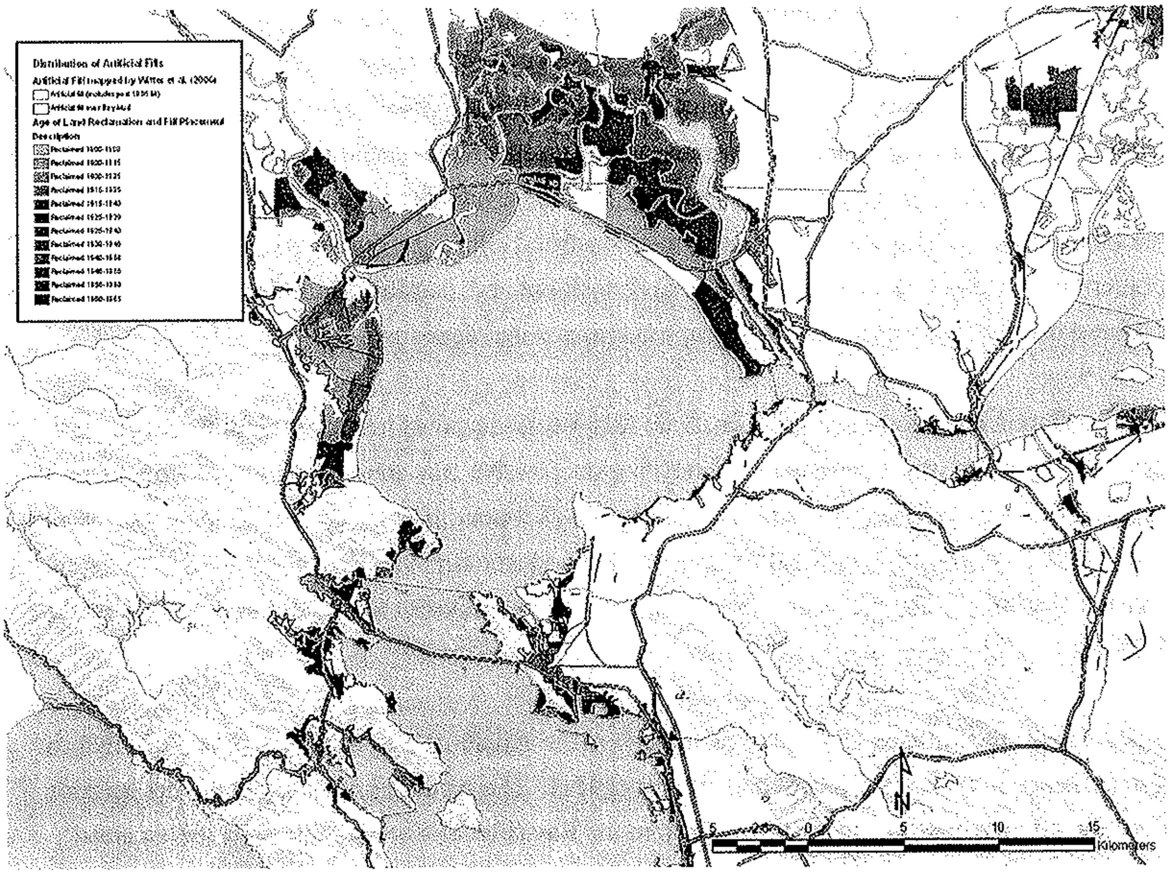

Figure 4. Map of reclaimed land and artificial fills in the northern Bay Area.

Minimal undocumented (pre-1965) fill was emplaced east of Mare Island, with the exception development of Benicia and Concord. Pleistocene deposits are poorly preserved within the Cartinquez Straight, with bedrock and only minor development present. Locally fill emplaced during construction of the major freeways includes some minor reclamation of marshlands but most modern development is on either bedrock or post-1965 engineered fill.

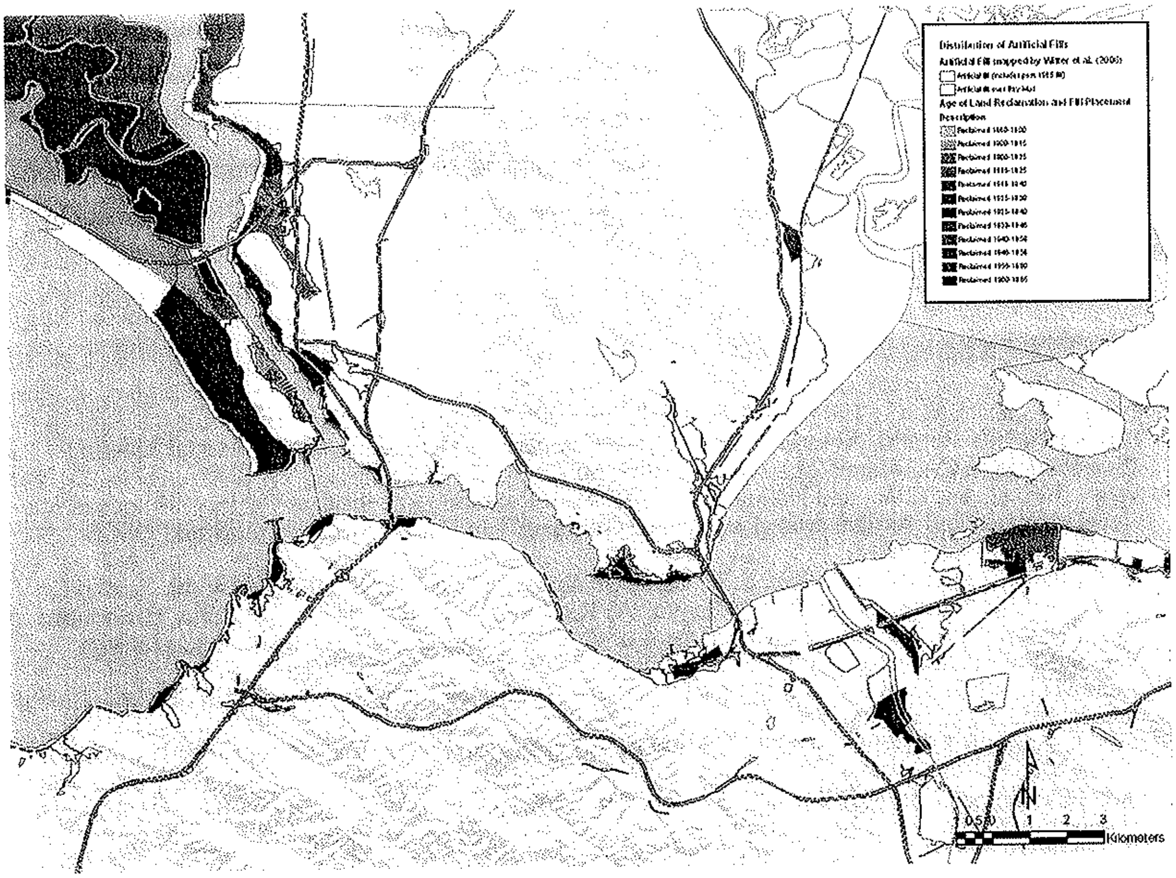

Figure 5. Map showing close-up view of artificial fills in northern study area (Mare Island area).

In summary, the results of our research include compilation and preliminary interpretation of boring logs and historical maps for seventeen 7.5-minute quadrangles that cover the southern San Francisco Bay margins. Interpretation of data compiled has resulted in preliminary mapping of the top of the Pleistocene and distribution of historic artificial fills in the northern San Francisco Bay Area. Our mapping contributes toward the ultimate goal of isopach maps showing the cumulative thickness of sandy sediments (i.e. potentially liquefiable sediments) and provides information on the geologic and geotechnical framework required to prepare three-dimensional liquefaction hazard maps in the southern San Francisco Bay area.

6.0 ACKNOWLEDGMENTS

We thank the agencies that provided access to borehole logs and other information on local geology. These include the California Division of Mines and Geology, California Department of Transportation, and the Bay Area Rapid Transit District. This work was supported by the U.S. Geological Survey National Earthquake Hazards Reduction Program Grant #02-HQ-GR-0038.

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial Standards or with the North American Stratigraphic Code. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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