Liquefaction Susceptibility Mapping at 1:24,000-scale, San Francisco Bay Area: Year 2

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Investigations Undertaken

The purpose of this study is to produce detailed Quaternary geologic maps to delineate areas susceptible to earthquake-induced liquefaction in the San Francisco Bay area. The products of our mapping project will consist of a series of 7.5-minute quadrangles located in high density population centers in the Bay area, including the cities of Berkeley, Fairfield, Hayward, Livermore, Pleasanton, Petaluma, Richmond, San Jose, San Mateo, San Rafael, San Ramon, Santa Clara, Santa Rosa, and Walnut Creek (Figure 1). Examination of liquefaction susceptibility in the San Francisco Bay area is timely because urban expansion is encroaching on lands underlain by potentially saturated Holocene deposits and artificially filled land -- areas that have historically experienced liquefaction-related ground failure.

Damaging liquefaction occurred in the San Francisco Bay area during the 1868 Hayward earthquake, the 1906 San Francisco earthquake, 1983 Coalinga earthquake, and the 1989 Loma Prieta earthquake (Tinsley and others, 1998; Youd and Hoose, 1978). These and other historical earthquakes show that the distribution of liquefaction-related ground failure generally is restricted to alluvial basins that contain shallow layers of low-density, saturated, granular sediment. If these conditions can be delineated, planners, government agencies, and individuals will be able to prepare for and mitigate the effects of liquefaction, and better prepare disaster response plans. For example, if local governments have information on areas of possible liquefaction hazard, they can require that site-specific analyses be performed prior to new development and appropriate engineering mitigation be incorporated into project design. The California Division of Mines and Geology (CDMG) plans to develop liquefaction zonation maps that local governments will be able to use for this purpose. Our project will greatly facilitate and possibly accelerate CDMG's development of these maps.

The proposed map area has been targeted as high priority by CDMG for producing 1:24,000-scale liquefaction *zonation* maps. However, CDMG's program is not currently funded to produce detailed Quaternary geologic maps or liquefaction susceptibility maps of this area.

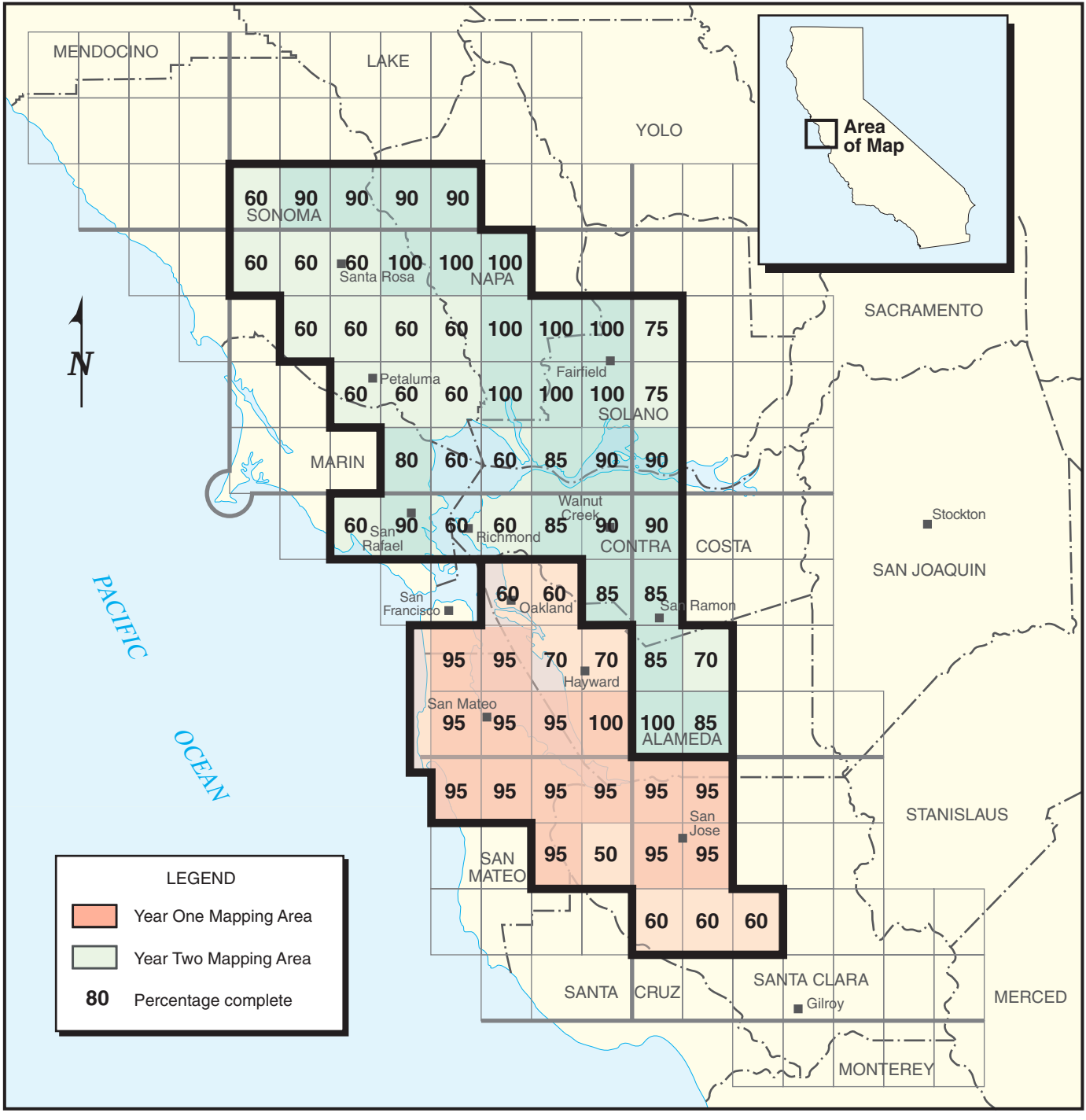

Figure 1. Map showing the San Francisco Bay project area and percentage of Quaternary geologic mapping completed for each quadrangle. Darker shade indicates maps that are 80% or greater complete.

We have collaborated with CDMG on past liquefaction mapping efforts and will provide data to CDMG at the level of accuracy and in the digital format required for their liquefaction zonation program. To accomplish this goal, we are revising maps that were produced for our earlier smaller-scale mapping projects (Knudsen and Lettis, 1997; Knudsen and others, 1997, 2000b; Sowers and others, 1995, 1997, 1998) by: (1) compiling additional existing or new mapping that was not utilized in our earlier mapping efforts; (2) performing aerial photograph interpretation; (3) performing limited field reconnaissance; (4) finalizing Quaternary geologic maps at 1:24,000 scale; and (5) developing liquefaction susceptibility maps using our Quaternary geologic maps, information on the depth to groundwater, and our past and ongoing geotechnical analyses of the susceptibility of various Quaternary deposits to liquefaction.

The geologic and liquefaction susceptibility maps that we produce have served as part of the baseline data from which CDMG develops liquefaction zonation maps (e.g. Hitchcock and others, 1996; Hitchcock and Wills, 1998). We will continue to consult and interact with CDMG to ensure that maps produced through this project are directly applicable in CDMG's zonation process. The proposed maps also are being submitted to the ongoing USGS effort (joint Earthquake Hazards/Geologic Mapping project through Carl Wentworth) for entry into the digital database for the Quaternary geologic map of the San Francisco Bay region and subsequent release by the USGS as a digital geologic map (Knudsen and others, 2000c). Development of the proposed Quaternary geologic maps also will provide valuable information to evaluate earthquake effects, and will directly assist in emergency preparedness efforts, mitigation of potential risks, and development planning.

Anticipated products of this project include two digital maps of each of the 7.5-minute quadrangles. The first map will depict the late Quaternary geology, showing Quaternary deposits mapped on the basis of their age and depositional environment. The second map will depict liquefaction susceptibility, based on the physical properties and groundwater conditions associated with each Quaternary unit. The maps will be accompanied by a report that describes the mapping procedures, Quaternary mapping units, and the criteria matrix used to create the liquefaction susceptibility maps.

Results

Second year efforts have focused on Quaternary mapping. We continue to follow the mapping standards and procedures that we specifically developed for this project. These procedures reflect our combined experience on other Bay Area mapping projects (Knudsen and Lettis, 1997; Knudsen and others, 1997, 2000b; Sowers and others, 1995, 1997, 1998). Each contact placed on the map is documented by a source code or codes along the contact that indicates the primary type of data that was used to draw that contact. Types of data that will be considered include pre-development aerial photography, topographic contours, soil surveys, historical maps of the shoreline, wetlands, and creeks, existing Quaternary mapping, and field reconnaissance. The precision of each line is indicated by the use of a solid line (+/- <100 meters), or dashed line(+/- >100 meters).

We also are continuing to refine a Quaternary stratigraphy and unit names that can be applied throughout the Bay Area. The development of the stratigraphy has been a work in progress through the several Bay area mapping projects we have conducted. Originally developed in collaboration with Dr. Ed Helley, a few new units recently have been added and the mapping criteria for some units have been refined. For example, we defined two new units that differentiate artificial fill placed over Bay Mud from artificial fill placed on upland deposits. This is an important distinction because about fifty percent of all historical liquefaction occurrences and about eighty percent of the liquefaction occurrences during the Loma Prieta earthquake occurred in the map unit we designate as artificial fill over Bay

Mud (Knudsen and others, 2000a). Furthermore, we have subdivided the Holocene basin map unit into Holocene fine-grained alluvial fan facies and Holocene basin deposits defined by topographic depressions and high ground-water levels.

The progress of our Quaternary geologic mapping is shown graphically on Figure 1. Because of opportunities to cooperate with other WLA projects located in the Year Two area, we elected to work on quadrangles in both the proposed Year Two and Year One areas. To generalize, quadrangles shown as 50 to 75% complete are those that have been mapped previously either by WLA at the 1:100,000 scale, or by other workers. This mapping needs varying amounts of additional work in order to bring it up to the standards for this project.

Quadrangles shown as 80 to 100% complete are those that have now been mapped to the standards set out for this project. They still may need a small amount of work, or peer review, or digitization in order to be considered 100% complete. This year we concentrated much of our effort in the San Francisco peninsula and East Bay areas, including the San Francisco South, Hunters Point, Montara Mountain, San Mateo, Redwood Point, Half Moon Bay, Woodside, Palo Alto, Mountain View, Benicia, Vine Hill, Honker Bay, Briones Valley, Walnut Creek, Clayton, and Las Trampas Ridge quadrangles. Several of these maps still need peer review and digitization, thus are not yet 100% complete.

Non-technical Summary

Using geologic analysis of Quaternary sediments, this study will produce a series of, 1:24,000-scale maps showing areas susceptible to liquefaction during an earthquake. Through a collaborative relationship with the California Division of Mines and Geology, these maps will facilitate the development of liquefaction zonation maps that will be accessible to local governments and urban planners for aid in emergency response planning, mitigation of potential seismicity risks, and realistic development planning. These maps will also contribute to the U.S. Geological Survey's digital database for the Quaternary geologic map of the San Francisco Bay region and subsequent USGS Open-File Report as a digital geologic map.

Reports Published

Twenty-four 1:24,000-scale quadrangles will be published as digital maps in a U.S. Geological Survey Open-File Report to be released in November 2000 (Knudsen and others, 2000c). Two maps will be published for each quadrangle. The first map will depict the late Quaternary geology, showing Quaternary deposits mapped on the basis of their age and depositional environment. The second map will depict liquefaction susceptibility, based on the physical properties and groundwater conditions associated with each Quaternary unit. The maps will be accompanied by a report that describes the mapping procedures, Quaternary mapping units, and the criteria matrix used to create the liquefaction susceptibility maps.

The digital maps published in Knudsen and others (2000c) will feature thirty-five percent of the 7.5-minute quadrangles proposed in this project. The quadrangles include: San Francisco South, Hunters Point, Montara Mountain, San Mateo, Redwood Point, Newark Woodside, Palo Alto, Mountain View, Milpitas, Calaveras Reservoir, Mindego Hill, San Jose West, San Jose East, Kenwood, Rutherford, Yountville, Napa, Mt. George, Fairfield North, Cuttings Wharf, Cordeia, Fairfield South, and Niles.

The digital maps and accompanying report will be available in digital format as PDF or post-script files at the following USGS website:

http://geopubs.wr.usgs.gov/docs/wrgis/of-00.html

For further information on the digital U.S. Geological Survey Open-File Report 00-444 you may contact Keith Knudsen at California Division of Mines and Geology, 185 Berry Street, Suite 210, San Francisco, CA 94107; by phone at: 415-904-7707; or by email: kknudsen@consrv.ca.gov.

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