F1-025

I. Executive Summary

a. Project Title and Applicant Name

STRONG GROUND MOTION MAPS FOR EVALUATION OF POTENTIAL CATASTROPHIC LEVEE COLLAPSE FROM STRONG EARTHQUAKES

Thomas M. Brocher/Carl Wentworth/Jack Boatwright
345 Middlefield Road, MS 977
U.S. Geological Survey
Menlo Park, California 94025

b. Project Description and Primary Biological/Ecological Objectives

The primary habitat targeted by this project are the islands and other low lying floodplain areas protected by the existing levee system in the Delta. Widespread failure of the Delta system during earthquake shaking could draw in saline water from the San Francisco Bay, increasing the salinity of the fresh water in the Delta to the extent that it compromises existing ecosystems and and agricultural and industrial use. This project will reevaluate potential seismic sources local to the Sacramento Delta and based on this analysis conduct a deterministic and a probabilistic hazard assessment that will help to predict the likelihood of earthquake-induced levee failure and widespread island flooding in the Sacramento Delta. The proposed work is a necessary step towards identifying the portions of the levee system which may be particularly vulnerable to failure during earthquake shaking. This hazard assessment of levee failure due to moderate to large earthquakes will provide another basis for assessing future plans for retrofitting or maintaining the current levee system. An integrated, multidisciplinary study of the Sacramento Delta region will be conducted by a diverse team of geologists, geophysicists, and earthquake seismologists.

c. Approach/Tasks/Schedule

The approach to be followed is to (1) assess uncertainty in the location, recurrence, magnitude and other characteristics of potential seismic sources, particularly of local earthquakes in the eastern Coast Range-western Sacramento Delta, (2) reduce this uncertainty by acquiring new geologic and geophysical data and reanalysis of existing data, and (3) using these new insights conduct a new probabilistic hazard assessment that will, in conjunction with other studies of the geotechnical properties of the levee system, help predict the likelihood of earthquake-induced levee failure and island flooding in the Sacramento Delta. The four proposed tasks are (1) Construct a three-dimensional structural (geologic) model for the eastern Coast Ranges and western Sacramento Delta. (2) Refine our understanding of historical and recent earthquakes in the Delta region. (3) Test a new method for the subsurface imaging of faults to determine recency of latest fault offset in the Sacramento Delta region at two locations. (4) Using results from Tasks 1 through 3, Task 4 estimates ground motion in the Delta from seismic sources identified in Tasks 1 and 2. These tasks are to be performed over a two-year period.

d. Justification for Project and Funding by CALFED

This proposed probabilistic hazard assessment of levee failure in the Sacramento Delta due to moderate to large earthquakes will facilitate evaluation of remediation strategies based on other criteria being considered by CALFED. The potentially fragile levee system is vulnerable to both moderate sized (magnitude 6 to 6.5) earthquakes in the Delta region and to larger sized (magnitude >7) earthquakes in the greater San Francisco bay region. NEHRP addresses larger events and provides information on the principal strike-slip sources in the Bay Area. The proposed work focusses on the Delta itself and on local earthquake sources of principal concern only to the Delta. The USGS will cost share, see below.

e. Budget Costs and Third Party Impacts

This proposal is to support work lasting two years. The total amount requested from CALFED is $471,514.33. Four tasks are proposed. The total for each task is as follows: Task 1 $319,831.03; Task 2 $12,370.65, Task 3 $106,988.70, and Task 4 $32,323.96. The requested funds would support field work and provide salary support to analyze the new and existing data. As a research effort, no third party impacts are known or anticipated. **Note that considerable cost sharing with the National Earthquake Hazard Reduction and the National Geologic Mapping Programs of the USGS are available for this project. Forty-percent of the salaries of the permanent full-time USGS employees will be paid by these programs for this work. This $117,766.42 commitment by the USGS substantially lowers the cost of the proposed work to CALFED.**

f. Applicant Qualifications

The proposed project staff have extensive education and experience working on similar problems throughout the San Francisco Bay area.

g. Monitoring and Data Evaluation

Any publications based on our work will undergo technical peer review, both within the USGS, and by reviewers selected by the journal of publication. Proposed revisions to the database of seismic sources in Northern California will be submitted to the Working Group on Northern California Earthquake Potential for consideration for future inclusion into their earthquake occurence model for Northern California.

h. Local Support/Coordination with other Programs/Compatibility with CALFED Objectives

Considerable cost-sharing of the proposed work comes from similar or related ongoing work funded by the National Earthquake Hazard Reduction and National Mapping Programs. The proposed work will supply necessary geologic and geophysical information for complementary proposals from the USGS and William Lettis & Associates entitled "Liquefaction Potential of Levee Foundations: Implications for Catastrophic Levee Failure" and "A Framework For Risk Communication To Evaluate Ecosystem Restoration And Hazard-Loss Avoidance". Together, these three USGS proposals will provide CALFED with the ability to incorporate the risk of levee foundation failure during earthquakes into their plans.

II. Title Page

a. Title of Project

STRONG GROUND MOTION MAPS FOR EVALUATION OF POTENTIAL CATASTROPHIC LEVEE COLLAPSE FROM STRONG EARTHQUAKES

b. Applicant Information:

Thomas M. Brocher/Carl Wentworth/Jack Boatwright,
U.S. Geological Survey, 345 Middlefield Road, Menlo Park, CA 94025;
Phone (415) 329-4737, FAX (415) 329-5163, brocher@andreas.wr.usgs.gov

c. Tax Status: Federal Agency, tax exempt

d. Tax Identification Number

e. Technical and Financial Contact person(s)

Technical: Thomas M. Brocher, at address and phone number above
Financial: Ellen Myren, USGS, at above address and (415) 329-4855

f. Participants/Collaborators in Implementation

Participants: Bakun, Brabb, Burdette, Catchings, Graymer, Goldman, Hillhouse, Howell, Jachens, Jayko, Jones, Mc Dougall, Rymer, Seekins, Schwartz: all of the USGS, Menlo Park

Collaborators:

Thomas L. Holzer/Robert Kayen, USGS, Menlo Park, CA
William Lettis and Associates, Oakland, CA (see attachment)

g. RFP Project Group

Type III. Other Services

III. Project Description

a. Project Description and Approach

The purpose of the proposed project is to refine existing probabilistic maps (Calif. Dept. of Water Resources, 1992; Frankel and others, 1996) of strong motion in the vicinity of the Sacramento Delta produced by earthquakes in the San Francisco Bay region. These maps will be produced by improving our knowledge of potential earthquake sources local to the Delta and by calculating the ground motions in the Delta produced by these earthquakes. In conjunction with other studies proposed in separate proposals to CALFED, the proposed work will help CALFED evaluate the potential for widespread, catastrophic failure of levees during local, moderate sized earthquakes in the Sacramento Delta.

Background of Problem

Levee failure has been a common occurrence in the San Joaquin-Sacramento River Delta since reclamation started in the 1850's. Each of the 60 islands and tracts in the Delta has been flooded at least once, with several flooding multiple times. About 100 levee failures have occurred since the early 1890's. Initially, most of the levee failures were caused by overtopping during periods of spring flooding. Although construction of upstream reservoirs since the 1940's has reduced the threat of overtopping, ironically it has not reduced the incidence of levee failure. Since about 1950, levee failures have been twice as likely to be caused by foundation or levee instability as by overtopping. The primary reason for instability is the ongoing subsidence of the islands and tracts protected by the levee system and the resultant progressive increases in height of the levees. The subsidence is caused by oxidation and shrinkage of the peat and muck soils in the Delta as they are drained to maintain agriculture. Maximum subsidence exceeds 7 m on some islands and annual rates of subsidence range from about 4 to 11 cm/yr.

As the heights of levees have increased, concern by Federal, State, and local agencies has been growing about the stability of the levees under seismic loading conditions. Another factor prompting the concern is recognition of the earthquake potential in the Delta region itself. The Delta sits atop the blind fault system along the western edge of the Great Valley. Moderate earthquakes in 1892 near Vacaville and in 1983 near Coalinga demonstrate the seismic potential of this structural belt. The concern about levee stability is also based on the nature of levee foundations and the materials used to build the levees. The levees consist of uncompacted weak local soils that may be dynamically unstable. The presence of sand and silts in the levees and the foundations indicate liquefaction also may be a source of instability. Although no historic examples of seismically induced levee failures are known in the Delta, the absence most likely is because the modern levee network has not been subjected to strong ground shaking. Levees were either small or nonexistent during the magnitude 6.25 1889 Pittsburg and magnitude 6.5 1892 Vacaville earthquakes (Figure 1) and in 1906 when the region was last strongly shaken by an earthquake. The magnitude 7.9 San Francisco 1906 earthquake did, however, caused failures of railroad embankments in the Delta, that were similar in composition to the modern levees.

Given the likelihood that levee failure may occur even at relatively low levels of strong ground shaking (0.1 to 0.2 g), the historic occurrence of a local, moderate-sized earthquake (magnitude 6 to 6.5) warrants investigation, as such an earthquake could cause serious, widespread levee failure.

Existing strong ground shaking maps for California and the nation (Frankel and others, 1996) lack a specific focus on the Sacramento Delta. Furthermore, although constantly updated, these maps rely on existing compilations of geologic and geophysical data. New geological and geophysical data and new compilations of existing data will allow us to better characterize the location, geometry, recurrence intervals, and amount of slip on the most likely Delta earthquake sources. These fault parameters are necessary to calculate the ground motions produced by earthquakes on the faults.

For the most part, the geometry of the thrust faults beneath the Sacramento Delta has been modeled on the basis of structures observed to the south at Coalinga and to the north (Wentworth and Zoback, 1989; Unruh and others, 1996; Working Group on Northern California Earthquake Potential, 1996). Although this extrapolation may roughly approximate crustal structure, in truth the Delta represents a major anomaly along the Coast Range-Great Valley thrust system, in that the boundary has a pronounced westward embayment in this location and because major structural discordance is shown north and south of the Sacramento River. Strata south of the delta trend about north 70 west, while those north of the delta trend north 20 west (Figure 1). In addition, the stress field, as measured by well bore break-outs and small earthquakes (Wentworth and Zoback, 1989) shows a similar change in trend.

Recent work by Unruh and others (1997) has shown that there are significant, previously unrecognized faults in the western part of the San Francisco Bay delta (Figure 2). This work, based on electric logs and seismic surveys, shows a system of south vergent thrust faults trending approximately north 70 west in the area north of Antioch and Pittsburg. In addition, it suggests that these structures may be active, and related, at least in part, to the Quaternary uplift of the Montezuma Hills. Many of these faults are not exposed at the surface. These so-called blind thrusts must be studied using methods that can image structure below the surface; of these the seismic reflection method provides the highest resolution.

To address the potential for damaging earthquakes in the vicinity of the Delta four main tasks are proposed. (1) Construct a three-dimensional structural (geologic) model for the eastern Coast Ranges and western Sacramento Delta to better define the location and geometry of earthquake sources local to the Delta. (2) Reassess the location and magnitude of several pre-1900 earthquakes and instrumental seismicity in the vicinity of the Delta. (3) Conduct a pilot study of an application of a seismic reflection method successfully applied elsewhere to obtain subsurface images of possible earthquake-producing faults. (4) Estimate ground motion in the Delta from seismic sources identified in Tasks 1 to 3.

b. Location and/or geographic boundaries of project

The proposed work will provide a better understanding the seismic hazard to the levees in the Delta Basin. Because these levees will be strongly shaken by earthquakes as far as 100 km from the Delta, seismic sources up to 100 km will be evaluated during the project. The project will incorporate revised source characterization for the major Bay Area strike-slip faults from the new USGS Bay Area earthquake probability study scheduled to start in October 1997. However, because local earthquake sources are currently the least well-understood seismic threat to the Delta, we anticipate that most of our effort will be focused on the eastern Coast Ranges and Delta region (Figure 3).

c. Expected benefits

The primary habitat targeted by this project are the islands and other low lying floodplain areas protected by the existing levee system in the Delta. Widespread failure of the Delta system during earthquake shaking could draw in saline water from the San Francisco Bay, increasing the salinity of the fresh water in the Delta to the extent that it compromises both existing ecosystems and industrial use. This flooding could also induce secondary entrainment of sewage systems throughout the floodplain. In addition to the destruction or deterioration of fresh water habitat for many species, catastrophic levee failure places at risk more than a million acres of productive farmland, major manufacturing facilities, and human habitation that rely on fresh water. The proposed work is a necessary step towards identifying the portions of the levee system which may be particularly vulnerable to failure during earthquake shaking.

d. Background and Biological/Technical Justification

The existing levees in the Delta are known to be at risk to strong ground shaking during earthquakes. Existing maps showing expected ground motion during earthquakes could be used to estimate ground motions beneath the levees (USGS/CDMG National Seismic Hazard Maps, Frankel and others, 1996; Calif. Div. Water Resources, 1992). These existing maps, however, contain a great deal of uncertainty in the location and character of the thrust faults along the Great Valley-Coast Range boundary. In addition, no potential seismic sources located to the east of this boundary (e.g. the Midland fault system) are included in these analyses. The proposed work is aimed at significantly improving our understanding of the geometry and slip rate of the Great Valley-Coast Range thrust fault system and possible earthquake faults to the east of the boundary that are capable of ground motions leading to levee failure.

The expected benefit is increased understanding of the seismic hazard posed by local earthquakes to the levees in the Delta. This benefit will be of lasting impact and it is our expectation that this increased understanding will help CALFED planners make future decisions based on more realistic probable seismic hazards to the levee system.

This proposal is new. The proposed project personnel have extensive experience conducting similar investigations in the San Francisco Bay Area, California, and elsewhere.

e. Proposed Scope of Work

Four main tasks are proposed:

Task 1. Constraining fault geometry, area, offset, displacement rates, recurrence intervals and magnitudes of displacement from a three-dimensional structural (geologic) model for the eastern Coast Ranges and western Sacramento Delta.

Constructing a plausible sub-surface geologic model requires identification of major fault-bounded blocks and stratigraphic relations within the blocks. Borehole and well data combined with balanced cross-sections provide stratigraphic constraints for magnitude of slip and sense of offset along major faults The slip-magnitude and off-set horizons will be used to estimate potential ranges of recurrence intervals which will be used in the probabilistic modeling. The fault surface area, a major factor determining earthquake magnitude, as well as other characteristics of fault geometry including depth of tip line and *inclination can be constrained* by potential field modeling (gravity and magnetic) and interpretation of existing seismic reflection and refraction data. An overlay that includes hypocentral locations of microearthquakes in the USGS/UC Berkeley catalog will help establish recency of activity of inferred faults.

We will build upon and collaborate with a similar, smaller study funded by National Earthquake Hazards Reduction Program (NEHRP) on the eastern Coast Ranges being conducted by Jeff Unruh, William Lettis & Associates, Scott Hector, Gary Drilling Company, Jamie Rector, U.C. Berkeley and Pat Williams, Lawrence Berkeley National Laboratory, on the Ph.D. thesis work of Janine Weber-Band at the UC Berkeley, and on ongoing studies of bedrock and Quaternary geology being conducted at the USGS, which have identified a number of previously unknown buried structures, both folds and faults. In light of the presence of previously unknown, potentially active faults in the westernmost portion of the delta, as well as the regional nature of the structural discontinuity along the Coast Range front, we propose to work to identify and characterize seismogenic faults in the main part of the delta east of Antioch. A major fault, the Midland fault zone (Figure 3), lies within the proposed study area and will be one focus of further investigations, particularly establishing recency of displacement. The activity of the Midland fault zone and its linkage with the thrust faults mapped to the west, if any, are not presently constrained.

During this task we will provide structural interpretation, field checking of the surface geology and geomorphology, new paleontologic control from existing borehole data, new dense high-resolution gravity and magnetic data along proposed pilot seismic lines, and acquisition and interpretation of existing seismic reflection data (Figure 3 shows the location of some of these data). The 3-D structural model will be produced from these data sets using Earthvision software acquired to develop 3-D models in complex terranes. Earthvision is a powerful new software package allowing the construction and visualization of 3-D structural models, and allows easy visual correlation of differing data sets.

Task 2. Refine our understanding of historical and recent earthquakes in the Delta region.

Intensity values have long been used to assign magnitudes through empirical relations determined for recent earthquakes having instrumentally-determined magnitudes and seismic moments (e.g., Hanks and others, 1975). Typically the intensity values are used to define isoseismal lines to separate sites where different intensities have been assigned. Magnitudes are then estimated from the size (km^2) of the area within an isoseismal line. Magnitudes determined in this fashion are robust estimates when the quantity and spatial distribution of intensity observations are sufficient, however, for most. pre-1900 earthquakes in California the data are not sufficient.

W.H. Bakun and C.M. Wentworth of the USGS have recently developed a strategy for the analysis of the sparse intensity data that results in geographic contours bounding the earthquake source location and in an intensity magnitude that is calibrated to equal moment magnitude (Hanks and Kanamori, 1979) in the mean. They provide values for the contours and uncertainties in magnitude for different levels of confidence and different quantities of intensity observations. Their analysis strategy is particularly suited for analyzing early western California earthquakes for which the only available data are a small number of intensity observations.

The Bakun and Wentworth analysis provides important new constraints on historical seismic activity that, if repeated, would present significant hazards to the levee system of the Sacramento Delta. For example, consider the earthquakes that occurred near

Vacaville in 1892. Preliminary results for one of those shocks are shown in Figure 4. Intensity values at 91 locations (solid dots) for this shock are more than sufficient to constrain the magnitude and location of the earthquake: such bounds on location and magnitude of pre-1900 earthquakes are unique to Bakun and Wentworth's analysis.

The historical record of earthquakes, owing to the short time span for which observations are available, may not completely represent the earthquake potential in the greater Delta region. Similarly, relevant geologic observations (Task 1) may not identify all the potential sources of earthquakes that could affect the Delta region. Therefore, we will investigate the need to supplement the historical and geologic observations with a model of earthquake occurence based on the widespread distribution of smaller earthquakes that have been recorded by seismographs in the region during the 20th century. Because smaller earthquakes occur more frequently, a short observation period can be expected to provide a relatively complete estimate of the regional seismicity rate. We will build a "distributed source" model of earthquake activity for the area that could affect the Delta region based on these background earthquakes, and to scale the model to the larger magnitudes of interest with the Gutenberg-Richter (b-value) relation. **This work will be performed by Paul Reasenberg, seismologist, USGS, at no cost to CALFED.**

To summarize, during this task we will (1) perform a literature search, (2) compile available Modified Mercalli intensity data for all historic earthquakes that would have posed a threat to the levee system, (3) analyze intensity data for earthquake source parameters, (4) as appropriate, analyze the 20th century instrumentally recorded seismicity to develop a distributed source model of large earthquakes, and (5) integrate the geologic, historic and instrumental seismicity models to characterize the potential for seismic sources that could affect the levee system.

Task 3. Test a new method for the acquisition of shallow seismic reflection data in the Sacramento Delta region at two locations.

The judgement that a fault is active and capable of generating earthquakes is generally based on how recently it has moved, and the frequency of such earthquakes on the rate of offset. Seismic reflection profiling provides the best subsurface information for buried faults, but the surficial peat layer makes the Delta a challenging place to acquire high-quality seismic reflection data. We propose in this task to test a promising new method for the acquisition of seismic reflection and refraction data on land using source-receiver offsets longer than are normal. Two short (3-km) pilot lines are proposed, one crossing the Great Valley-Coast Range boundary and one straddling mapped subsurface faults within the Delta (the Midland fault system). Both lines will be high-resolution (10 m source and receiver interval), and will focus on providing new data on the recency (offset of Holocene and/or Late Quaternary units) and rate of faulting of mapped faults (need fault geometry) in the Delta region. Interpretation of existing seismic reflection profiles by Unruh and others (1997) suggests that the Holocene glacial low-stands has formed a regional unconformity. High-resolution profiling can reveal whether this Holocene unconformity has been offset by subsequent faulting.

Task 4. Using results from Tasks 1 to 3, Task 4 estimates ground motion in the Delta from seismic sources identified in Tasks 1 and 2.

This task has three components. The first is to quantify the expected maximum magnitude earthquakes and recurrence intervals for the earthquake sources that affect the

Delta. The second will be to better estimate levels of ground motion in the Delta for normal attenuation processes for thrust faults. The third component will be to implement these results into both deterministic and probabilistic estimates of ground motions using the refined recurrence estimates for the boundary thrust events.

The thrust earthquakes occurring along the eastern boundary of the Coast Ranges pose a great hazard to the levee system in the Sacramento delta area. Two recent examples of such events are the magnitude 6.7 1983 Coalinga and the magnitude 6.2 1985 Kettleman Hills earthquakes. The Coalinga earthquake was recorded by 50 strong motion instruments (mostly near Parkfield at distances of 30 to 60 km), while magnitude 5.3, 5.2, and 6.0 aftershocks were well recorded in the near-field. The Kettleman Hills earthquake was not recorded by strong motion instruments. At the present time, the expected ground motions from these thrust events on the Coast Ranges boundary are relatively poorly known, although regressions determined by Campbell and Bozorgnia (1994) and Boore et al. (1997) suggest that thrust earthquakes radiate larger accelerations than strike-slip earthquakes with similar magnitudes. In particular, the attenuation curves of Idriss (1985) and Boore et al. (1993) that have been used to estimate ground motions both deterministically for scenario events and statistically for probabilistic hazard maps do not sufficiently represent these thrust events. More critically, the measures of source-receiver distance in these models do not accommodate the focusing of seismic energy associated with dipping fault systems.

We propose to combine the Coalinga recordings with the abundant strong motion recordings obtained from thrust events in southern California, in particular, the magnitude 6.6 1971 San Fernando, M=6.0 1983 Whittier Narrows, magnitude 5.8 1991 Sierra Madre, and magnitude 6.6 1994 Northridge earthquakes to determine more suitable attenuation curves for boundary thrusts earthquakes, both in peak acceleration and for velocity response spectral ordinates. Because we explicitly incorporate fault dip in the regressions, the attenuation curves are directly applicable to estimating ground motion in the Delta from boundary thrust events on mapped faults.

Work performed after the 1989 Loma Prieta earthquake suggests that damage to San Francisco and Oakland was enhanced due to a strong reflections from the base of the crust (Moho) (Figure 5). As part of an ongoing study for PG&E, the USGS has compiled maps of the depth to Moho throughout the Bay Area. As part of this task we will investigate using synthetic seismograms and available microearthquake recordings whether a strong Moho bounce from a large earthquake on the San Andreas fault could locally enhance ground shaking in the Delta Region.

We will prepare a report of our regression results that will include a complete comparison with commonly used attenuation relations. We will also implement these results both into deterministic estimates of the ground motion associated with these boundary thrust events and into probabilistic estimates by refining the Probabilistic Seismic Hazard Assessment methodology of the USGS's National Seismic Hazard Mapping Project explicitly for these boundary thrust events.

f. Monitoring and Data Evaluation

Our new geological and geophysical data, compilations of existing data, and new structural interpretations will be subjected to peer review and discussion at national and/or regional meetings of professional geological societies such as the Geological Society of America. The results of the proposed work will be published as appropriate and in that process will undergo future USGS and journal review. Proposed revisions to the database of seismic sources in Northern California will be submitted to the Working Group on Northern California Earthquake Potential, cochaired by David Schwartz, USGS.

g. Implementability

As a research effort, there are no anticipated impediments to the proposed work. Casual use permits for field work will be obtained from the appropriate landowner or agency. No permanent markers are left behind after our field studies are completed.

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California Department of Water Resources, 1992, Seismic stability evaluation of the Sacramento-San Joaquin Delta Levees, Vol. 1, Phase I Report: Preliminary Evaluations and Review of Previous Studies.

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Wentworth, C.M. and Zoback, M.D., 1989, The style of late Cenozoic deformation at the eastern front of the California Coast Ranges: Tectonics, v. 8, p. 237-246.
Working Group on Northern California Earthquake Potential, 1996, Database of Potential Sources for Earthquakes Larger Than Magnitude 6 in Northern California, U.S. Geological Survey Open-file Report 96-705, 40 p., 13 figures.

IV. Costs and Schedule

a. Budget Costs

Project Phase and Task	Staff	Direct Labor Hours	Direct Salary and Benefits	Overhead (General, Admin and Fee)	Service Con-tracts	Material and Acquisition Contracts	Miscellaneous and other Direct Costs	Total Cost
	Permanent							
	Schwartz	0	No Charge				$10,000.00	
	Brocher	320	17,655.04					
	Wentworth	480	27,250.80				(transportation,	
	Jayko	480	19,876.08				air photos, field	
	Howell	160	8,848.92				expenses,	
	Hillhouse	160	8,615.36				maps, per diem	
Task 1	Jachens	160	8,617.86				for field work)	
	McDougall	240	8,250.00					
	Total Perm.	2000	$99,114.06					
	USGS Share	**40%**	**$39,645.62**				$5,000.00	
Phase 1								
	CALFED Share		$59,468.44				(Purchase of existing data)	
	Temporary							
	Graymer	480	13,500.00					
	GS-7	1600	22,539.80				Total to	
	Total Temp.	2080	$36,039.80				CALFED	
	Total to CALFED		$95,508.24	$47,360.67			$15,000.00	$157,868.91
	Permanent							
	Schwartz	0	No Charge					
	Brocher	320	$18,184.69				$10,000.00	
	Wentworth	480	28,068.32					
	Jayko	480	20,472.36				(transportation,	
	Howell	160	9,114.39				air photos, field	
	Hillhouse	160	8,873.82				expenses,	
Task 1	Jachens	160	8,876.40				maps, per diem	
	McDougall	240	8,497.50				for field work)	
	Total Perm.	2000	$102,087.48				$5,000.00	
	USGS Share	**40%**	**$40,834.99**					
Phase 2	CALFED Share		$61,252.49				(Purchase of existing data)	
	Temporary							
	Graymer	480	13,905.00					
	GS-7	1600	23,215.99				Total to	
	Total Temp.	2080	$37,120.99				CALFED	
	Total to CALFED		$98,373.48	$48,588.64			$15,000.00	$161,962.12
	Permanent						(Computer	
Task 2	Bakun	240	$13,599.09				support)	
	USGS Share	**40%**	**$5,439.64**					
Phase 1	Total to CALFED		$8,159.45	$3,711.19			$500.00	$12,370.65

	<u>Permanent</u>						(rentals, drilling, explosives, expendables, precise positional surveying, per diem and travel for geophysical field work, software maintenance)	
	Catchings	240	$11,426.97					
	Brocher	80	4,413.76					
	Burdette	240	7,080.36					
Task 3	<u>Rymer</u>	<u>80</u>	<u>2,955.87</u>					
	Total Perm.	640	$25,876.96					
	USGS Share	**40%**	**$10,350.78**					
Phase 1	CALFED Share		$15,526.18					
	<u>Temporary</u>							
	Goldman	240	$5,958.27					
	Total to CALFED		$21,484.45	$24,936.19			$36.700.00	$83,120.64
	<u>Permanent</u>							
	Catchings	240	$11,769.78					
	Brocher	80	4,546.17				(software maintenance)	
	Burdette	0	0					
Task 3	<u>Rymer</u>	<u>80</u>	<u>3,044.55</u>					
	Total Perm.	400	$19,360.50					
	USGS Share	**40%**	**$7,744.20**					
Phase 2	CALFED Share		$11,616.30					
	<u>Temporary</u>							
	Goldman	160	$4,091.35					
	Total to CALFED		$15,707.65	$7,160.42			$1000.00	$23.868.06
	<u>Permanent</u>							
	Boatwright	200	$10,508.20					
Task 4	<u>Seekins</u>	<u>240</u>	<u>6,426.75</u>					
	Total Perm.	440	$16,934.95					
Phase 1	**USGS Share**	**40%**	**$6,773.98**				(Computer maintenance)	
	Total to CALFED		$10,160.97	$4,783.27			$1,000.00	$15,944.24
	<u>Permanent</u>							
	Boatwright	200	$10,823.45					
Task 4	<u>Seekins</u>	<u>240</u>	<u>6,619.55</u>					
	Total Perm.	440	$17,443.00					
Phase 2	**USGS Share**	**40%**	**$6,977.20**				(Computer maintenance)	
	Total to CALFED		$10.465.80	$4,913.91			$1,000.00	$16,379.71

TOTAL REQUEST TO CALFED FOR BOTH PHASES (TASKS 1 THROUGH 4) $471,514.33

Note that considerable cost sharing with the National Earthquake Hazard Reduction and the National Geologic Mapping Programs of the USGS are available for this project. Forty-percent of the salaries of the permanent full-time USGS employees will be paid by these programs for this work. This $117,766.42 commitment by the USGS substantially lowers the cost of the proposed work to CALFED.

b. Schedule Milestones

The proposed work will be divided into two phases, each phase lasting one year. Phase 1 will involve the search for and obtaining available datasets for Task 1, as well as planning and execution of the pilot seismic reflection work for Task 3. We anticipate that Task 2 will be completed during Phase 1 and that the attenuation rate analysis of thrust earthquakes proposed for Task 4 will be completed during Phase 1 as well.

Phase 2, the second year of the proposed work, involves the filling of data gaps recognized during Phase 1, synthesis of the results of Tasks 1 to 3, and completion of Task 4. Under Task 4, probabilistic and deterministic maps of ground motions in the Sacramento Delta will be prepared.

c. Third Party Impacts

There are no known or anticipated third party impacts that would result from the implementation of this project.

V. Applicant Qualifications

Project Management (see Biographies below)

Brocher will serve as overall director of the proposed research program. In addition, he will be concerned with the acquisition of existing seismic reflection data, interpretation of existing and new seismic reflection data, and development of a three-dimensional structural model for the study region.

Wentworth will serve as director of and participate in the geological studies in Task 1. His activities will also include participation in an ongoing compilation of surface Quaternary geology at 1:24,000 (in a separately funded complement to the proposal, plus any additional information developed by William Lettis Associates under proposed CALFED funding). Graymer, Jack Hillhouse (USGS, paleomagnetist), Howell, Jayko, Kris McDougall (a USGS biostratigrapher), and collaborators (Earl Brabb, David Jones, and other Ph.D. emeritus scientists) will perform the new geologic mapping, construction of cross sections, and will help develop 3-D structural models under Task 1.

Bakun will perform Task 2. Catchings will have responsibility for Task 3, and will be aided in the processing and interpretation of the new seismic lines by Brocher. Boatwright will perform and have responsibility for Task 4.

BIOGRAPHIES of PRINCIPAL INVESTIGATORS

William H. Bakun, seismologist, USGS 1973-present. Ph.D. in Geophysics UC Berkeley 1970. Experience in monitoring earthquake activity, earthquake recurrence and prediction, seismic discrimination of explosions and earthquakes, earthquake magnitude and seismic moment. Formerly Chief of Branch of Seismology and NEHRP Northern California Region Coordinator, USGS. Author of more than 100 contributions in scientific journals.

John Boatwright, seismologist, USGS 1978-present, since gaining his Ph.D. from Columbia University in 1979 where he studied under Paul Richards. He has conducted research primarily in the physics of earthquake rupture, in the analysis of strong ground motions, and in the quantification of earthquake damage. He has published more than 40 journal articles on seismological and engineering topics.

Earl E. Brabb, geologist USGS 1959-1994, geologist emeritus 1994-present. PhD in Geology, Stanford 1960. Experience in regional tectonics, reactor hazard evaluation, and landslide failures worldwide. Keynote speaker at several international meetings on geologic hazards and use of Geographic Information Systems. 162 publications including editor of a book on worldlandslide hazards.

Thomas M. Brocher, geophysicist, USGS 1985-present. Specializing in the acquisition and processing of seismic reflection and refraction data for crustal structure. Education: Ph.D. in geophysics, Princeton University, 1980. Tom is the author or co-author of 74 peer-reviewed publications and 134 abstracts presented at national scientific meetings. He currently heads a PG&E and NEHRP funded project to compile a 3-D velocity and structural model for the crust in the San Francisco Bay Area.

Rufus Catchings, geophysicist, USGS 1988-present. A specialist in the acquisition and processing of seismic reflection and refraction data, received Ph.D. from the Dept. of Geophysics, Stanford University, 1986. Experience in high-resolution and deep penetration seismic data acquisition, processing, and interpretation. Rufus is the author or co-author of 36 peer-reviewed publications and 38 abstracts presented at national scientific meetings.

Russ Graymer, geologist, USGS 4/94 - present. Ph.D. U.C. Berkeley, 1992. Specializing in bedrock and Quaternary geology of the San Francisco bay region, and in the preparation of digital geologic maps of the region. Experience includes bedrock mapping, Quaternary mapping, digital geologic databases, and structural geology.

David G. Howell, geologist, USGS 1974-present. A specialist in crustal deformation, analyses based on stratigraphic and structural field relationships. Education: Ph.D in geology, U.C. Santa Barbara, 1974. Author of approximately 150 scientific articles, fellow of the Geologic Society of America and The American Association for the Advancement of Science.

Robert Jachens, geophysicist, USGS 1975-present. Ph.D. in geophysics from Lamont-Doherty Geological Observatory, Columbia University in 1971. Experienced in the acquisition and interpretation of gravity and magnetic data in terms of earth structure, and the development of 3-D earth structures using Earthvision software. He currently heads the USGS's Geophysical Unit in Menlo Park. Author of more than 120 contributions in scientific journals.

Angela Jayko, geologist, USGS 1979-present, Ph.D. U.C. Santa Cruz 1984. Experience in regional tectonics, neotectonics, structural geology, digital geomorphology and spatial digital databases. She headed a NEHRP funded study of Quaternary transpressive tectonics in the San Francisco Bay region from 1993 to 1996, and headed a radioactive waste disposal bedrock mapping project 1986 to 1989. Author on about 45 scientificc papers and 30 abstracts.

David L. Jones, geologist USGS 1956-1985, geologist emeritus 1987-present. PhD in Geology, Stanford 1956. Experience in tectonics of the California Coast Ranges, accreted terranes of the North American Cordillera, terrane analysis of Alaska, sedimentology and biostratigraphy of radiolarian cherts, tectonics of the San Andreas fault system, structural development of the Sierra Nevada foothills, regional structure and stratigraphy of the Delta area (with graduate student Janine Band). 142 publications.

David P. Schwartz, geologist, USGS 1985-present. Woodward-Clyde Consultants 1973-1985, Ph.D State University of New York at Binghamton 1976. Broad experience in earthquake geology, particularly characterizing earthquake sources and quantifying estimates of maximum magnitude and earthuake recurrence intervals for critical facilities. Presently Northern California coordinator for the NEHRP, chief of the San Francisco Bay Area Earthquake Hazards project, and director of the Bay Area earthquake probability revision. He will serve as a consultant to the project.

Carl Wentworth, geologist, USGS 1963-present, Ph.D. Stanford Univ. 1967, specialized in tectonics, earthquake and landslide hazards, areal geology, geomorphology, and GIS. Registered Geologist and certified Engineering Geologist in the State of California. Experience includes management of a national research program on geologic hazards to nuclear power reactors and design, study of the areal geology, tectonics, and geologic hazards in the San Francisco Bay region, and leadership of a major geophysical study of the structure of the Coast Range/Great Valley boundary. Bibliography includes 42 abstracts and more than 60 maps and reports.

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VI. Compliance with standard terms and conditions

All terms and conditions consistent with a Federal Agency and RFP project group type (3: Services) are agreeable to and are able to be complied with by the applicant.

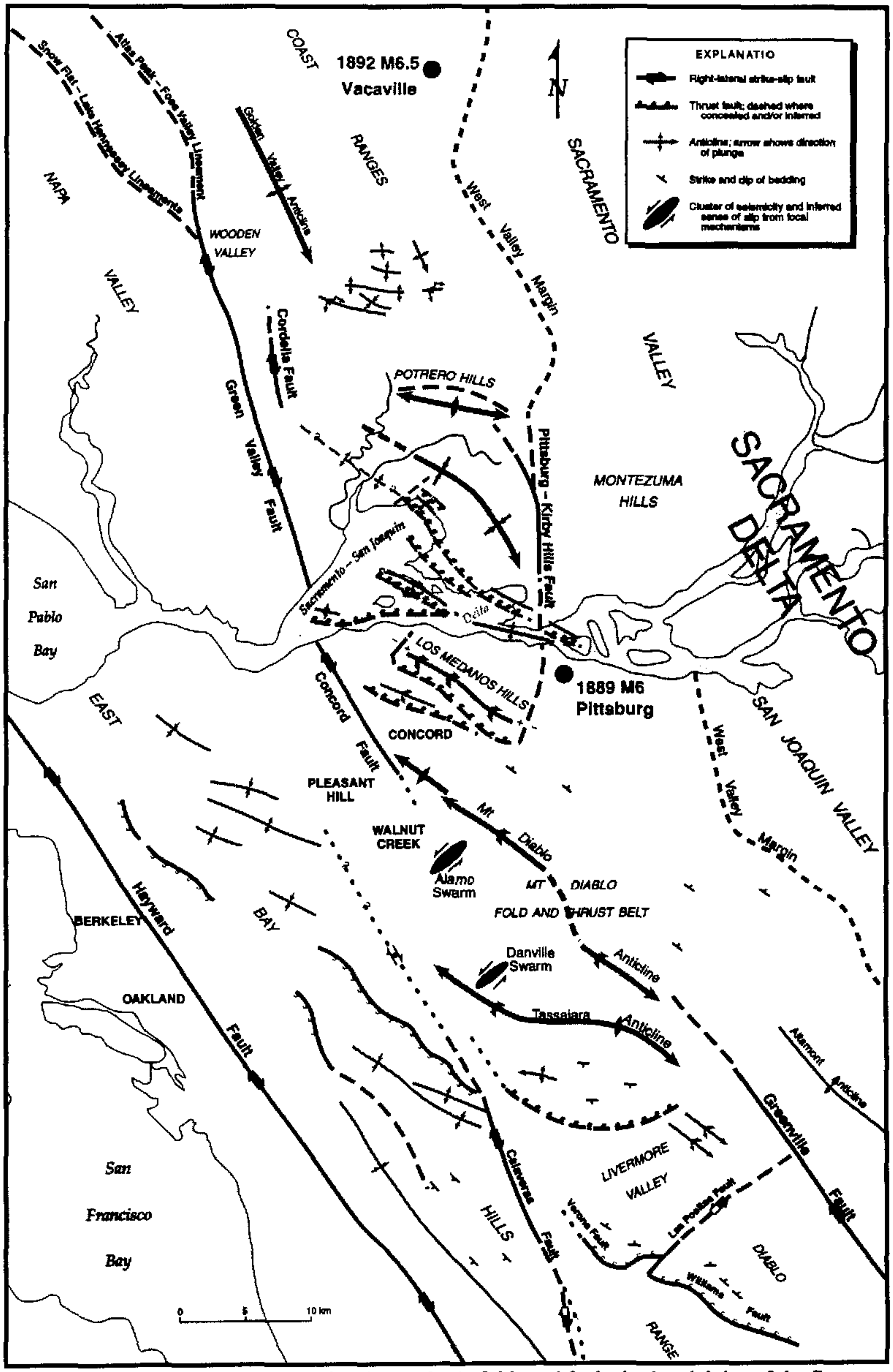

Figure 1. Map showing locations of major geologic folds and faults in the vicinity of the Sacramento Delta, as well as the location and magnitudes of two historic earthquakes in the region (modified from Unruh and others, 1997).

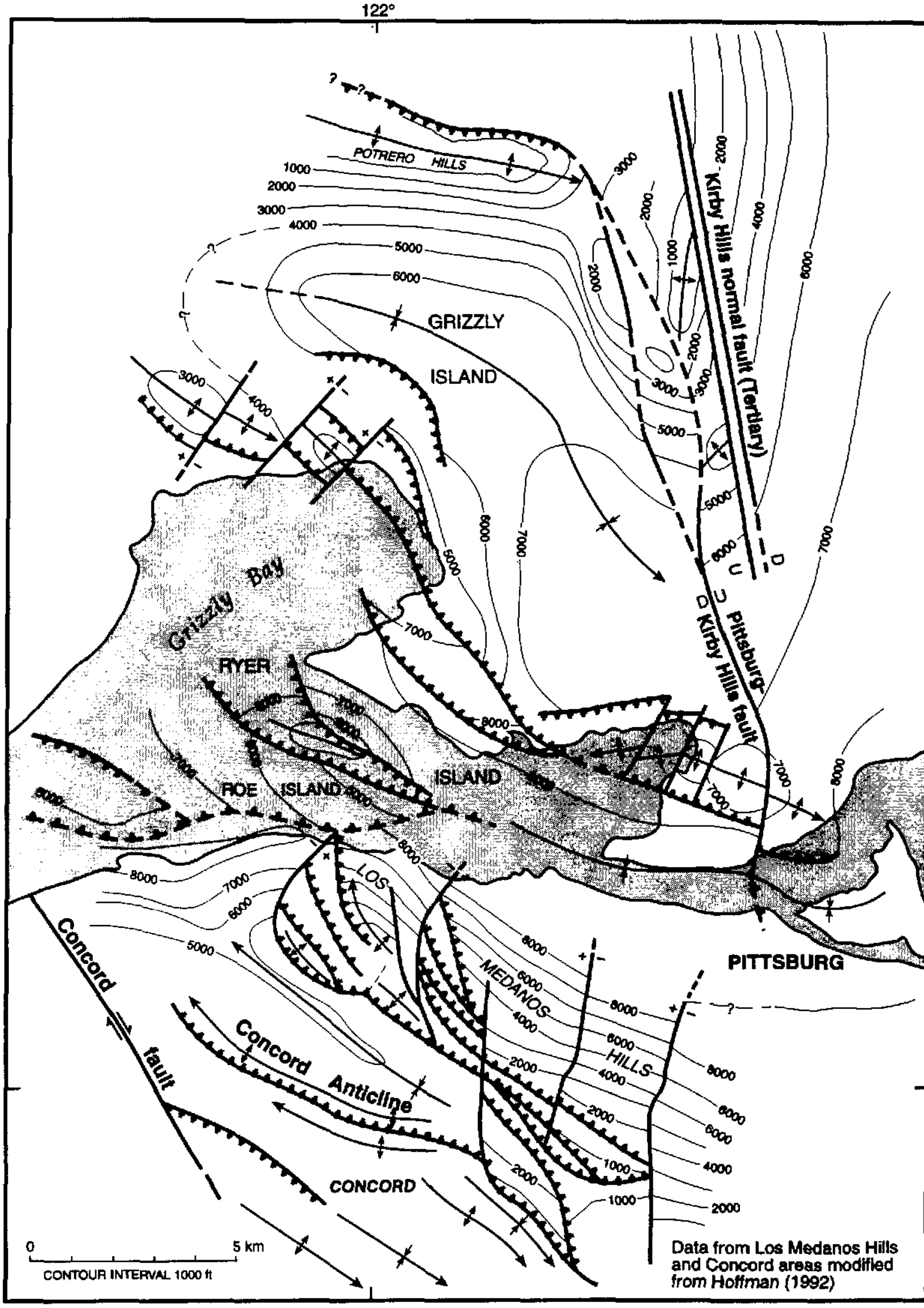

Figure 2. *Structure contours on the top of the Eocene Domengine sandstone, western* Sacramento–San Joaquin delta (from Unruh and others, 1997)

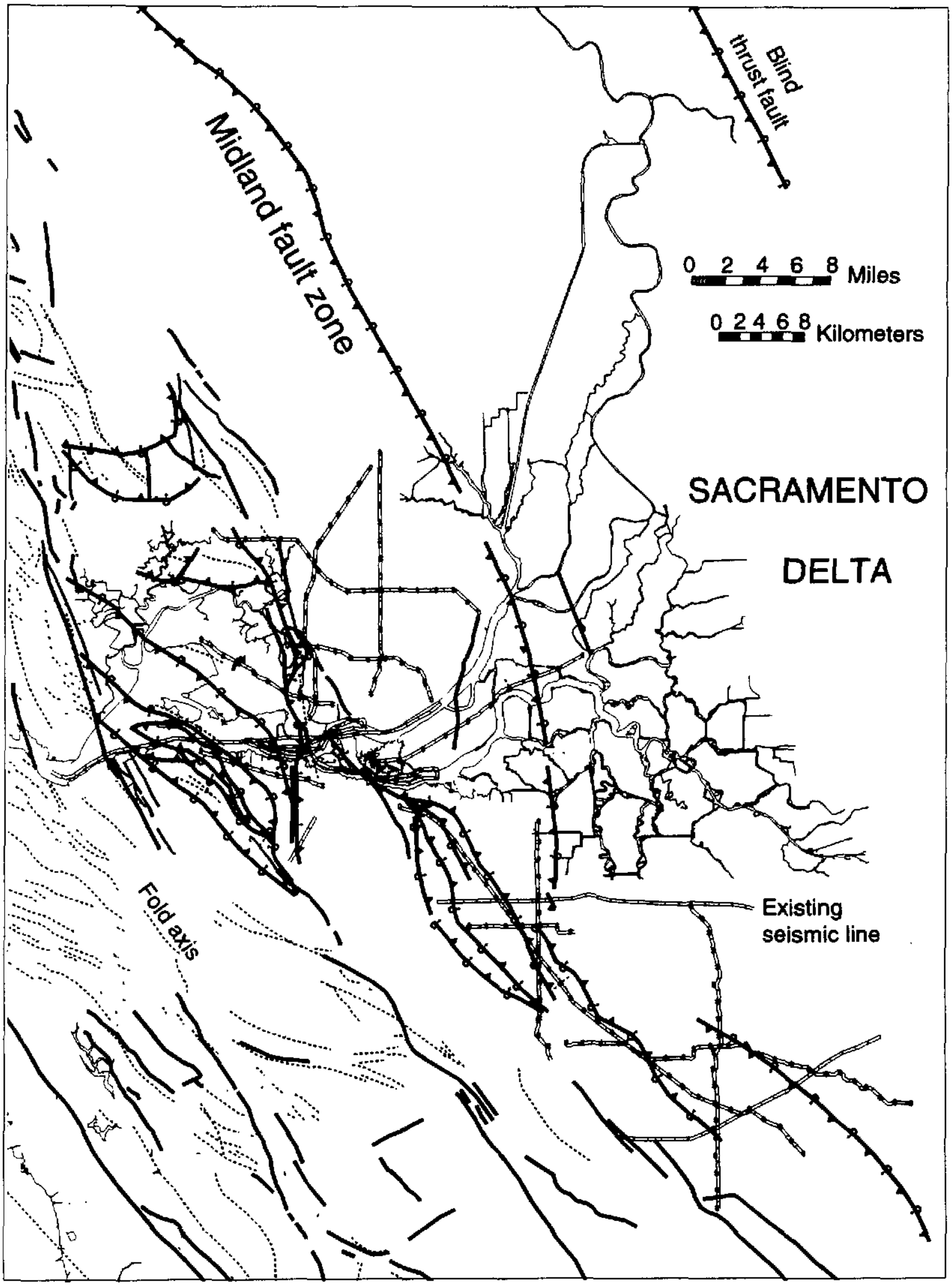

Figure 3. Map of proposed study area showing blind thrust faults (queried), some of the existing seismic lines (segmented lines), fold axes and some of the waterways in the Sacramento Delta (modified from Jayko and Lewis, 1996).

4-19-1892

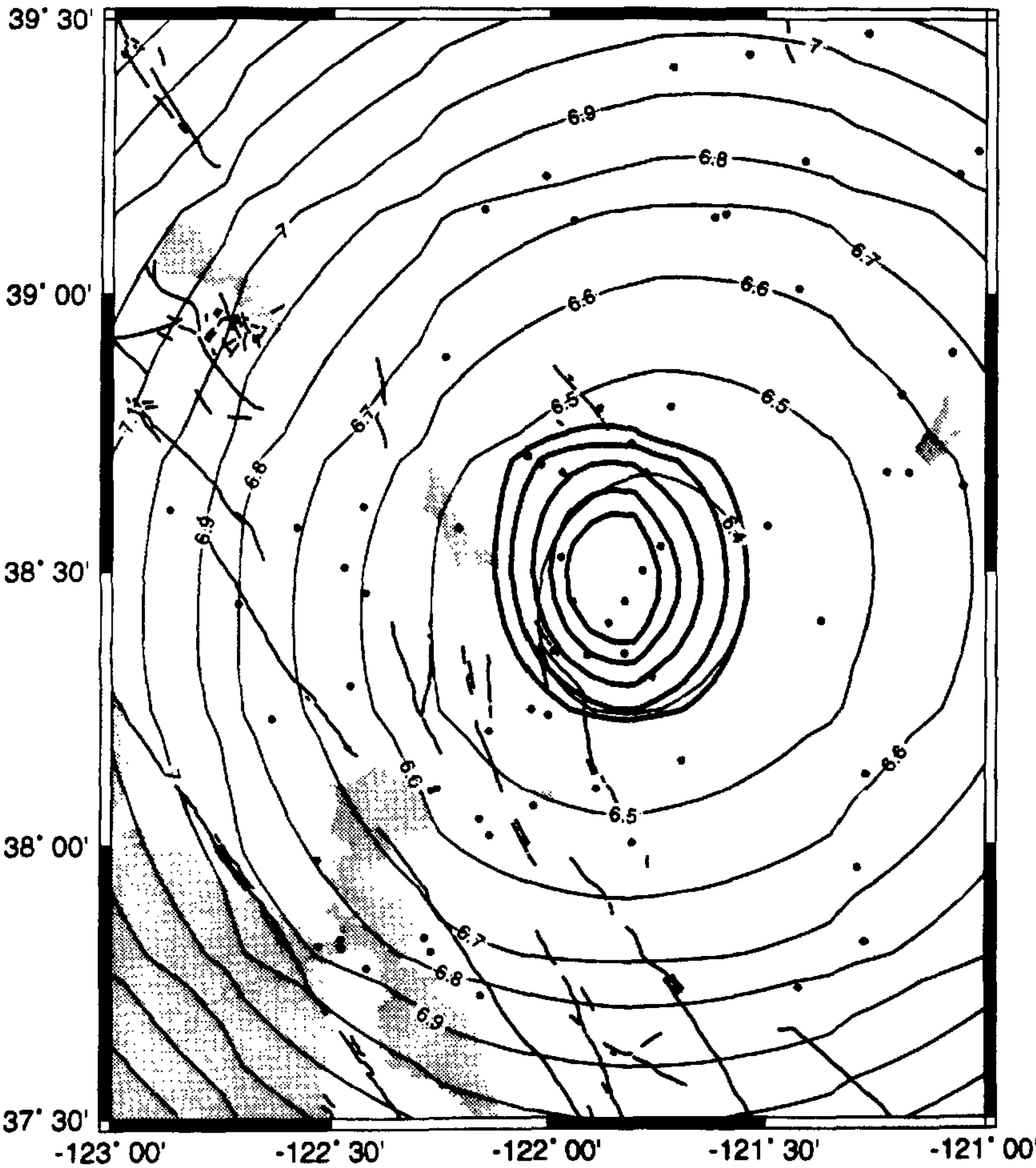

Figure 4. Map illustrating procedure followed by Bakun and Wentworth to constrain location and magnitude of historical earthquakes from intensity values (dots). The five heavy contours near the center of the figure provide bounds on the location of the epicentral region. The innermost heavy contour outlines the earthquake location with 50% confidence; the outer most contour defines the earthquake location to a 95% level of confidence. The light contours are intensity magnitudes (MI) for different assumed epicentral locations. For this 1892 Vacaville earthquake they fall between 6.3 and 6.5 for the heavy contour defining the 95% level of confidence.

I-000805

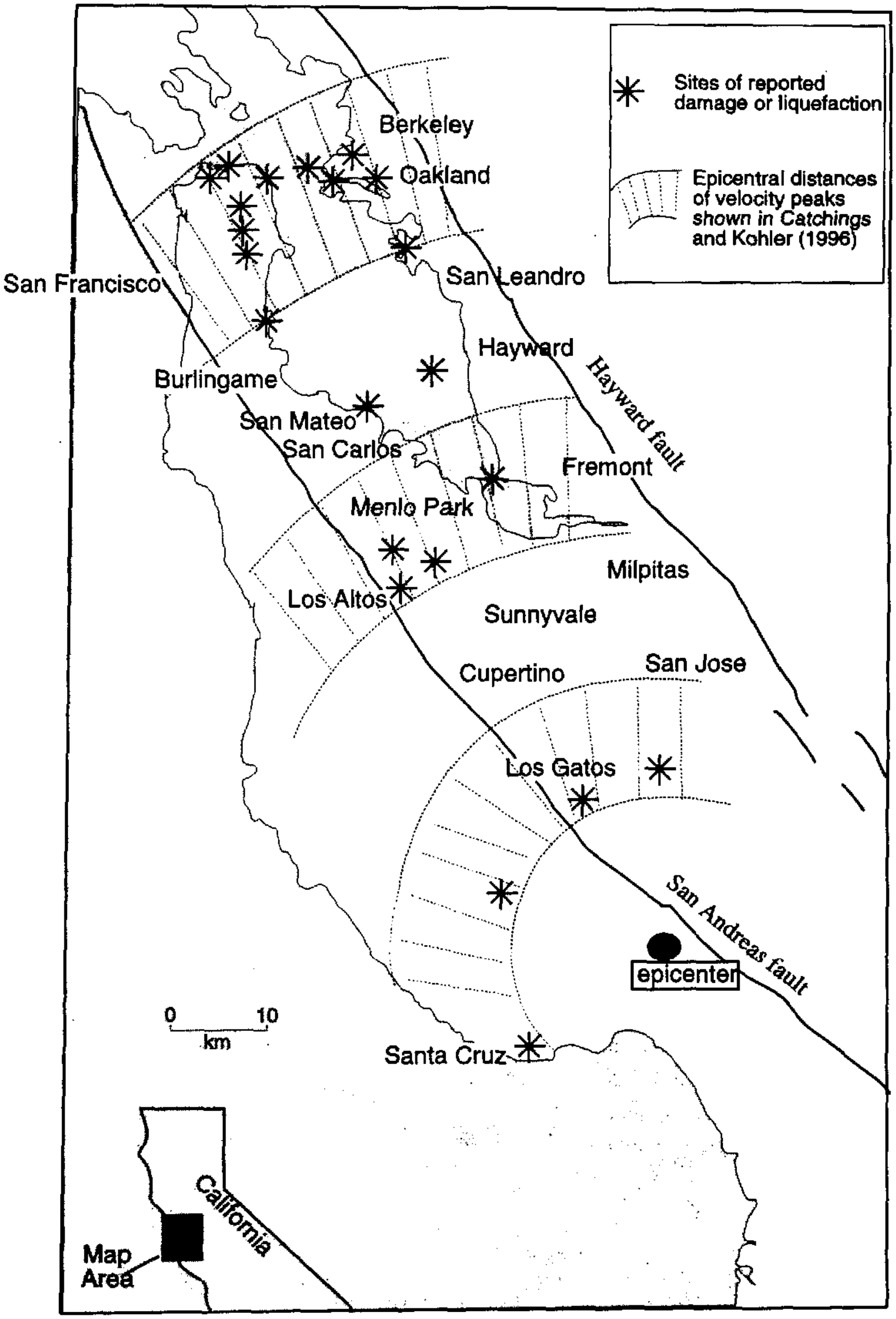

Figure 5. Map of the San Francisco Bay region with the location of sites that experienced shaking strong enough to produce appreciable damage or liquefaction during the 1989 Loma Prieta earthquake. The dotted lines outline the epicentral distances and widths of the ground peaks produced by Moho and crustal bounces. With two exceptions, all areas of major damage fall within the distance ranges where ground motion peaks were observed from controlled explosions. From Catchings and Kohler (1996).

ATTACHMENT

WLA

William Lettis & Associates, Inc.

1777 Botelho Drive, Suite 262, Walnut Creek, California 94596
Voice: (510) 256-6070 FAX: (510) 256-6076

July 23, 1997

Dr. Thomas Brocher
U.S. Geological Survey
345 Middlefield Rd. MS 977
Menlo Park, CA 94025

Re: Collaborative Investigation of Seismic Hazards in the Sacramento-San Joaquin Delta

Dear Tom:

The purpose of this letter is to strongly affirm my interest in collaborating with you and your colleagues at the U.S. Geological Survey on an investigation of seismic hazards in the Sacramento-San Joaquin Delta region. As you know, I have been collaborating with Dr. Jamie Rector (University of California, Berkeley) and Dr. Pat Williams (Lawrence Berkeley Laboratory) on a study of potentially active faults in the western Delta region. Our work currently is funded by the U.S. Geological Survey under the auspices of the National Earthquake Hazards Reduction Program (NEHRP). To date, we have focused our efforts on characterizing seismic sources in the area around Suisun Bay and the Pittsburg-Kirby Hills fault. The study you describe in your proposal to CALFED would provide important data and constraints on fault activity to the east of the Pittsburg-Kirby Hills fault, and thus extend the scope of on-going seismic hazard investigations to encompass the greater Delta region.

As we discussed in our recent phone conversation, Jamie, Pat and I are planning to submit a proposal to CALFED for funding to acquire additional data to constrain the activity of buried or "blind" thrust faults we have identified in the western Delta region, characterize the engineering properties of shallow sediments, and evaluate strong ground motions from near-field sources. If funded by CALFED, this work would supplement our on-going seismic hazard studies in the western Delta. In the interest of furthering collaboration between our group and your group, we are willing to share data and interpretations from all of our work to date, as well as any future work. One way to facilitate exchange of data and ideas would be to hold a workshop on earthquake hazards and geologic structure in the Delta involving members of our research team, the USGS participants in the proposed CALFED work, CALFED representatives, and other interested parties. If we schedule such a workshop midway through the grant cycle, we could prepare a short, executive summary to CALFED describing the results obtained to date by both of our groups. Our research team strongly endorses this approach as a means to strengthen the collaborative ties between our group and report our results rapidly.

On behalf of Jamie and Pat, I look forward to working with you and your colleagues at the USGS on this very interesting and timely study.

Sincerely,

Jeffrey R. Unruh
Senior Project Geologist, William Lettis & Associates, Inc.
Assistant Research Geologist, University of California, Davis