Overview of Earthquake Hazards in California

and

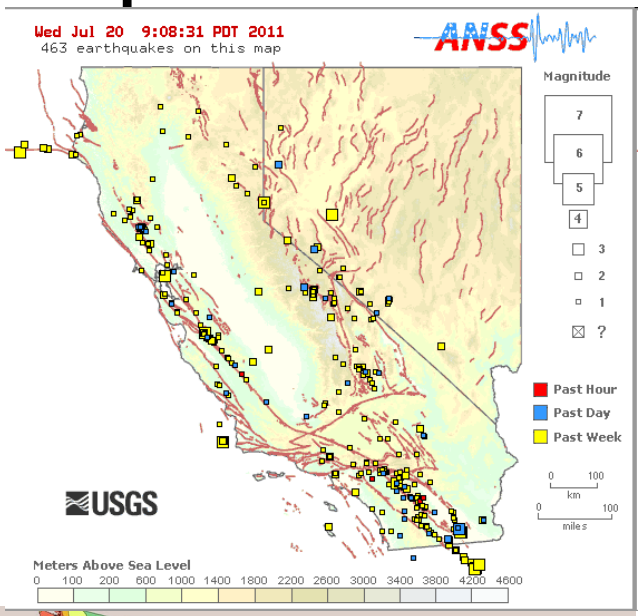
Current Research Aimed at Reducing Uncertainty

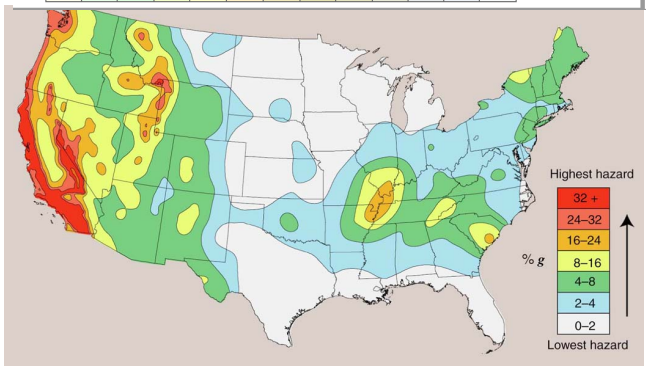
William L. Ellsworth
U. S. Geological Survey
Menlo Park, CA

USGS
science for a changing world

The USGS role in the National Earthquake Hazard Reduction Program partnership

- Provide earthquake monitoring and notifications,
- Assess seismic hazards,
- Conduct targeted research needed to reduce the risk from earthquake hazards nationwide, and
- Work with NEHRP agencies and many other partners to support public awareness of earthquake hazards and impacts.



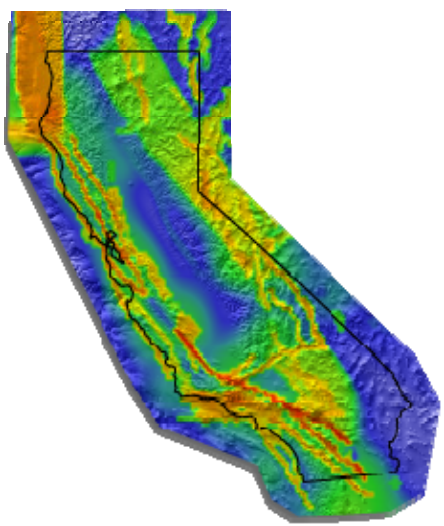


Seismic Hazard Analysis

Two main model components:

1) Earthquake ***Rupture*** Forecast

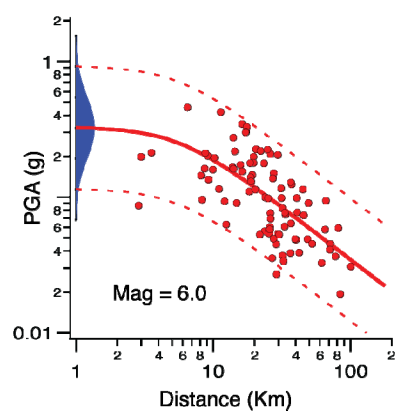
Gives the probability of all possible earthquake ruptures (fault offsets) throughout the region and over a specified time span



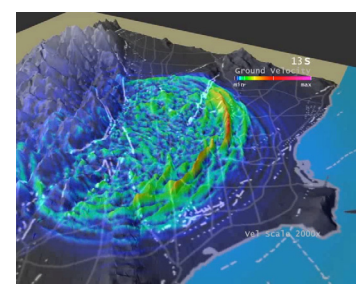
2) Earthquake ***Shaking*** model

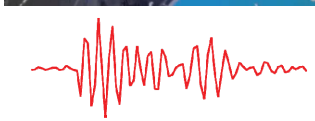
For a given earthquake rupture, this gives the probability that an intensity-measure type will exceed some level of concern

Empirical
"Attenuation Relationships"



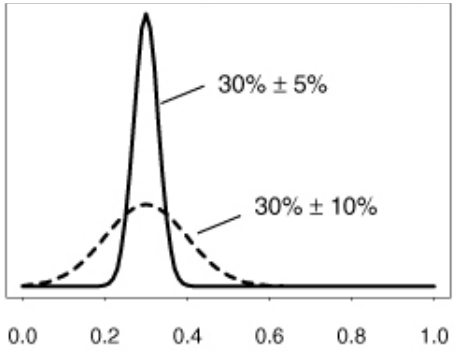
Physics-based
"Waveform Modeling"



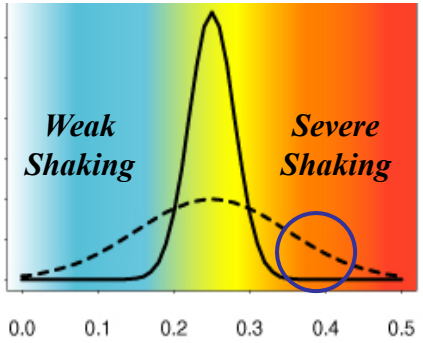


Uncertainties in current earthquake hazard models may lead to seismic-resistant designs that are overly conservative (biased too high).

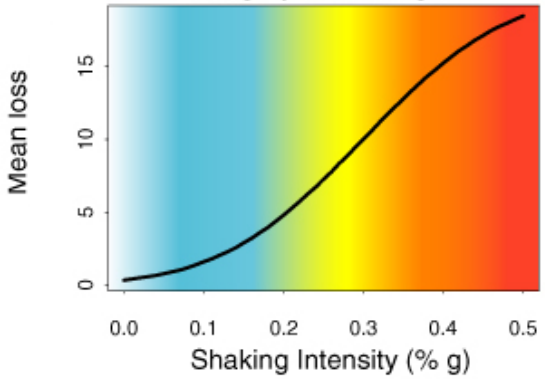
Earthquake Rupture Forecast



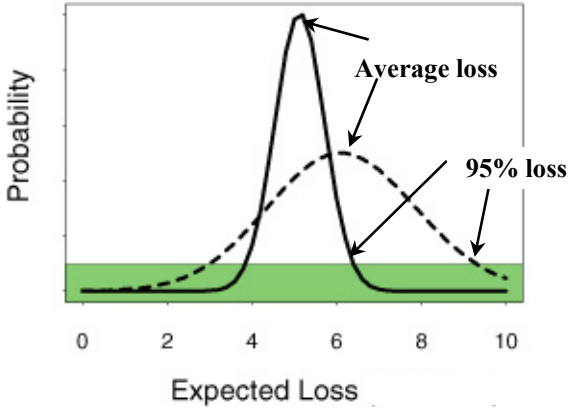
Earthquake Shaking Model



Structural Fragility



Expected Losses



Increasing precision in hazard assessment through better data and improved understanding can reduce this bias, hence, lowering the cost of seismic safety.

Improved Seismic Monitoring, Improved Decision-Making, *National Research Council*, 2006

Seismic Hazard Analysis

NGA Project

http://peer.berkeley.edu/ngawest/

The “Next Generation of Ground-Motion Attenuation Models” (NGA) project is a multidisciplinary research program coordinated by the Lifelines Program of the Pacific Earthquake Engineering Research Center (PEER), in partnership with the U.S. Geological Survey and the Southern California Earthquake Center.

The objective of the project is to develop new ground-motion prediction relations.

Research on physics based shaking models is a major research focus of the Southern California Earthquake Center (SCEC) http://www.scec.org/m8/

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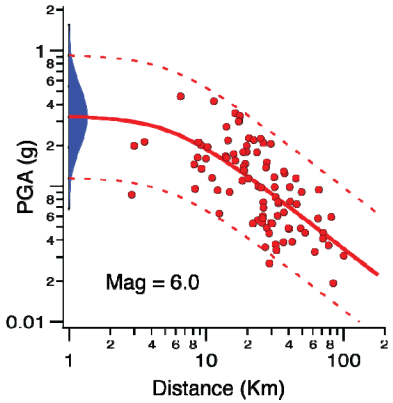

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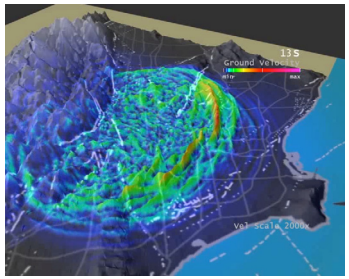
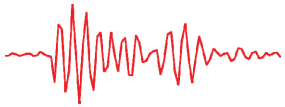
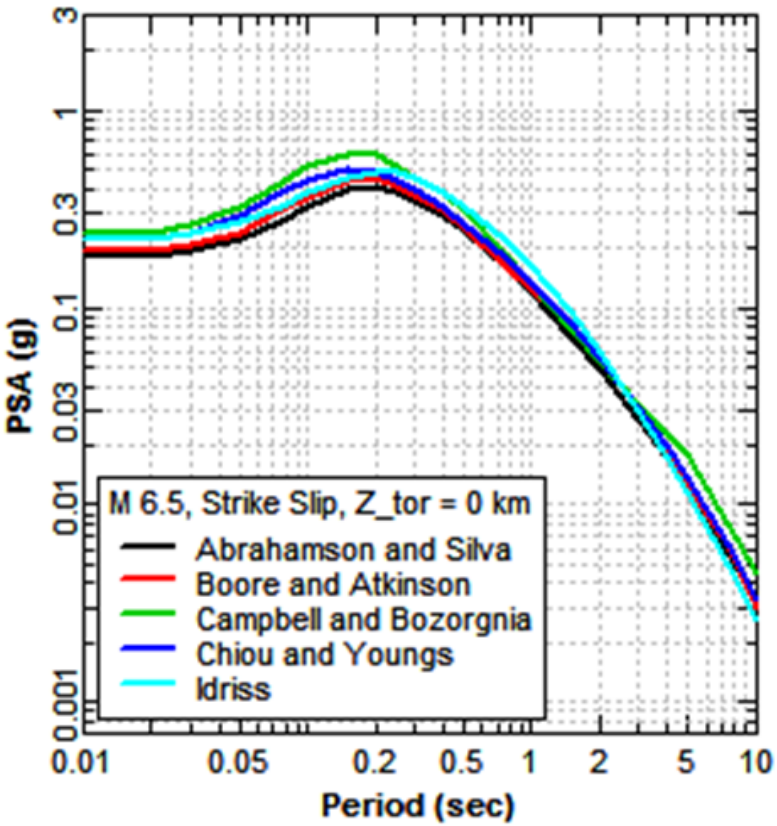
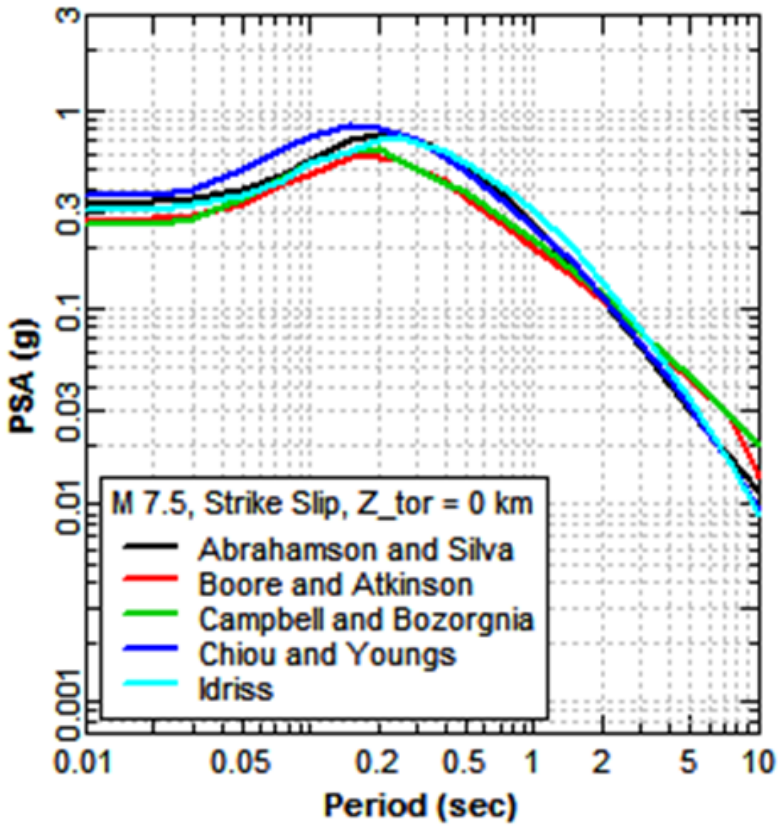




NGA Results for Strike-Slip Fault Mechanism @ 10 km Magnitude = 6.5 (left), 7.5 (right)

NEHRP BC Site Conditions (V_{S30}=760 m/s)





All 5 models are in good agreement (within a factor of 1.5)

Slide from Yousef Bozorgnia, PEER

NGA Results for Reverse-Slip Fault Mechanism @ 10 km Magnitude = 6.5 (left), 7.5 (right)

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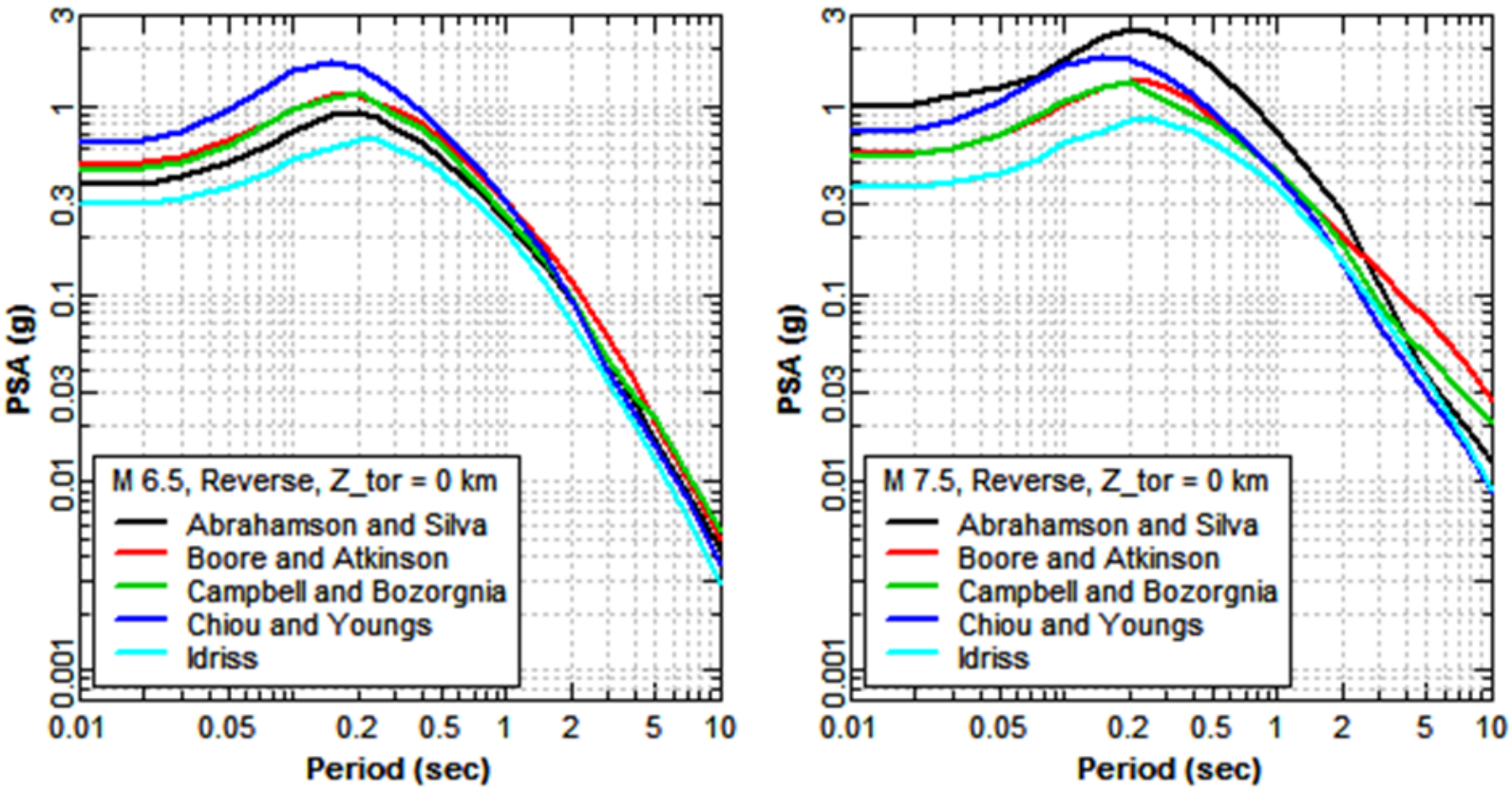
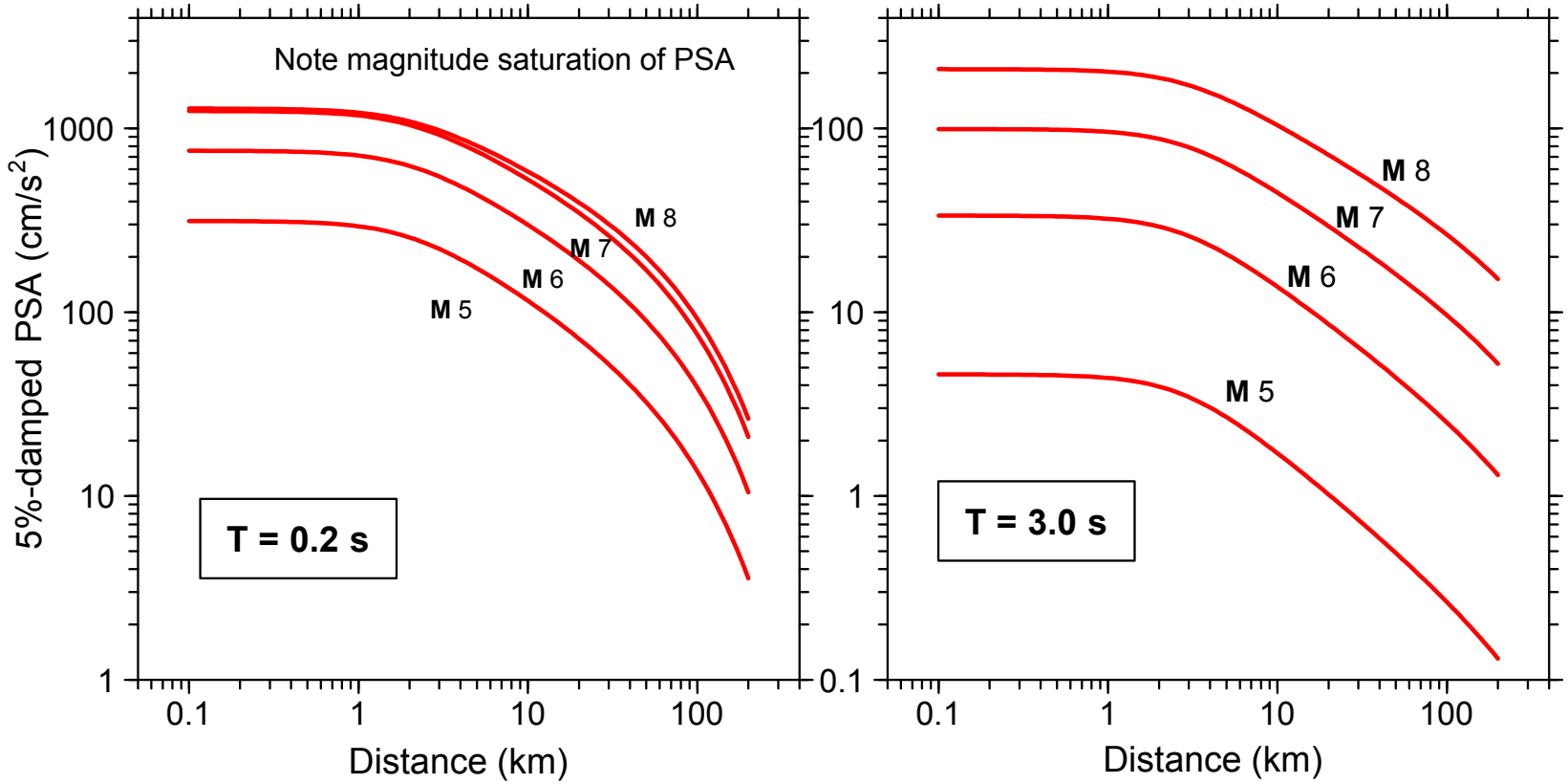


Epistemic uncertainty at short periods

Slide from Yousef Bozorgnia, PEER

Magnitude and Distance Dependence of Ground Motion
5% Damped Pseudo-Acceleration (PSA)



"At all periods, the new equations predict significantly smaller motions than do the [Boore-Joyner-Fumal 1997] equations for large magnitude."

(from Boore and Atkinson, EERI, v. 24, pp. 99-138, 2008)

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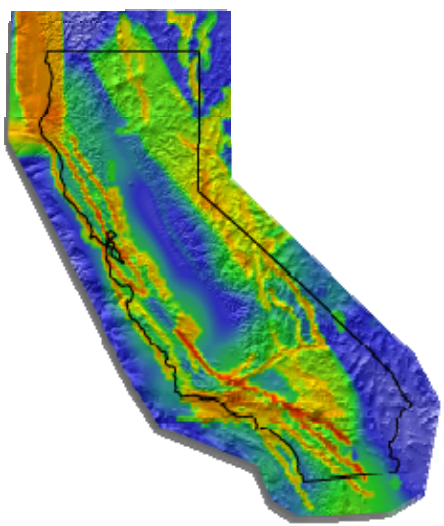

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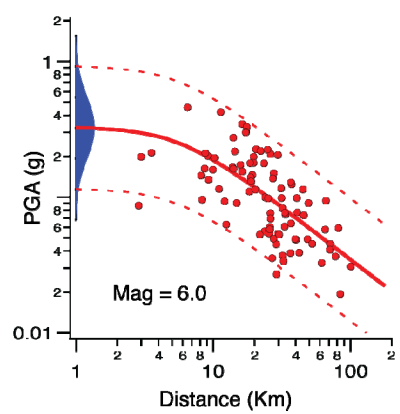

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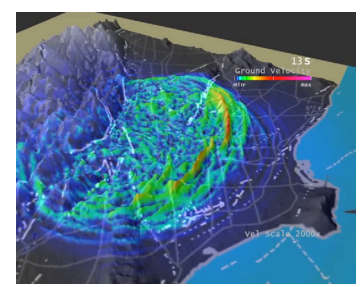

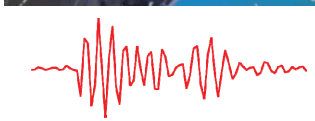

Components of the Uniform California Earthquake Rupture Forecast 2

Fault Models

Specifies the spatial geometry of larger, more active faults.

→

Deformation Models

Provides fault slip rates used to calculate seismic moment release.

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Earthquake-Rate Models

Gives the long-term rate of all possible damaging earthquakes throughout a region.

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Probability Models

Gives the probability that each earthquake in the given Earthquake Rate Model will occur during a specified time span.

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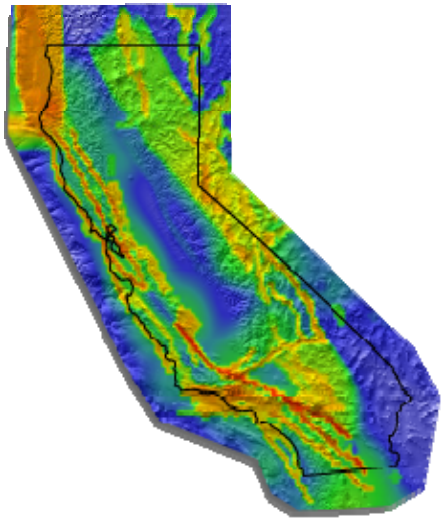

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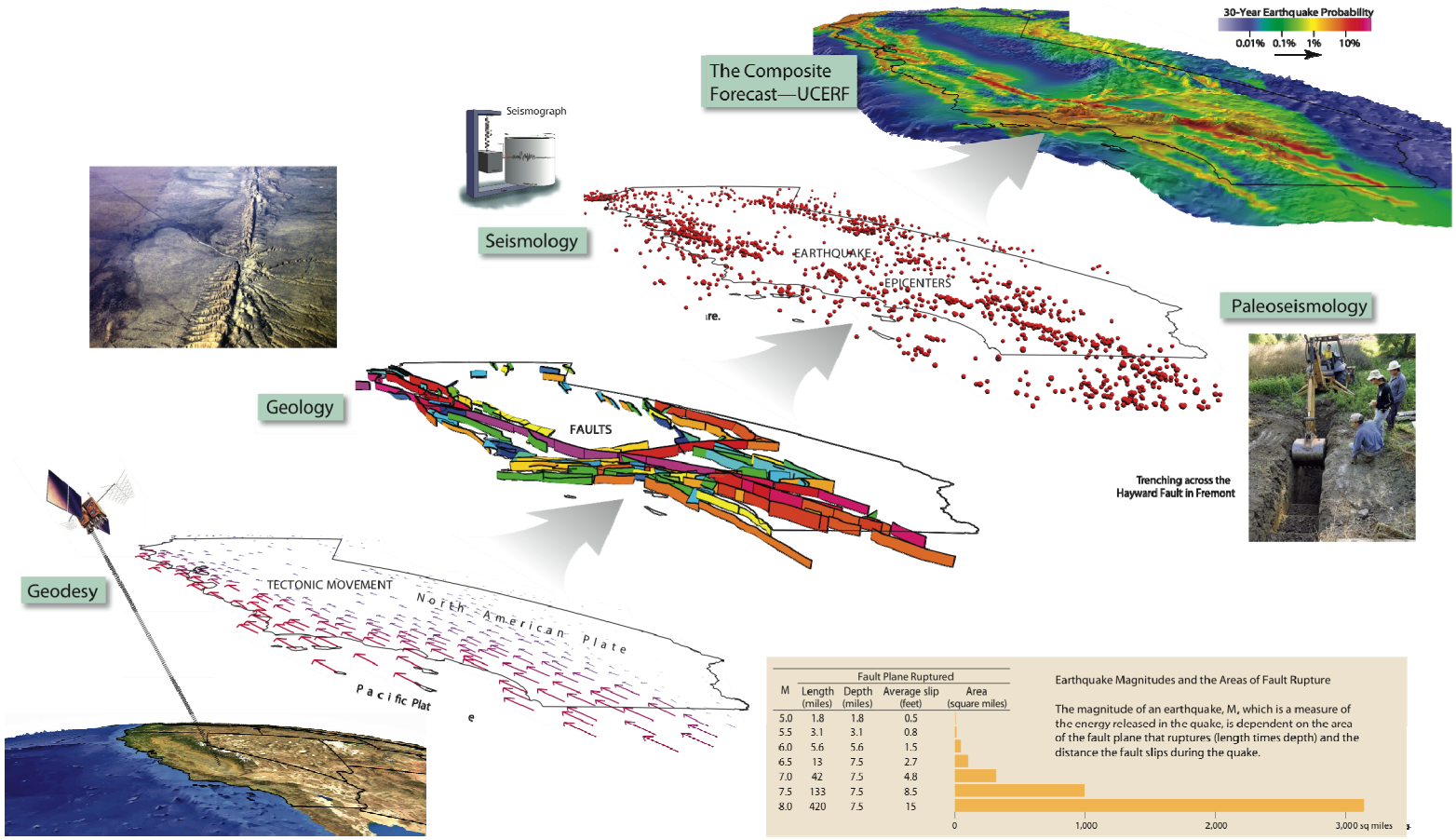


Earthquake Magnitudes and the Areas of Fault Rupture

The magnitude of an earthquake, M, which is a measure of the energy released in the quake, is dependent on the area of the fault plane that ruptures (length times depth) and the distance the fault slips during the quake.

M	Fault Plane Ruptured: Length (miles)	Depth (miles)	Average slip (feet)	Area (square miles)
5.0	1.8	1.8	0.5	
5.5	3.1	3.1	0.8	
6.0	5.6	5.6	1.5	
6.5	13	7.5	2.7	
7.0	42	7.5	4.8	
7.5	133	7.5	8.5	
8.0	420	7.5	15	

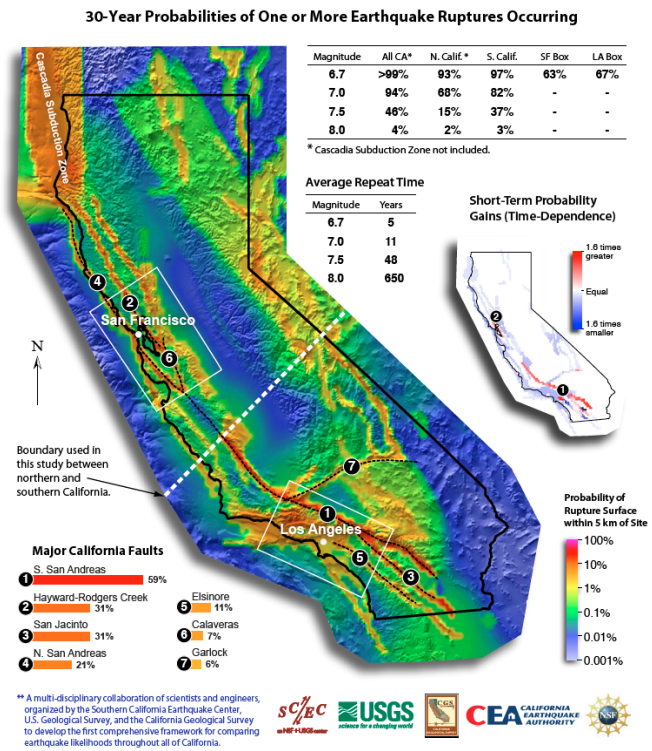
0 1,000 2,000 3,000 sq miles

Working Group on California Earthquake Probabilities (WGCEP)

http://wgcep.org/

Uniform California Earthquake Rupture Forecast (UCERF)

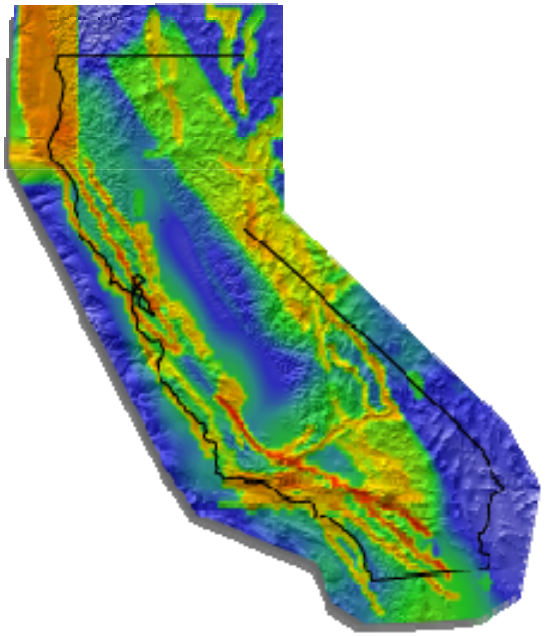
UCERF2



Released April 2008

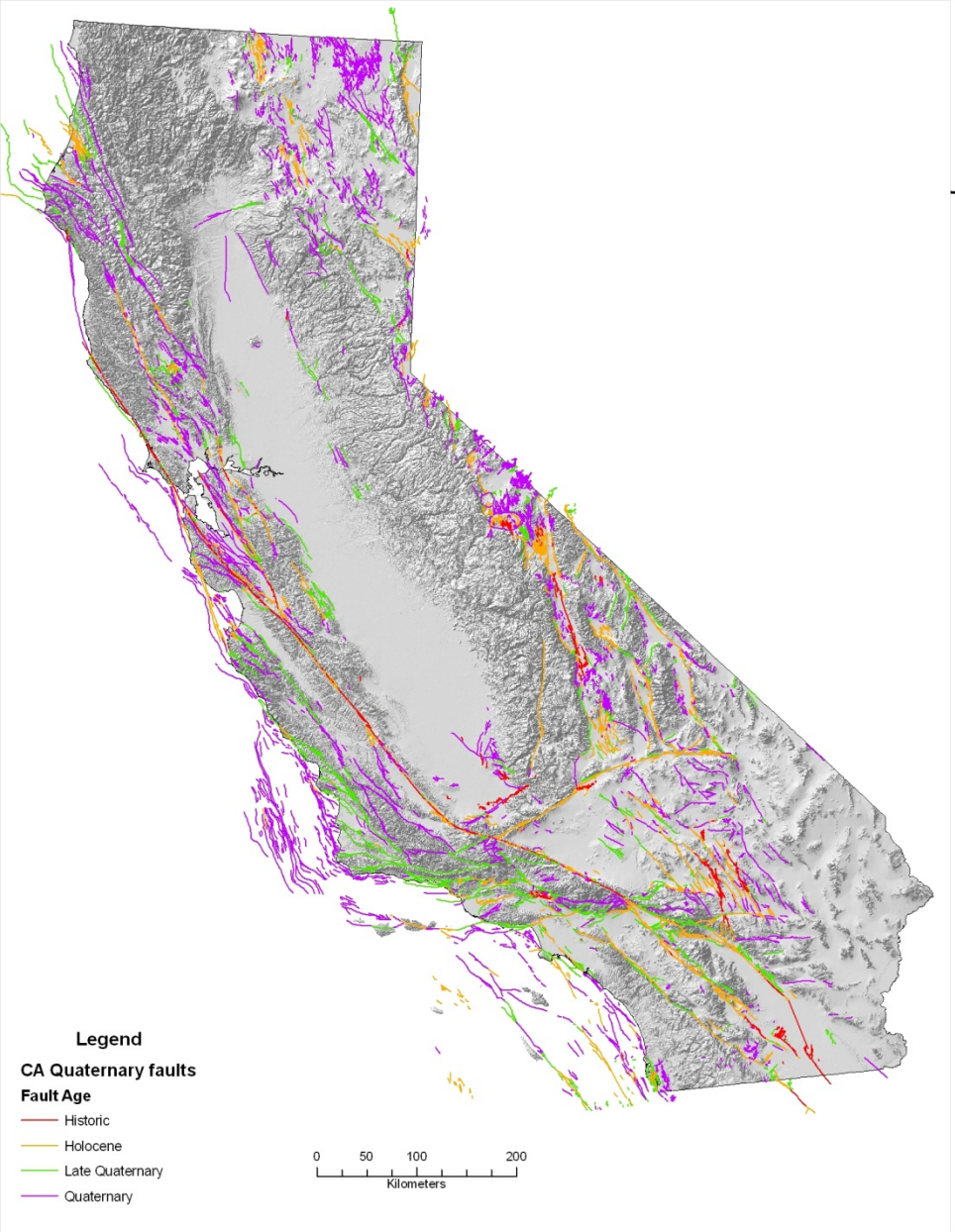
http://pubs.usgs.gov/fs/2008/3027/

UCERF3



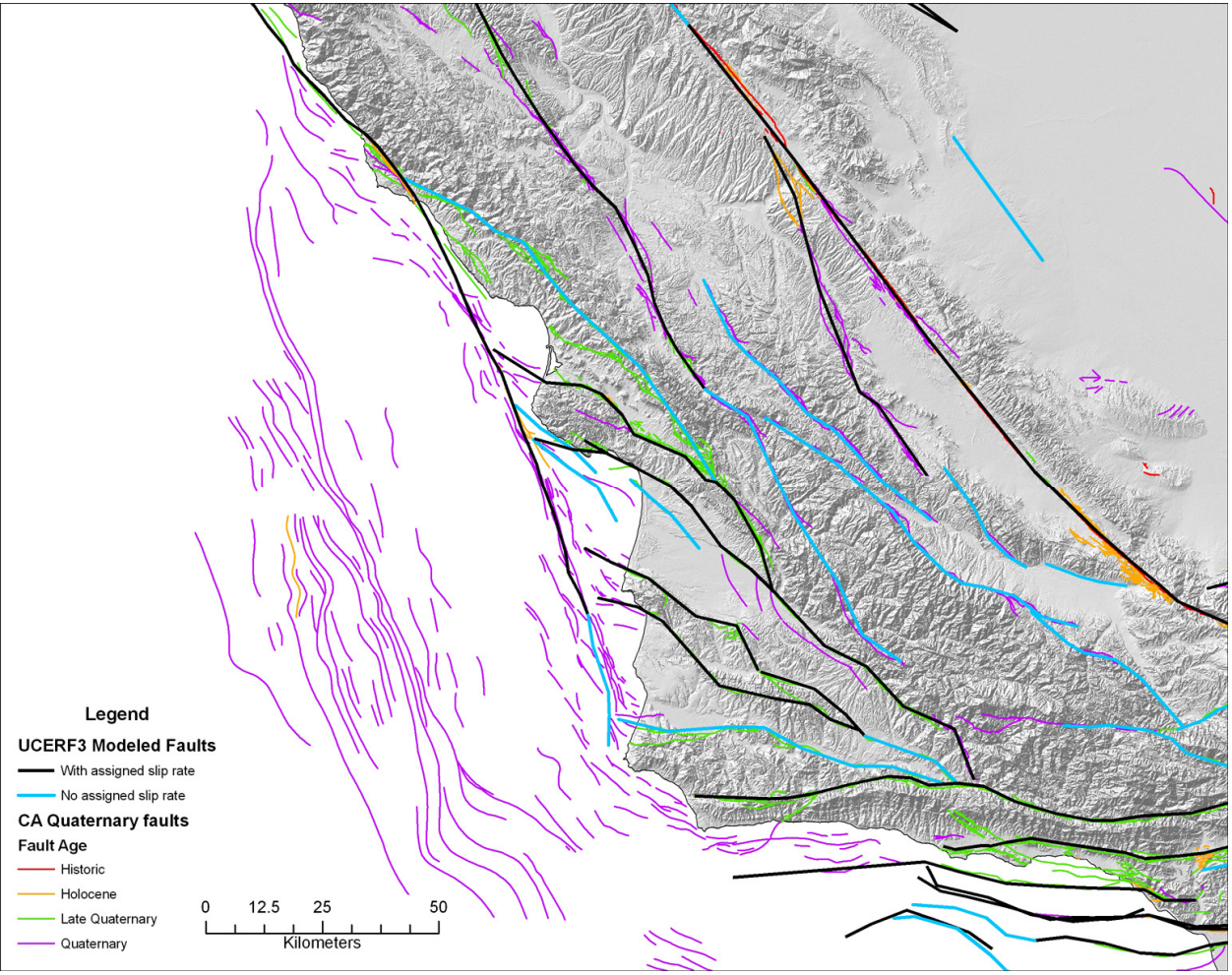
Due June 2012

Quaternary Active Faults



UCERF2 Fault Model

Research to Improve the Hazard Model for the Central Coast



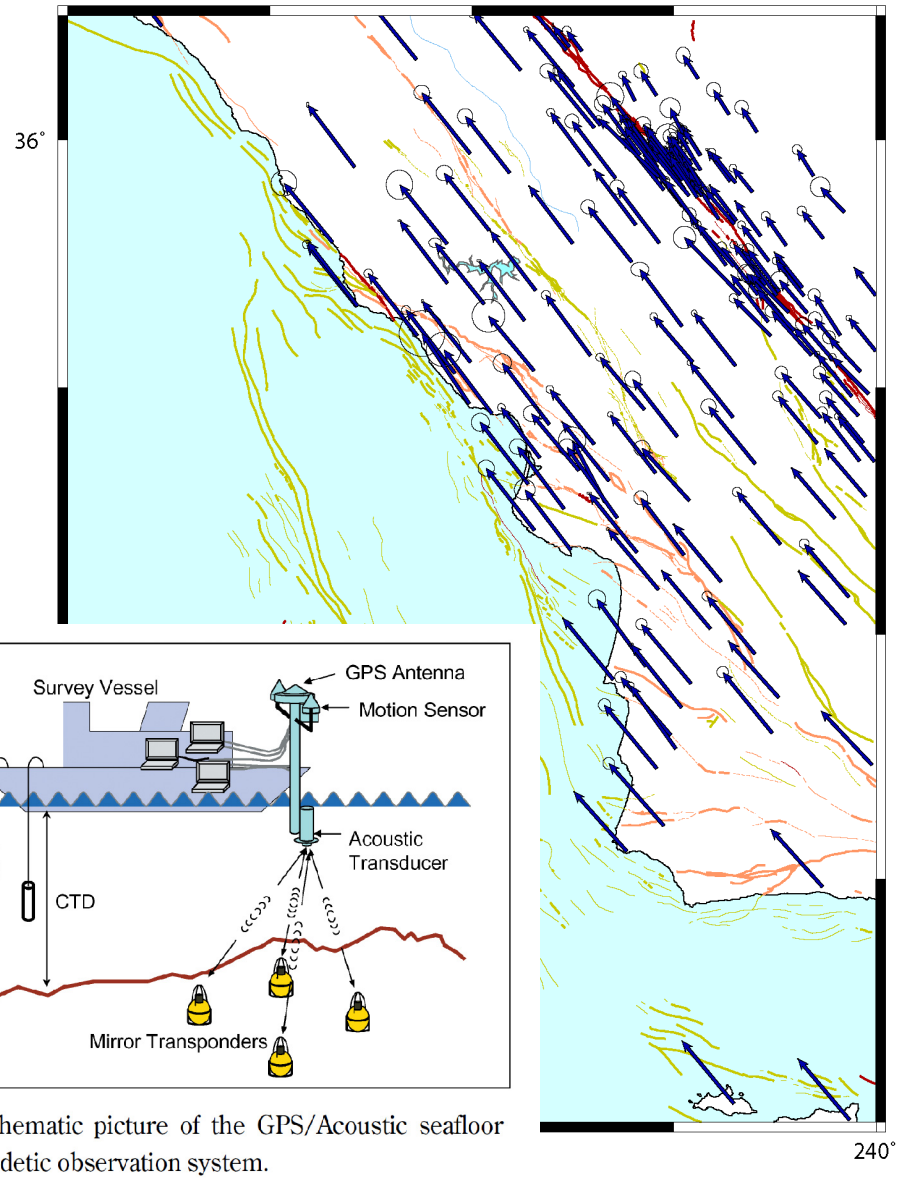
Investigations conducted under the Cooperative Research and Development Agreement (CRADA) between PG&E and USGS

- Aeromagnetics
- Gravity
- Marine magnetics
- Seismic reflection
- High-resolution bathymetry
- Geologic mapping
- Geodesy
- Seismicity

<u>Joint data collection</u>

<u>Independent interpretation</u>

GPS Crustal Velocity Field along the California Central Coast



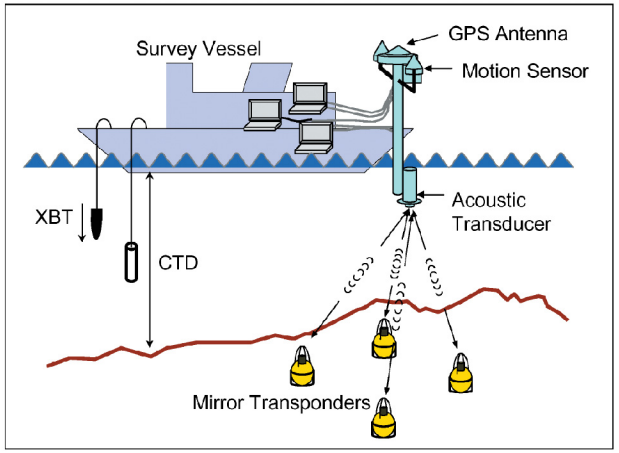
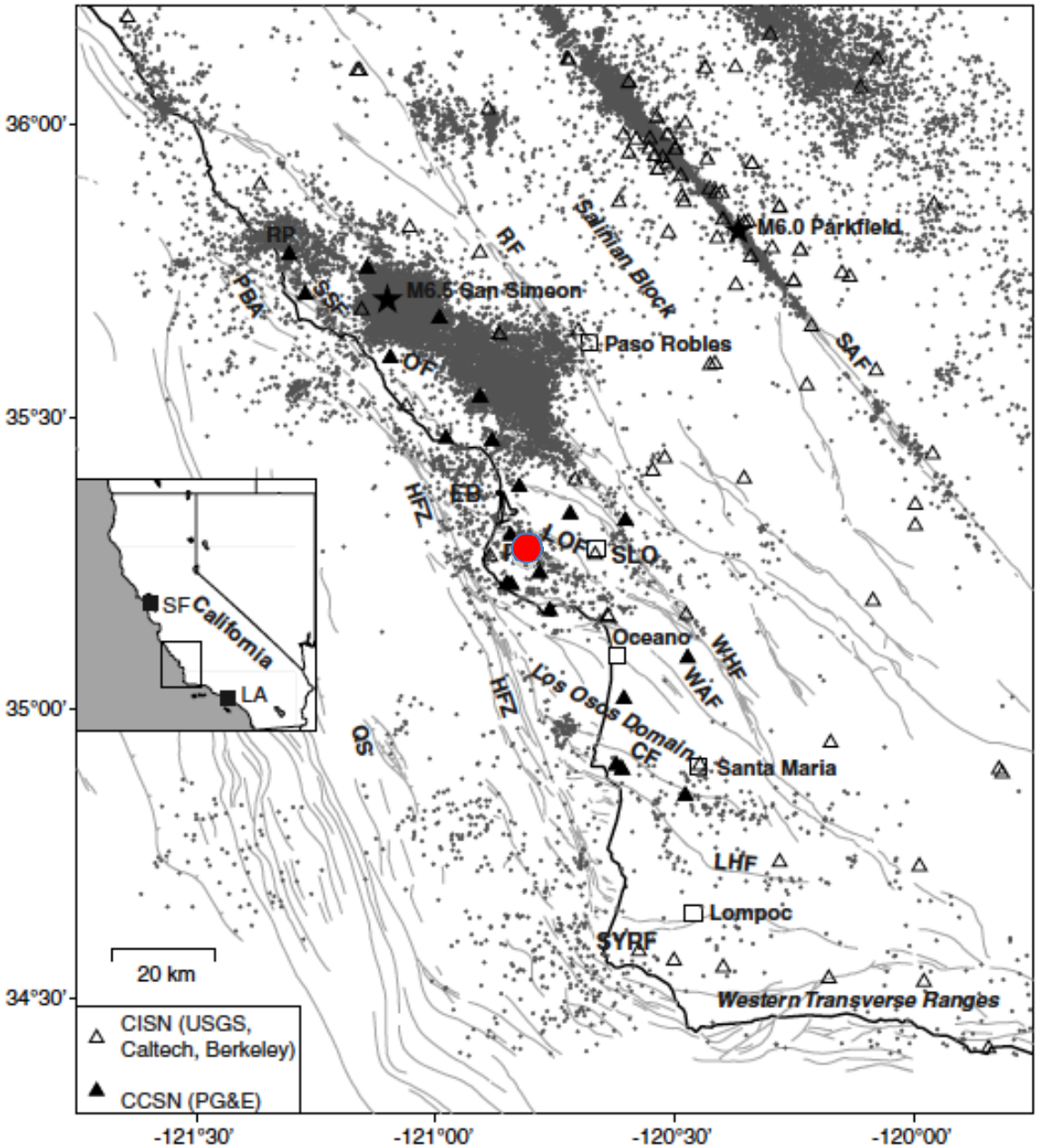


Fig. 1 Schematic picture of the GPS/Acoustic seafloor geodetic observation system.

Velocity with respect to stable North America

- Vectors generally point to the northwest, reflecting North America – Pacific plate motion
- Systematic lengthening of vectors from northeast to southwest reflects strain accumulation across the San Andreas fault system
- The crustal velocity field is being used in UCERF3 to determine the slip rate of the faults
- The existing GPS network has little sensitivity to offshore faults
- These offshore faults could be studied using ocean floor GPS

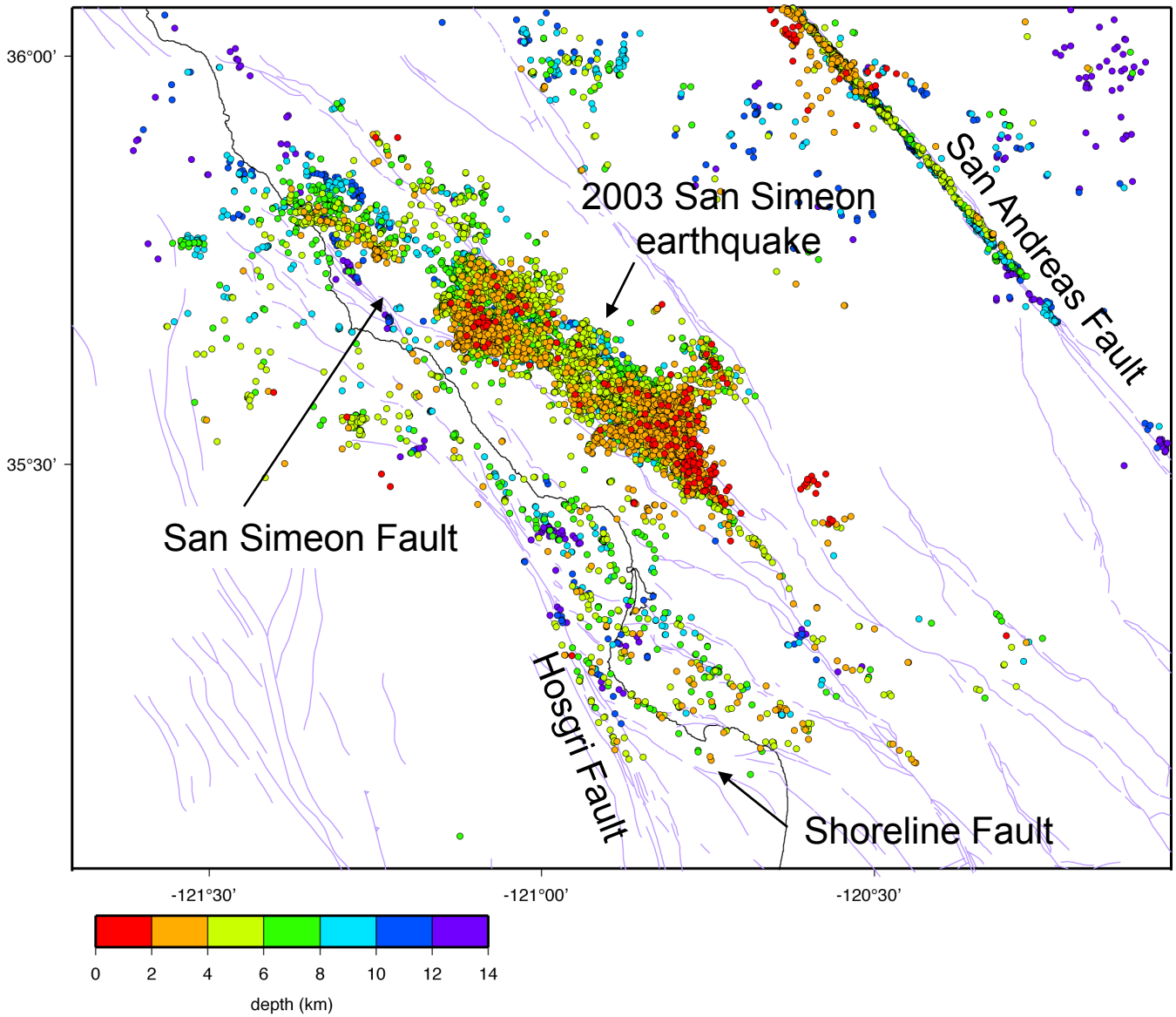
USGS science for a changing world



Seismic monitoring along the Central Coast is a partnership between the California Integrated Seismic Network and PG&E. All data are available through the Northern California Earthquake Data Center at U.C. Berkeley.

CGS USGS CalEMA Caltech UC Berkeley

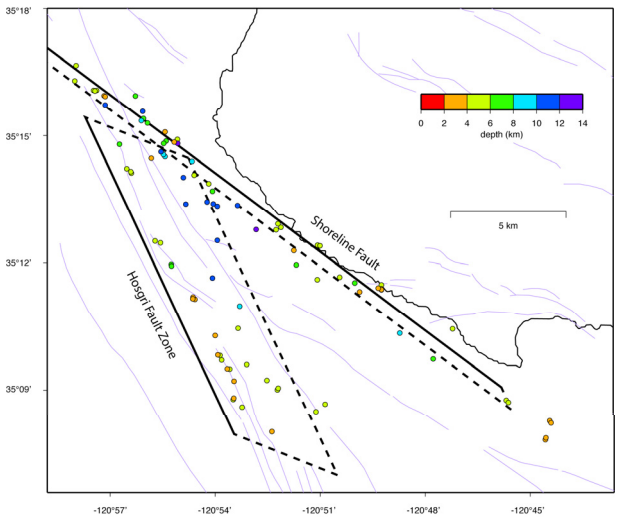
Reanalysis of earthquakes from the combined PG&E and CISN networks by Jeanne Hardebeck (USGS) revealed the Shoreline Fault



Jeanne Hardebeck, 2011 Sesimological Society of America meeting

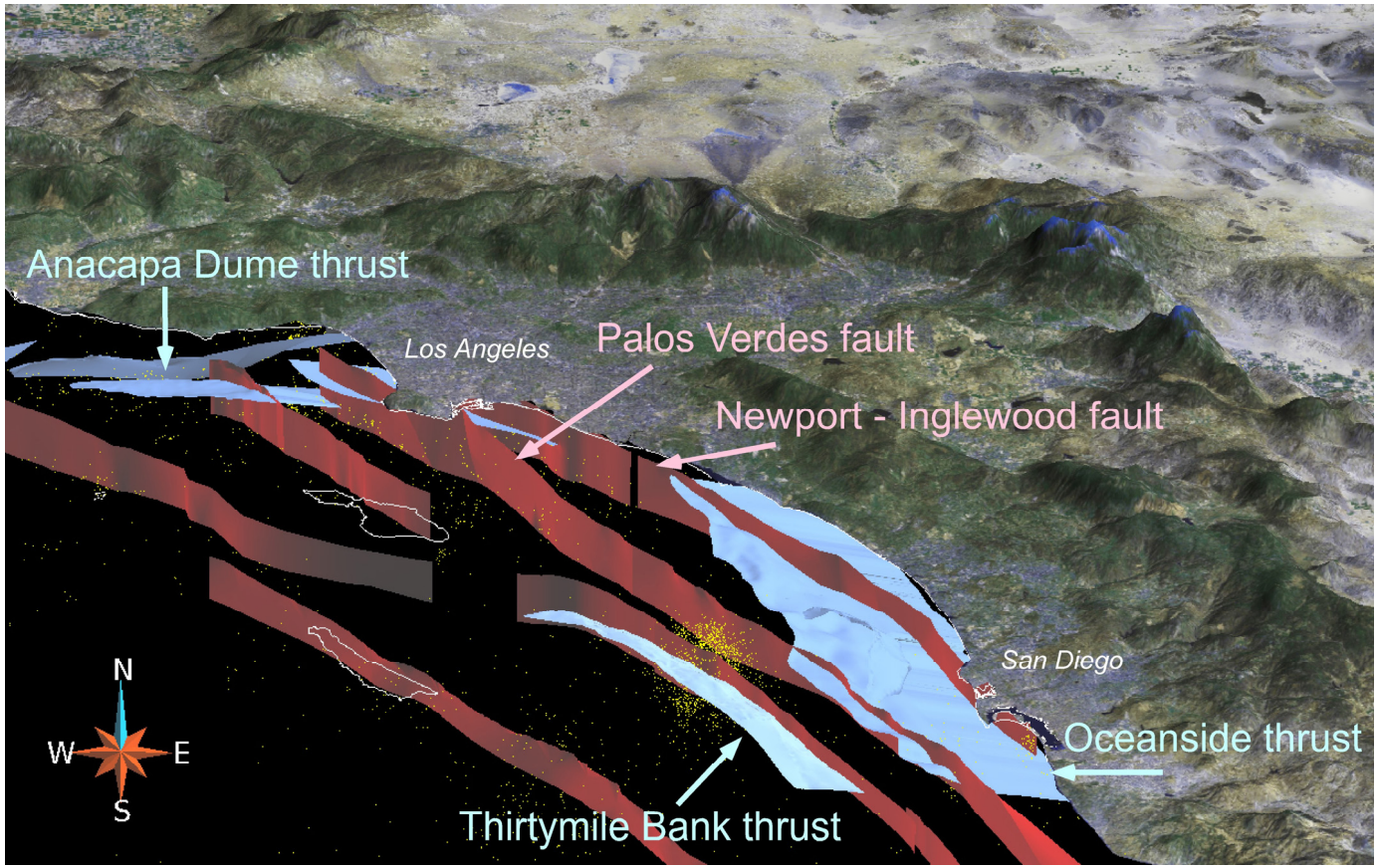
USGS science for a changing world

Key Findings from Seismicity



1) Depth extent of seismicity:
   - Microseismicity down to ~14 km depth offshore Pt Buchon.
   - Microseismicity down to ~14 km depth along San Simeon Fault.
2) Geometry of the Shoreline Fault:
   - Objective method of fitting fault planes to seismicity.
   - Shoreline Fault fit by a single plane. No objective evidence for any discontinuities or segmentation at seismogenic depths.
   - Discontinuities smaller than the location uncertainty of ~1 km may be undetected, but would be too small to be barriers to earthquake rupture [e.g. Wesnousky, BSSA 2008].
   - Northwest end of Shoreline Fault extends to the mapped trace of the Hosgri Fault, indicating that there is no gap between these faults at seismogenic depths.

Faulting in the Inner California Borderlands



• Both strike-slip and thrust faults accommodate crustal deformation in the Inner California Borderlands.
• Challenges are to define the recent activity, slip rates, and seismogenic potential of these faults, including the blind thrust systems.

Modified from presentation by Andreas Plesch at UCERF3 Statewide Fault-Model & Paleoseismic Data Workshop, April2011

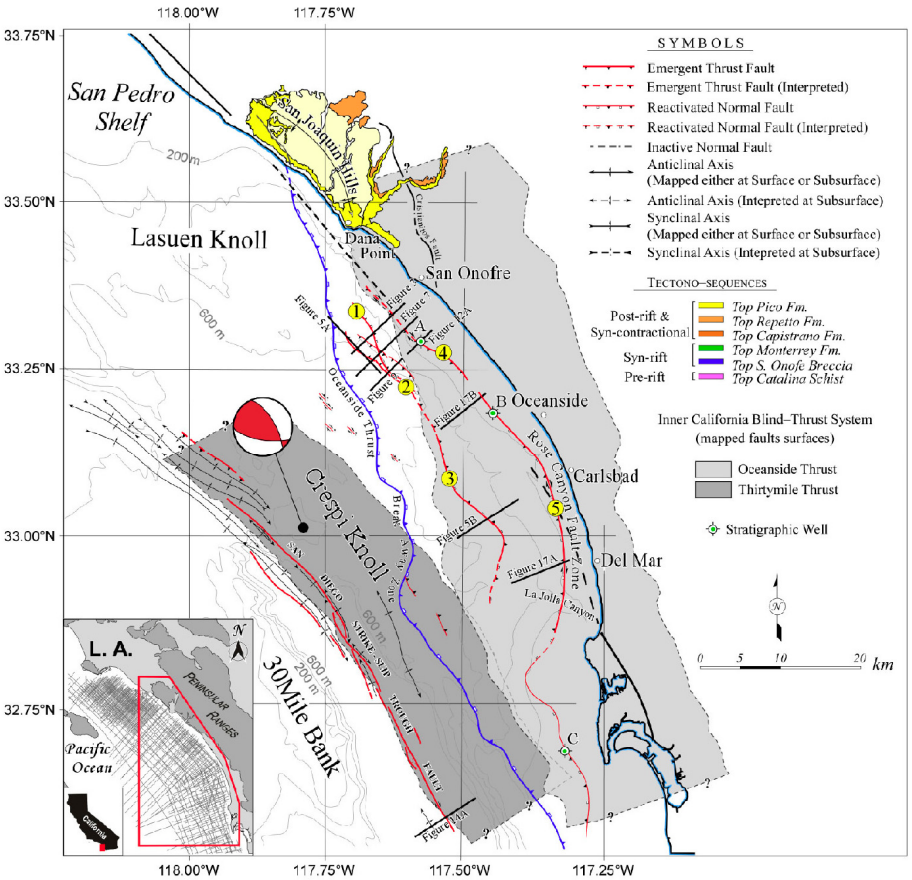
Faulting in the Inner California Borderlands

- We lack critical information about these offshore thrusts systems that compromises our ability to assess the hazards that they pose.

- We do not have unequivocal evidence of late Pleistocene to Holocene activity and slip rate on some of these faults.

- There are several possible modes of interaction between thrust and strike-slip systems that will influence source geometries at depth.

- We lack direct knowledge about slip styles and magnitudes in past earthquakes.



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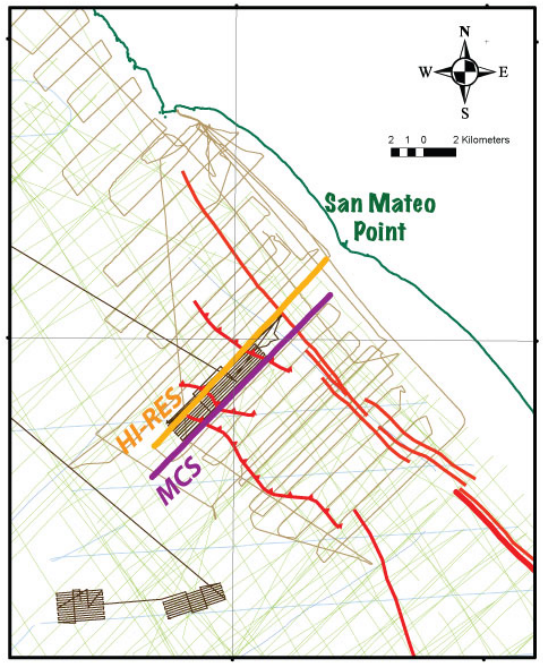
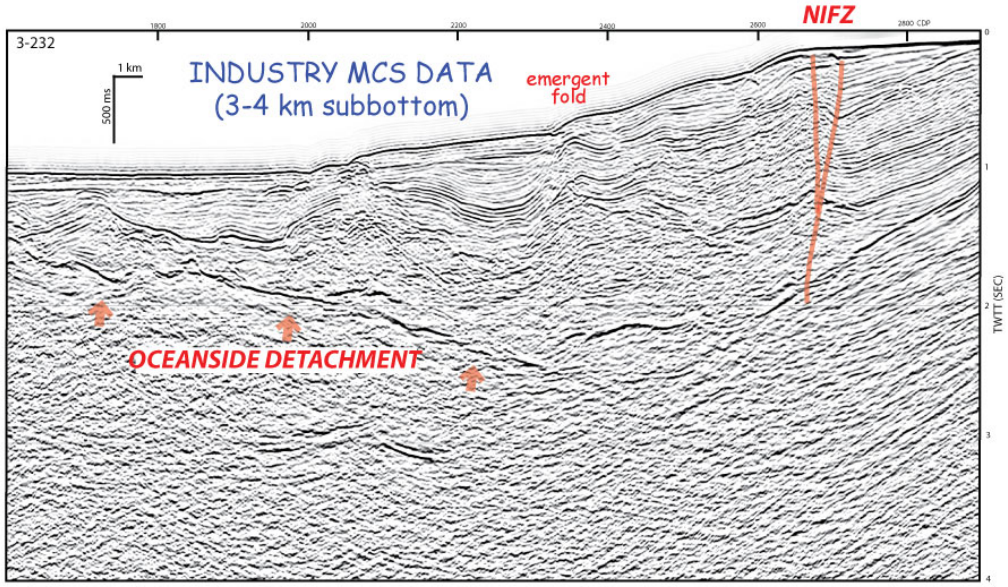
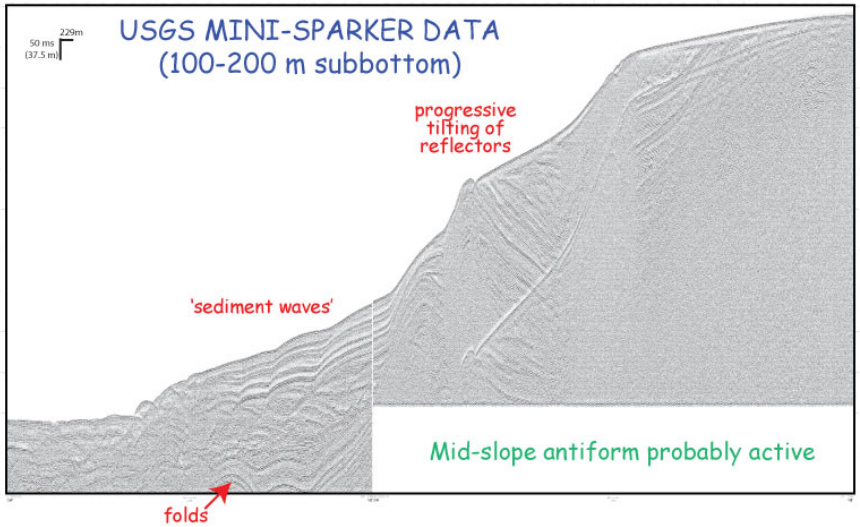
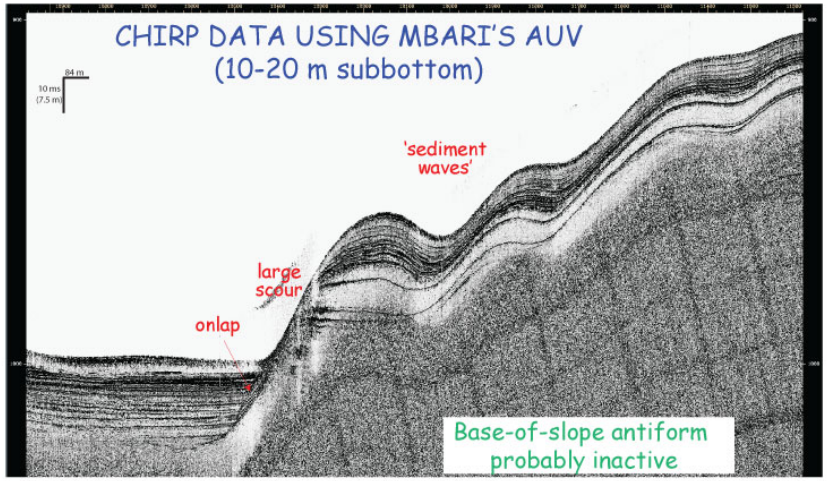
EVIDENCE FOR REACTIVATION OF THE OCEANSIDE DETACHMENT OFFSHORE OF SAN MATEO POINT USING SEISMIC REFLECTION PROFILES





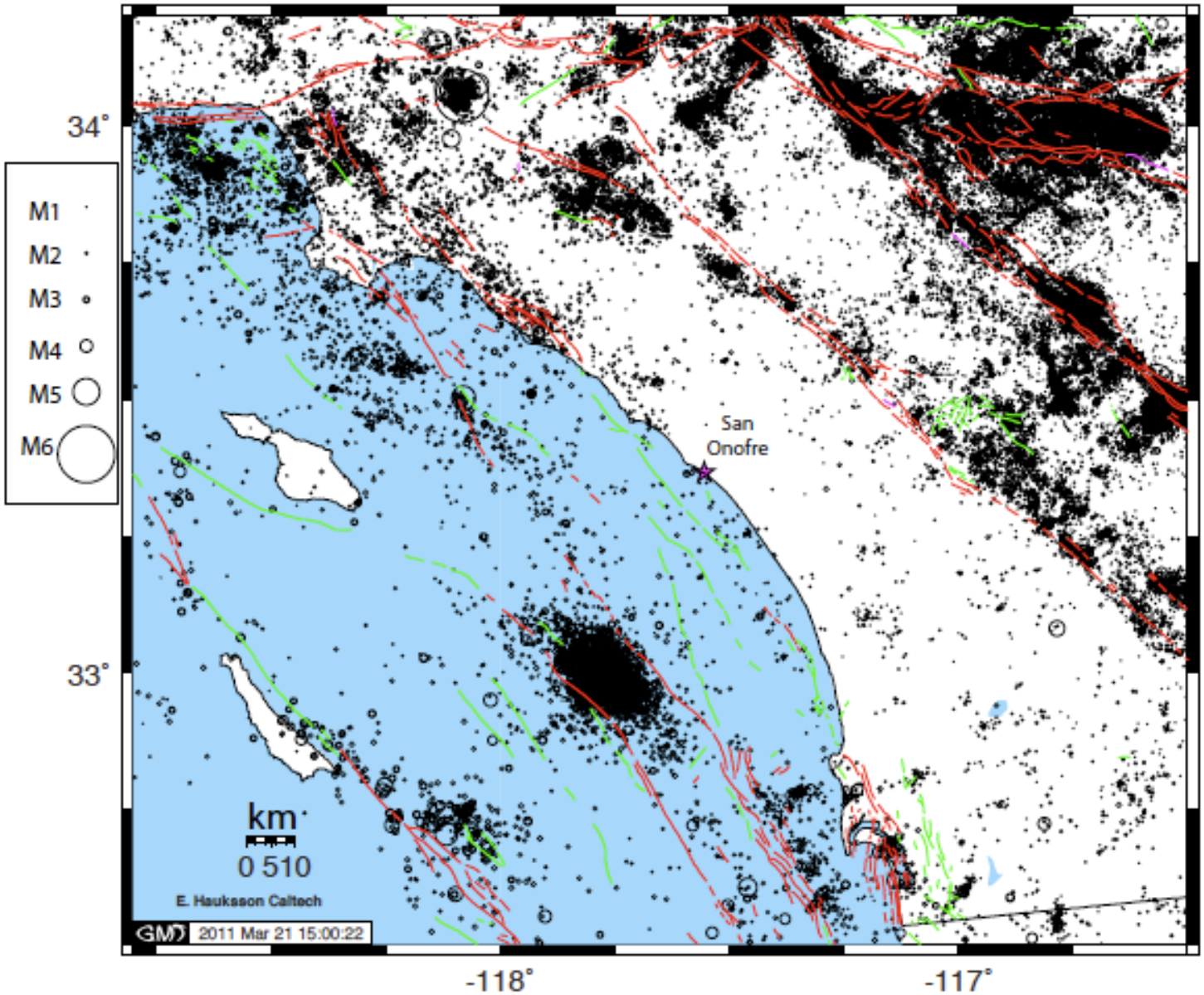




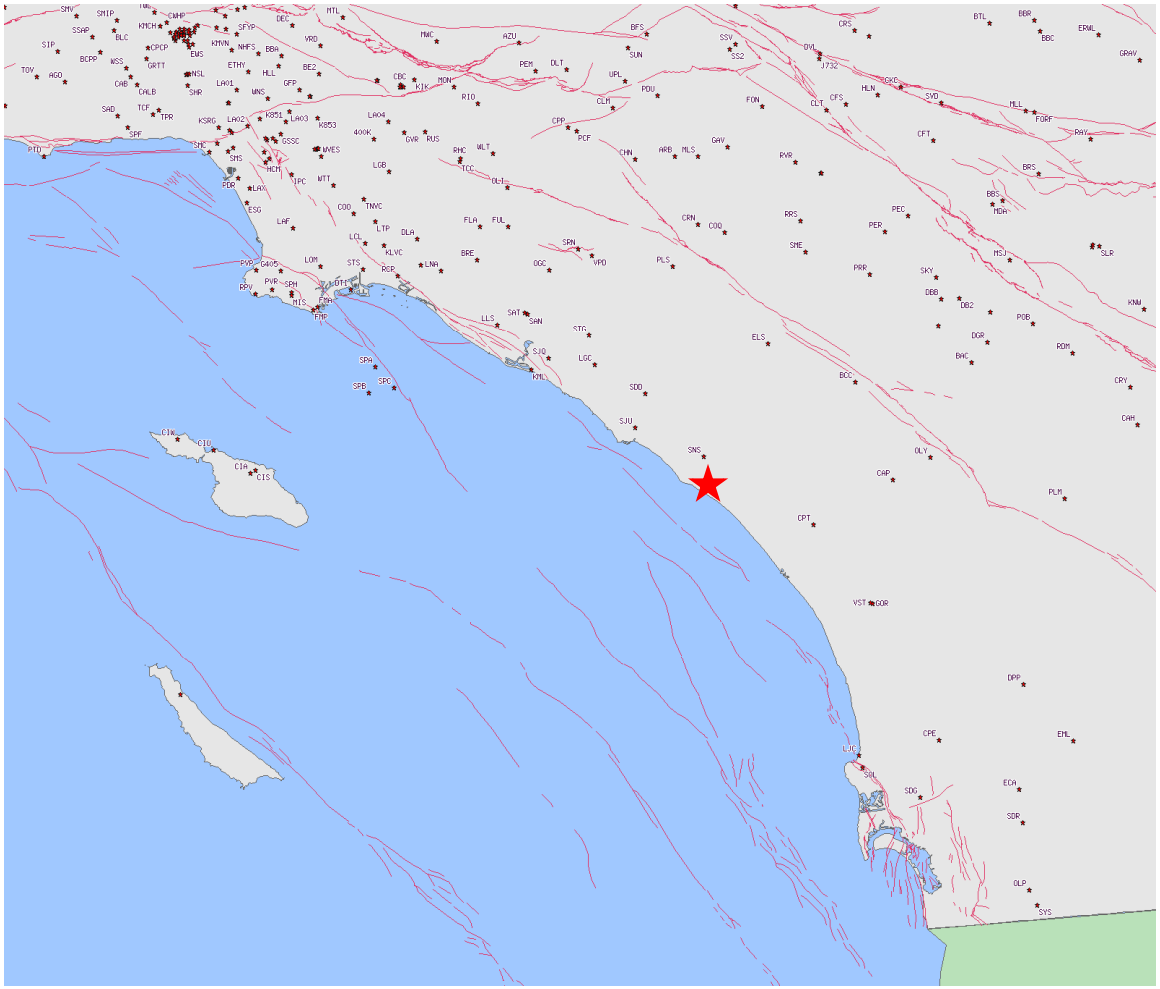
Modified from presentation by Holly Ryan at UCERF3 Statewide Fault-Model & Paleoseismic Data Workshop, April2011

Caltech/USGS Southern California Seismic Network: Relocated Seismicity 1981 -- 2010

Holocene faults (red), and Late Quaternary faults (green)

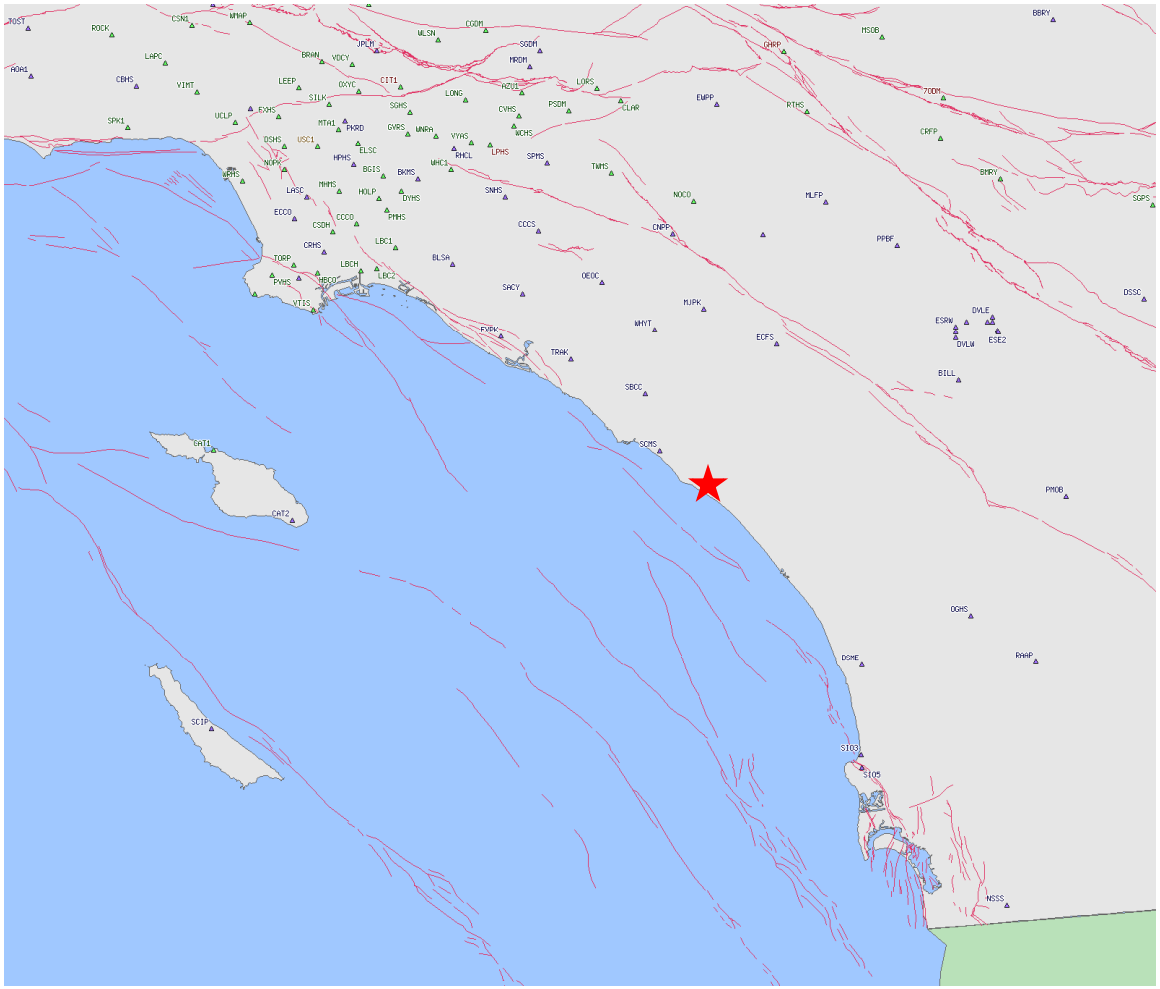


Seismic Monitoring Stations in Southern California



The existing seismic network in southern California has few stations near SONGS. As a consequence, detailed studies similar to those that led to the discovery of the Shoreline Fault are not possible at present.

Geodetic Monitoring Stations in Southern California



The existing continuous GPS network in southern California has few stations near SONGS. The technology now exists to make GPS measurements on the ocean floor, as was shown by the Japanese before the Tohoku earthquake.

Research Needs for Improved Understanding of Seismic Hazard Affecting the California Coast

Identification of Active Faults

- High-resolution bathymetry (marine) and LiDAR (land)
- Aeromagnetic survey
- Marine and land gravity surveys
- New and reprocessed seismic reflection surveys
- Augment existing land-based seismic stations
- New ocean bottom seismic stations

Seismic Potential

- Detailed geologic investigations to establish slip rates
- Augment existing land and island GPS stations
- New ocean floor GPS

Recency of Faulting

- Detailed geologic investigations to date fault offsets
- High-resolution seismic surveys
- Sampling of marine deposits (ROV & piston core)