Seismic Hazard in the Sacramento-San Joaquin Delta

Sacramento, CA
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Lateral spread:1995, M 6.9

Lateral Spread: 1940, M7.0, Imperial Valley, CA

Lateral Spread: 2010, M7.2 Sierra El Mayor-Cucupah, Baja BC

Photo: Hstenner, Exponent

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Lateral spreads, subsidence, sand blows:2010, M7.1 Darfield , NZ

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Regional hazard is driven by

slip between the Pacific and

North American Plates

at a rate of ~40mm/yr

Northern California and the greater Bay Area have experienced lower than average seismic activity for the past 105 years. This reflects the regional stress release associated with the 1906 San Francisco earthquake rupture. The regional suppression in earthquake rate is referred to as the “1906 stress shadow.”

Modeling indicates that the the stress shadow has dissipated and rates of moderate to large earthquakes will increase, certainly within the next 100 years.

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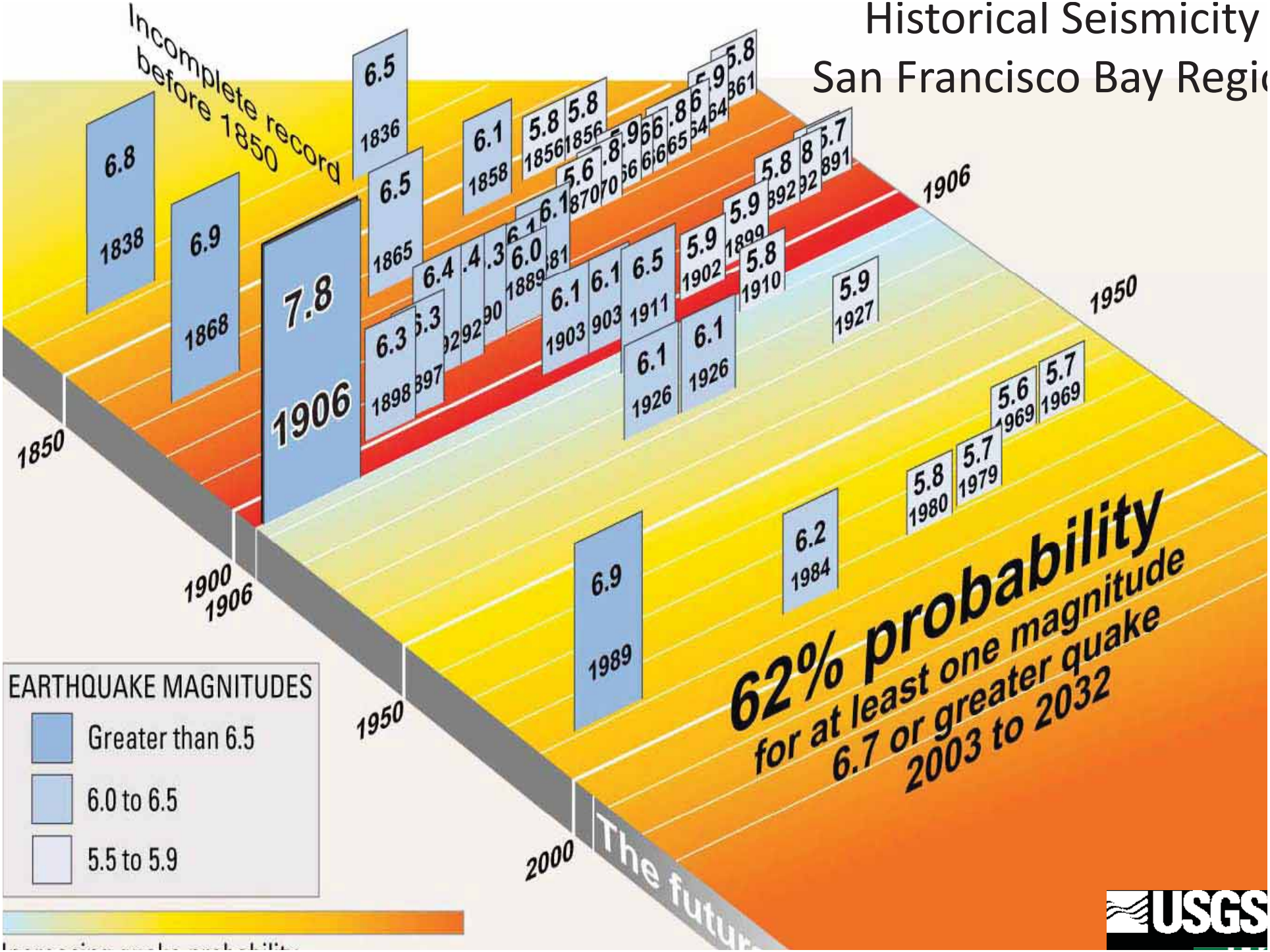
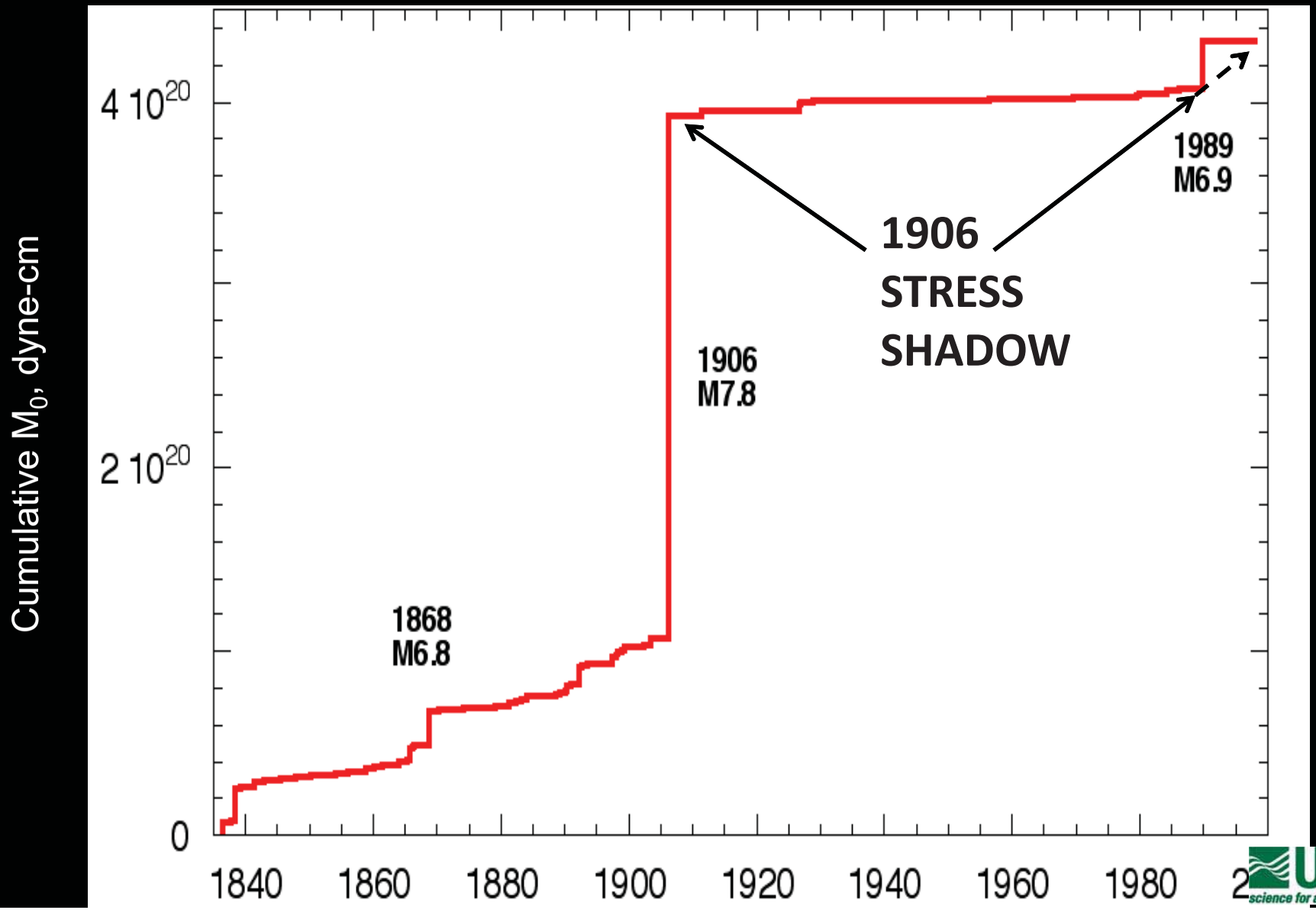
Historical Seismicity San Francisco Bay Regi

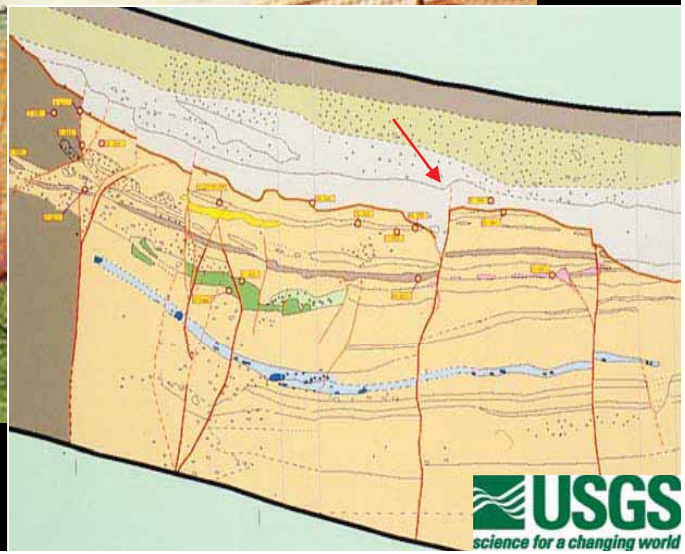


Historical Seismic Energy Accumulation and Release in the SF Bay Region

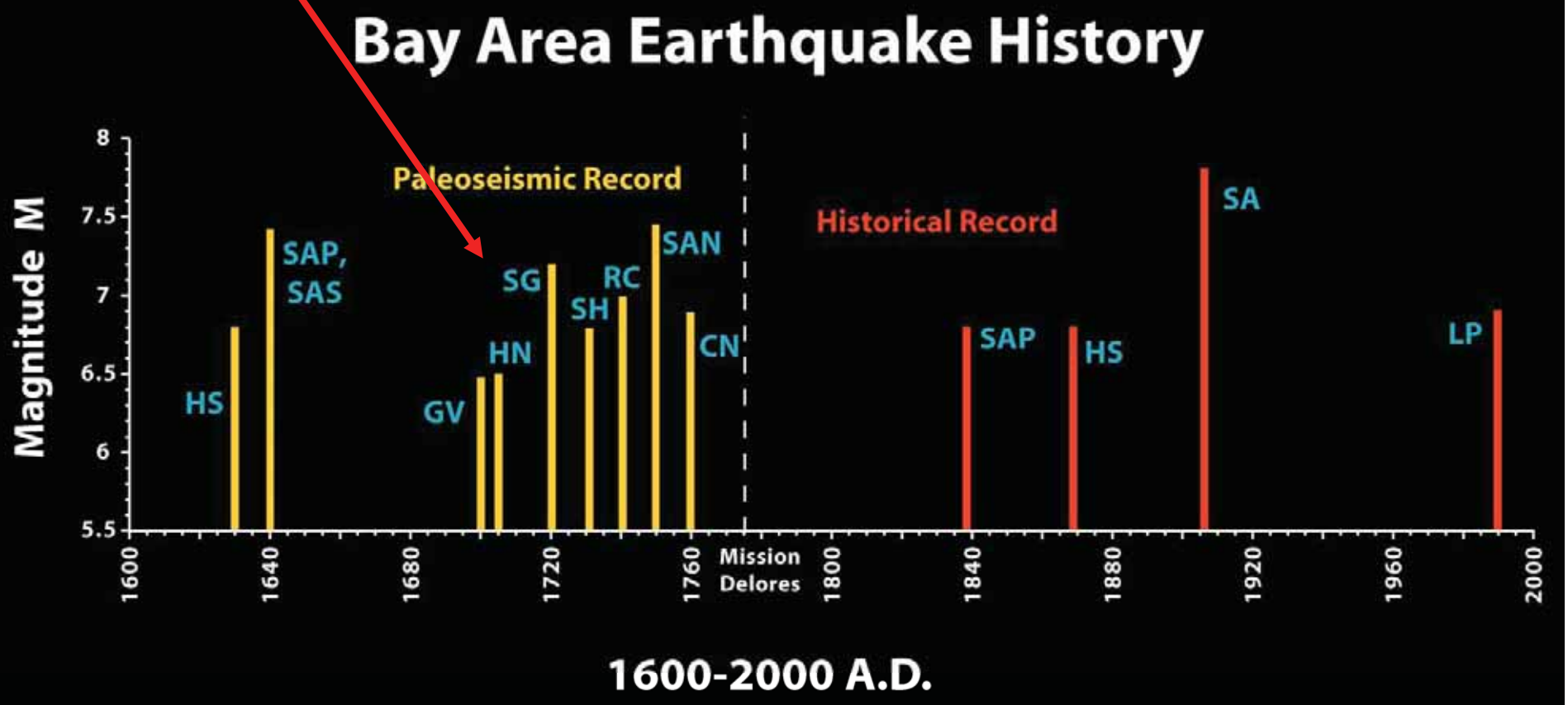


Dating pre-historic earthquakes
NORTHERN HAYWARD (HN) fault
Mira Vista golf course
El Cerrito, CA

1705

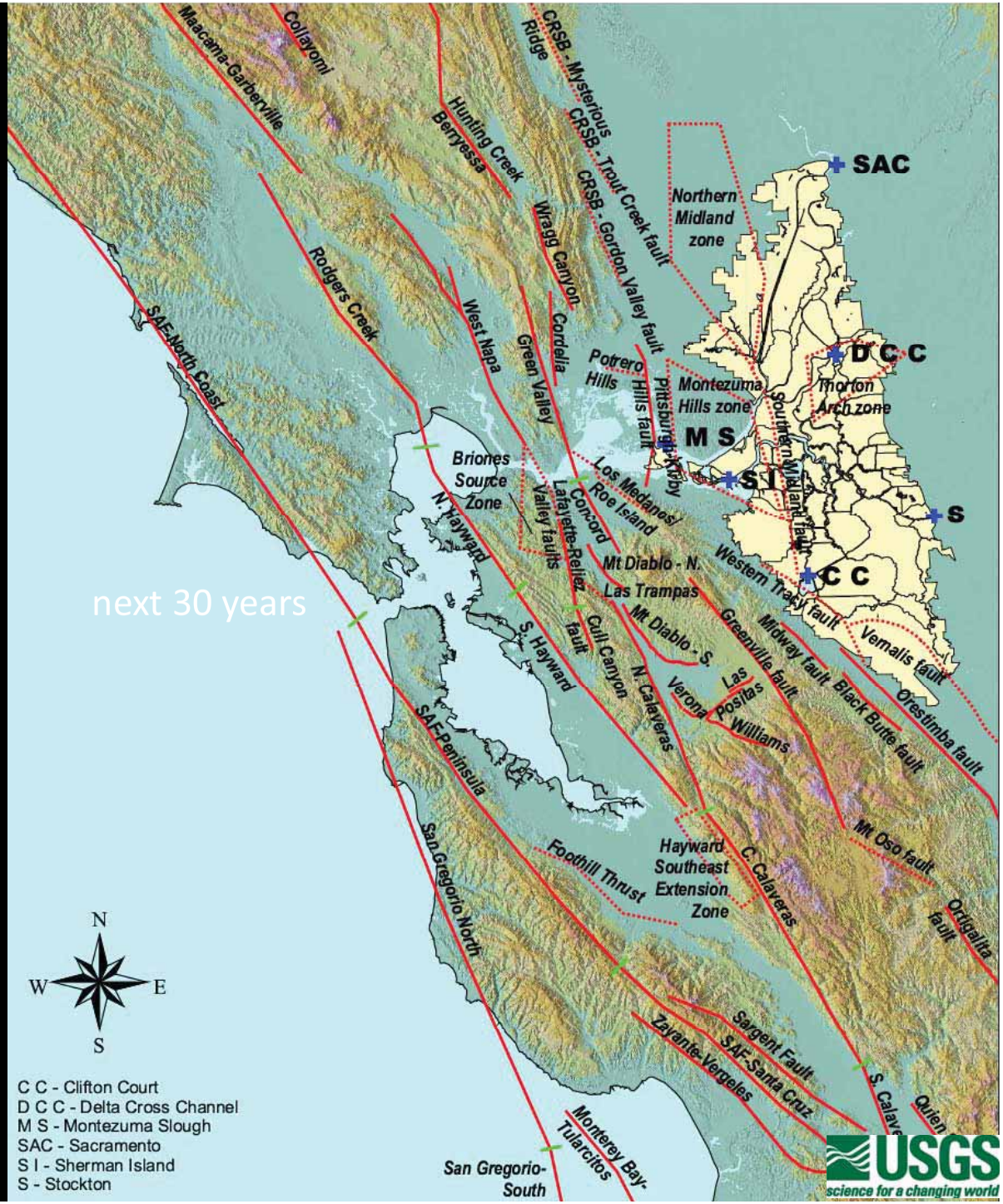


The next large earthquakes?



Sometimes the plate boundary stress is released as a great earthquakes like 1906; other times it is released in temporal clusters of large earthquake such as the one that occurred between ~1700-1776. We expect the coming decades to produce large events on individual regional faults rather than a repeat of 1906

Faults Used in the Delta Risk Management Strategy (DRMS) Probabilistic Seismic Hazard Analysis as Sources of Strong Ground Motion for the Sacramento-San Joaquin Delta



URS (2008)

The primary sources of strong ground motion for the Delta, certainly within the next 100 years, are the large plate boundary faults in the Bay Area, particularly those in the East Bay.

The East Bay fault group includes the Hayward, northern Calaveras, Greenville, and Concord-Green Valley strike-slip faults and the Mt. Diablo blind thrust fault.

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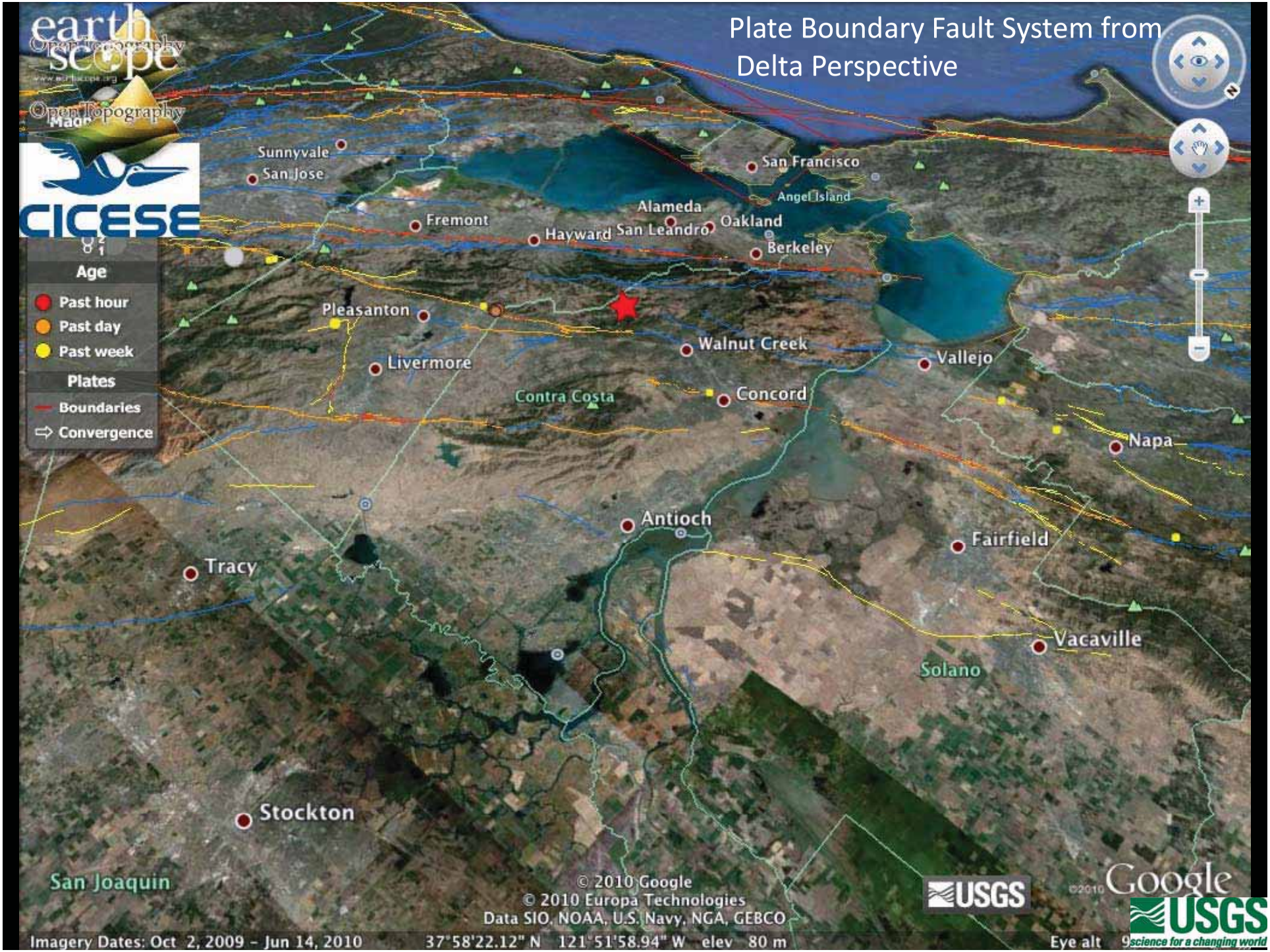
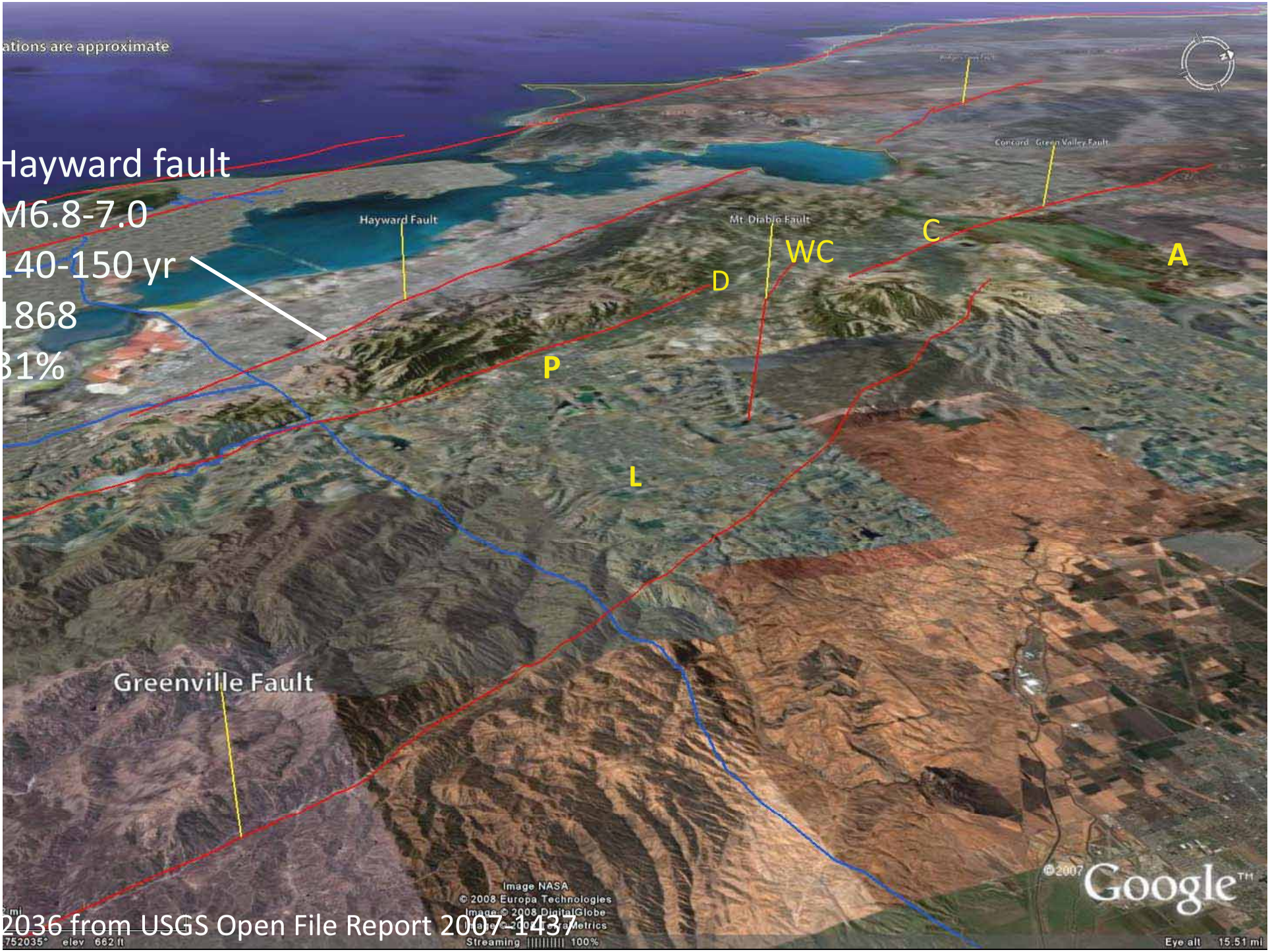
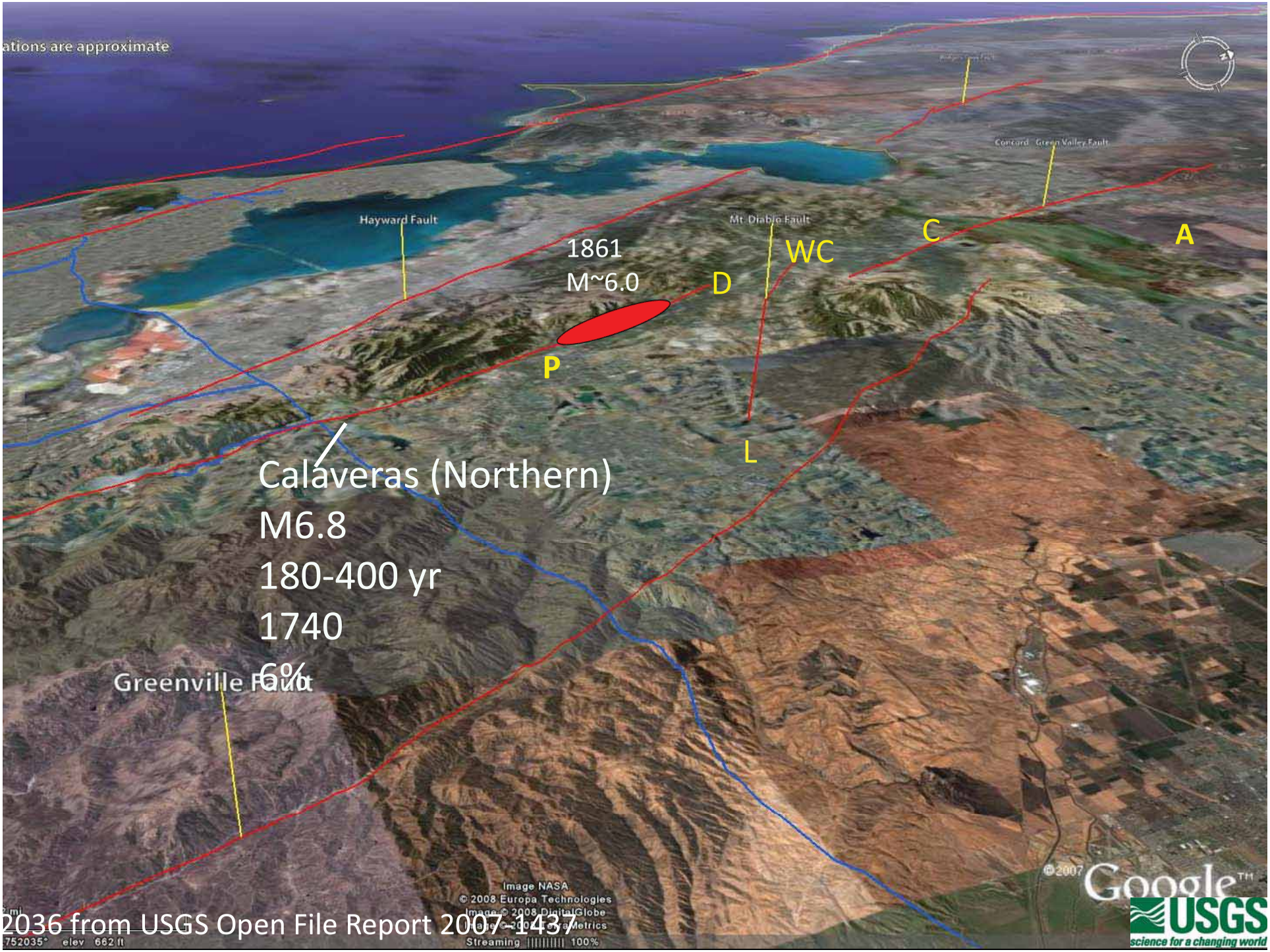
Plate Boundary Fault System from Delta Perspective

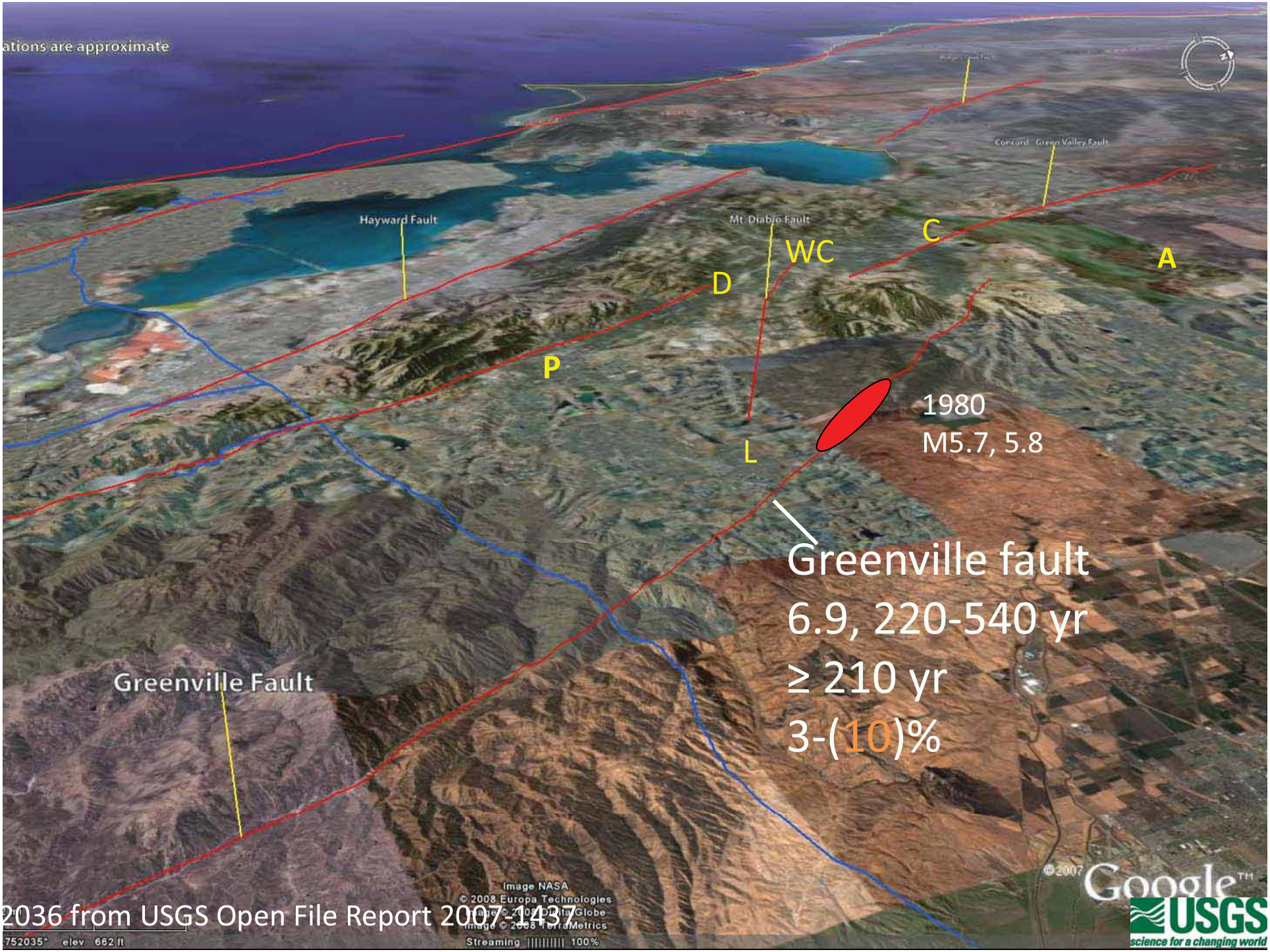




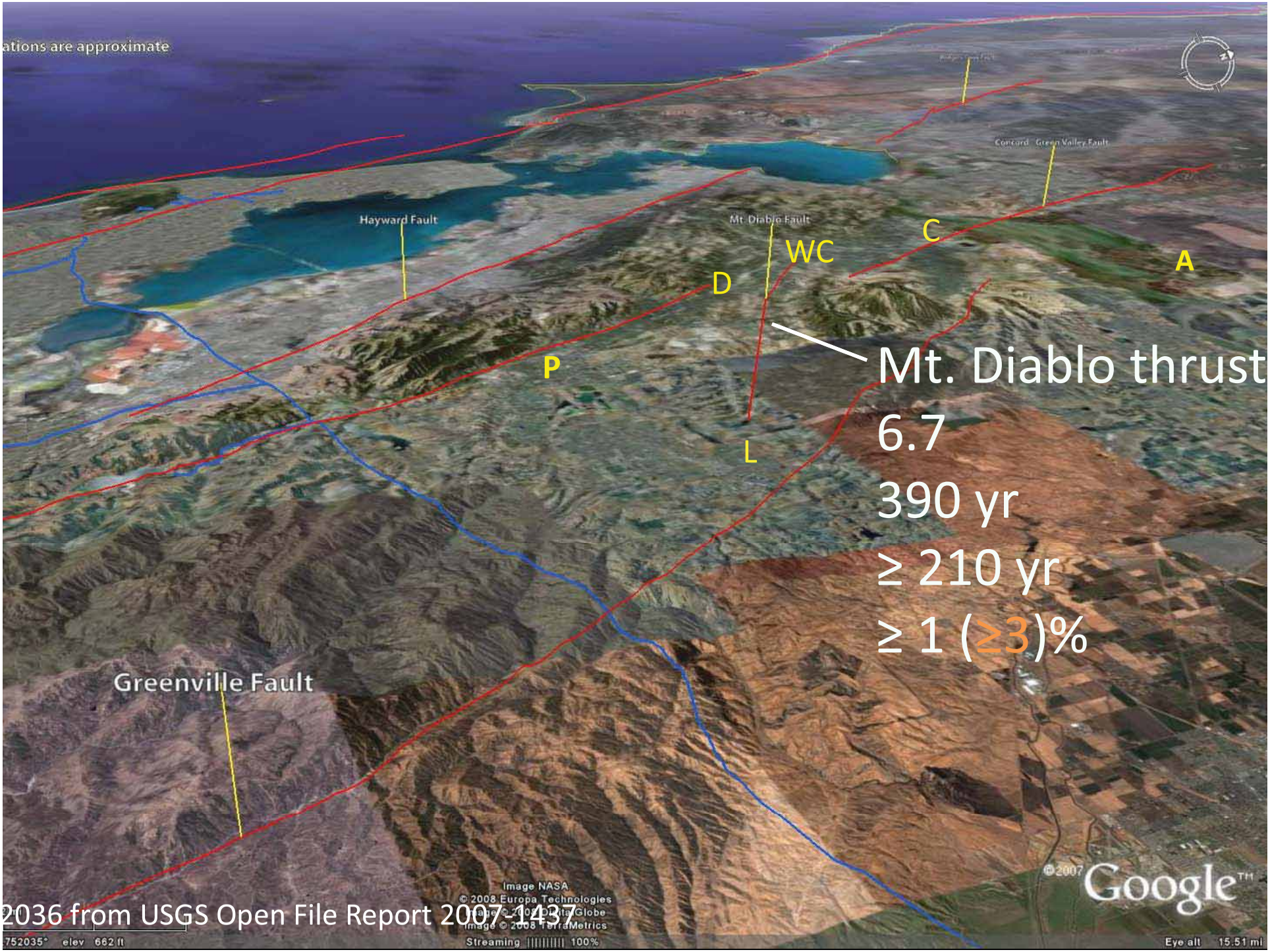
2036 from USGS Open File Report 2007-1437



2036 from USGS Open File Report 2007-1437



2036 from USGS Open File Report 2007-1437

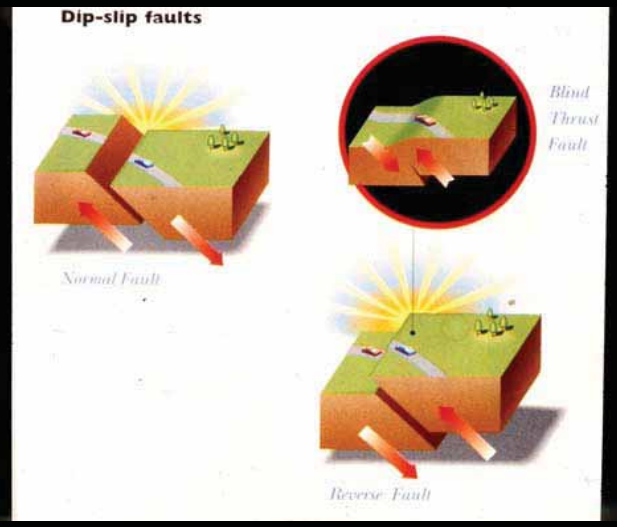


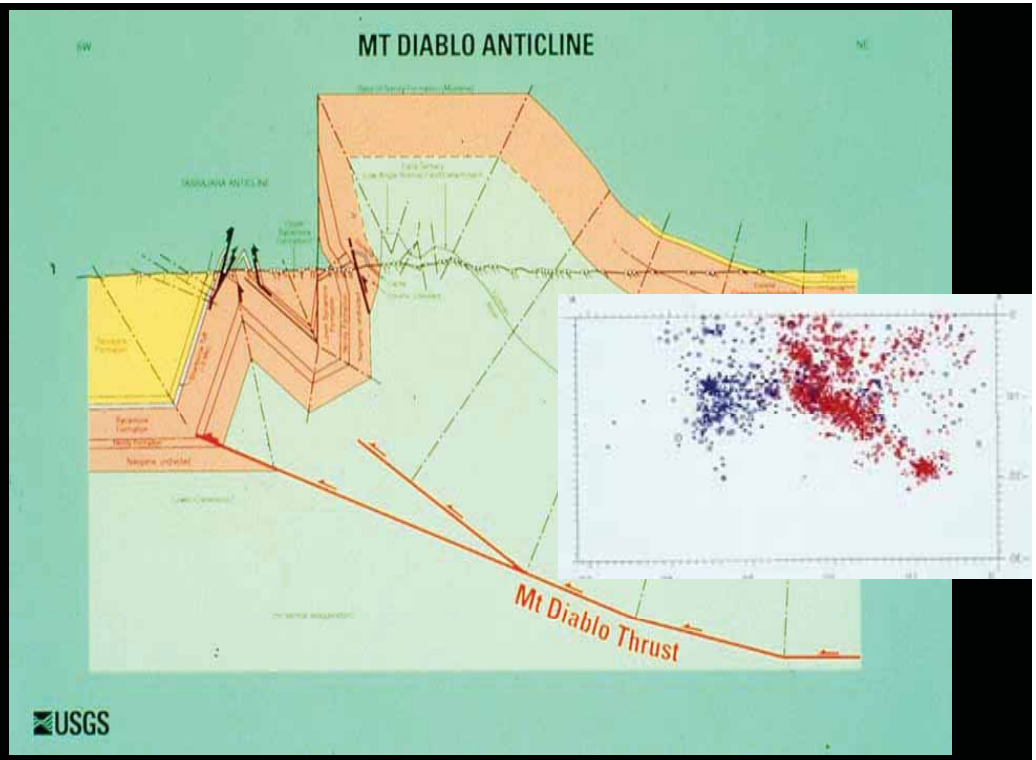
Mt. Diablo thrust
6.7
390 yr
≥ 210 yr
≥ 1 (≥3)%

2036 from USGS Open File Report 2007-1437

Blind Thrust Faults

we didn't know they were there





Coalinga 1983, M 6.7
Whittier Narrows 1987, M 5.9
Loma Prieta 1989, M6.9
Northridge 1994, M6.7

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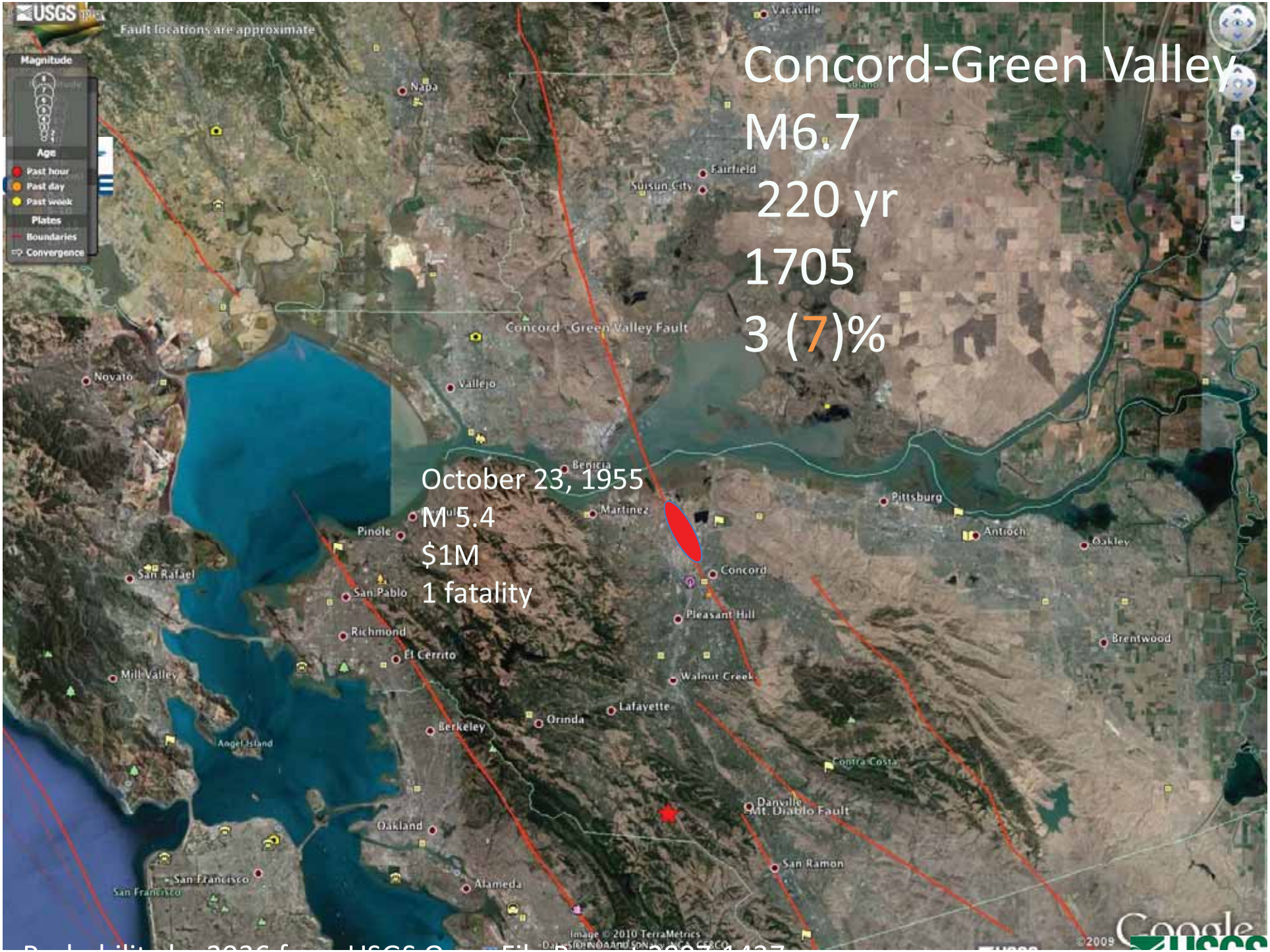
Fault locations are approximate
Magnitude
Age
Past hour
Past day
Past week
Plates
Boundaries
Convergence
Concord-Green Valley
M6.7
220 yr
1705
3 (7)%
October 23, 1955
M 5.4
$1M
1 fatality
Concord - Green Valley Fault
Mt. Diablo Fault
Napa
Vacaville
Fairfield
Suisun City
Novato
Vallejo
Benicia
Martinez
Pittsburg
Antioch
Oakley
Pinole
San Rafael
San Pablo
Richmond
El Cerrito
Concord
Pleasant Hill
Brentwood
Walnut Creek
Mill Valley
Lafayette
Orinda
Berkeley
Angel Island
Contra Costa
Danville
Oakland
San Ramon
San Francisco
Alameda
Image © 2010 TerraMetrics
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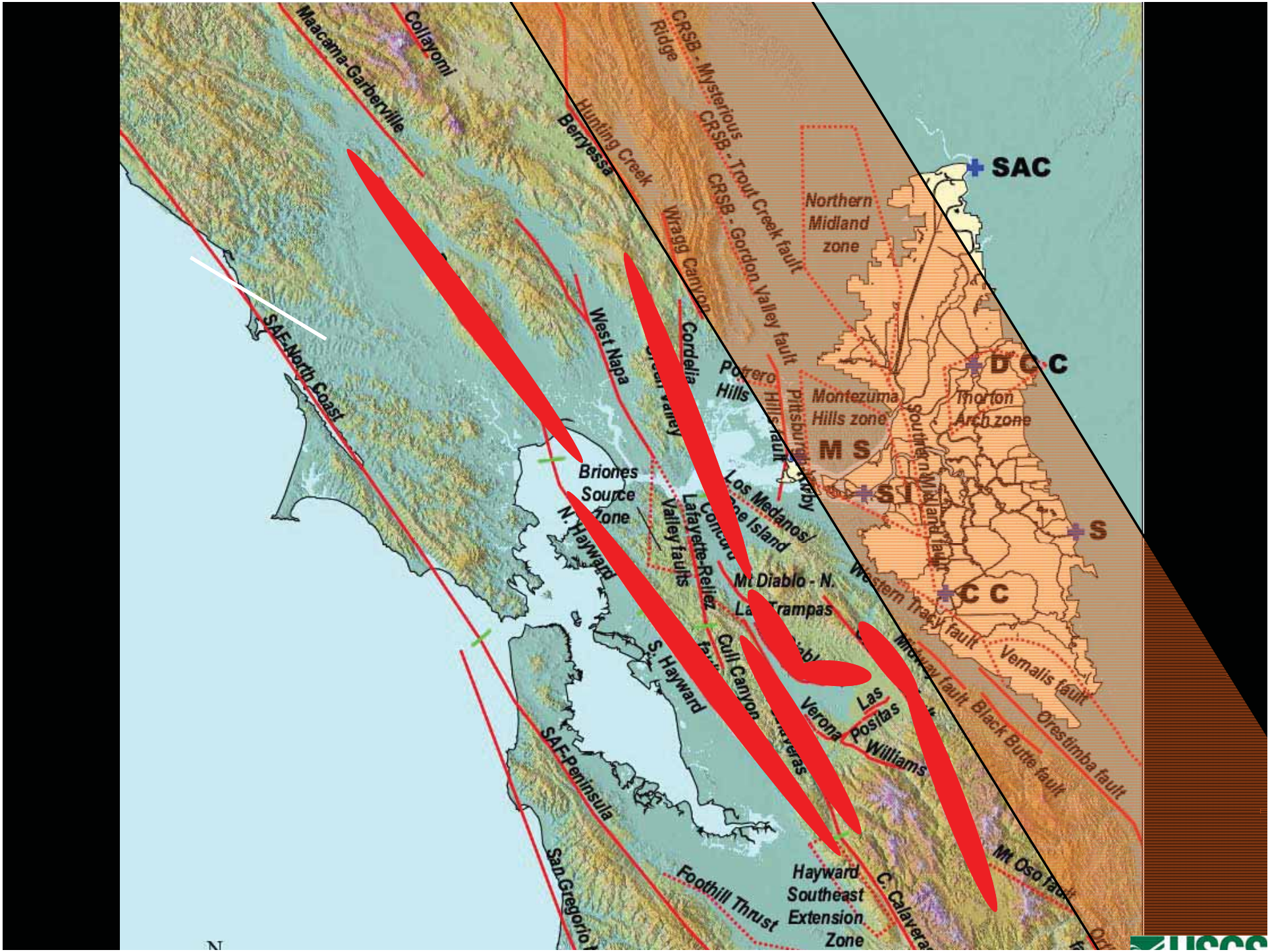
Google


Maacama-Garberville
Collayomi
Berryessa
Hunting Creek
CRSB - Mysterious Ridge
CRSB - Trout Creek fault
CRSB - Gordon Valley fault
Wragg Canyon
West Napa
Cordelia
Potrero Hills
Pittsburg/Kirby Hills fault
SAF-North Coast
Briones Source Zone
N. Hayward
Los Medanos/ Ione Island
Concord
Lafayette-Reliez Valley faults
Mt Diablo - N. La Trampas
Gull Canyon
S. Hayward
SAF-Peninsula
San Gregorio
Foothill Thrust
Hayward Southeast Extension Zone
C. Calaveras
Verona
Las Positas
Williams
Mt Oso fault
Western Tracy fault
Midway fault
Black Butte fault
Vernalis fault
Orestimba fault
Northern Midland zone
Montezuma Hills zone
Southern Midland fault
Thornton Arch zone
SAC
D C C
M S
S I
S
C C
N

Faults Beneath the Delta and Along the Delta Margin

	Slip Rate mm/yr	Mean Expected Magnitude
Morton Arch zone	0.1	6.5
Montezuma Hills zone	0.25	6.25
Northern Midland zone	0.5	6.25
Southern midland fault (blind)	0.5	6.6
Pittsburgh-Kirby Hills fault (blind)	0.5	6.5
CRSB-Gordon Valley fault (blind)	1.25	6.5-6.8
CRSB-Trout Creek fault (blind)	1.25	6.5
Los Medanos (blind)	0.5	6.0-6.5
Western Tracy (blind)	0.5	6.5
Vernalis fault (blind)	0.25	6.25
Potrero Hills (blind)	0.3	6.0
CRSB-Mysterious Ridge	1.0	6.5
Cordelia fault	0.6	6.6
Wagg Canyon fault	0.3	6.5
Midway fault	0.5	6.5
Black Butte fault	0.5	6.5
Orestimaba fault	0.4	6.7

These are not well-characterized

Low rates of activity (slip rates) = recurrence intervals ≥ 1000 yr

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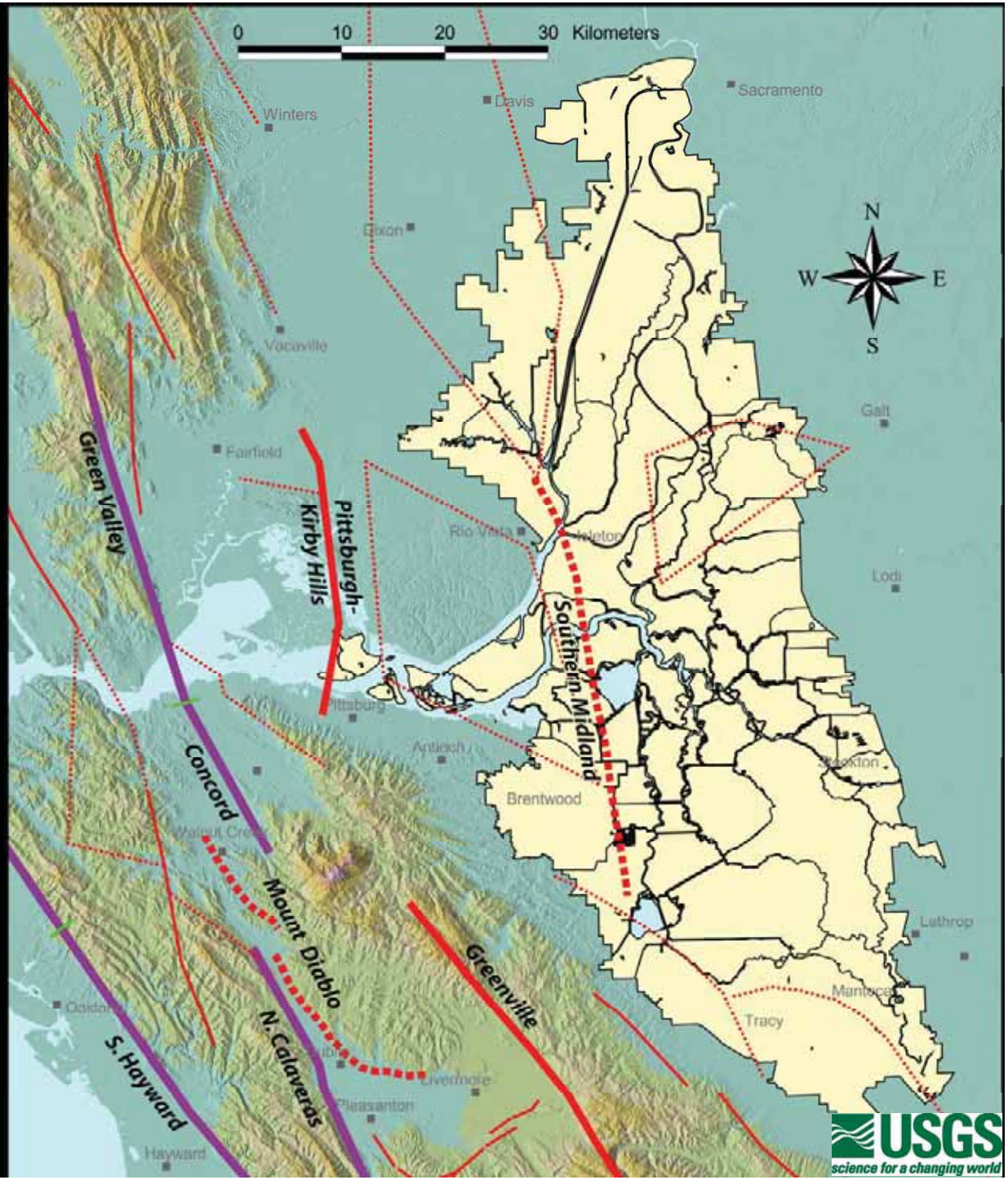
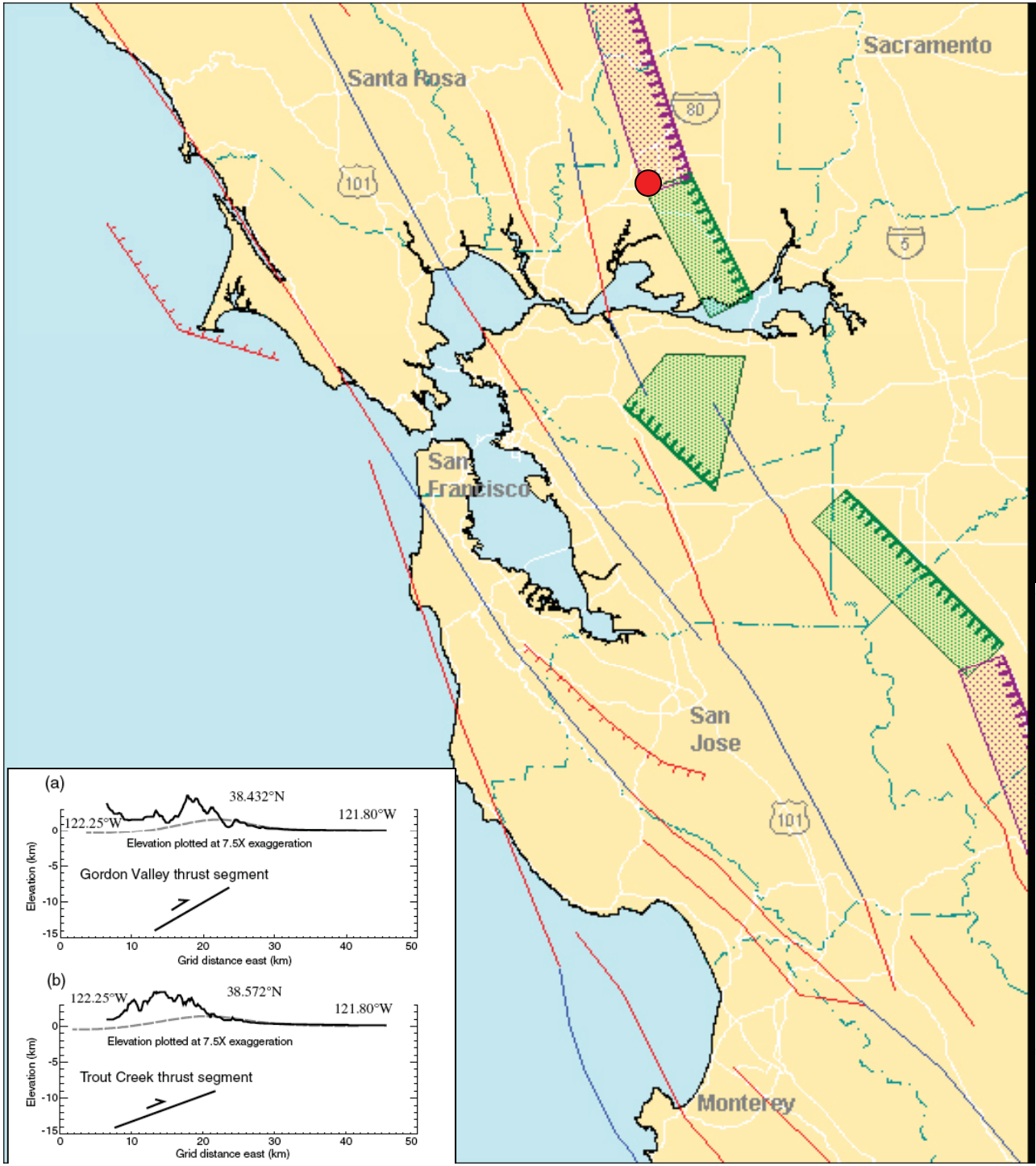
Extending the time-frame out to 500 years the smaller faults closer to the Delta also begin to contribute to the hazard

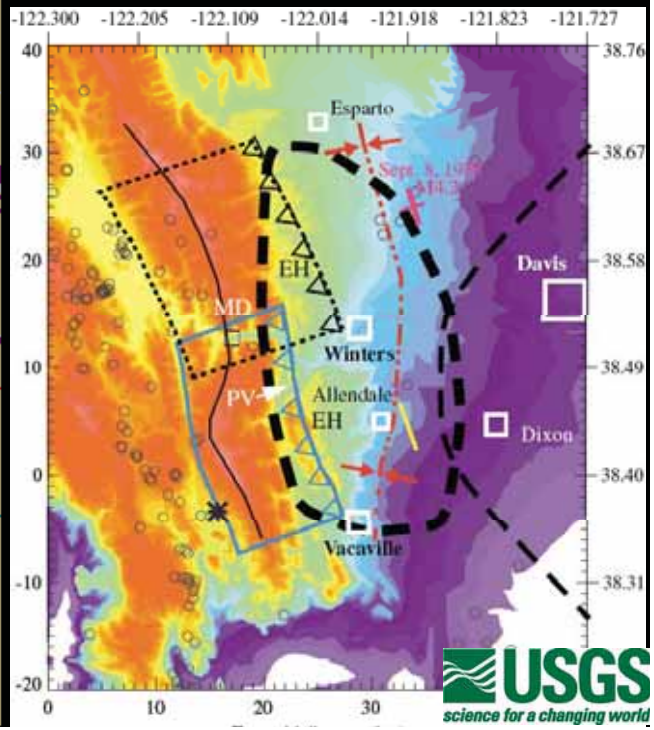


Historical events on Delta faults:

1892 Vacaville-Winters Earthquakes

April 19 M ~6.5
April 21 M ~6.2





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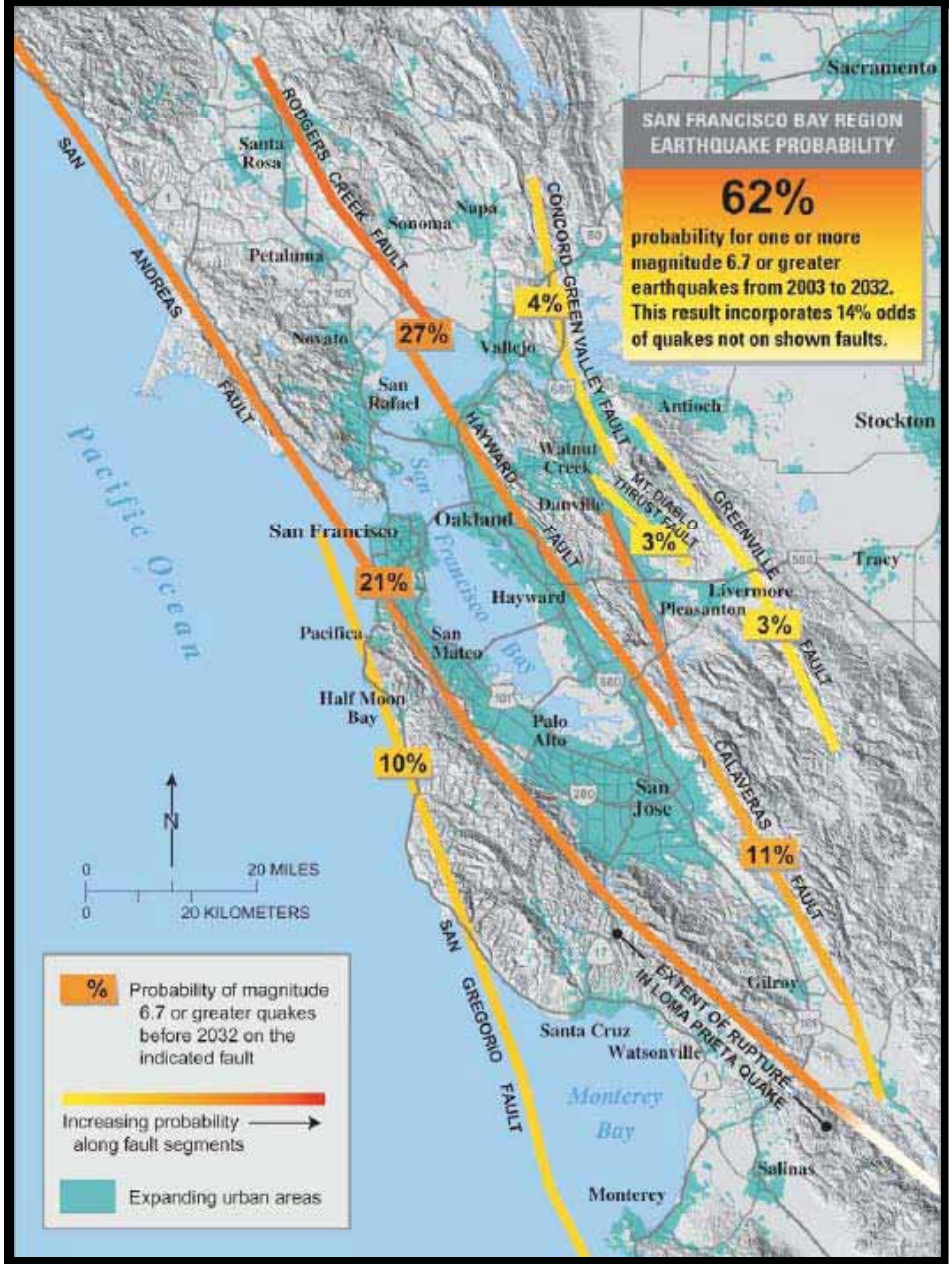
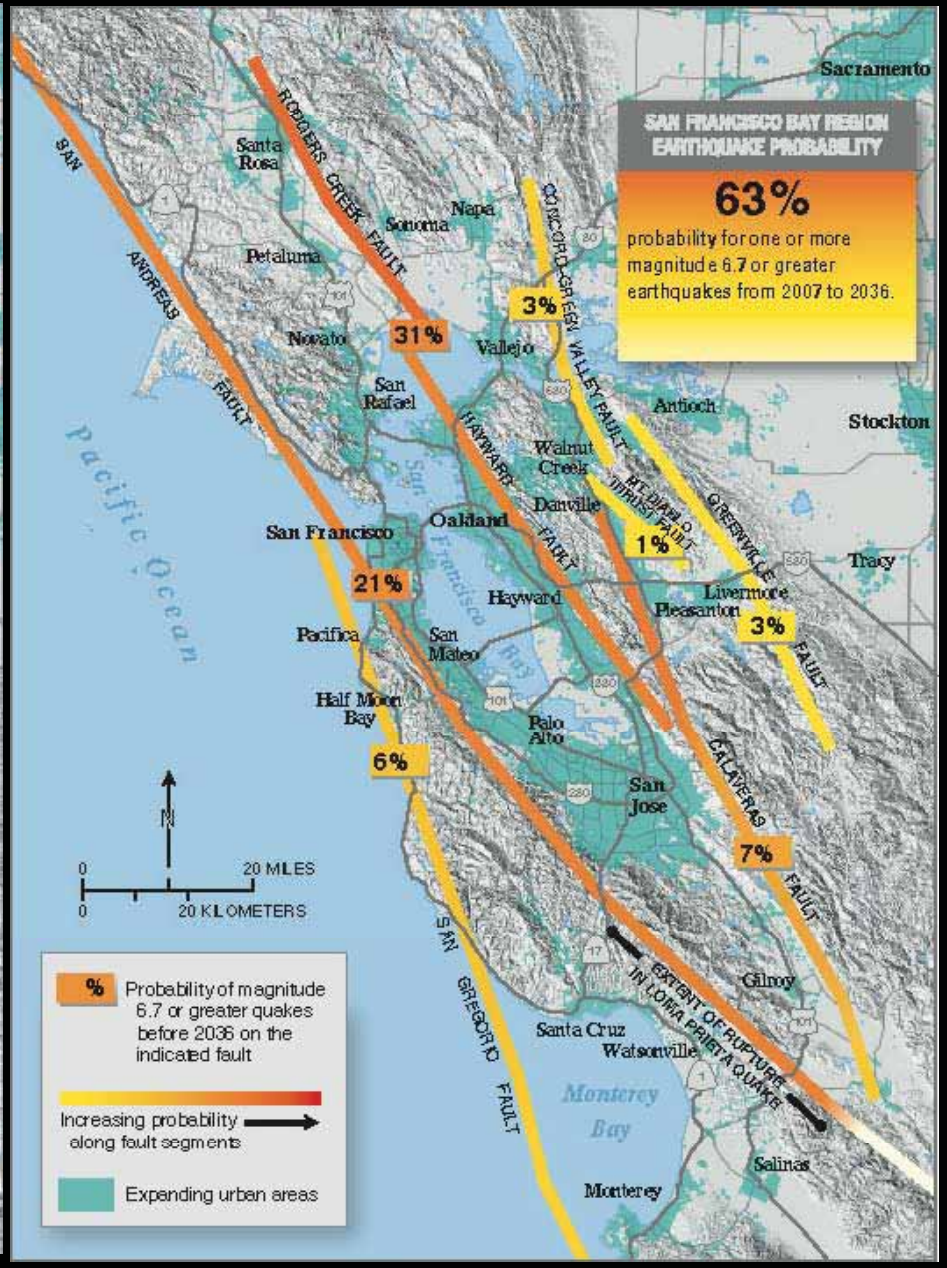
Bay Area Earthquake Probabilities





WG03 2003-2032

UCERF 2007-2036

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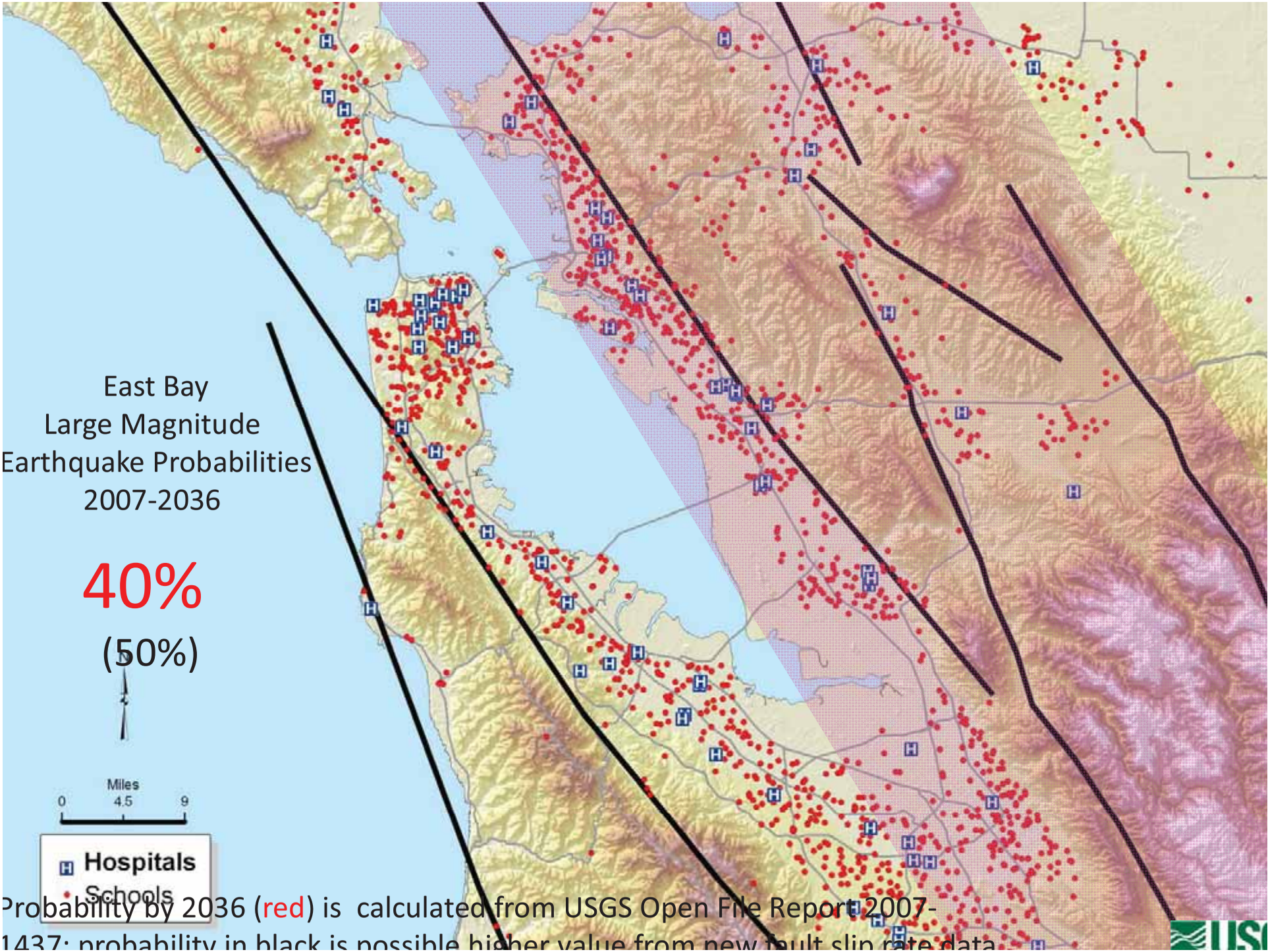
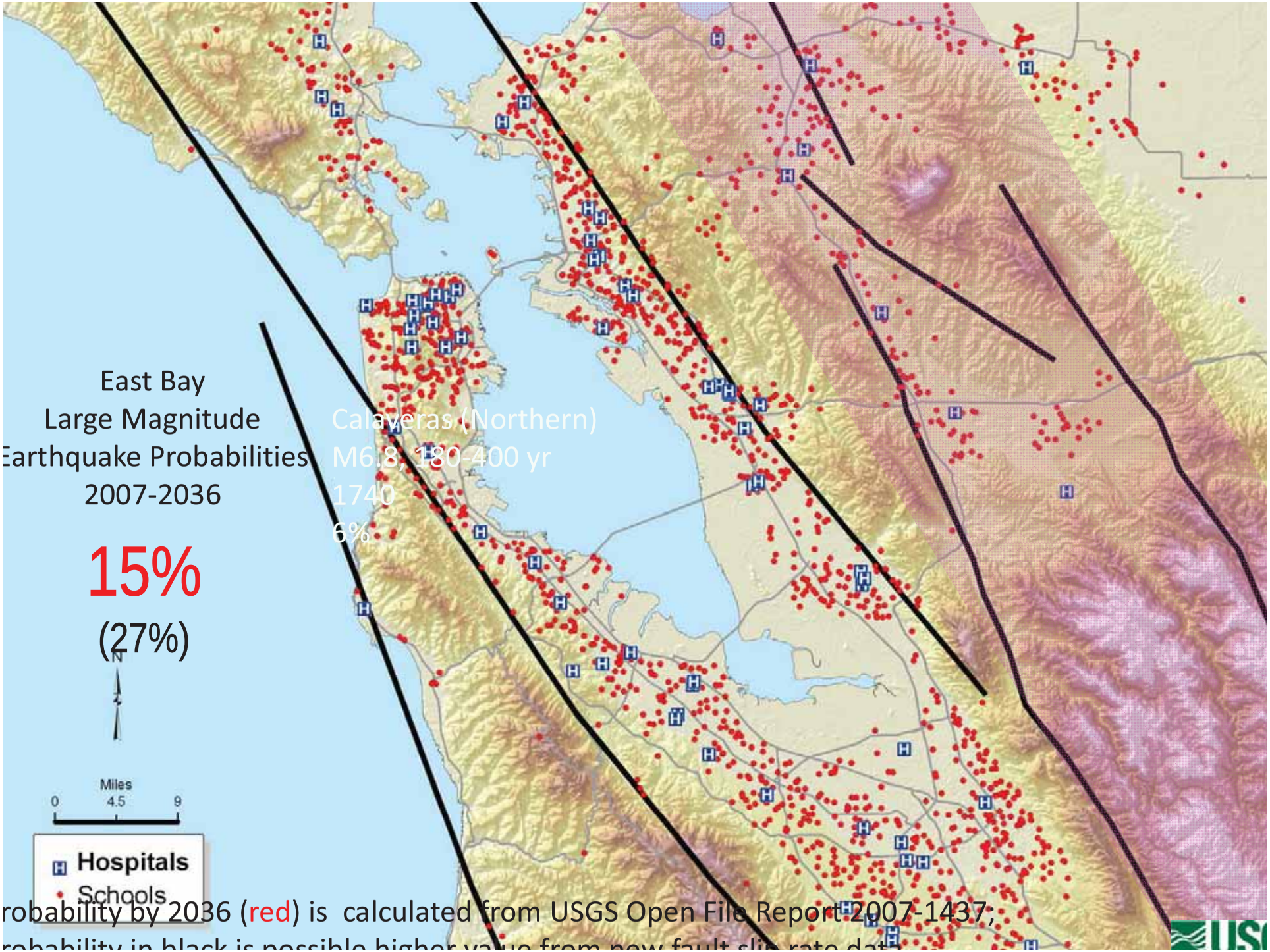


Probability by 2036 (red) is calculated from USGS Open File Report 2007-1437; probability in black is possible higher value from new fault slip rate data



robability by 2036 (red) is calculated from USGS Open File Report 2007-1437;
robability in black is possible higher value from new fault slip rate data

Probability of M≥6.7 Earthquakes in the Bay Area in Various Exposure Times

Table 6.2. Probability of M≥6.7 earthquakes in the SFBR in various exposure times

Exposure Time (years from 2002)	Weighted Models	Poisson Model (Time-independent)
1	0.04 [0.02 - 0.08]	0.03 [0.02 - 0.04]
5	0.16 [0.07 - 0.32]	0.14 [0.11 - 0.18]
10	0.29 [0.14 - 0.49]	0.26 [0.21 - 0.33]
20	0.49 [0.27 - 0.74]	0.46 [0.37 - 0.55]
30	0.62 [0.38 - 0.85]	0.60 [0.51 - 0.70]
100	_	0.96[1] [0.92 - 0.99]

1. Equivalently, the number of M≥6.7 earthquakes expected in the SFBR in 100 years is 3.1 [2.4 – 4.1]

USGS Open-File Report 03-214

You can run--
but you can't hide

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Modified Mercali Intensity (MMI) Shaking Estimates in Delta from Large, Distant Historical Earthquakes

1906 San Andreas

1868 Hayward

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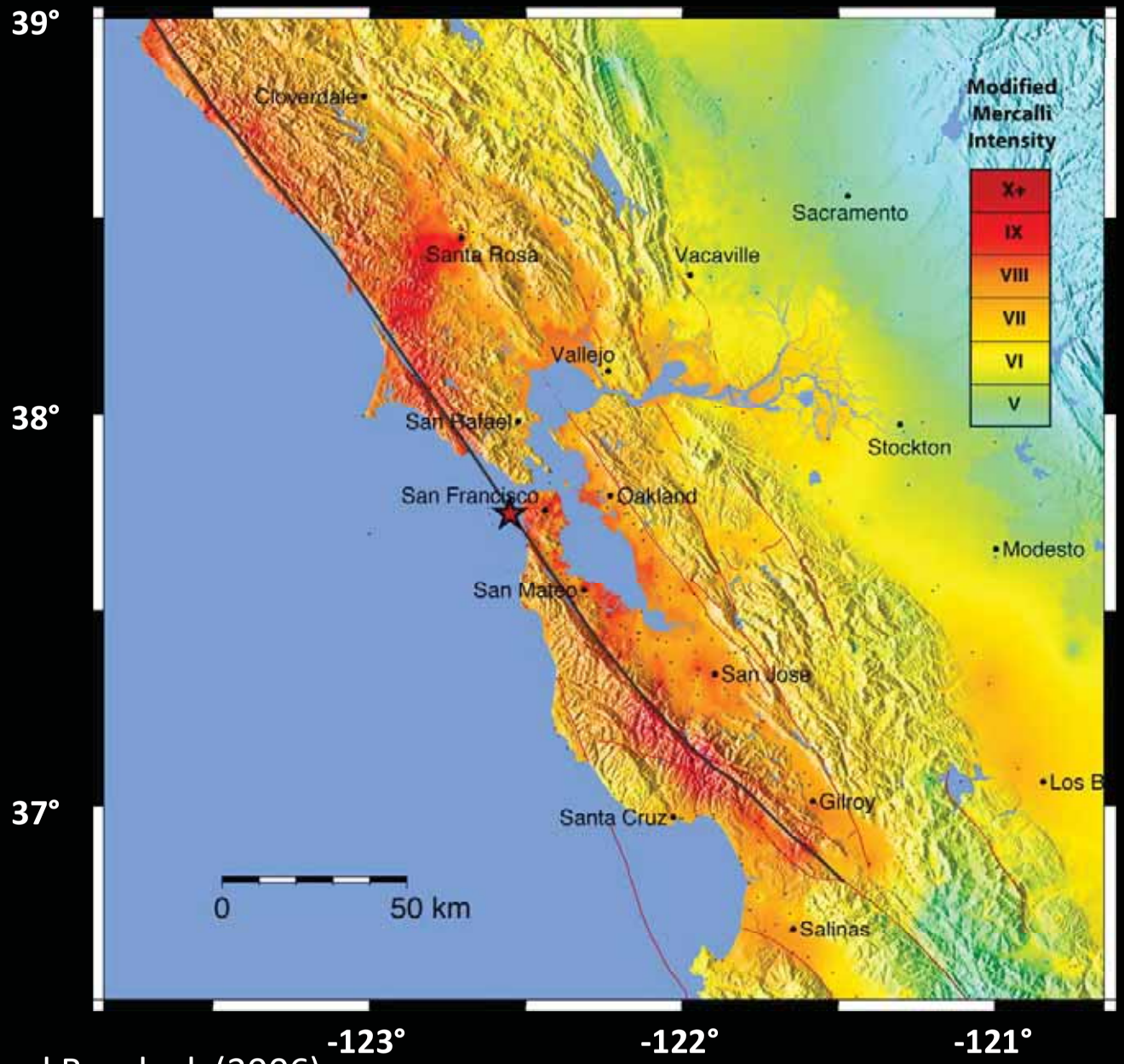
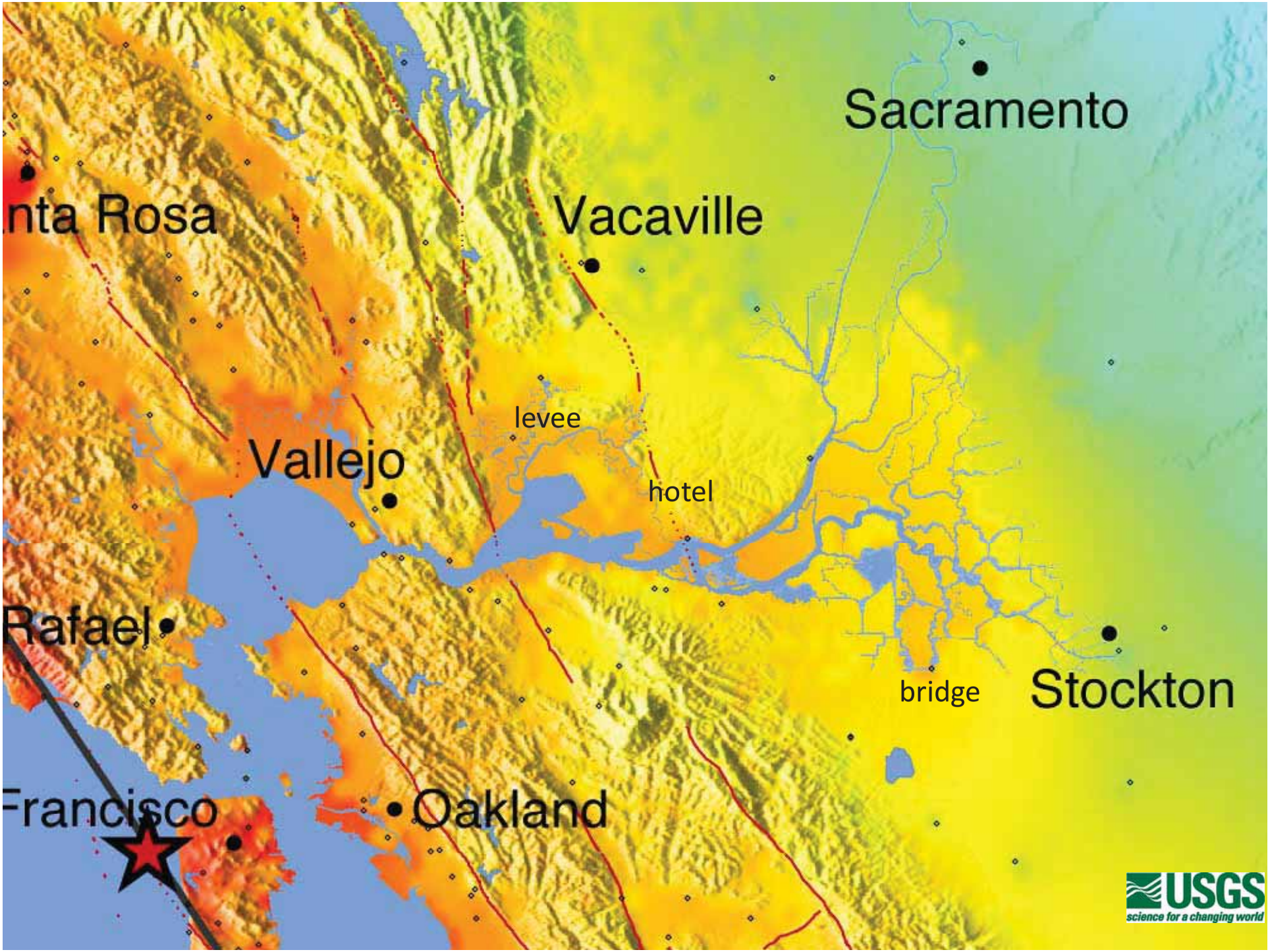
April 18, 1906, San Francisco Earthquake M 7.9



Boatwright and Bondock (2006)


Sacramento
nta Rosa
Vacaville
levee
Vallejo
hotel
Rafael
bridge
Stockton
Francisco
Oakland
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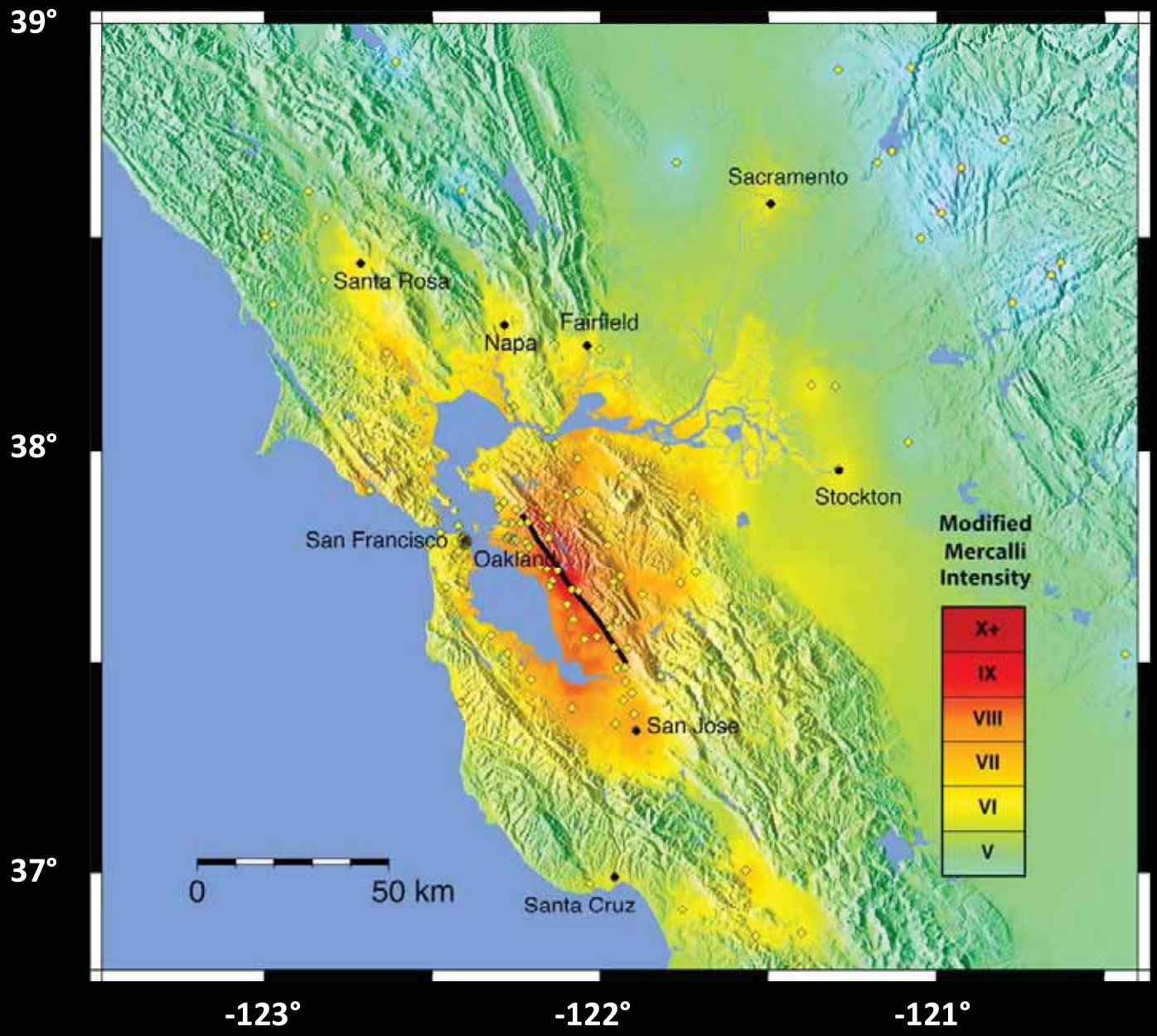
October 21, 1868, Hayward Fault Earthquake M 6.8



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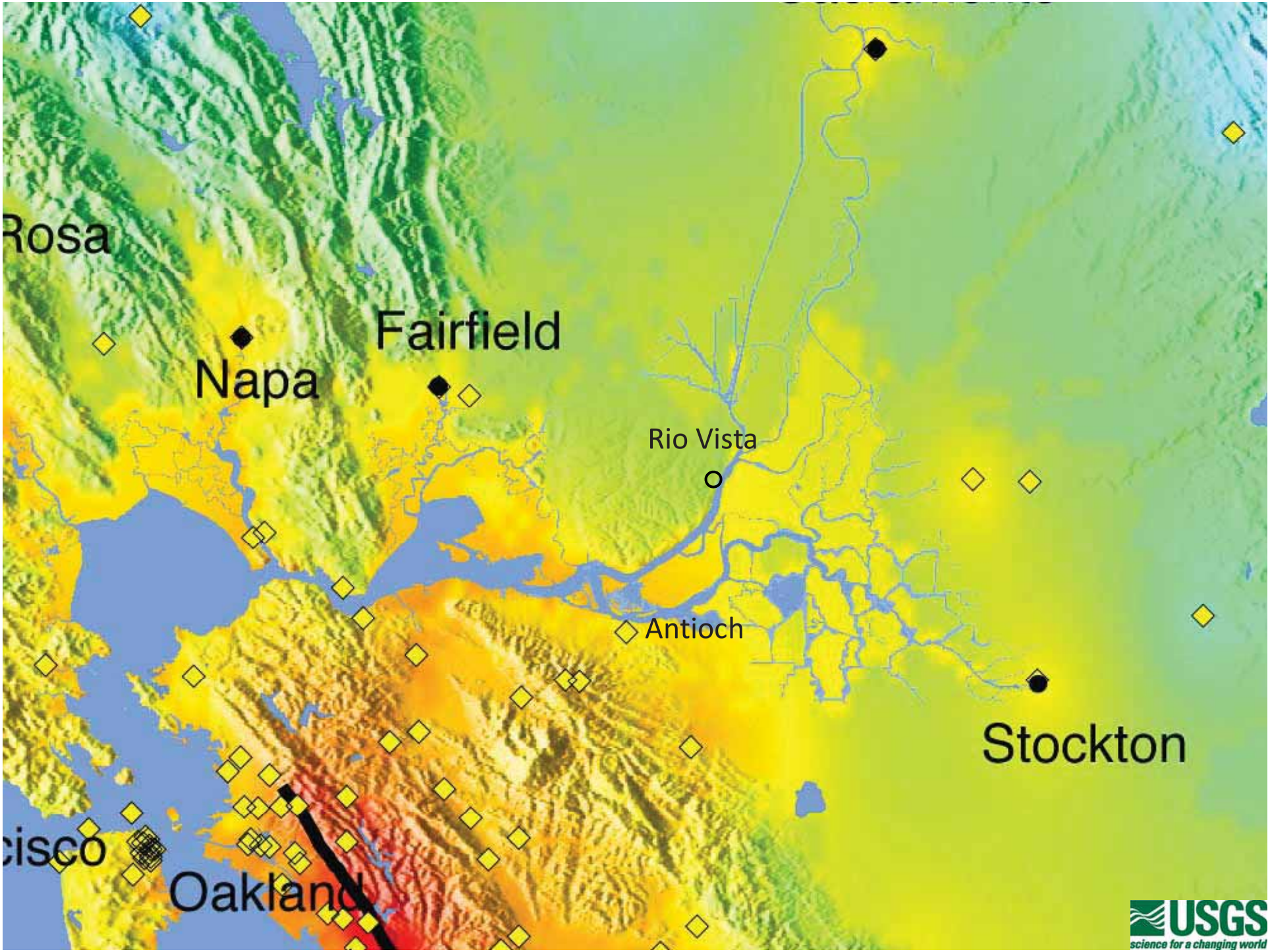
Rosa
Fairfield
Napa
Rio Vista
Antioch
Stockton
cisco
Oakland
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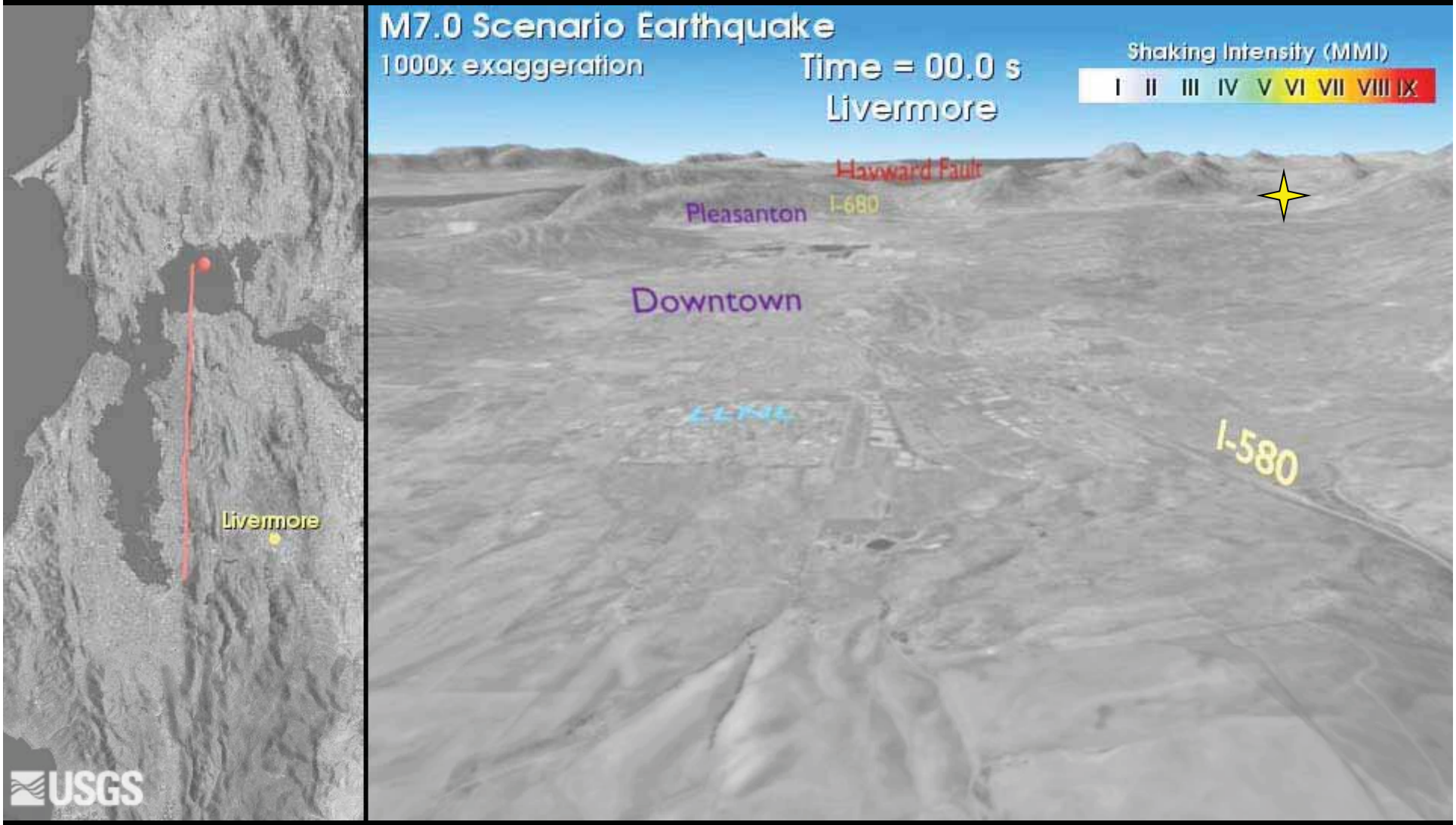

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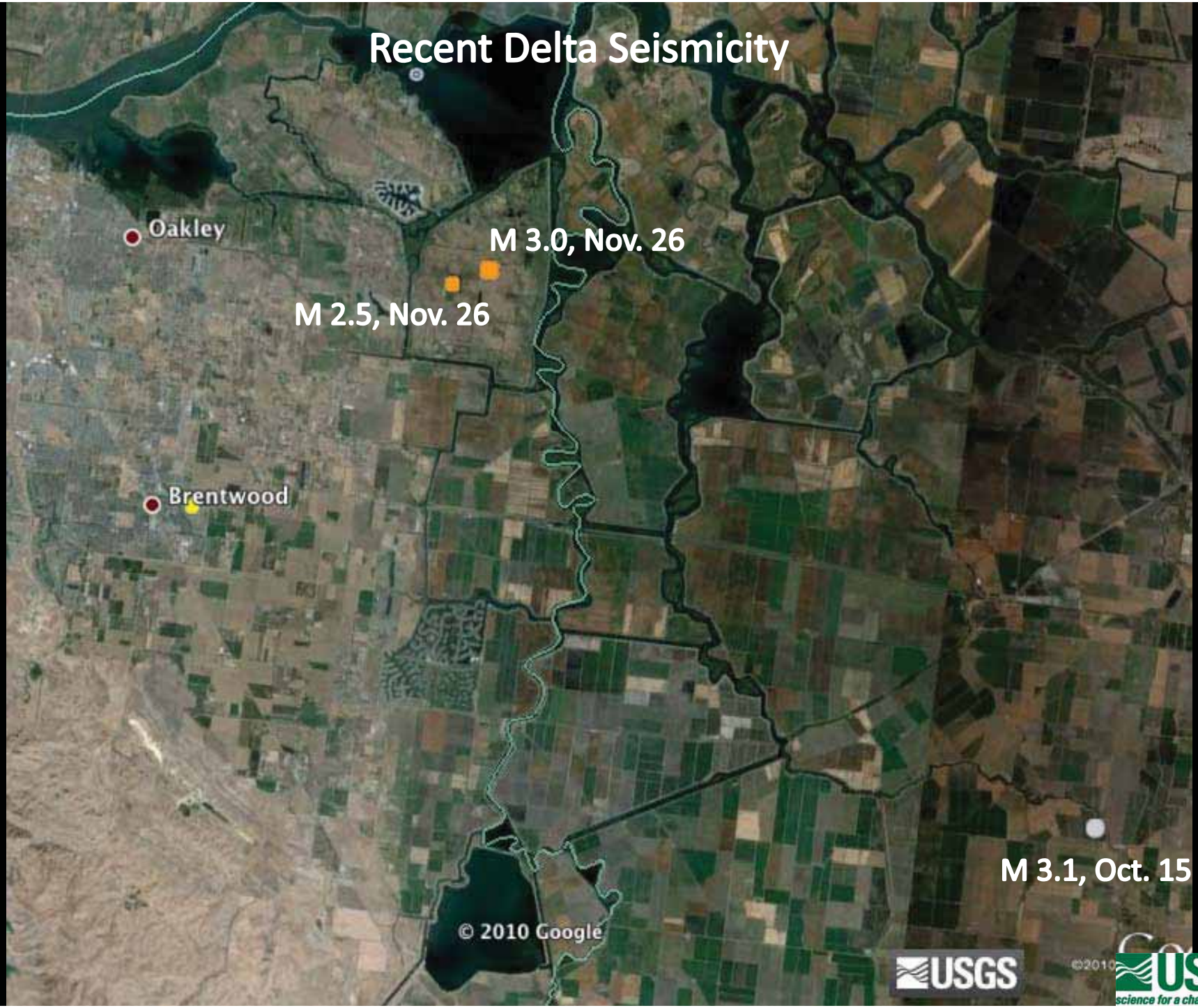
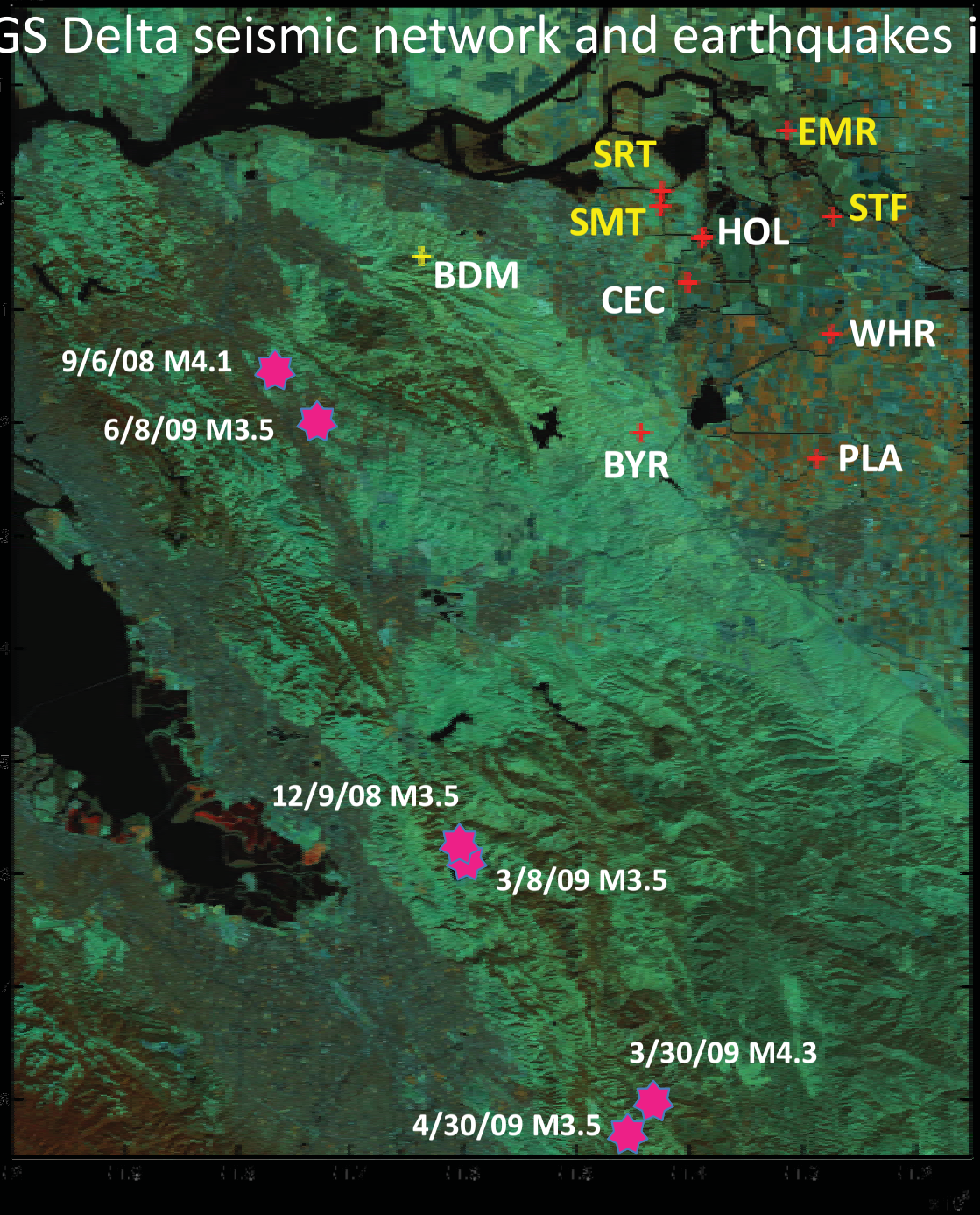
Recent Delta Seismicity



Present USGS Delta seismic network and earthquakes it has recorded



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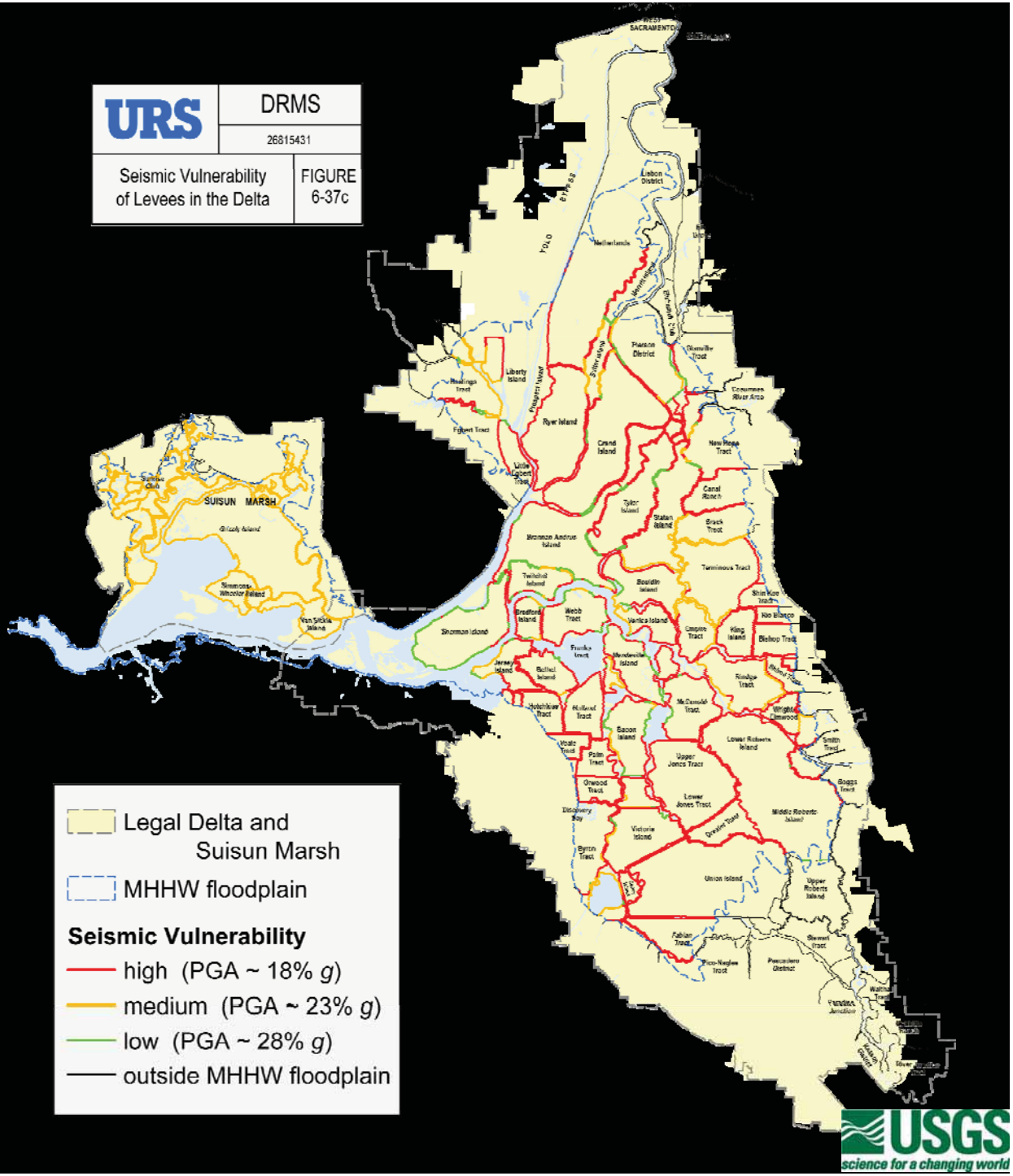
There are ~1,100 miles of levees in the Delta

The CALFED DRMS report grades most of the Delta levees as highly vulnerable where an M6.5 earthquake that produces PGA ≥ 18% *g* could cause failure that breaches the levee



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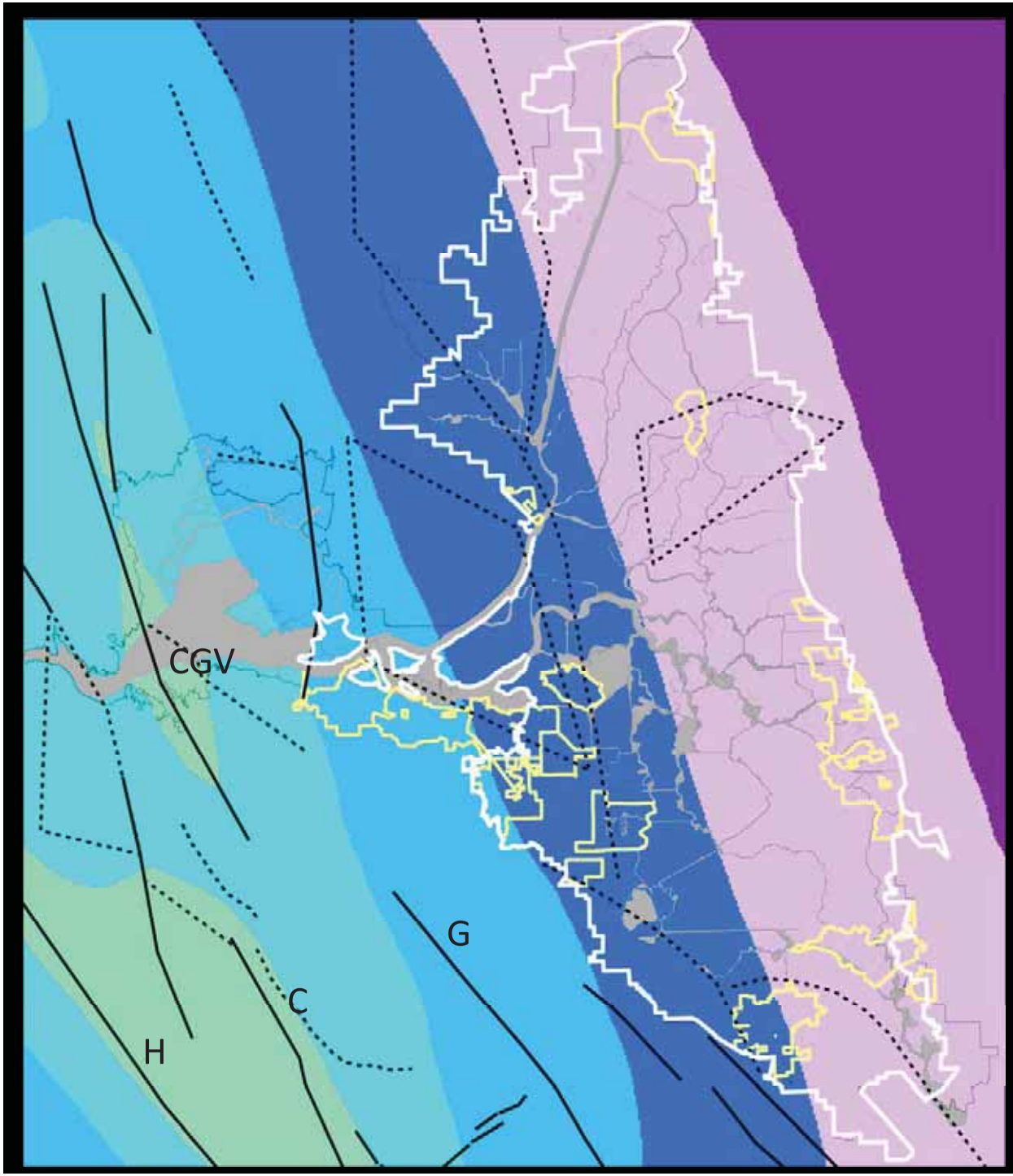

Legend

Mapped Faults

Surficial faults used in the hazard analysis

Blind Faults

Blind faults used in the hazard analysis

Legal Delta & Suisun Marsh Boundary

PGA, 100 Year Return Period

- 0.00 - 0.10 %g
- 0.11 - 0.15 %g
- 0.16 - 0.20 %g
- 0.21 - 0.25 %g
- 0.26 - 0.30 %g
- 0.31 - 0.35 %g
- 0.36 - 0.40 %g

URS	DRMS
	26815431
PGA Hazard for a 100-Year Return Period	FIGURE 6-19

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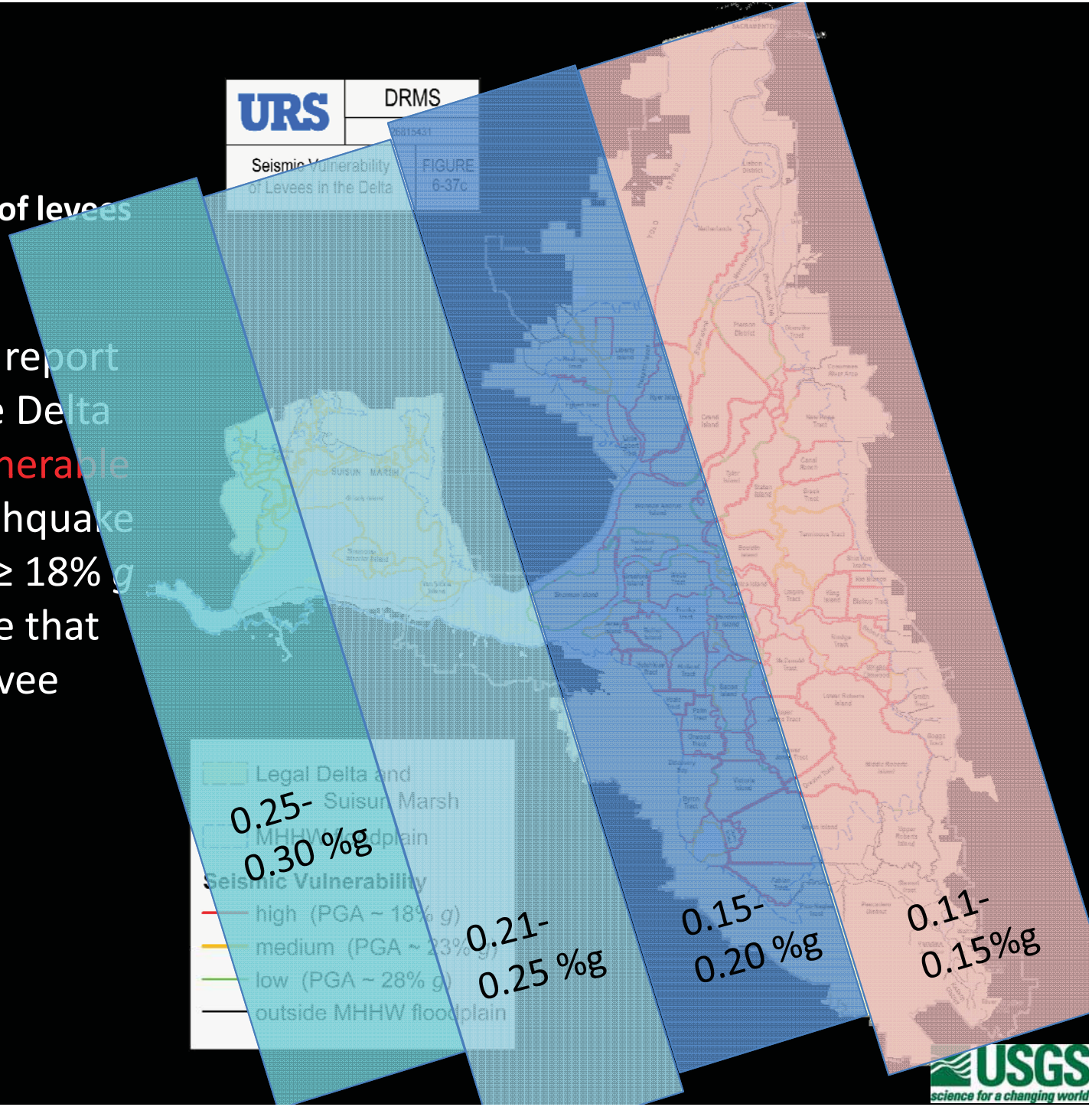
The CALFED DRMS report grades most of the Delta levees as highly vulnerable where an M6.5 earthquake that produces PGA ≥ 18% *g* could cause failure that breaches the levee



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DRMS study is a starting point:

Fault characterization based on existing data at time of DRMS. Delta faults and Great Valley/Coast Range margin faults poorly constrained. Earthquake recurrence rates may be higher on Greenville, Mt. Diablo, Concord-Concord Green Valley faults;

Levee vulnerability estimates OK;

The model for expected shaking uses standard attenuation curves that account for distance from an earthquake source and assumed properties of the upper 30m. This is an untested assertion for the Delta. The linear bands of uniform ground motion this generates are likely unrealistic.

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Uncertainties not presently incorporated into existing ground motion estimates are:

3D-geology of the Delta and its western margin;

Valley edge effects on ground motion;

Variation in distribution of material properties throughout the Delta ;

Basin effects: amplification and increased duration of shaking

INCLUDING THESE, RESULTING GROUND MOTIONS ARE LIKELY TO BE HIGHER THAN THOSE PRESENTLY MODELED IN SOME PARTS OF THE DELTA

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What Does the USGS Need to Do in the Delta to Better Define the Seismic Hazard?

1) refine estimates of earthquake probability on nearby faults, particularly the Greenville, Mt. Diablo, Concord-Green Valley faults;

2) record ground motion in the Delta;

3) assess the surface geology and geotechnical properties of the levees;

4) extend the 3D geologic model eastward;

5) compute scenario earthquake ground motions

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