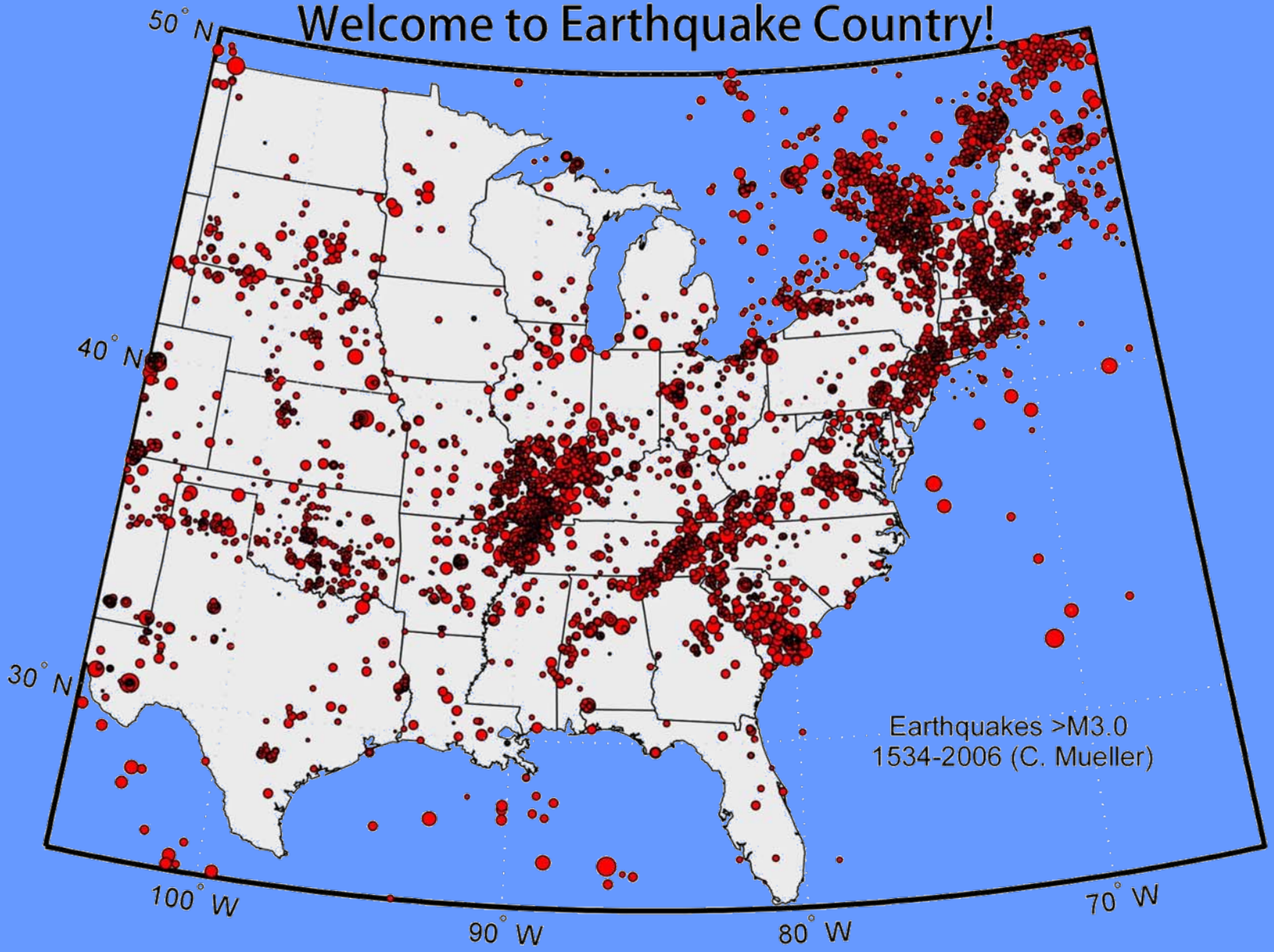
USGS Earthquake Hazards Program

Earthquakes in the Central and Eastern U.S.

Rob Williams
U.S. Geological Survey
Golden, Colorado

U.S. Department of the Interior
U.S. Geological Survey

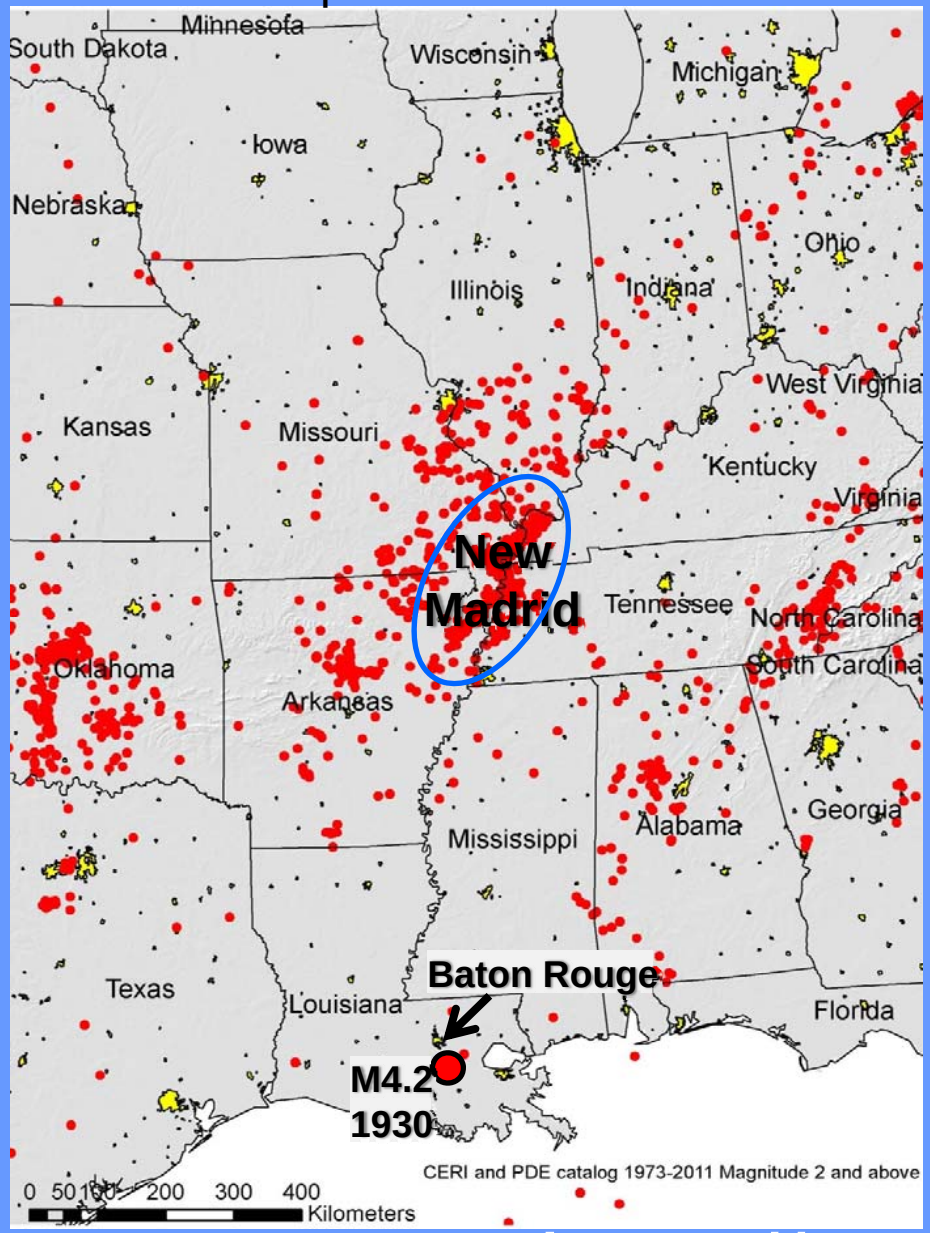
Welcome to Earthquake Country!



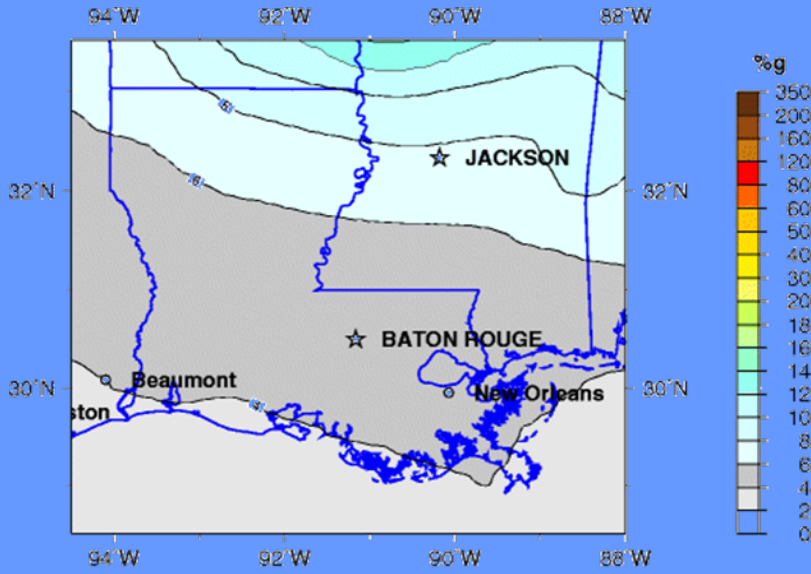
USGS

http: //earthquake.usgs.gov/

Earthquakes 1974-2011



LA Earthquakes Hazard - Low

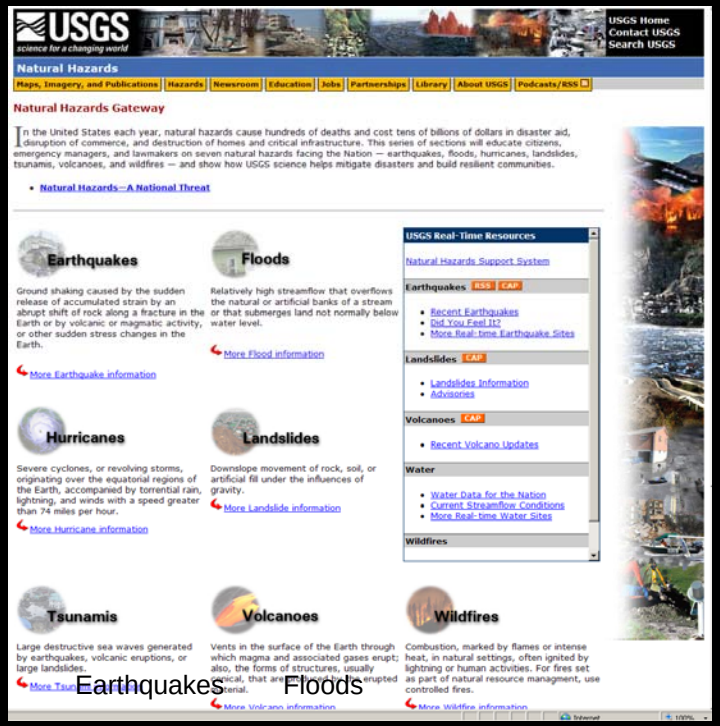


Peak Acceleration (%g) with 2% Probability of Exceedance in 50 Years
site: NEHRP B-C boundary
National Seismic Hazard Mapping Project (2008)

USGS

http: //earthquake.usgs.gov/

USGS Science Areas



Earthquakes Floods

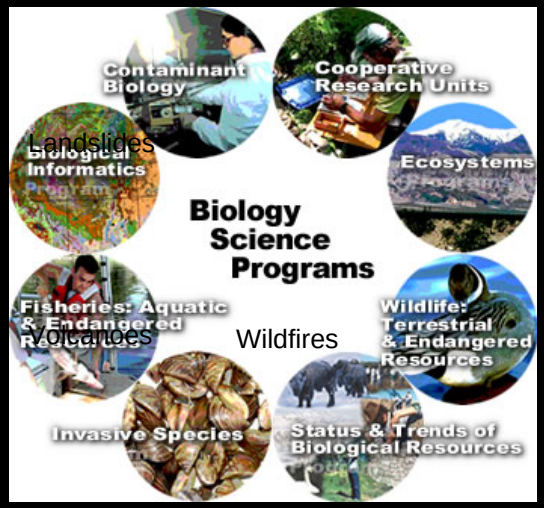
[Climate and Land Use](#)
[Ecosystems](#)
[Energy and Minerals](#)
[Natural Hazards](#)
[Water](#)

USGS
Employees: ~8,600
Budget: $1 billion

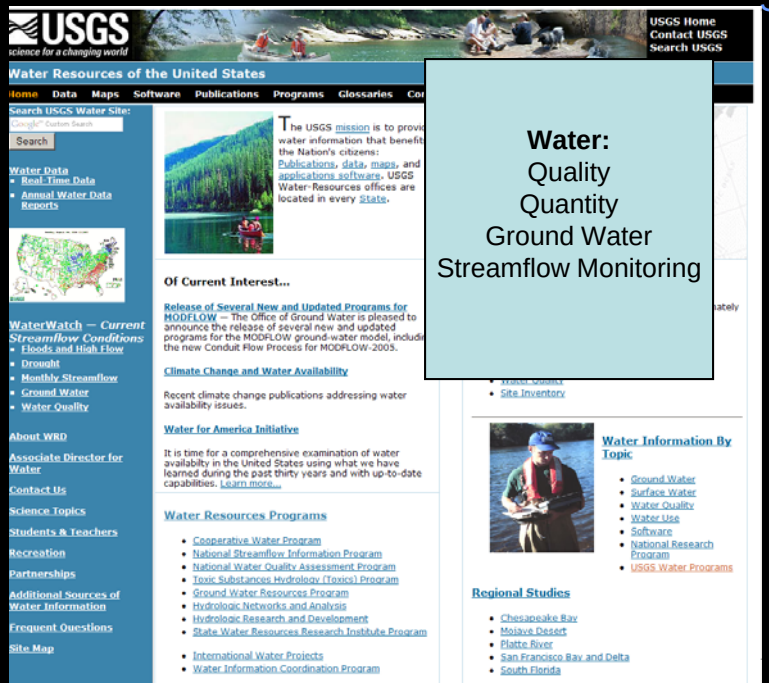
Bureau of Land Manage.
$2 billion

NOAA
$3.9 billion

Forest Service
$4.5 billion



Landslides Volcanoes Wildfires



Water:
Quality
Quantity
Ground Water
Streamflow Monitoring

USGS

Talk Outline

Part 1 – Earthquakes 101

Part 2

- Overview of USGS earthquake information tools

  ENS, DYFI, ShakeMap, PAGER, ShakeCast

Part 3

- Overview of U.S. earthquake hazard
- Differences between western and eastern U.S.
- Review the 1811-1812 earthquake sequence

  3 Mainshocks and a vigorous aftershock sequence

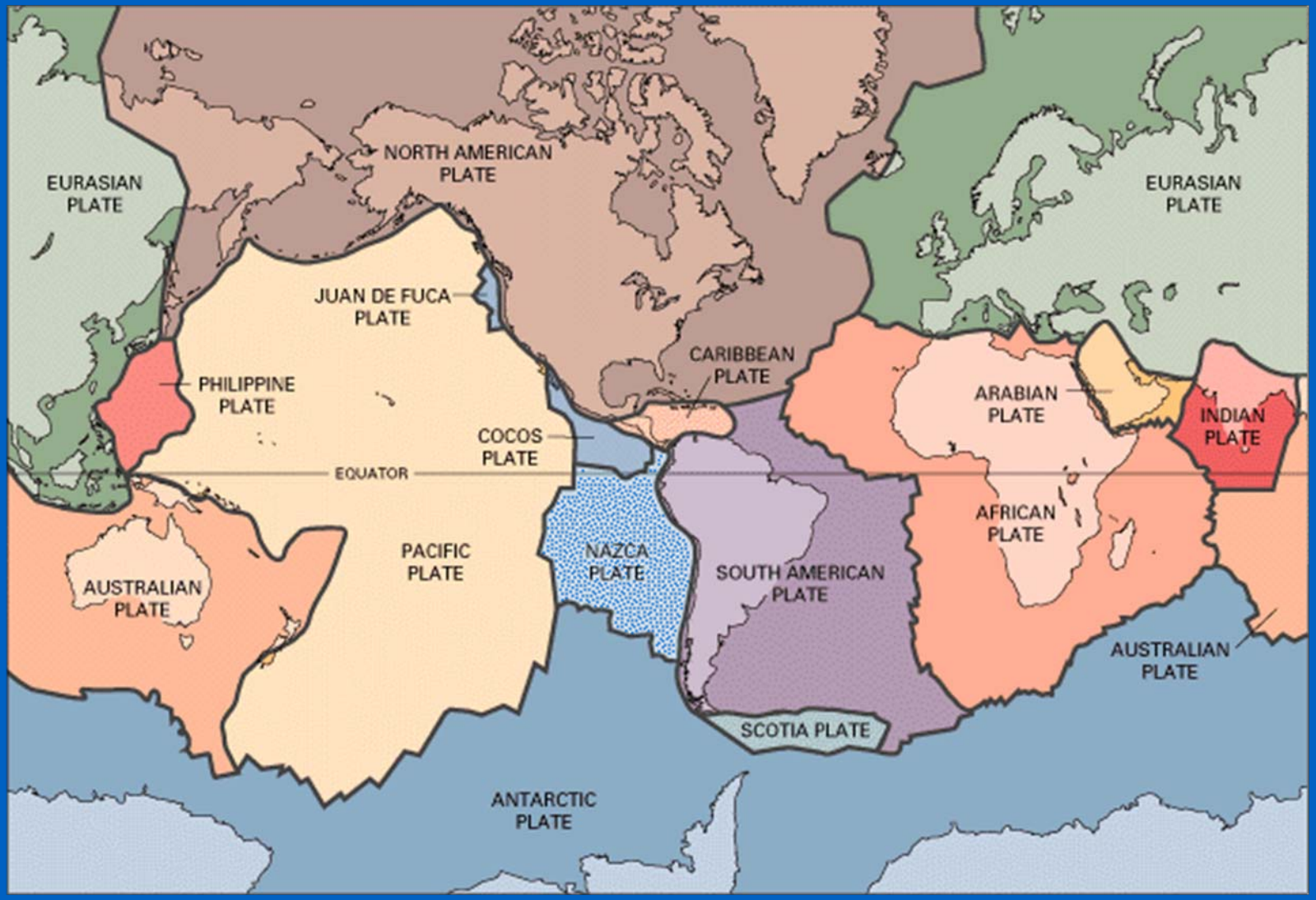
  Widespread ground failure and liquefaction

  Possible impacts to structures and houses

USGS

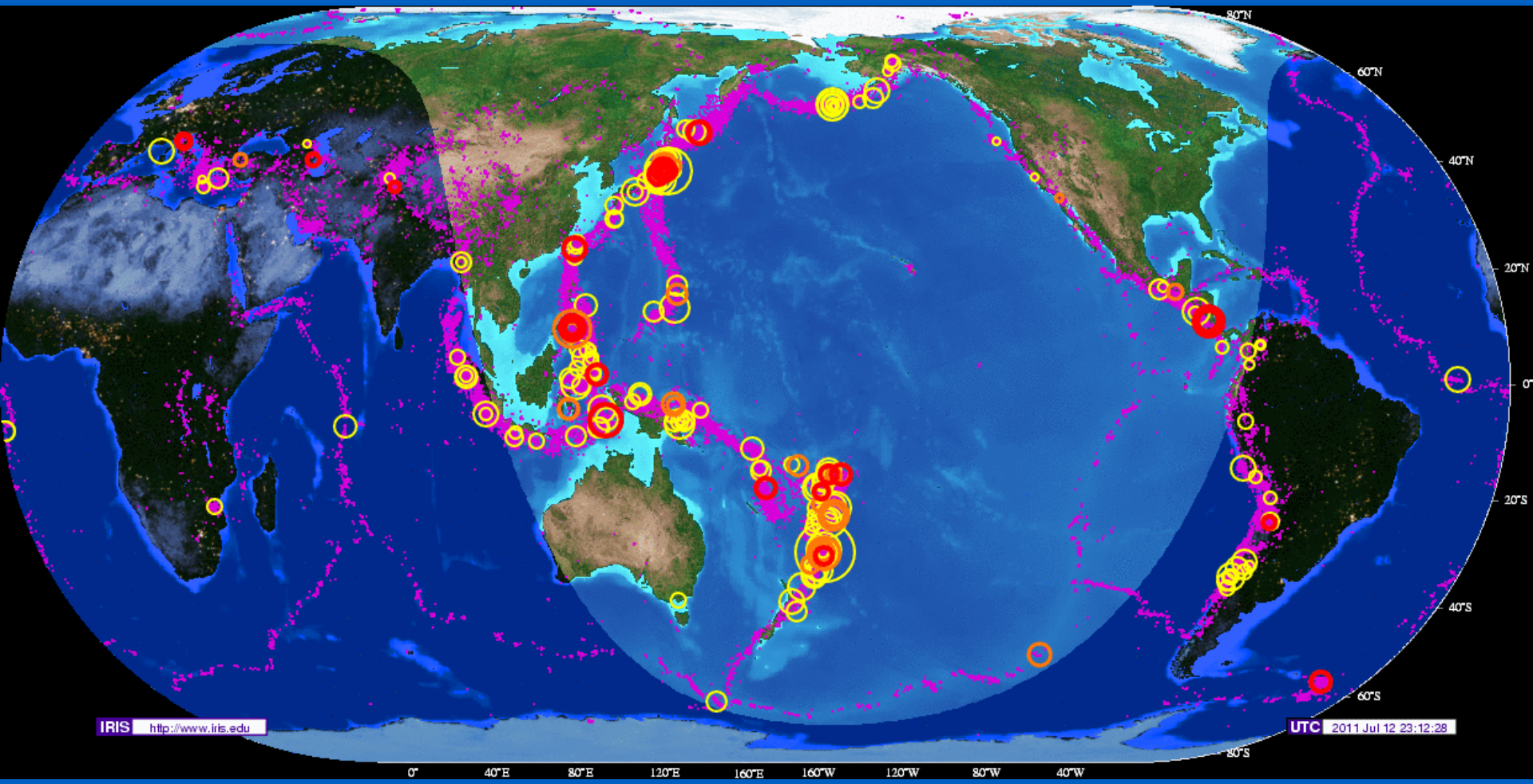
It's happened before 1811-1812!

Plate Tectonics



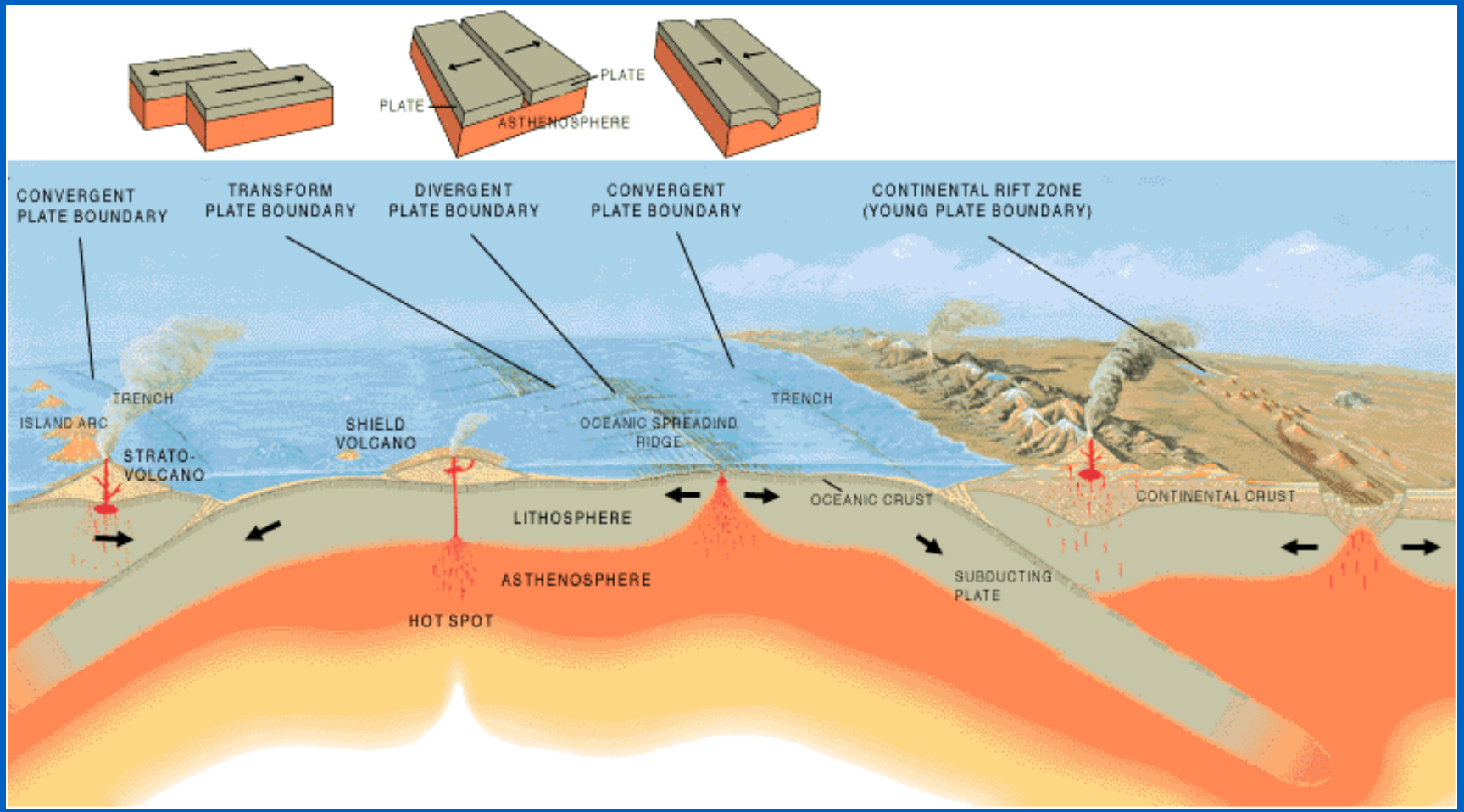
USGS

Worldwide Earthquakes – Past 5 Years



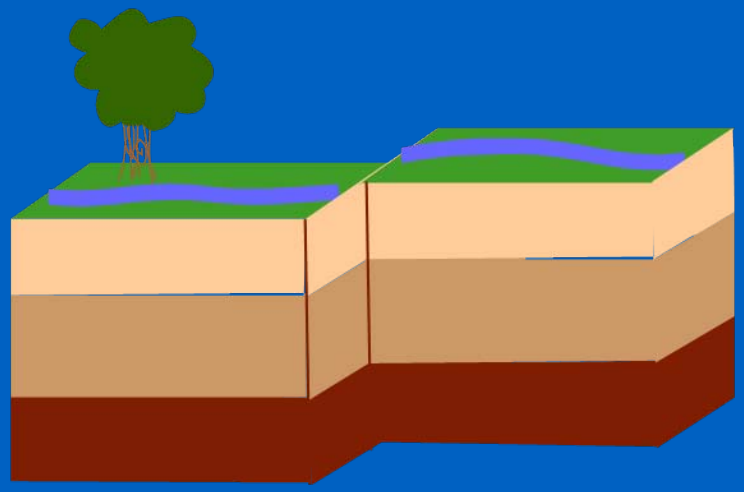
USGS

Plate Boundaries

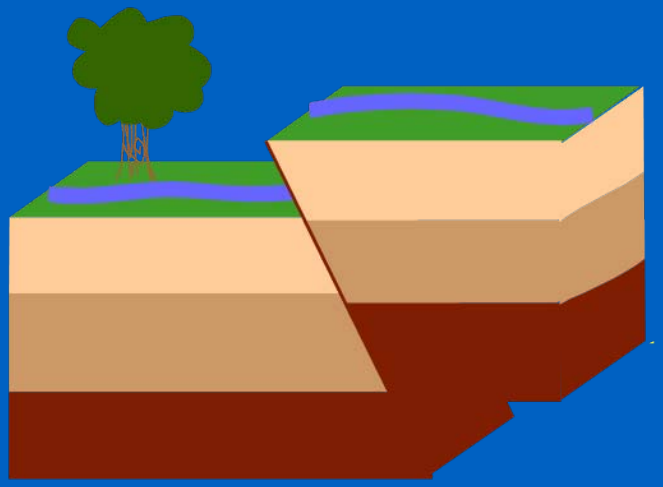


USGS

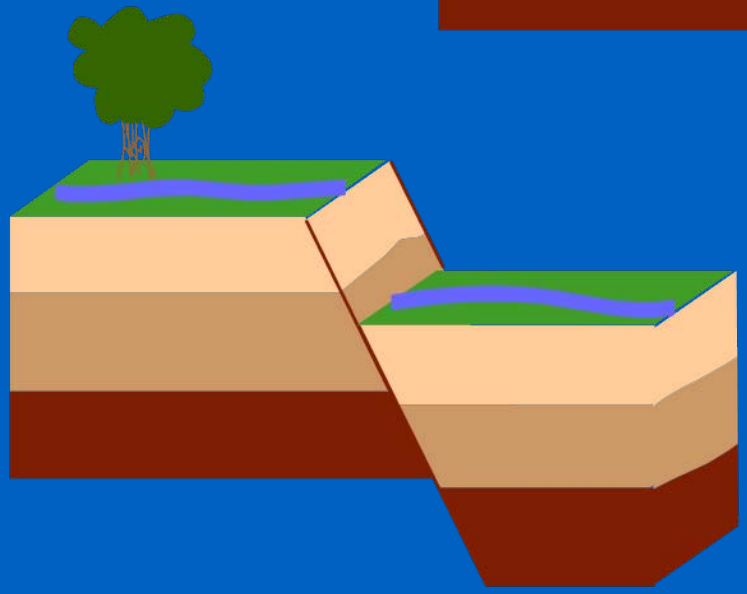
Three Types of Faults



Strike-Slip



Thrust

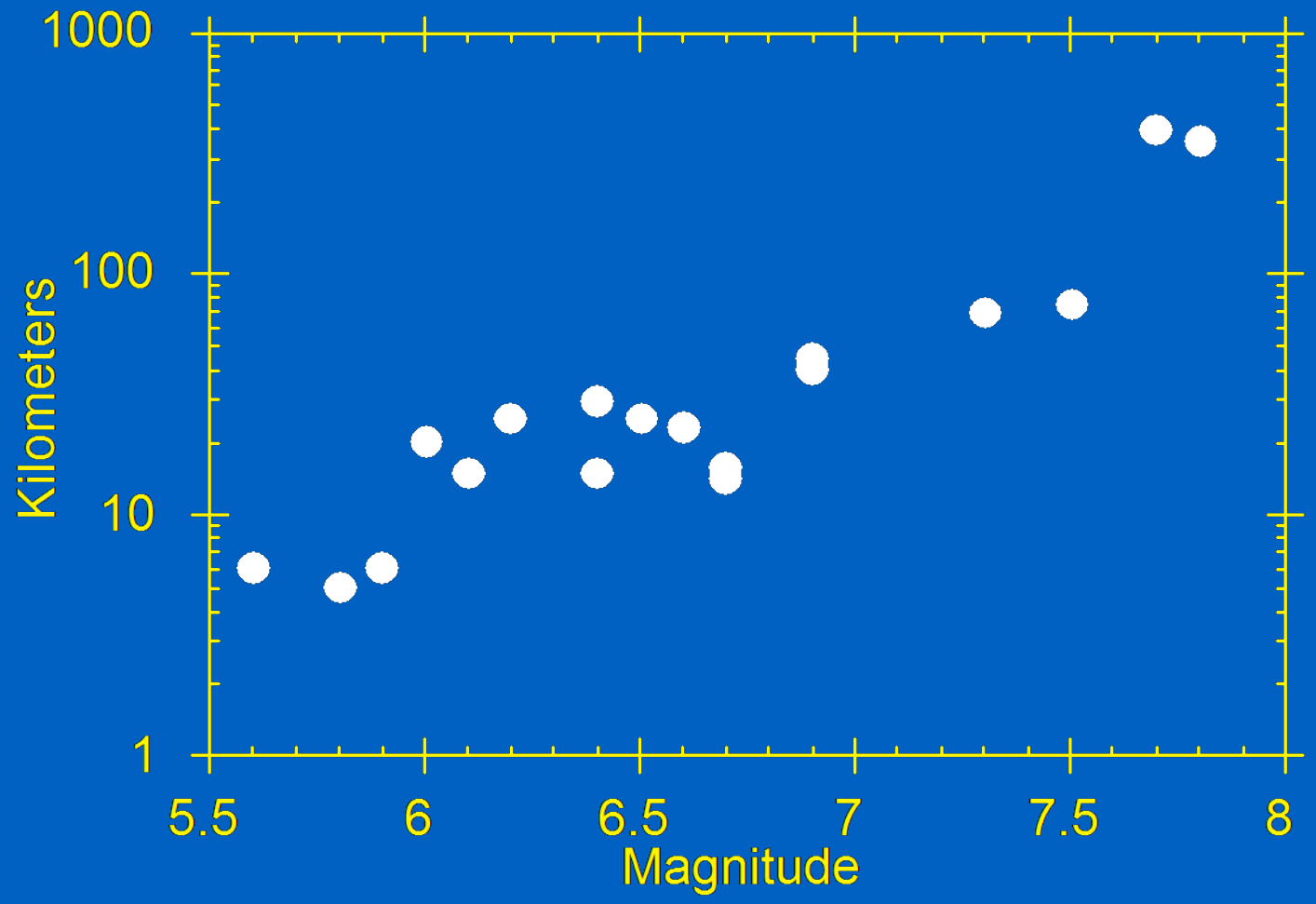


Normal

USGS

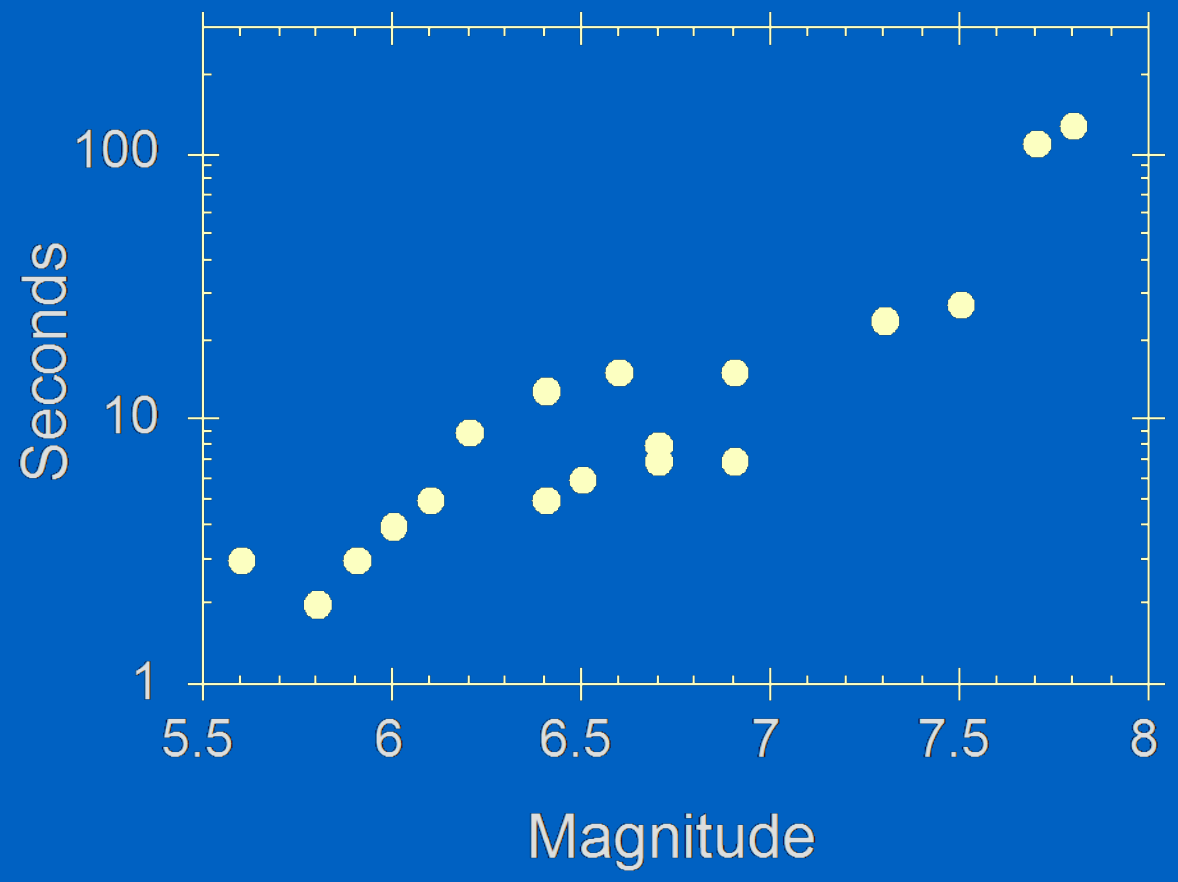
Strike-slip Fault Example

Bigger Faults Make Bigger Earthquakes



USGS

Bigger Earthquakes Last a Longer Time



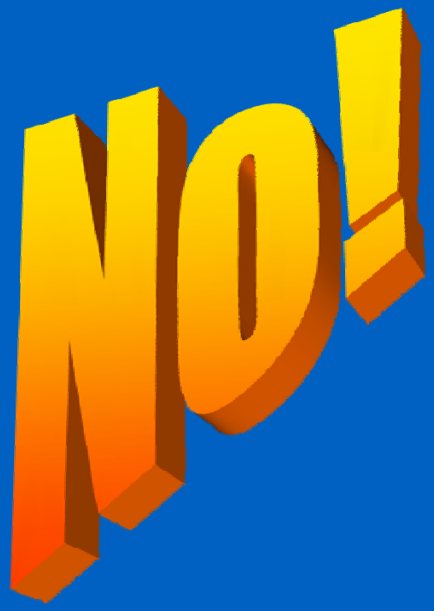
USGS

What Controls the Level of Shaking?

- **Magnitude**
  - More energy released
- **Distance**
  - Shaking decays with distance
- **Local soils**
  - amplify the shaking

USGS

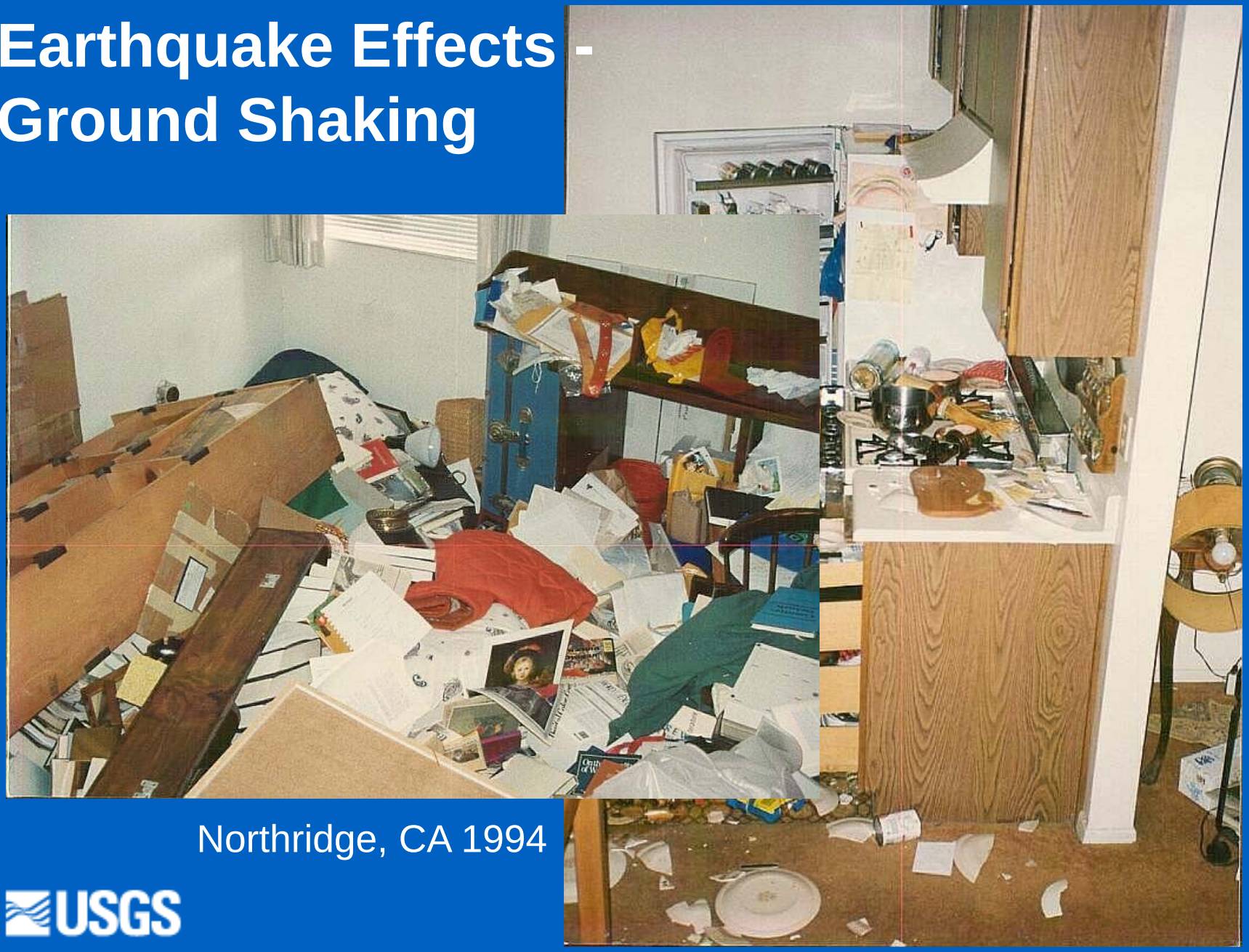
Is there such a thing as “Earthquake Weather”???



Earthquake Effects - Ground Shaking

Christchurch, New Zealand, Sept 2010

Earthquake Effects - Ground Shaking



Northridge, CA 1994

USGS

Earthquake Effects - Ground Shaking

Loma Prieta, CA 1989

USGS

KGO-TV News ABC-7

Earthquake Effects - Ground Shaking

Kobe, Japan 1995

Earthquake Effects - Surface Faulting

Landers, CA 1992

USGS

Earthquake Effects - Liquefaction

Source: National Geophysical Data Center

Niigata, Japan 1964

Earthquake Effects - Landslides

Turnagain Heights, Alaska,1964 (upper left inset);
Santa Cruz Mtns, California , 1989

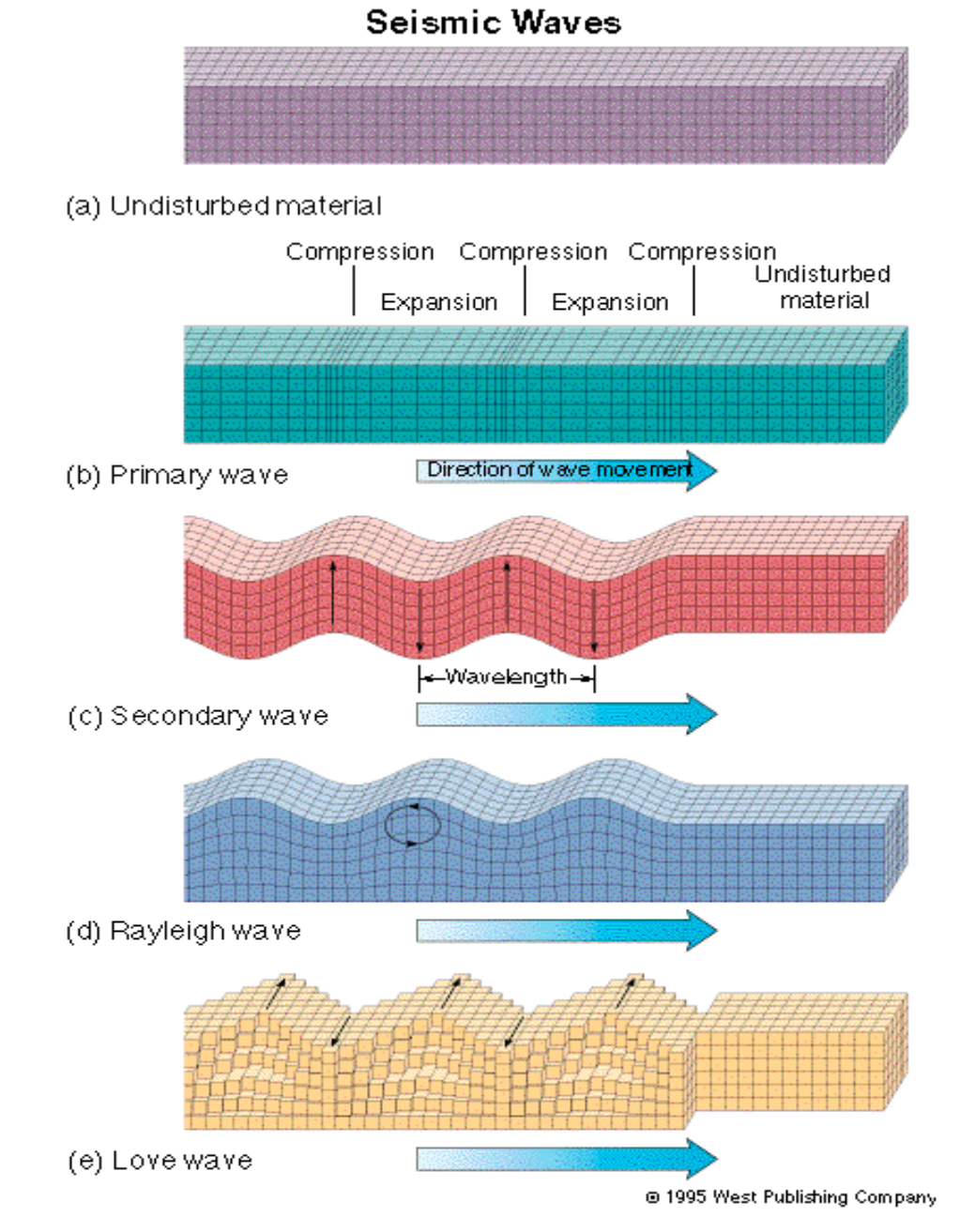
Earthquake Effects - Fires

Loma Prieta, CA 1989

USGS

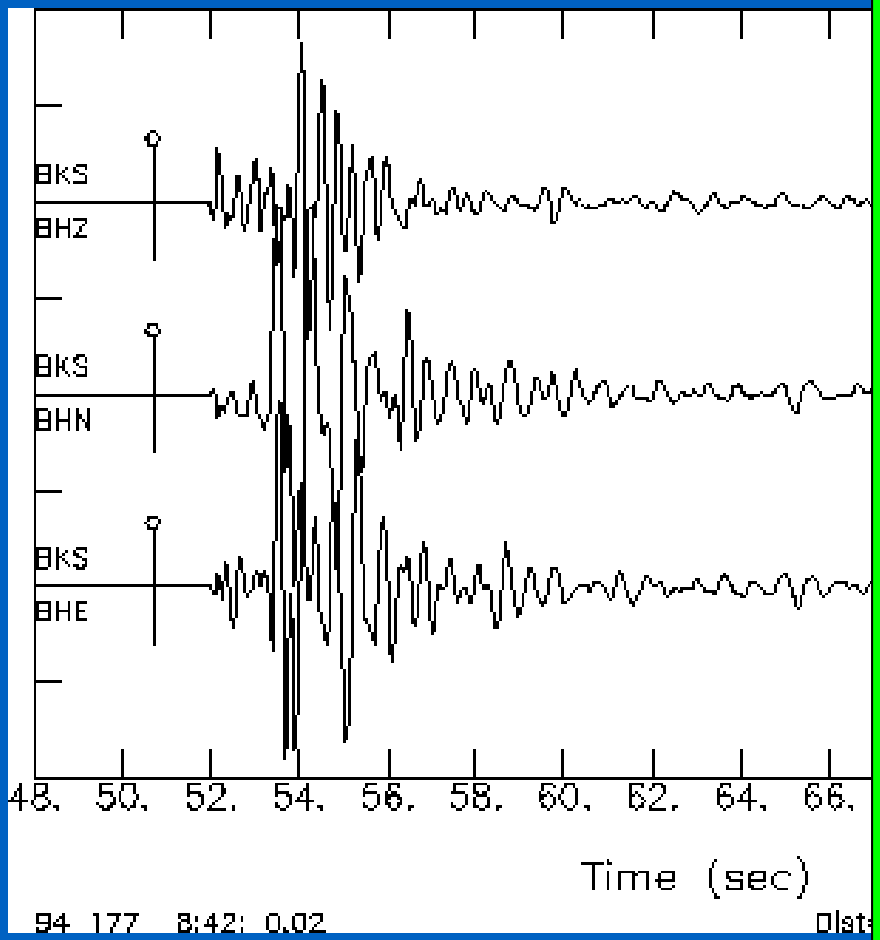
KGO-TV News ABC-7

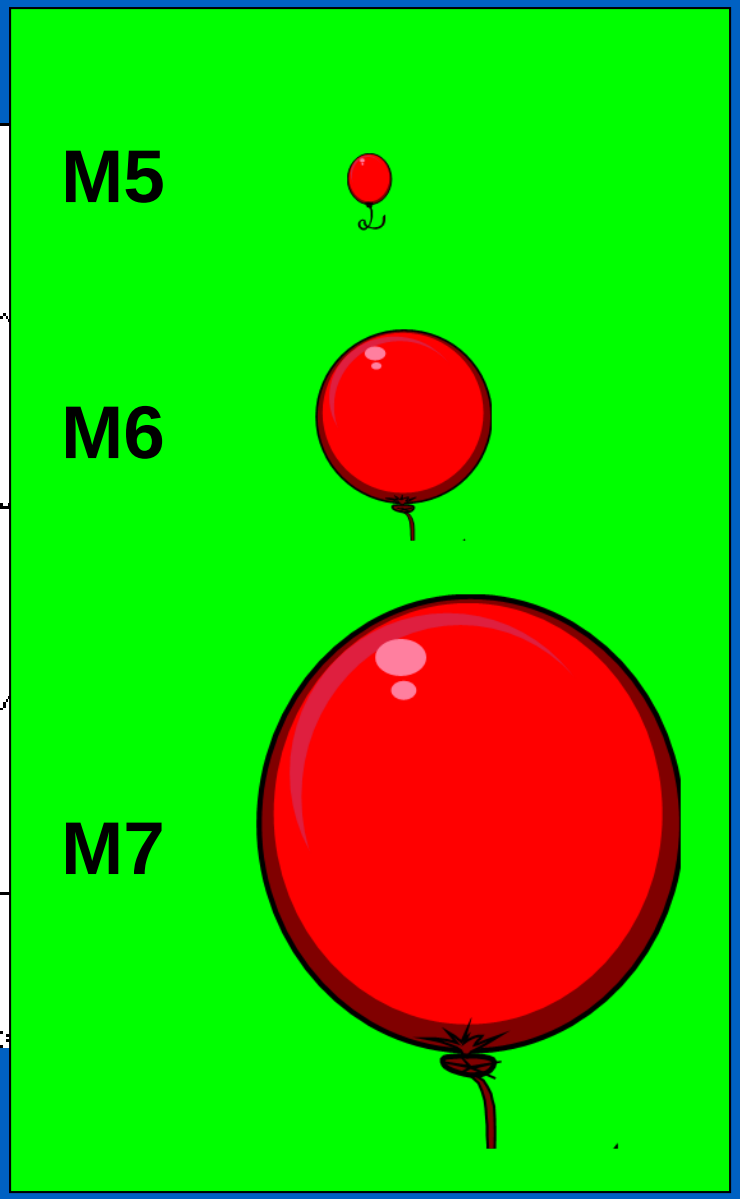
Seismic Waves



USGS

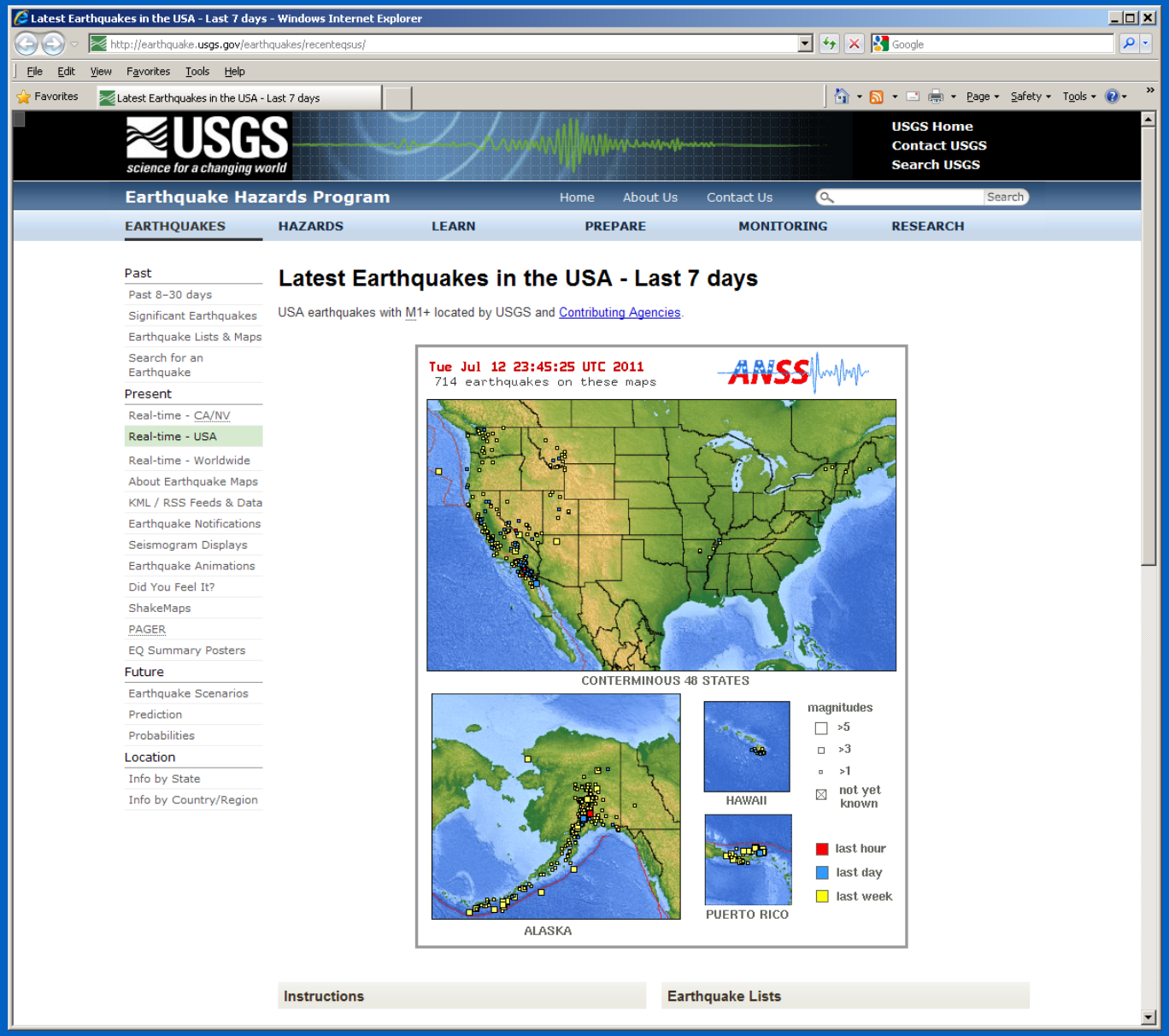
Earthquake Magnitude





USGS

Real-time Earthquake Information



USGS

http: //earthquake.usgs.gov/

US Earthquake Facts

- The largest recorded U.S. earthquake: M9.2
  Prince William Sound, Alaska, on March 28, 1964.

- Alaska is the most earthquake-prone State
  M7 earthquake almost every year
  M8 or greater earthquake every 14 yrs

- In the United States, six M6 or greater and 57 M5 or greater earthquakes each year.

- 10,000 earthquakes each year in southern California. Most are too small to be felt. Several hundred are >M3.0, and about 15-20 are >M4.0.

Oakland, CA, Loma Prieta, M6.9, 1989

Santa Cruz, CA, Loma Prieta, M6.9, 1989

USGS

World Earthquake Facts

- The largest recorded earthquake in the world M9.5 in Chile on May 22, 1960.

- **500,000** detectable earthquakes in the world each year. 100,000 can be felt, and **100** cause damage.

- The world's deadliest recorded earthquake occurred in 1556 in central China killing an estimated **830,000** people. In 1976 another deadly earthquake in Tangshan, China, where more than **250,000** people were killed.

Denali Quake, M7.9, Alaska 2002

USGS

Source: USGS National Earthquake Information Center, Golden

World Earthquake Facts

Frequency of Occurrence of Earthquakes

Magnitude	Average Annually
8 and higher	1 [1]
7 - 7.9	17 [2]
6 - 6.9	134 [2]
5 - 5.9	1319 [2]
4 - 4.9	13,000(estimated)
3 - 3.9	130,000(estimated)
2 - 2.9	1,300,000(estimated)

[1] Based on observations since 1900.

[2] Based on observations since 1990.

Denali Quake, M7.9, Alaska 2002

Photo by Patty Craw, DGGS.

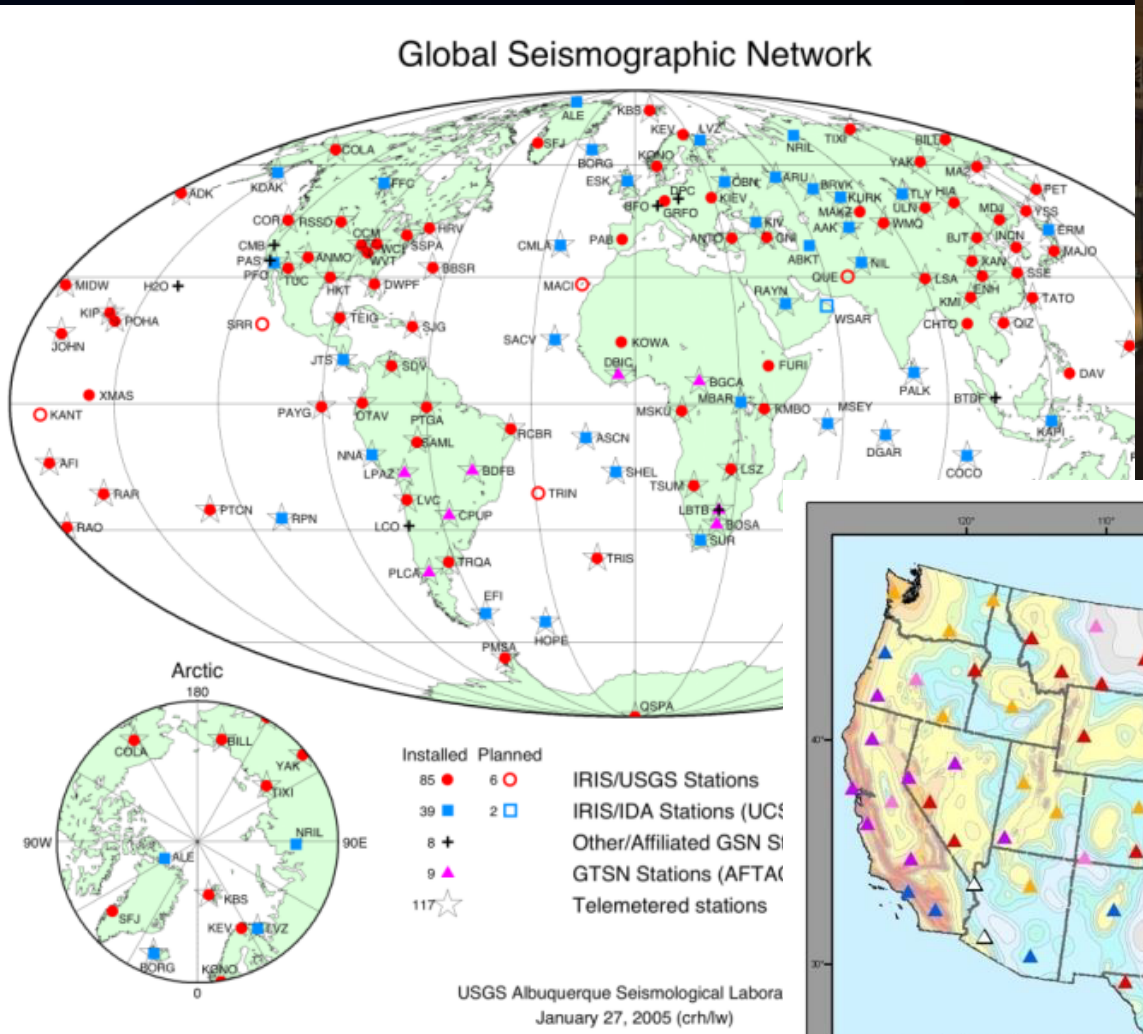
USGS

Source: USGS National Earthquake Information Center, Golden

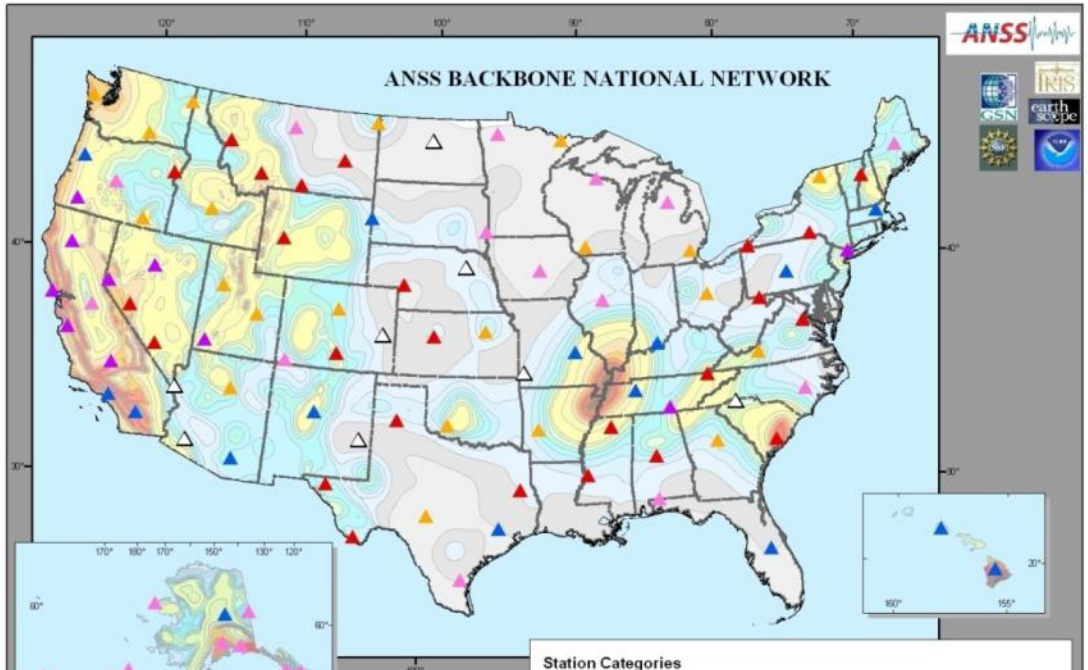
End Part 1

Part 2: USGS Earthquake Information

USGS provides rapid information on earthquakes worldwide



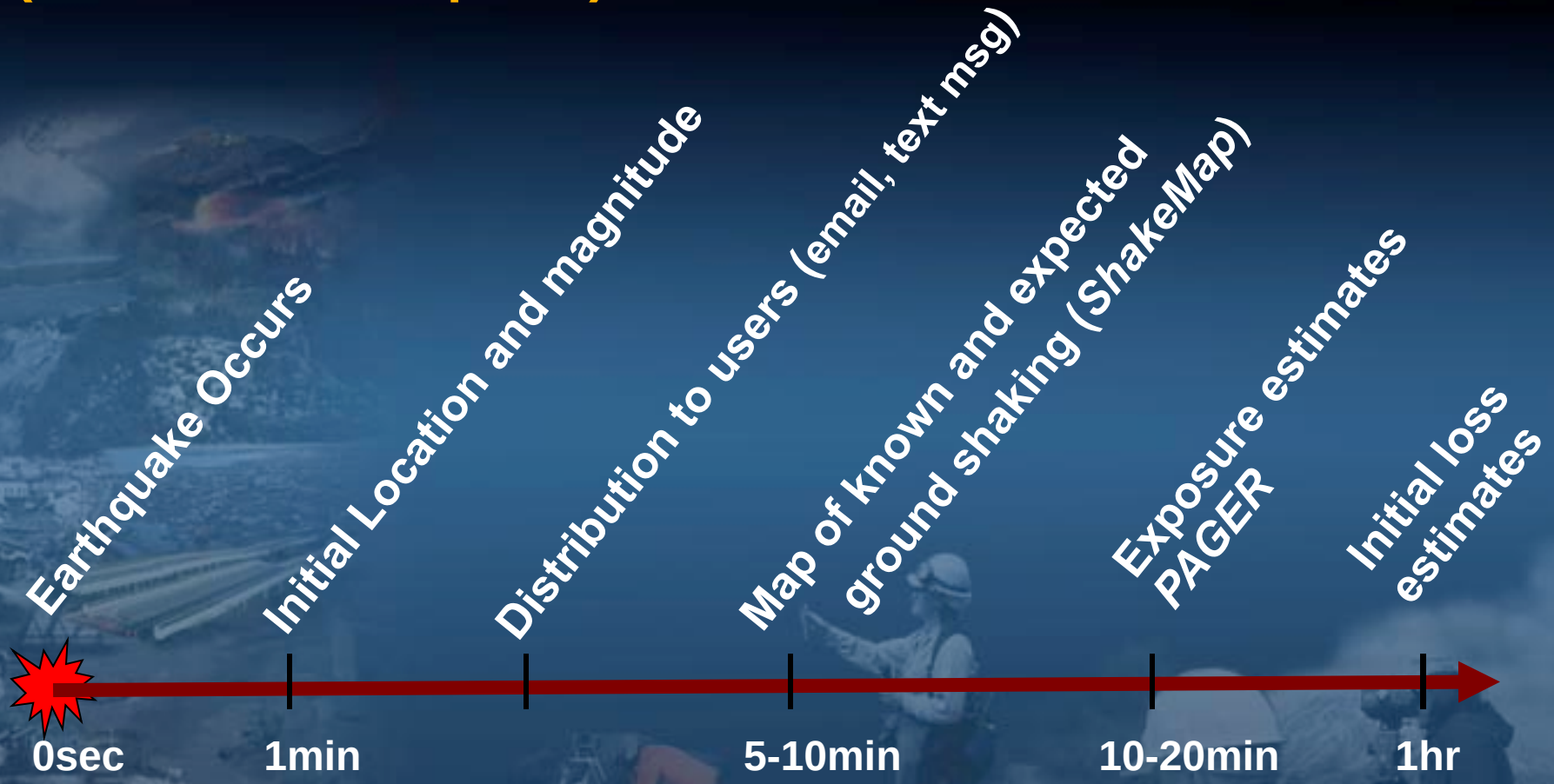
USGS *National Earthquake Information Center, Golden, Colorado*



USGS science for a changing world

IRIS

An Earthquake Information Timeline
(domestic earthquake)



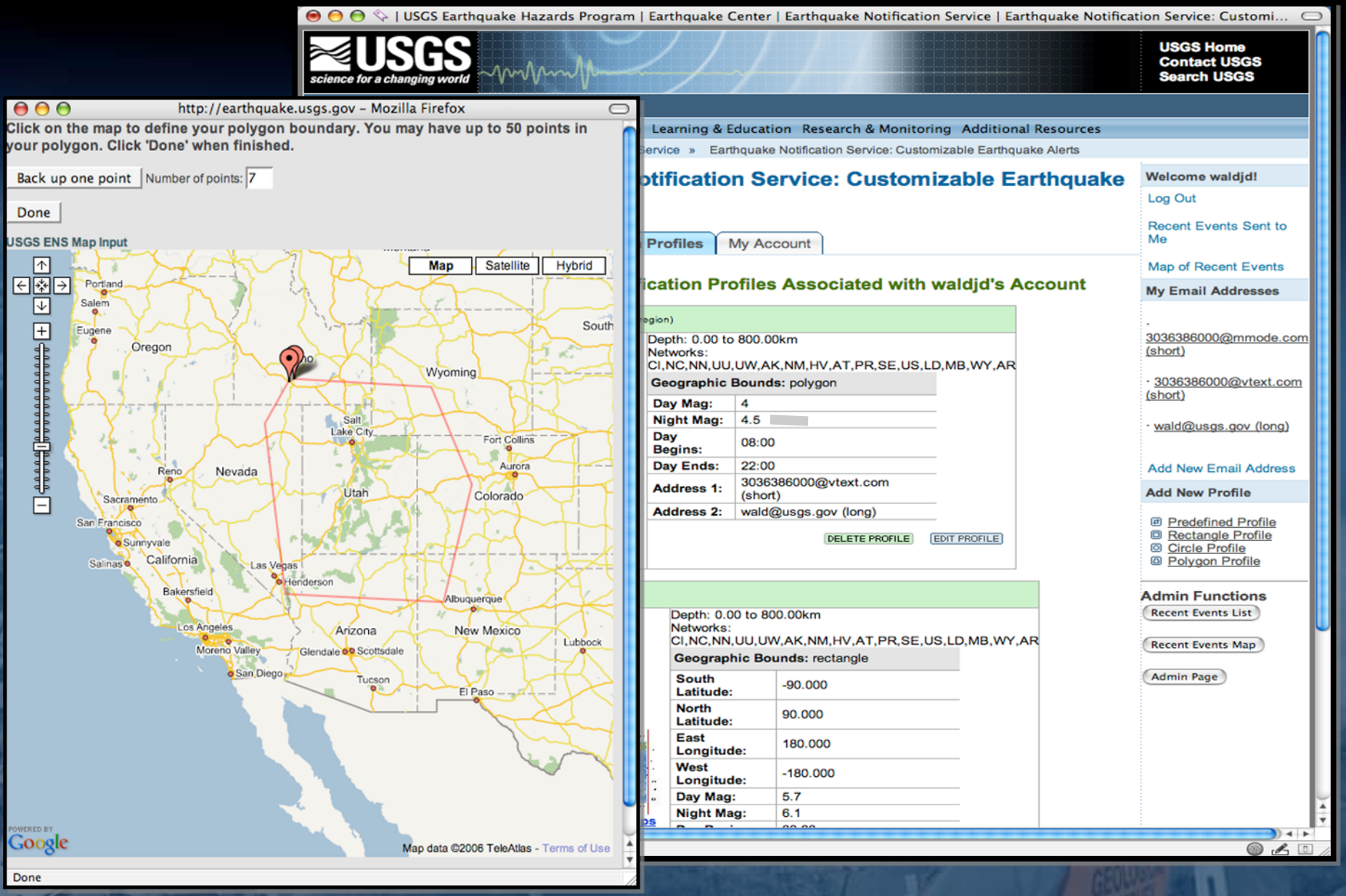
USGS nehrp

USGS Earthquake Notification System

Over 200,000 users

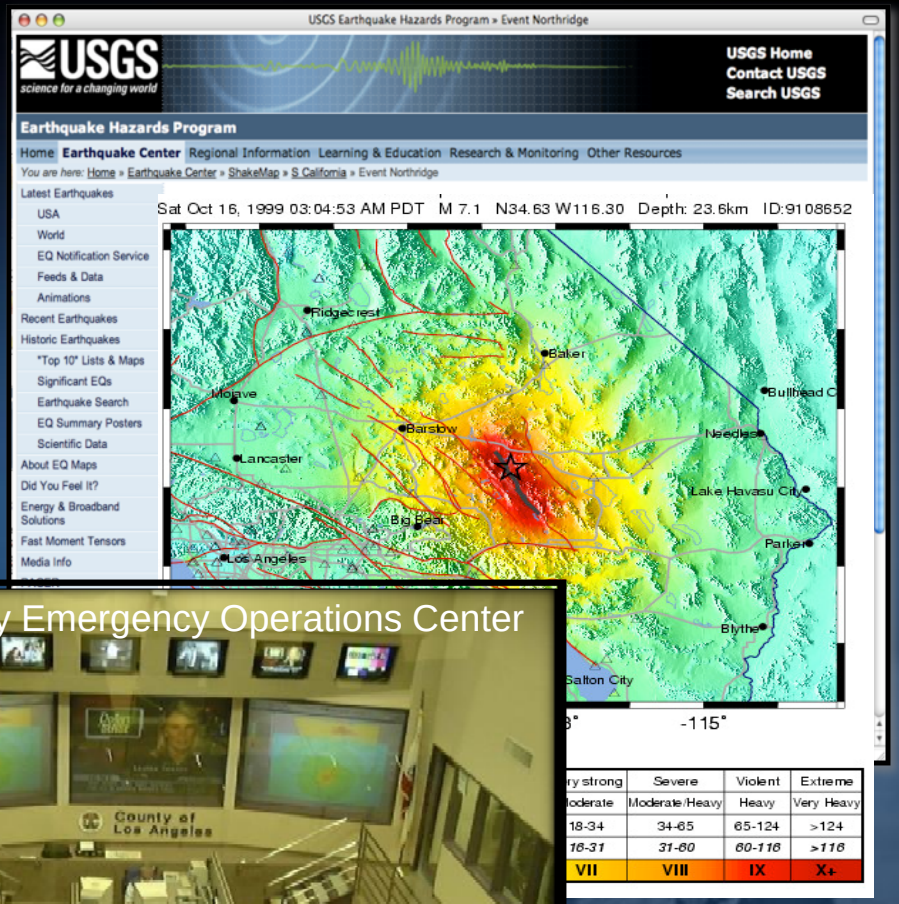
USGS

ENS can be customized to suit your needs



ShakeMap: A tool for rapid post-earthquake response, coordination, and situational awareness

California Governor Schwarzenegger pointing to ShakeMap at his press conference following the 2008 M5.4 Chino Hills earthquake that hit LA.



LA County Emergency Operations Center

ShakeMaps underlie four distinct products for situational awareness

- *ShakeMap* is posted to web and delivered to emergency response centers – Overview of shaking
- *ShakeMap* is pushed to subscribers; *ShakeCast* software calculates predicted shaking at user-defined facilities and generates customized alerts
- *ShakeMap* output flows to FEMA's *HAZUS* software, which generates detailed estimates of casualties, impacts and financial loss
- *PAGER* combines *ShakeMap*, *Did You Feel It*, and population data for rapid estimate of human impact

ShakeCast

Automated notifications to operators of critical facilities

Facility Damage Estimates from ShakeMap

Bridges presented in the table below are sorted in order of potential damage level.

Bridge Name	Bridge No	Dist-Cty-Rte-PM	Damage Level	Value	Exceedance Ratio
Pisgah Overhead	54 0689L	08-SBD-040-R37.41	RED	47.6856	1.163
Pisgah Overhead	54 0689R	08-SBD-040-R37.44	RED	47.6856	1.163
Lavic Road OC	54 0734	08-SBD-040-R41.91	YELLOW	56.4714	0.867
Ash Hill Wash	54 0758L	08-SBD-040-R54.75	GREEN	25.5495	0.887
Ash Hill Wash	54 0758R	08-SBD-040-R54.77	GREEN	25.5495	0.887
Argos Wash	54 0737L	08-SBD-040-R43.84	GREEN	48.8524	0.053
Argos Wash	54 0737R	08-SBD-040-R43.84	GREEN	48.8524	0.053

USGS nehrp

Situational awareness available in 20 minutes

Prompt
Assessment of
Global
Earthquakes
for
Response

Rapidly estimated that over 2 million people were exposed to violent shaking

USGS
science for a changing world

GSN

USAID
FROM THE AMERICAN PEOPLE

M 7.0, HAITI REGION

Origin Time: Tue 2010-01-12 21:53:10 UTC
Location: 18.46°N 72.53°W Depth: 13 km

PAGER
Version 8
Created: 1 day, 20 hours after earthquake

Estimated Population Exposed to Earthquake Shaking

ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	5,887k*	7,261k	1,049k	571k	314k	2,246k	332k
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

*Estimated exposure only includes population within the map area.

Population Exposure

population per ~1 sq. km from Landscan

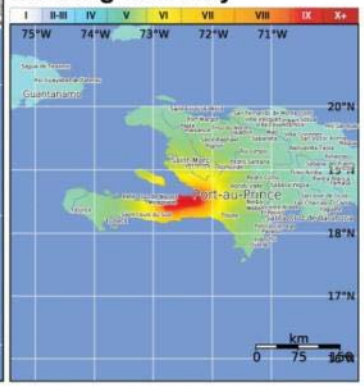
Selected City Exposure

MMI	City	Population
X	Grand Goave	5k
IX	**Port-au-Prince**	**1,235k**
IX	Carrefour	442k
IX	Petionville	108k
IX	Delmas 73	383k
IX	Croix des Bouquets	9k
VI	**Miragoane**	**6k**
V	**Verrettes**	**49k**
III	Santo Domingo	2,202k
III	**Guantanamo**	**273k**

bold cities appear on map (k = x1000)

Shaking Intensity

MMI



USGS nehrp

Newly released version of PAGER includes fatality and economic loss estimates

USGS
science for a changing world

Earthquake Shaking — Red Alert

GSN ANSS USAID FROM THE AMERICAN PEOPLE

M 8.8, OFFSHORE MAULE, CHILE

Origin Time: Sat 2010-02-27 06:34:14 UTC (02:34:14 local)

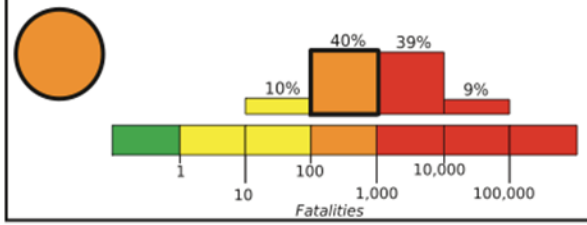
Location: 35.85°S 72.72°W Depth: 35 km

FOR TSUNAMI INFORMATION, SEE: tsunami.noaa.gov

PAGER Version 3

Created: 3 hours, 10 minutes after earthquake

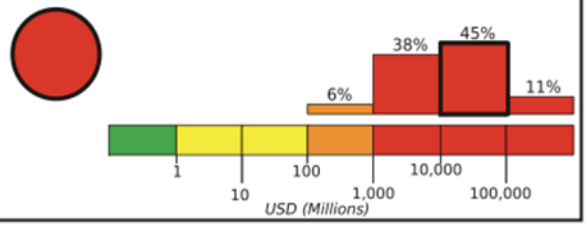
Estimated Fatalities



Red alert level for economic losses. Extensive damage is probable and the disaster is likely widespread. Estimated economic losses are 3-20% GDP of Chile. Past events with this alert level have required a national or international level response.

Orange alert level for shaking-related fatalities. Significant casualties are likely.

Estimated Economic Losses



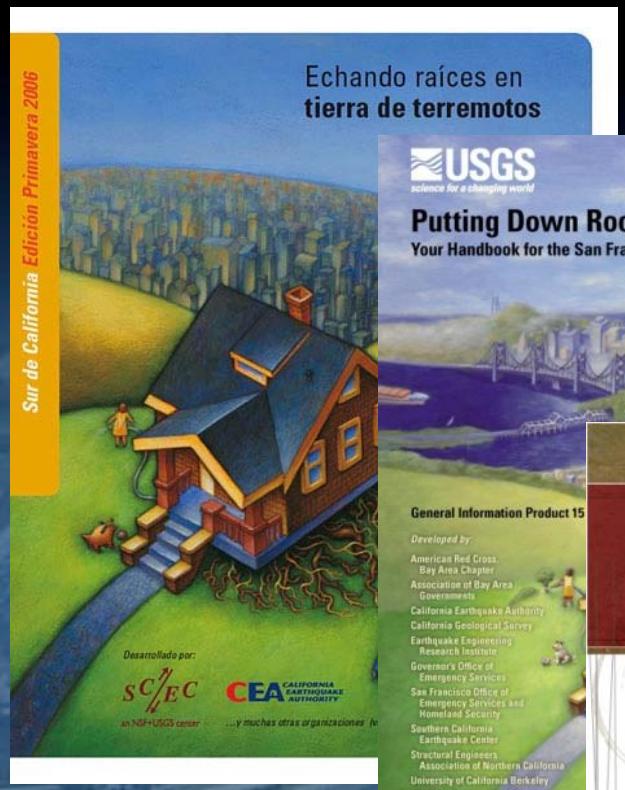
Estimated Population Exposed to Earthquake Shaking

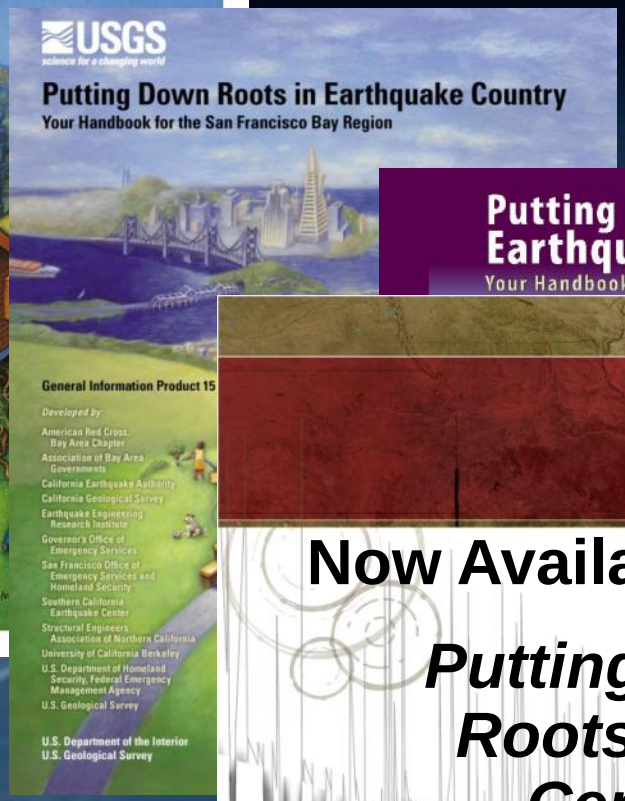
ESTIMATED POPULATION EXPOSURE (k = x1000)		- -*	- -*	487k*	2,147k*	3,657k	6,405k	3,083k	0	0
ESTIMATED MODIFIED MERCALLI INTENSITY		I	II-III	IV	V	VI	VII	VIII	IX	X+
PERCEIVED SHAKING		Not felt	Weak	Light	Moderate	Strong	Very Strong	Severe	Violent	Extreme
POTENTIAL DAMAGE	Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
	Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy

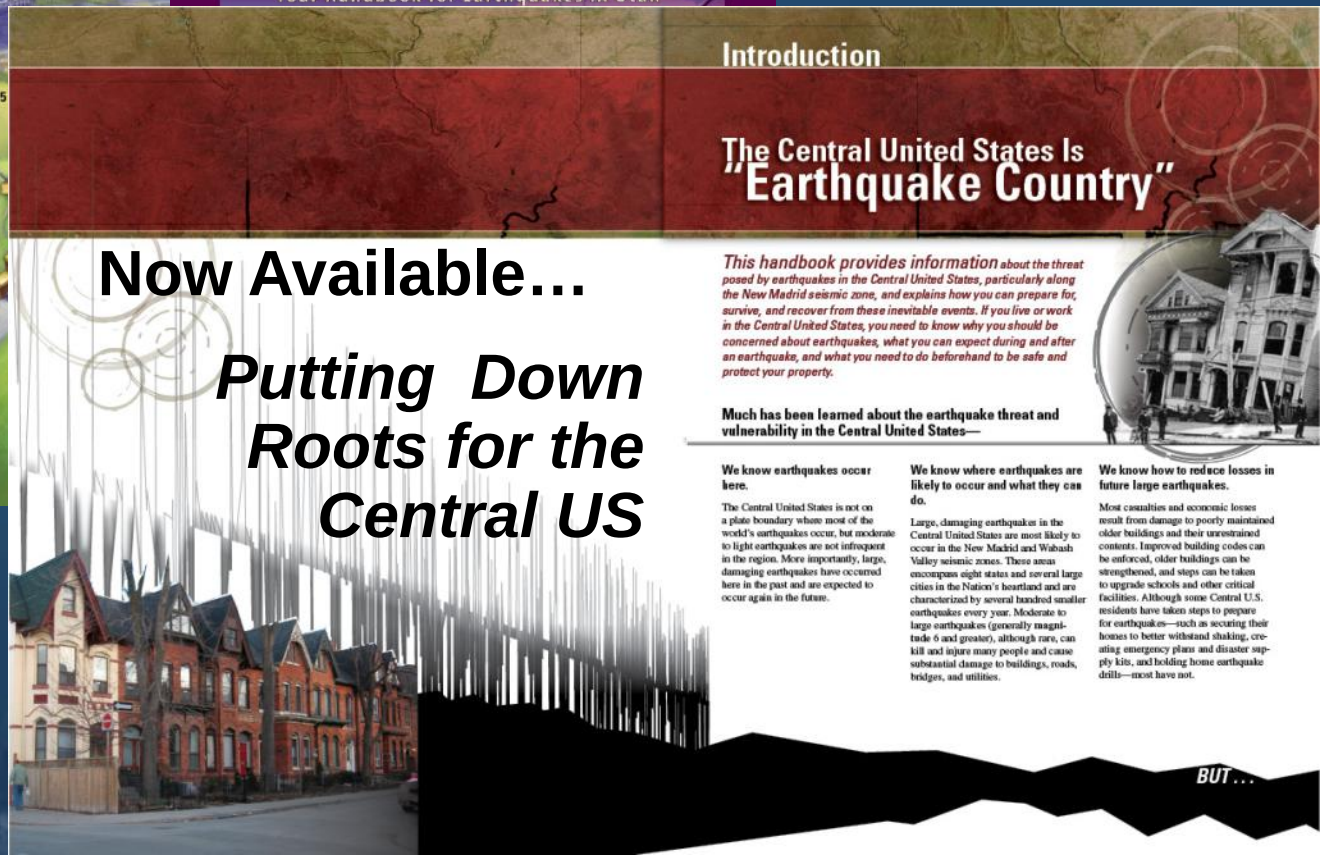
*Estimated exposure only includes population within the map area.

VIII Concepcion 215k
VIII Constitucion 38k

Putting Down Roots in Earthquake Country







Now Available…

Putting Down Roots for the Central US

CENTRAL UNITED STATES EARTHQUAKE CONSORTIUM
ILLINOIS · INDIANA · KENTUCKY · TENNESSEE · ALABAMA · MISSISSIPPI · ARKANSAS · MISSOURI

nehrp

THE UNIVERSITY OF MEMPHIS
Center for Earthquake Research and Information

Association of CUSEC State Geologists

FEMA

SCEC an NSF + USGS center

USGS science for a changing world

CGS CALIFORNIA GEOLOGICAL SURVEY

http://www.shakeout.org/centralus/

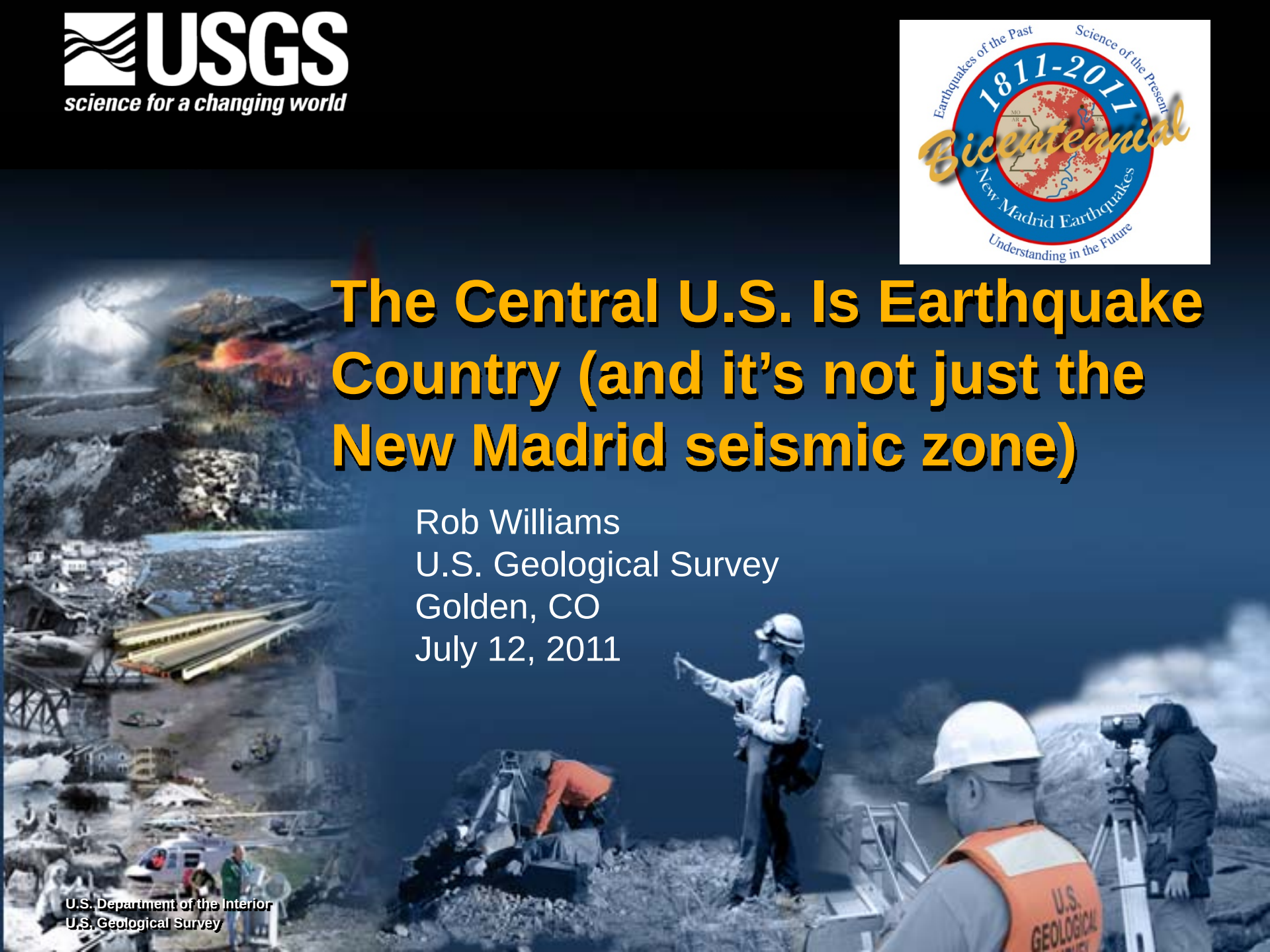
USGS

End Part 2

Part 3: New Madrid Earthquakes

The Central U.S. Is Earthquake Country (and it's not just the New Madrid seismic zone)

Rob Williams
U.S. Geological Survey
Golden, CO
July 12, 2011



Talk Outline

Part 3

- Overview of U.S. earthquake hazard
- Differences between western and eastern U.S.
- Review the 1811-1812 earthquake sequence

  3 Mainshocks and a vigorous aftershock sequence

  Widespread ground failure and liquefaction

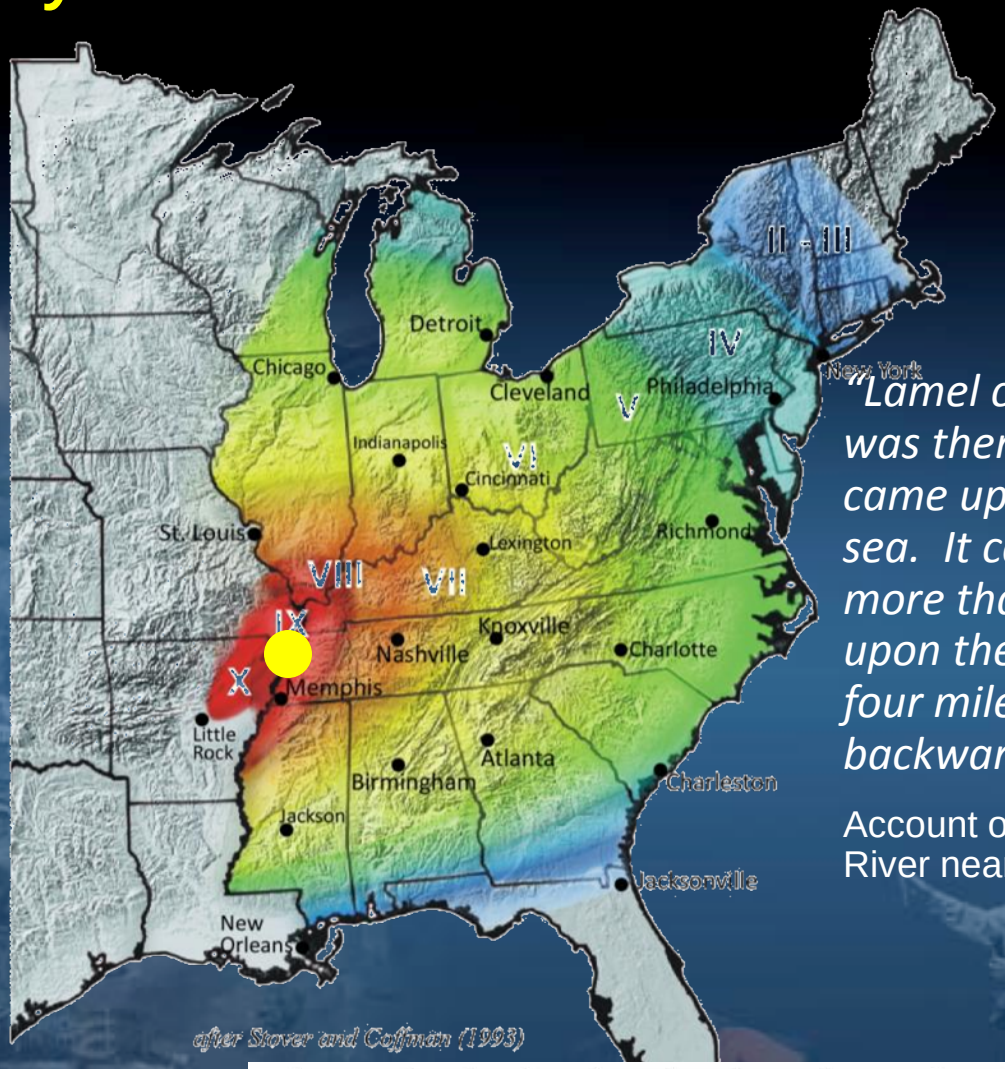
  What the faulting may look like at the ground surface

  Possible impacts to structures and houses

It's happened before 1811-1812!

USGS

Eye Witness Account: Mississippi River



"Lamel cut the rope that tied us to a log that was there, and in a moment so great a wave came up the river that I never seen one like the sea. It carried us back north, up-stream, for more than a mile, and the water spread out upon the banks, even covering maybe three or four miles inland. It was the current going backward..."

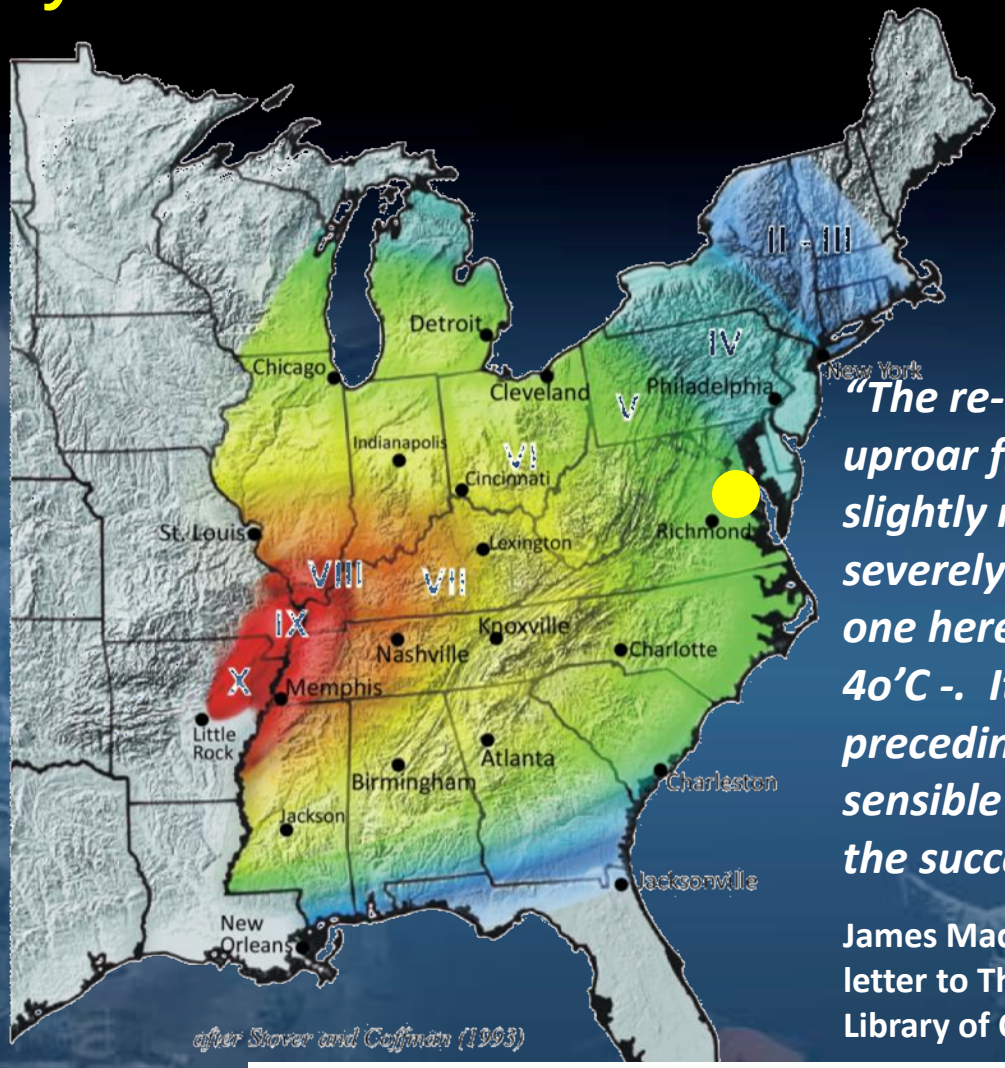
Account of sailor Firmin La Roche on the Mississippi River near New Madrid, MO., December 16, 1811.

Shaking	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
Damage	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
Intensity	I	II-III	IV	V	VI	VII	VIII	IX	X+

Modified Mercalli Intensities interpreted from written accounts. Stover and Coffman (1993) USGS PP 1527

USGS

Eye Witness Account: Wash. DC – James Madison



"The re-iteration of earthquakes continues the uproar from certain quarters. They have slightly reached the state of N. Y. and been severely felt W. & S. Westwardly. There was one here this morning at 5 or 6 minutes after 4o'C -. It was rather stronger than any preceding one, & lasted several minutes, with sensible tho very slight repetitions throughout the succeeding hour."

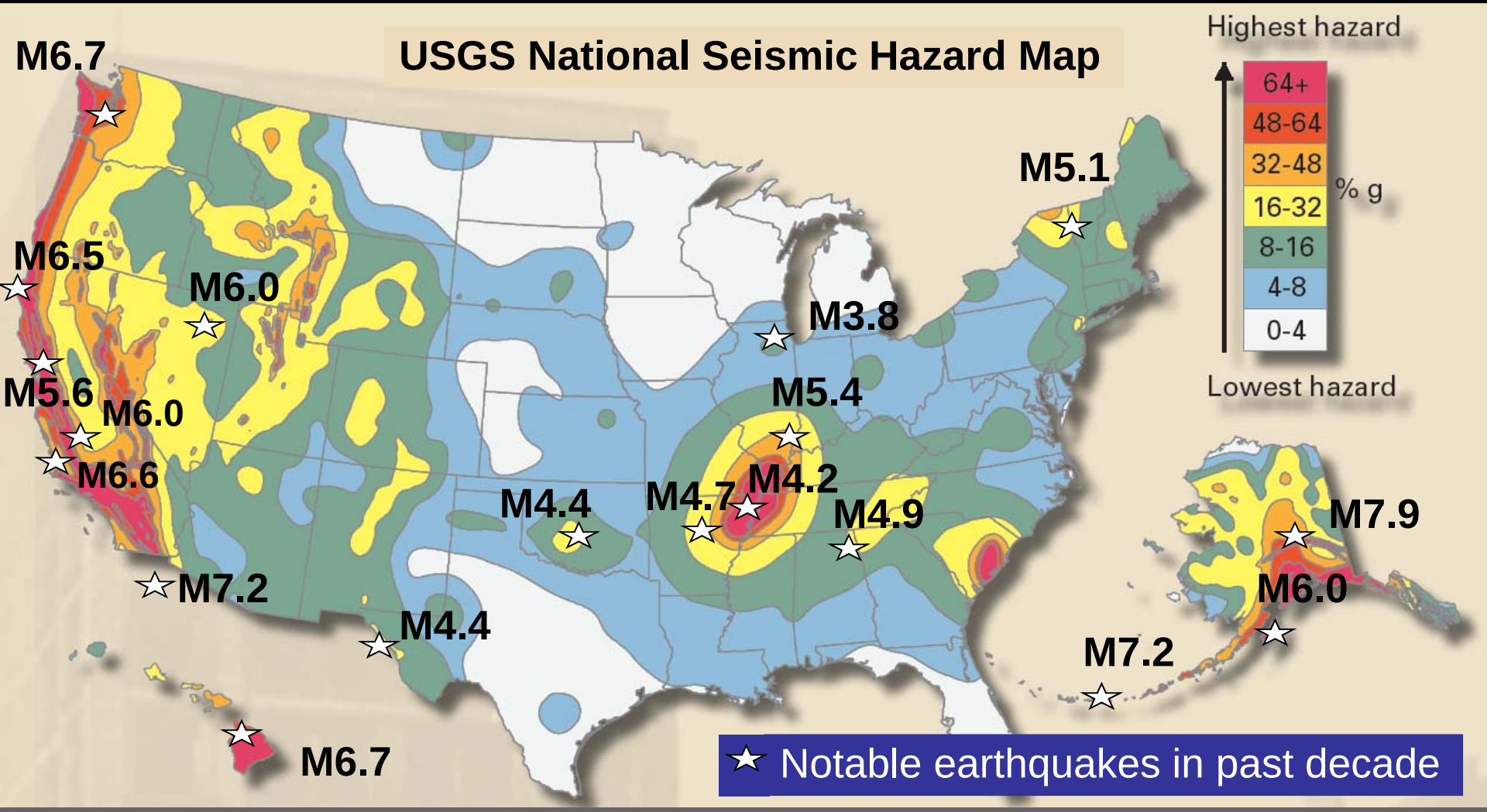
James Madison, 4th U.S. President, in a February 7, 1812 letter to Thomas Jefferson (The James Madison Papers, Library of Congress, Washington D.C).

Shaking	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
Damage	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
Intensity	I	II-III	IV	V	VI	VII	VIII	IX	X+

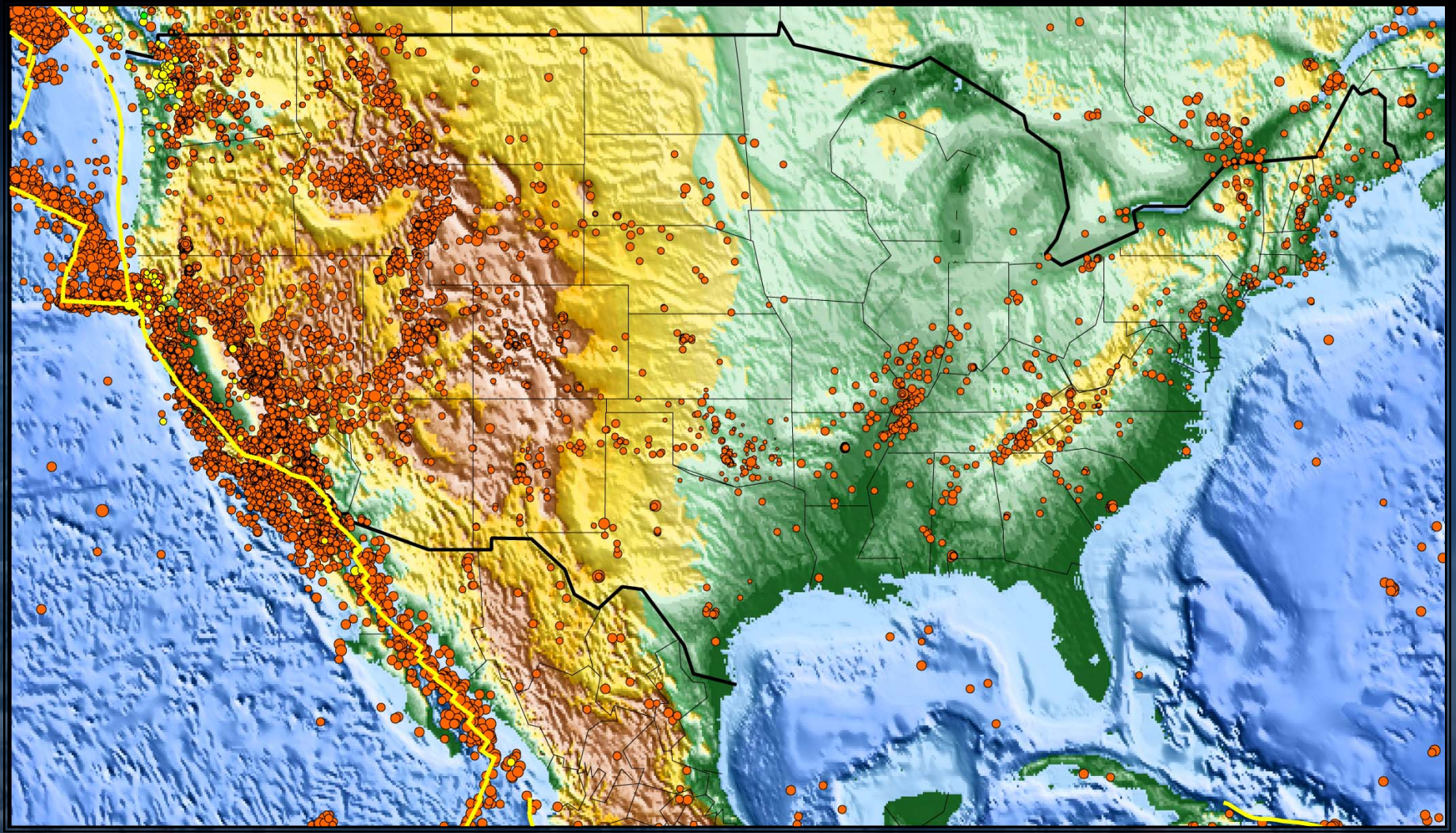
Modified Mercalli Intensities interpreted from written accounts. Stover and Coffman (1993) USGS PP 1527

USGS

Earthquakes are a national hazard



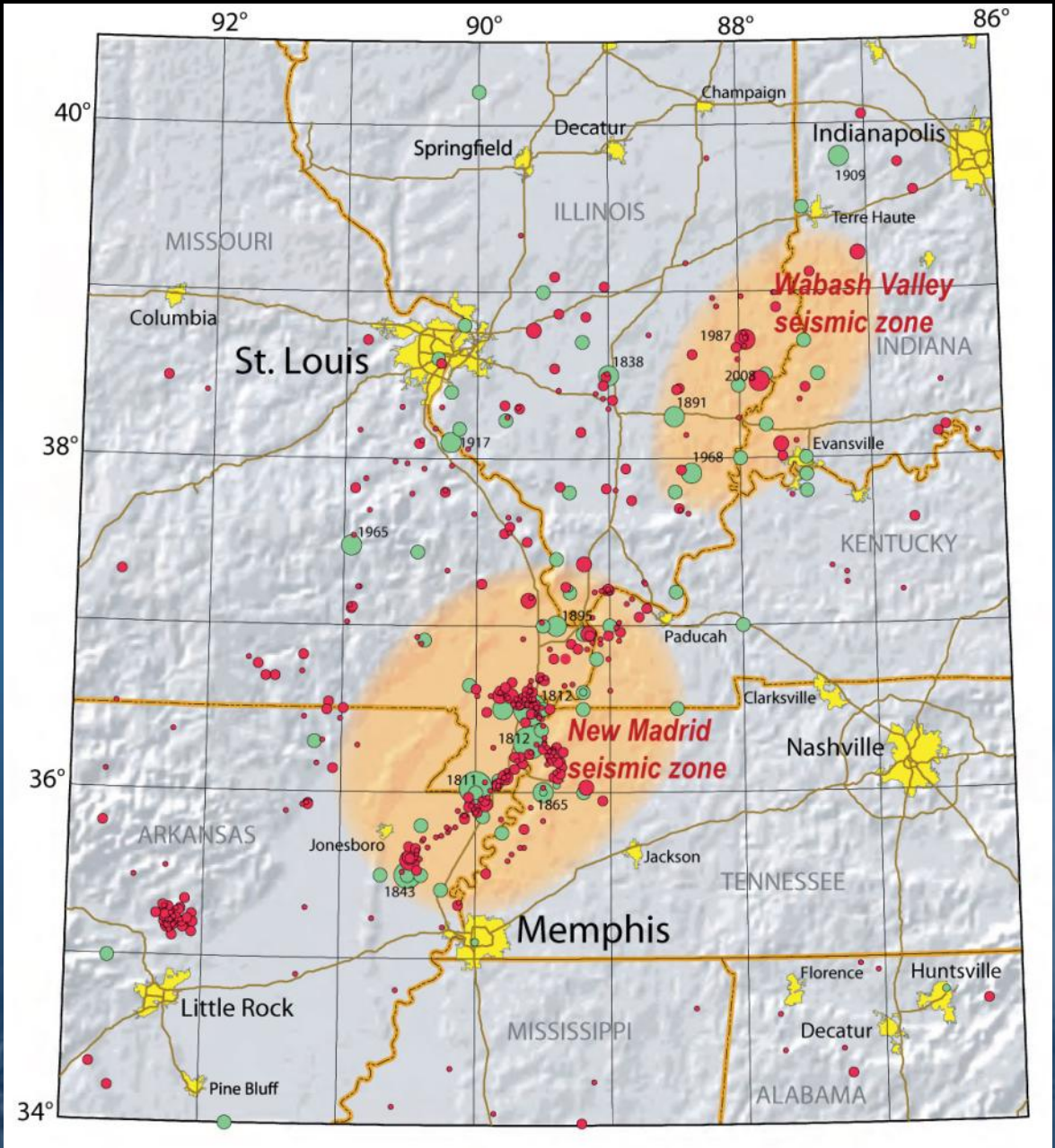
Most earthquakes occur along plate boundaries but not all of them!



USGS

Seismicity of the US, 1977-1997

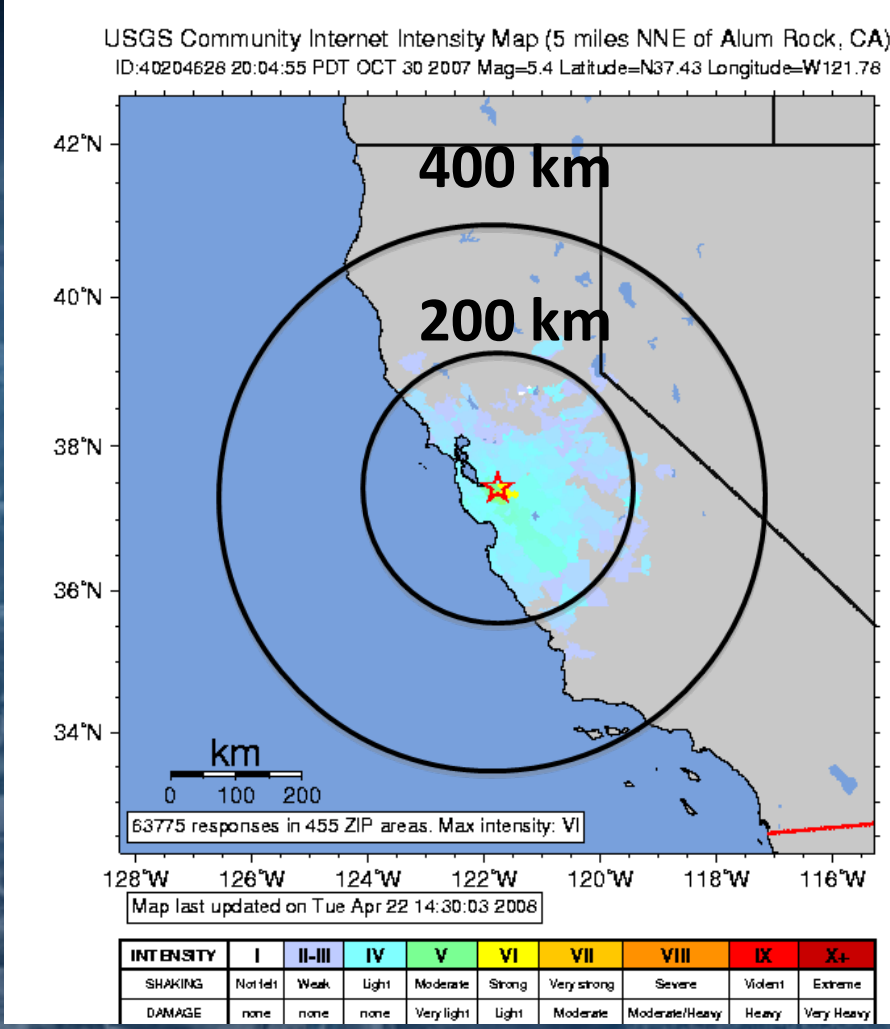
Earthquakes recorded in the New Madrid and Wabash Valley seismic zones



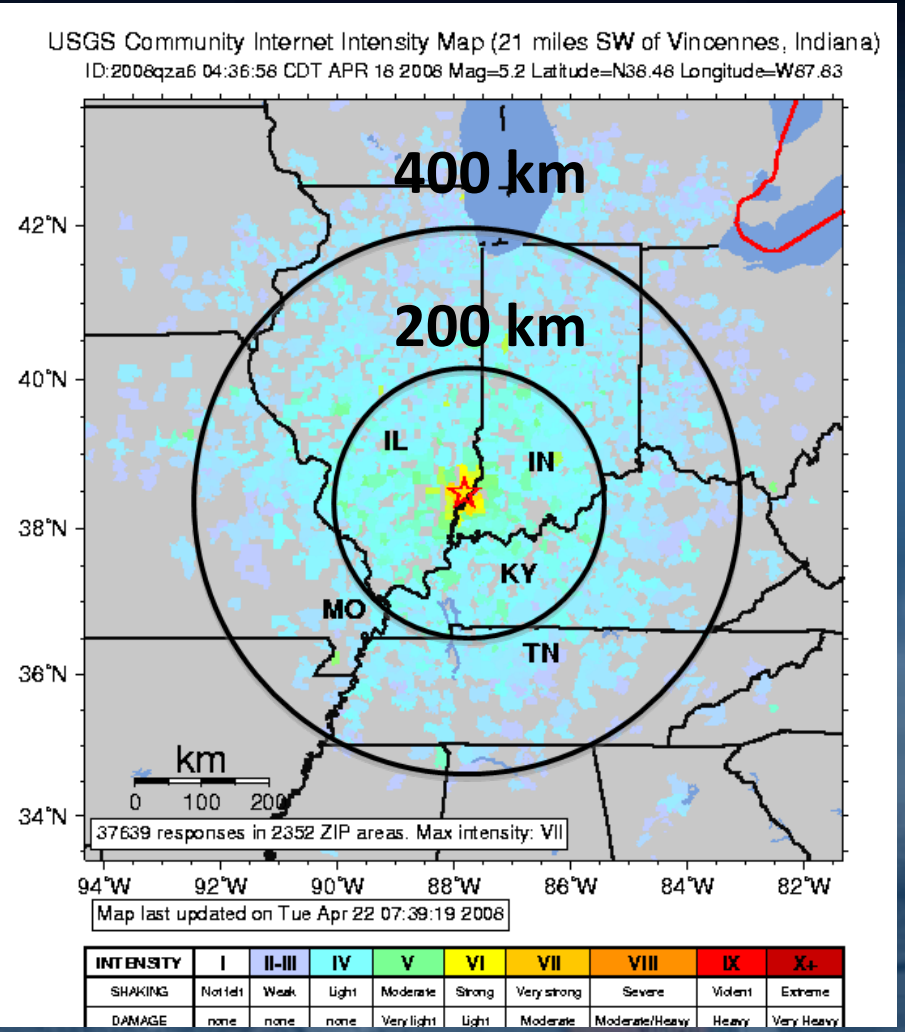
Red circles: 1974-2002
Green circles: Pre-1974
Larger earthquakes are represented by larger circles.
Earthquakes >M2.5

Central US earthquakes are widely felt

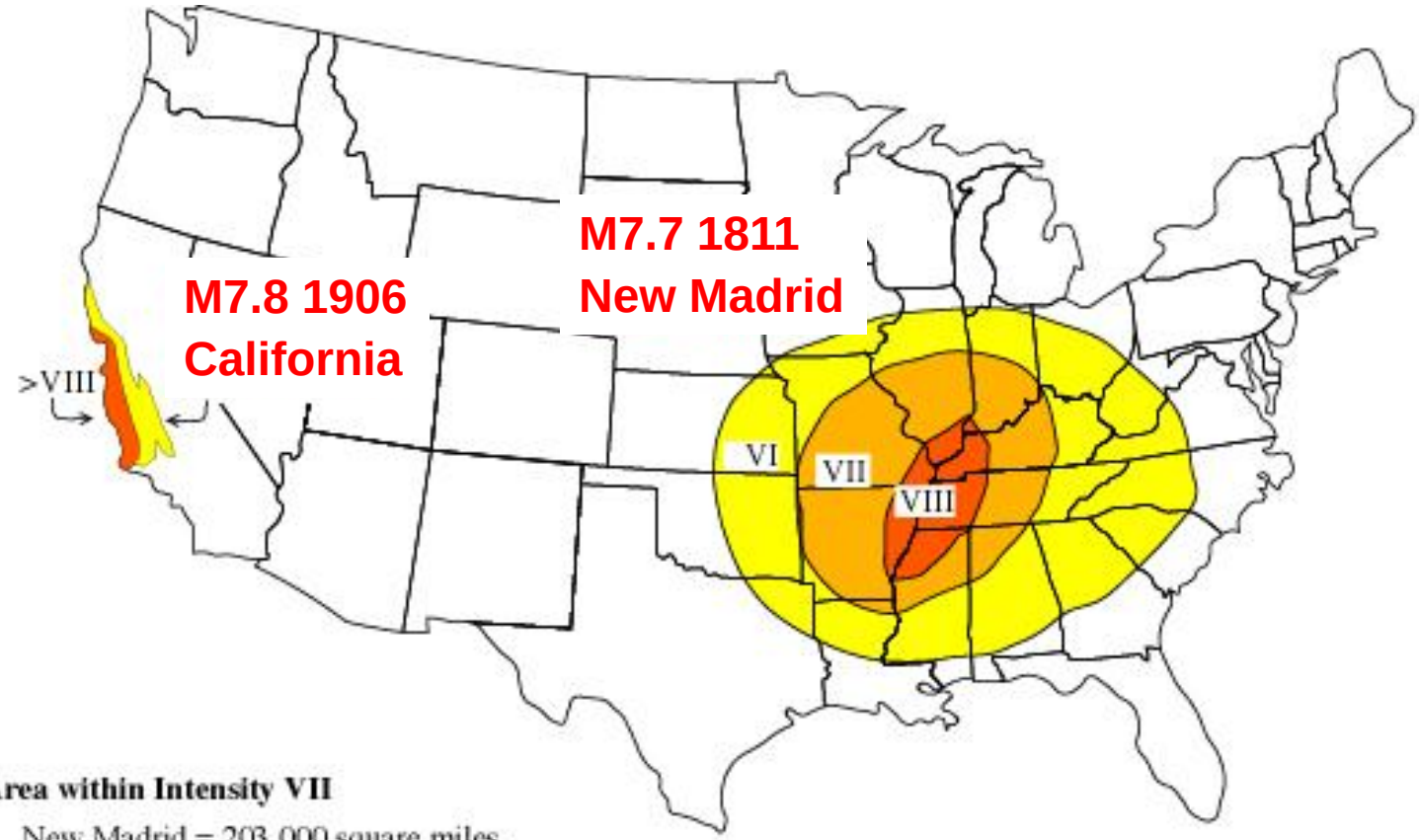
M5.4 Alum Rock, CA Oct 30, 2007



M5.4 Illinois, April 18, 2008



In the central & eastern U.S., earthquakes affect much larger areas than in the west

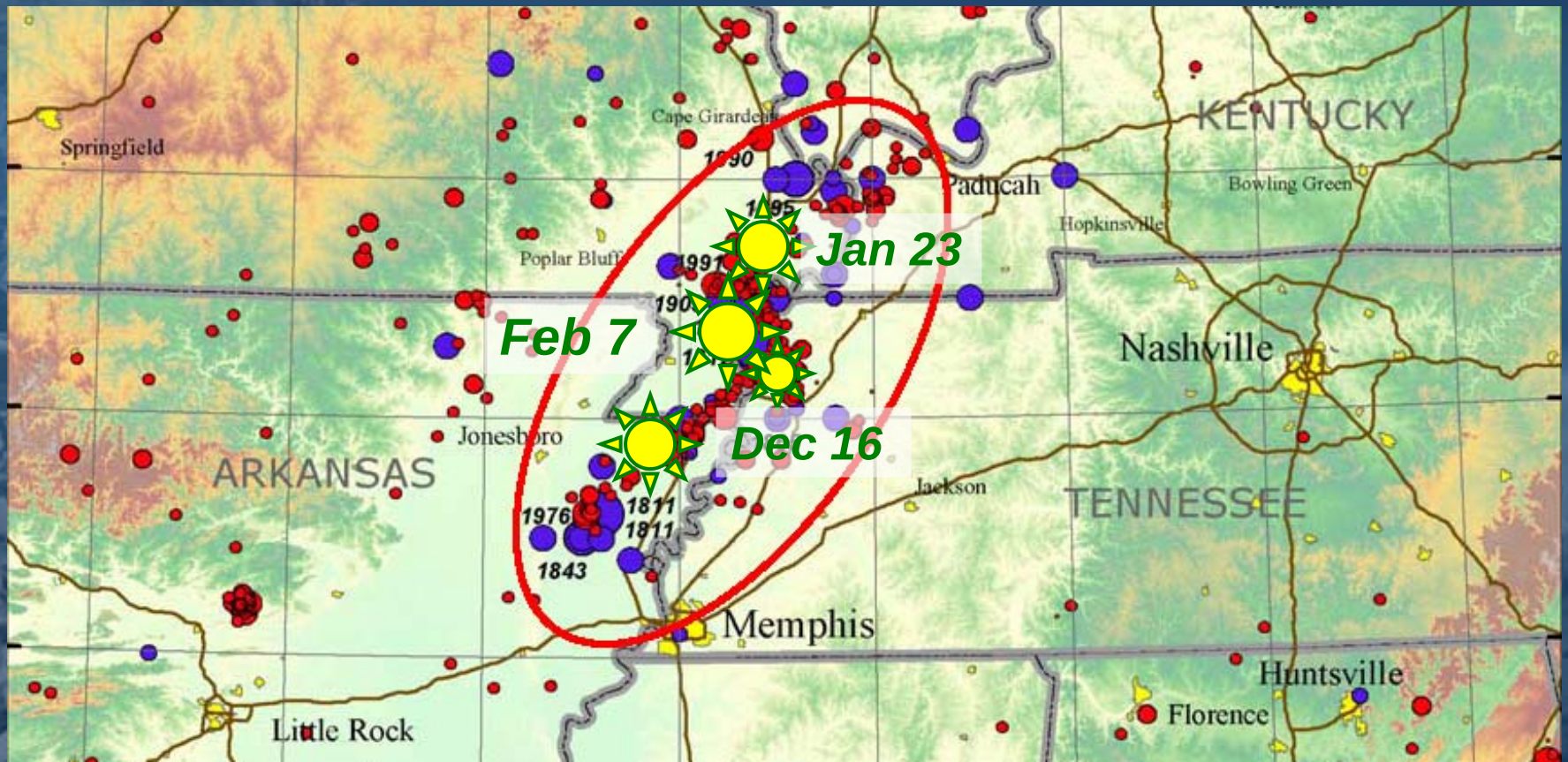


Area within Intensity VII

New Madrid = 203,000 square miles

San Francisco = only 12,000 square miles!

During the winter of 1811-1812, three magnitude-7 or greater earthquakes struck the New Madrid region along with thousands of aftershocks.



Aftershocks are Earthquakes! – New Zealand example

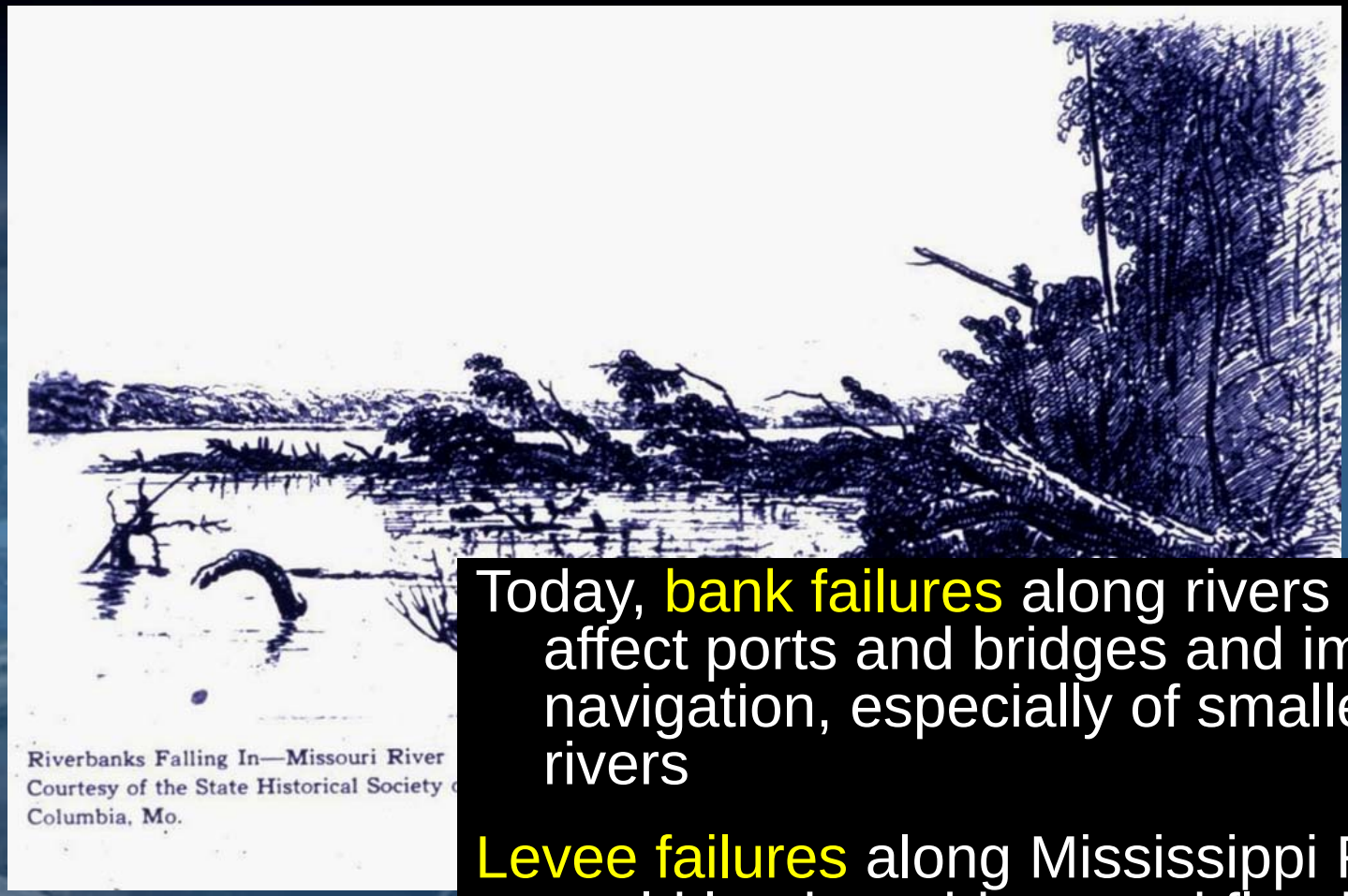
- 787 earthquakes >M3.0 as of October 4, 2010
- 11 aftershocks >M5.0 (largest at M5.6, 20 min after mainshock)

  M5.1 aftershock occurred Jan 20, 2011
- M4.9 on Dec 26, 2010, 6-10 miles from Christchurch, caused additional damage, knocking out power, and breaking sprinkler pipes – 7000 new damage claims
- Normal aftershock sequence for New Zealand (GeoNet)
- Aftershock zone grew to about *twice the length* of the surface rupture

USGS

•Slide provided by Hugh Cowan - EQC

Riverbanks caved (through liquefaction and lateral spreading)



Today, bank failures along rivers could affect ports and bridges and impede navigation, especially of smaller rivers

Levee failures along Mississippi River could lead to widespread flooding at time of event or later

Riverbanks caved – Sept 2010 New Zealand

Photo by Jongens, Cox, and Barrell, GNS Science

Lateral Spreading Near the Kaiapoi River, New Zealand

North banks of Kaiapoi River, photo by Jessica Rea

Lateral Spreading, Kaiapoi, New Zealand

Uplifted sewer-stormwater access. *Flotation and/or settlement due to liquefaction. (New Zealand)*

Lower Styx Road in Brooklands , east of Kaiapoi. Photo - Hannelie Bergmann

Flotation and/or settlement due to liquefaction.

Waste water system failures required hundreds (thousands?) of Port-a-Loos – Christchurch, New Zealand

USGS

Bexley, NZ

Vast tracts of land sank and were uplifted

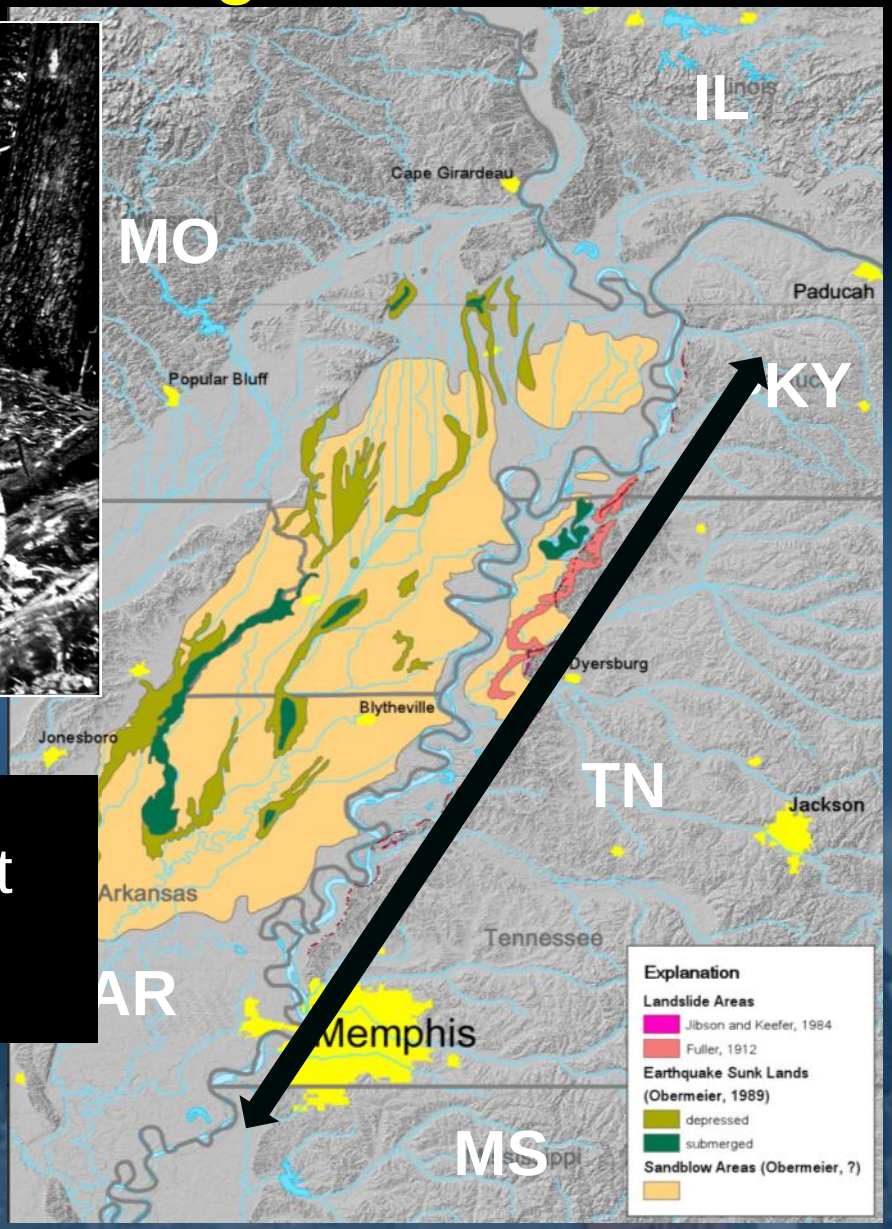
Reelfoot Lake

Movement of the Reelfoot fault in the Feb. 1812 earthquake produced waterfalls on the Mississippi River

Today, uplift and subsidence of large tracts of land could alter river courses and drainage ditches

USGS

Landslides occurred all along the bluffs



Today, slope failures along Chickasaw Bluffs could impact roads and major highways crossing the region

USGS

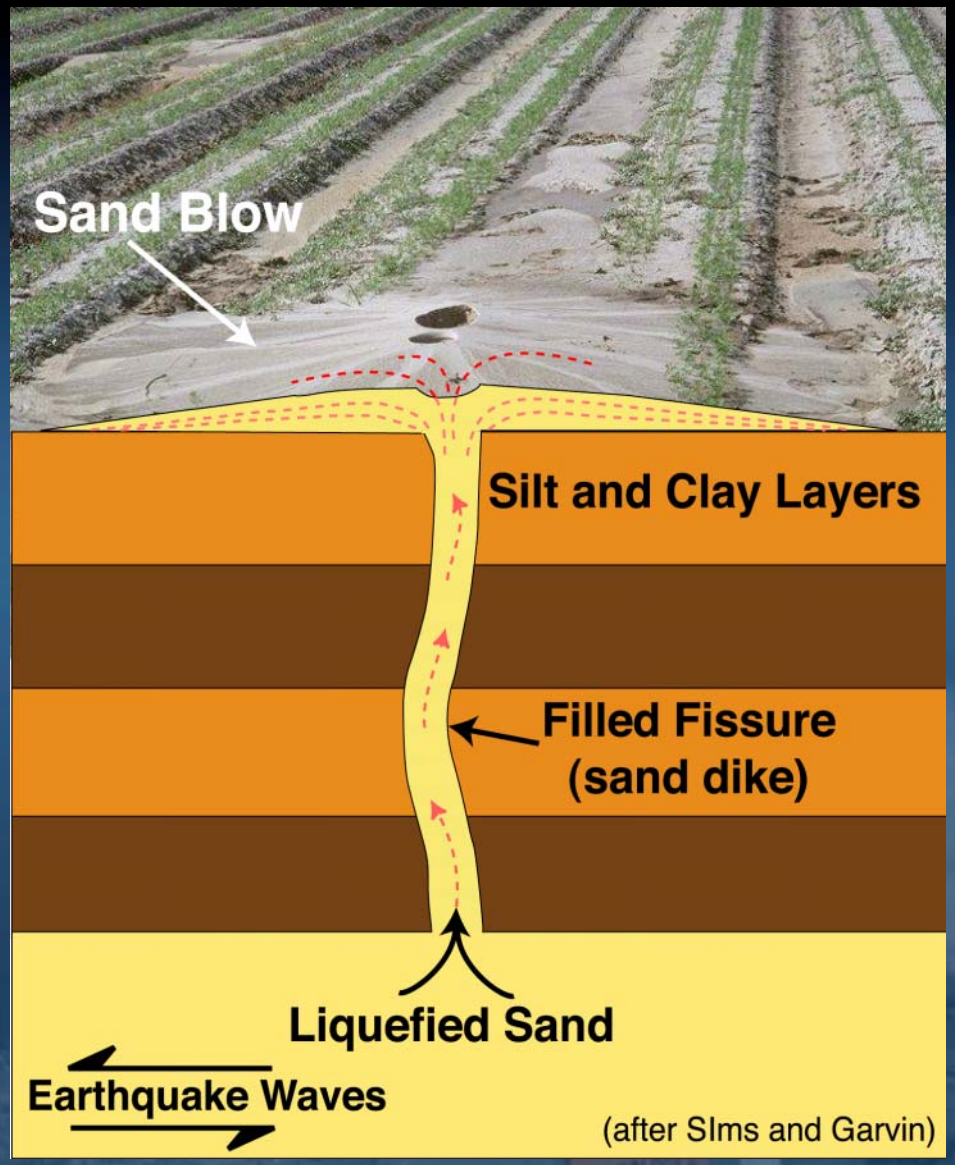
Sand blows erupted on floodplains …

From Fuller, 1912, *U.S. Geol. Surv. Bull. 494*

Widespread and severe liquefaction—leading to loss of bearing strength of soils and lateral spreading—could cause failures of foundations (bridge, building and tank), pipelines, and roads

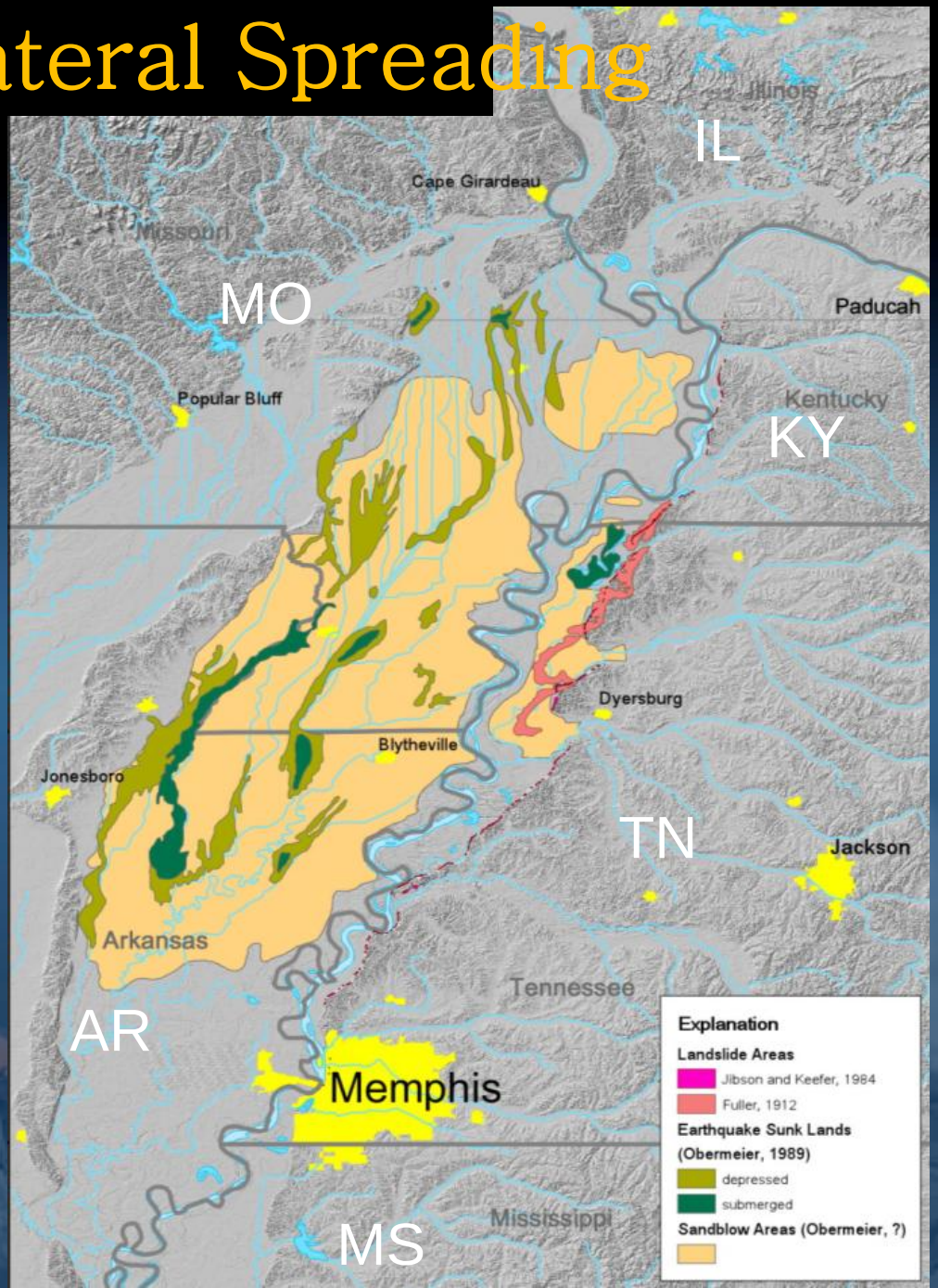
Liquefaction and sand blow formation

- During earthquake, water-saturated sand is shaken.
- If shaking is strong and lasts long enough, pore-water pressure builds up, sand loses its strength and acts like a liquid.
- A pressurized slurry of water and sand erupts to the surface, forming sand blows.



Liquefaction and Lateral Spreading

1811-1812 New Madrid Liquefaction



USGS

New Zealand Surface Faulting

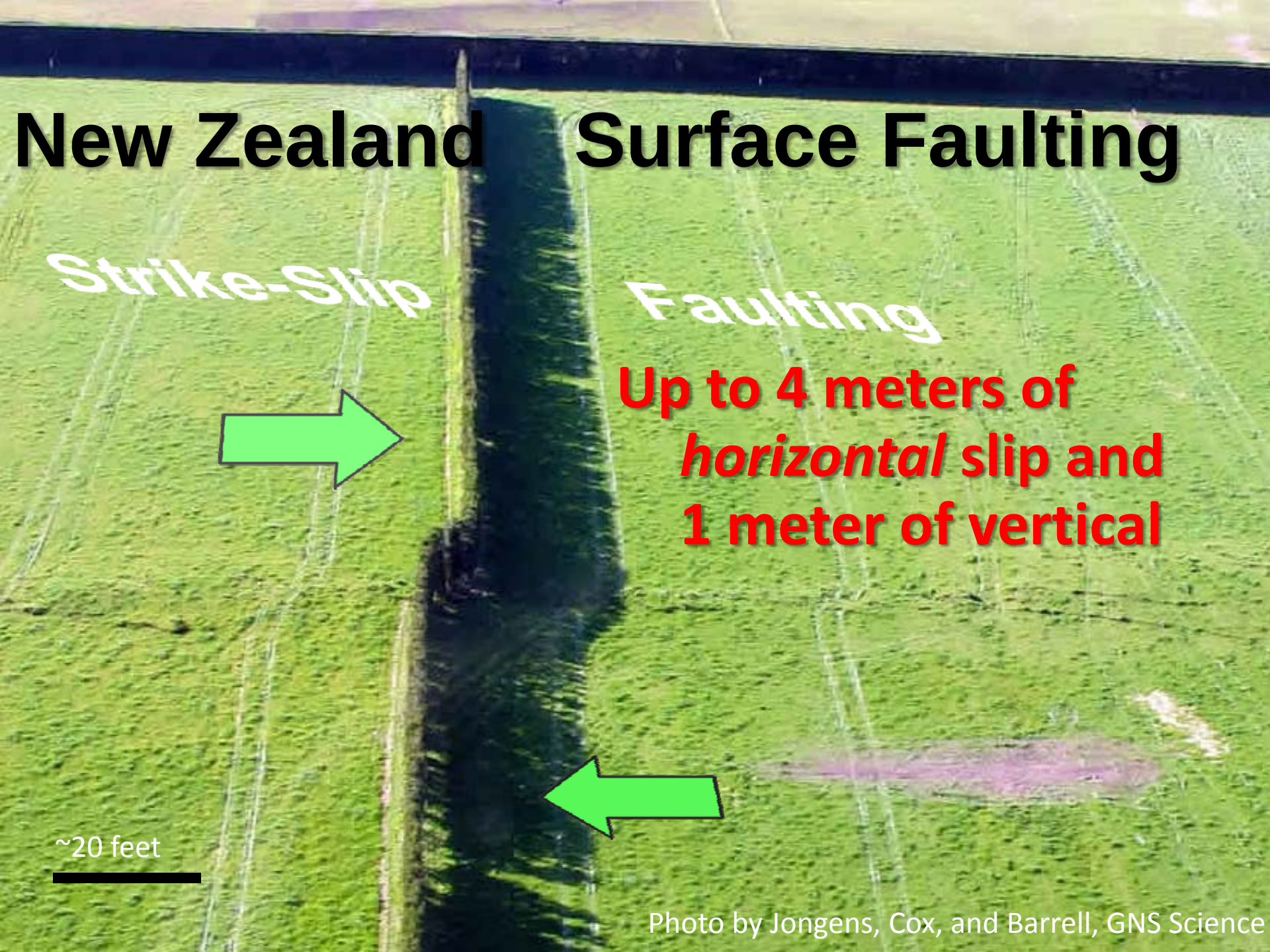


Photo by Jongens, Cox, and Barrell, GNS Science

New Zealand Surface Faulting

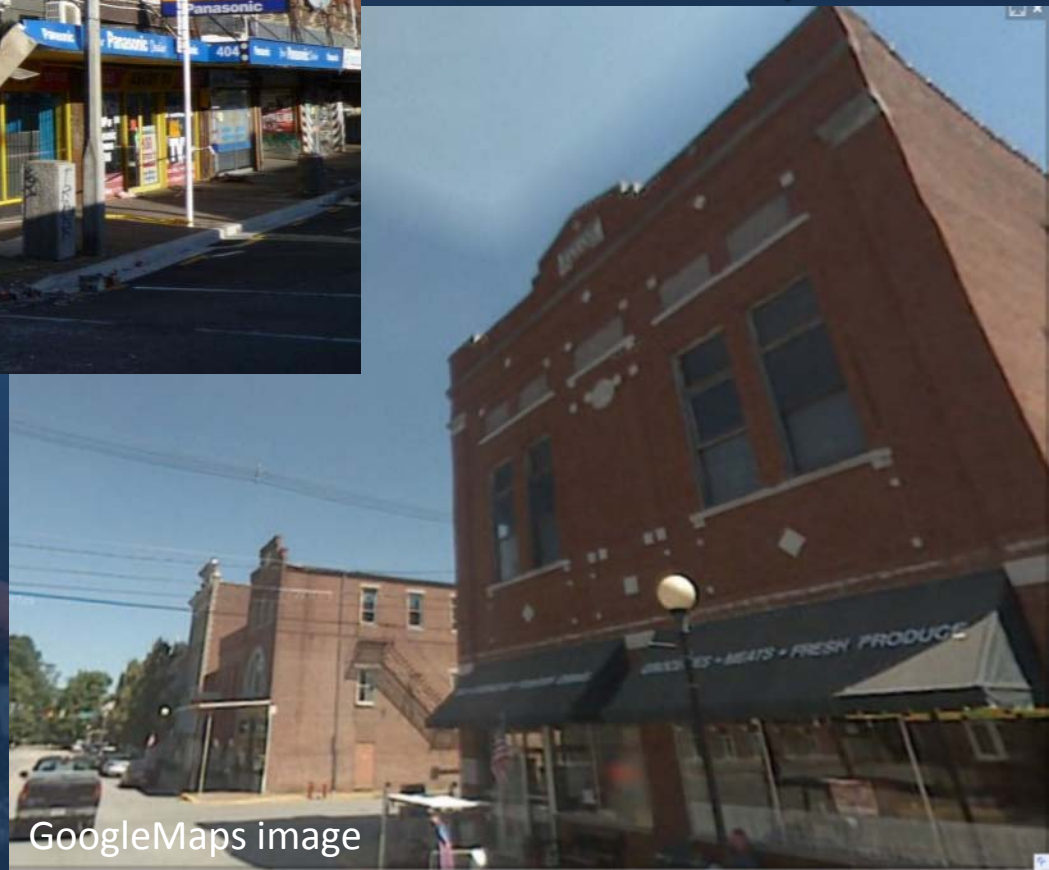
USGS

•GNS photo taken on about Sept 4, 2010 or perhaps Sept 5, 2010

Building Impacts

Christchurch, NZ

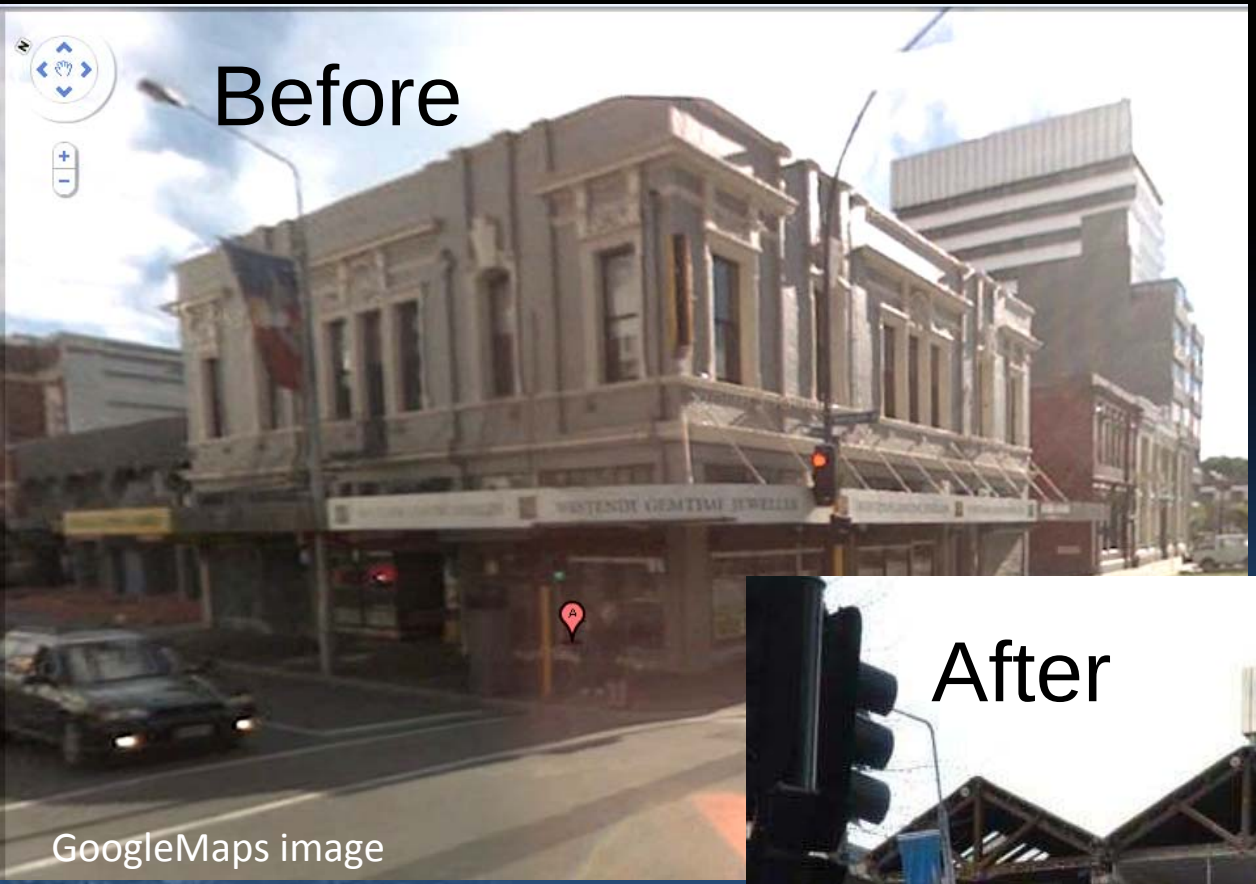
Main Street, USA



GoogleMaps image

USGS

Building Impacts



GoogleMaps image

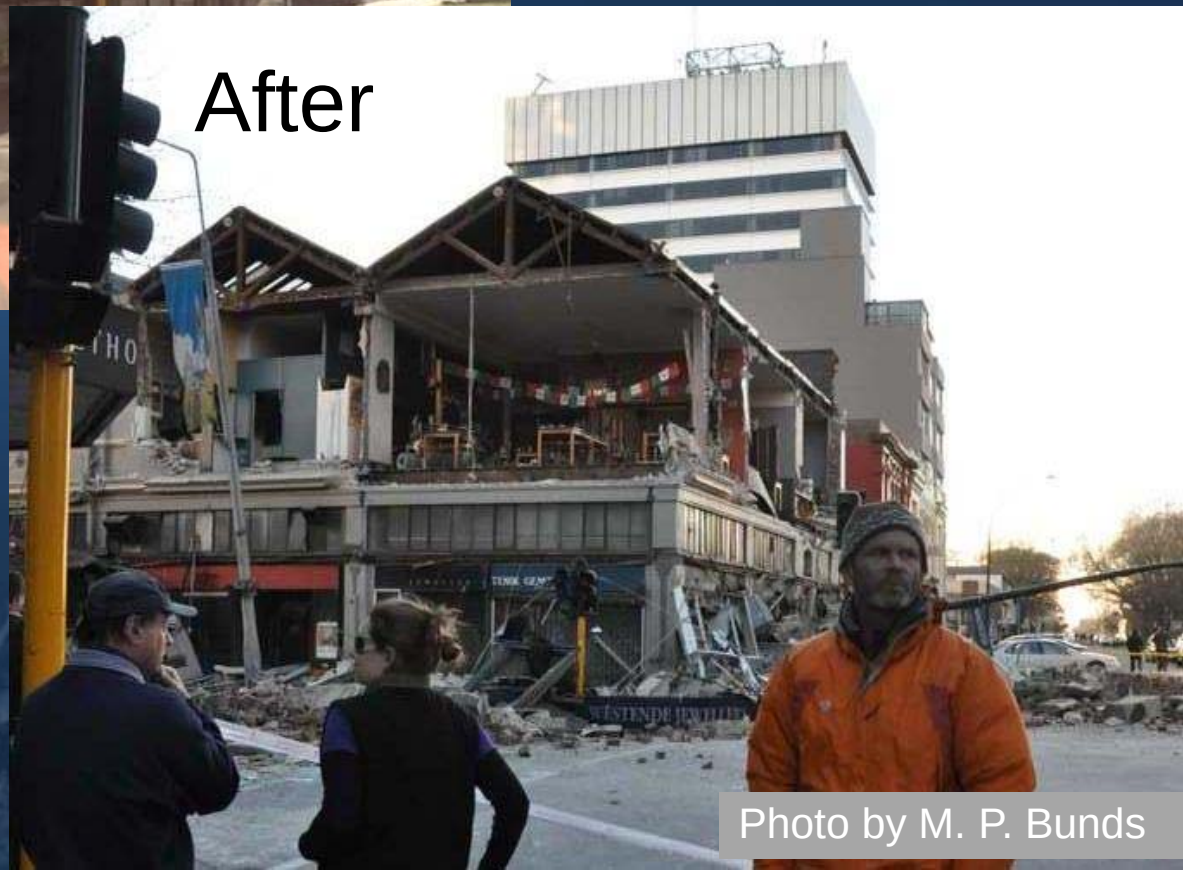
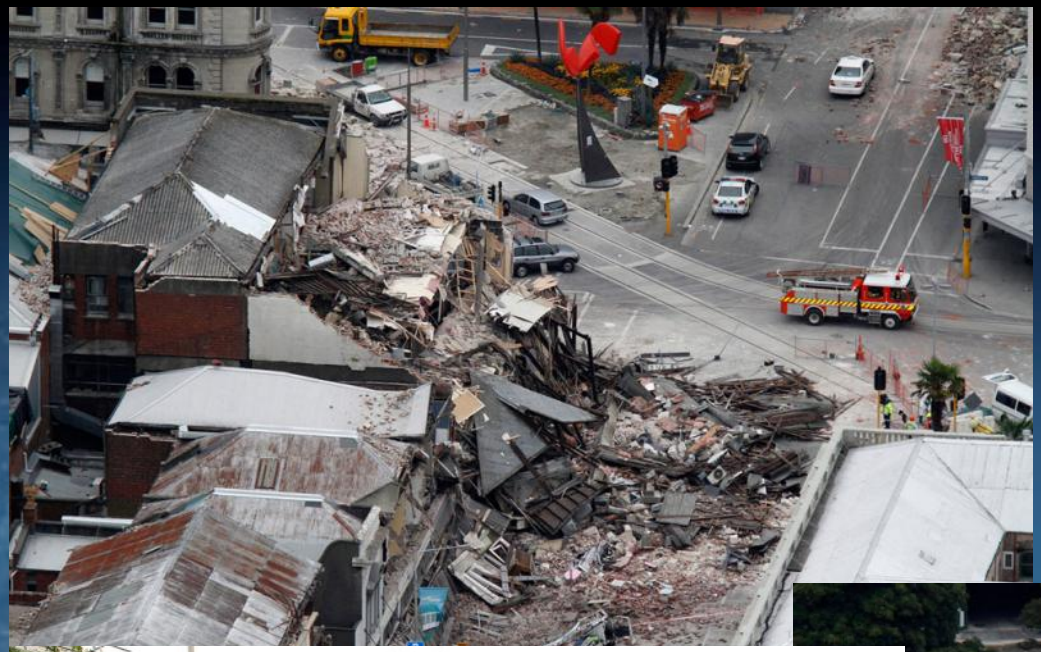


Photo by M. P. Bunds

Christchurch, NZ

USGS

Christchurch NZ magnitude-6.1 earthquake



Likely New Madrid region ground failures and impacts

- **Slope failures** along Chickasaw Bluffs could impact roads and major highways crossing the region
- **Bank failures** along rivers could affect ports and bridges and impede navigation especially of smaller rivers
- **Levee failures** along Mississippi River could lead to widespread flooding at time of event or later
- Widespread and severe **liquefaction**—leading to loss of bearing strength of soils and lateral spreading—could cause failures of foundations (bridge, building and tank), pipelines, roads, cell-phone towers, power lines.
- **Uplift, faulting and subsidence** of large tracts of land could alter rivers courses and drainage ditches
- Repeated large earthquakes and **aftershocks** could cause additional ground failures and damage to weakened structures

USGS nehrp

From geologic studies we now know

- New Madrid Seismic Zone produced large quakes in 1811-12, ~1450 AD, ~900 AD, and ~2350 BC
- The average time between these events is about 500 years at least during past 1200 years
- The prehistoric earthquakes were similar in size to the 1811-1812 earthquakes
- Each New Madrid event was a sequence of earthquakes, including multiple very large mainshocks, much like the 1811-1812 sequence

Summary of the hazard

- Currently producing earthquakes; most active zone in eastern North America over the last 40 years
- We cannot predict earthquakes; but it is reasonable and prudent to expect NMSZ to behave as it has in recent past
- A magnitude-7+ earthquake is a low-probability, high-consequence event; a magnitude-6.0+ earthquake has higher probability and also can cause significant damage
- Broad agreement in earth science community that NMSZ continues to pose a significant and ongoing hazard

Probabilities of large earthquakes in the New Madrid region in the next 50 years

- Repeat of 1811-1812 (magnitude 7.5-8.0)
  - Approximately 7-10%

- Magnitude 5.0 or greater
  - High probability, several

- Magnitude 6.0 or greater
  - Approximately 28-46%

USGS

Sources of additional information

U.S. Geological Survey:

Near real-time and background information on earthquakes & hazards

http://earthquake.usgs.gov

New Madrid bicentennial web site:

http://newmadrid2011.org

National Earthquake Hazards Reduction Program:

http://www.nehrp .gov

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303-273-8636