BRIEF OVERVIEW OF SEISMIC THREAT POSED BY THE NEW MADRID SEISMIC ZONE

for

Earthquakes Mean Business Seminar
AT&T Data Center St. Louis, MO

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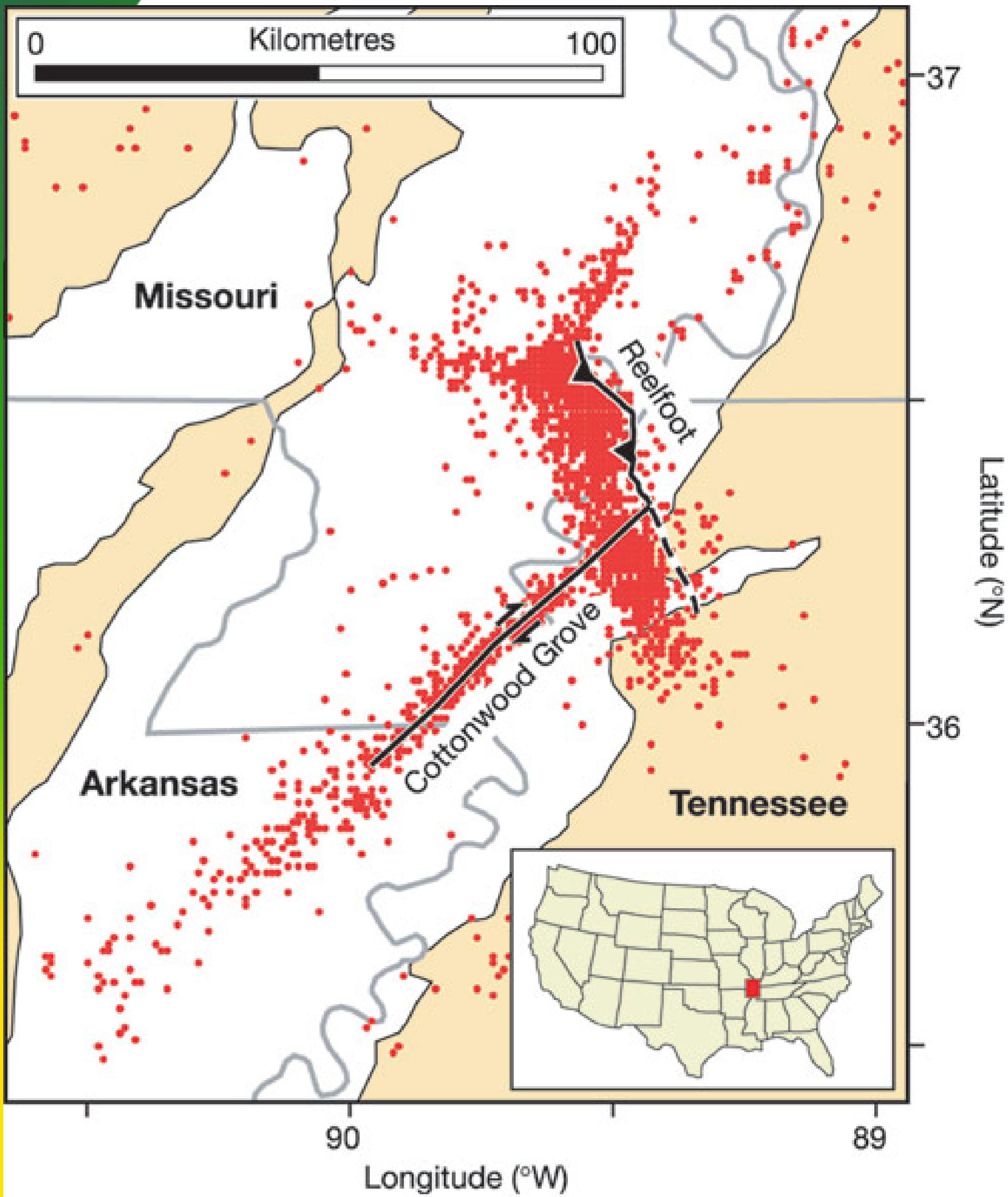
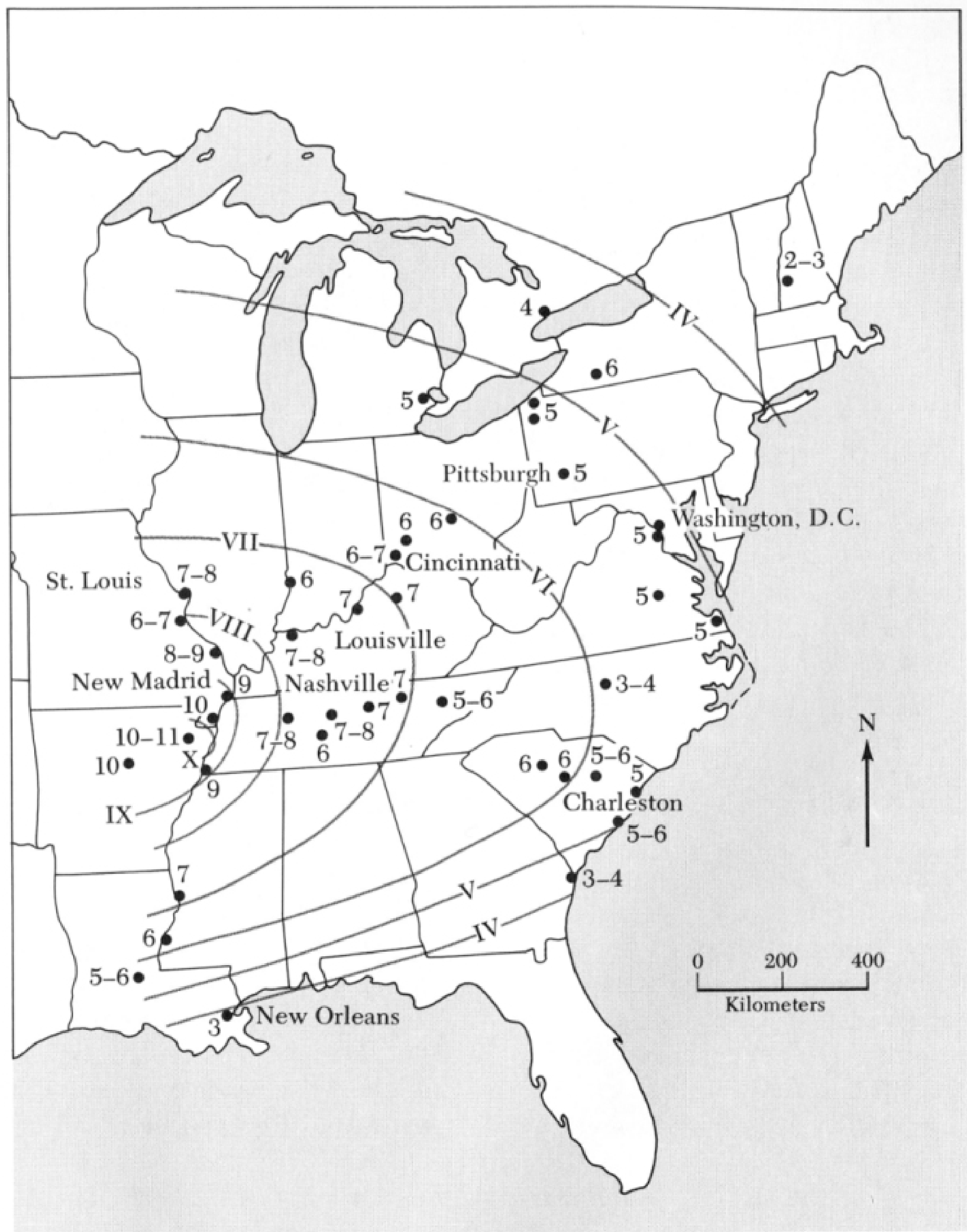
New Madrid Seismicity

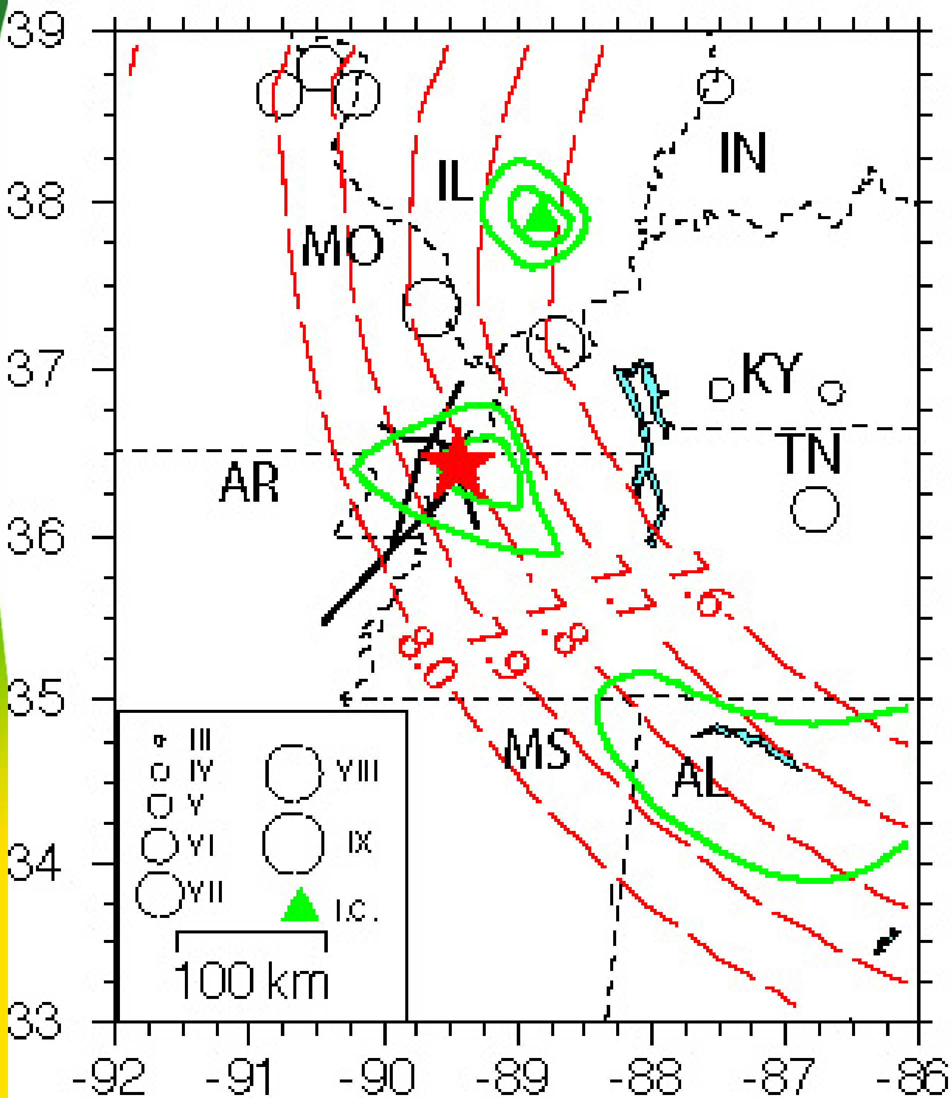


- Epicenters recorded between 1974-96 describe a seismically active zone of complex intraplate tectonics
- Right lateral strike slip and blind thrust faulting occur in the same region



- Isoseismal lines for the December 16, 1811 M 7.7 New Madrid earthquake
- Felt over an area greater than 1 million square miles
- Extensive damage to masonry in Cincinnati
- Rang church bells in Boston
- Most people lived along rivers in Midwest and no inhabitants west of the Mississippi

M_I 7.8 quake of 7 February 1812



- Location: Reelfoot blind thrust
  - M_I =7.8
  - M_W = 7.0-8.1 (±2s range)

- **Best constrained event:**
  1) Largest quake
  2) Physical evidence of thrusting
  3) Reelfoot fault well imaged

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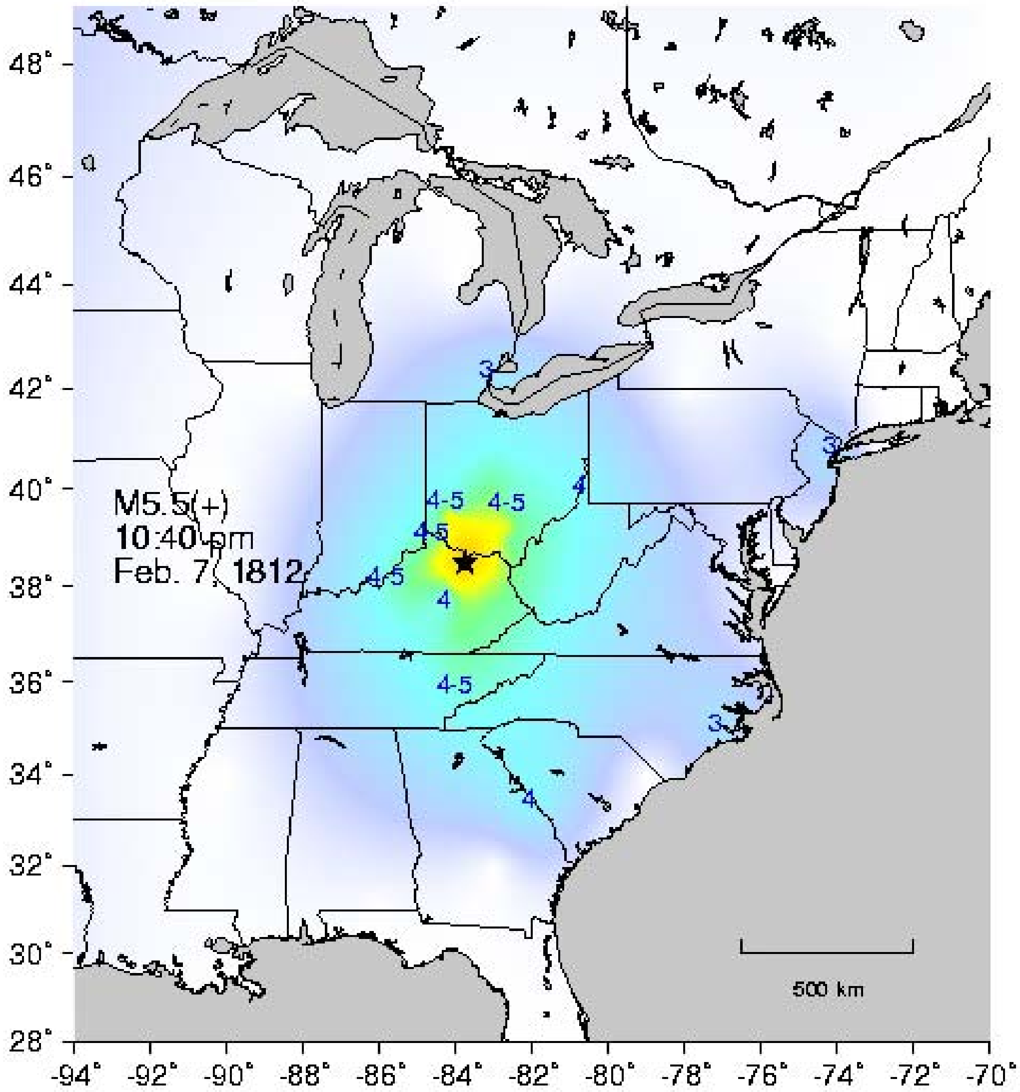
Remotely triggered earthquakes have only been recognized since 1992



The largest historic earthquake in Kentucky may have been a M 5.5 triggered event that occurred on February 7, 1812 at 10:40 PM, after the largest New Madrid quake had occurred at 3:15 AM that same morning.

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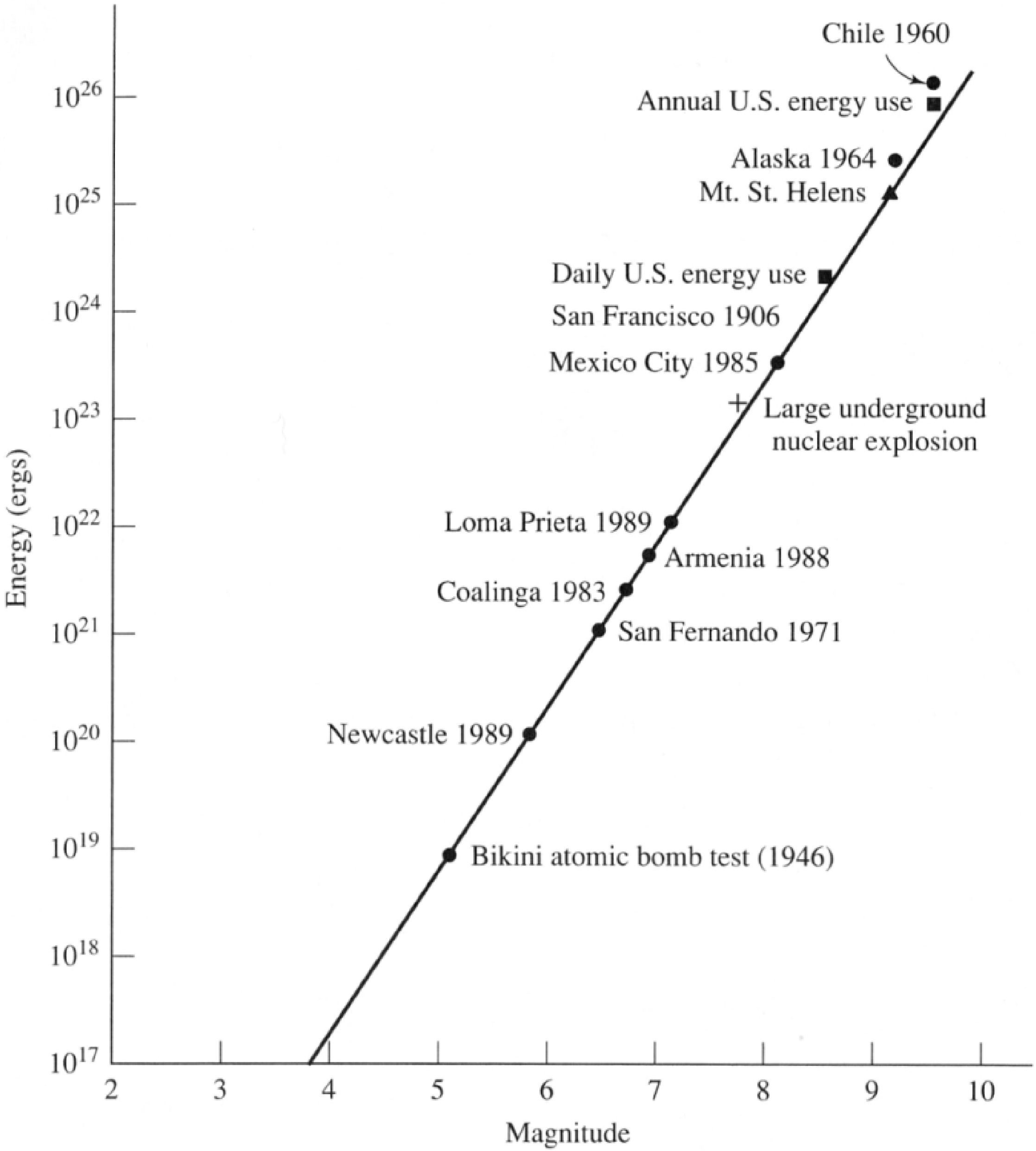
Earthquake Magnitude versus Energy Release



- Modern earthquake magnitudes are based on energy release using a logarithmic scale
- Each numerical magnitude is about 33X the energy release of preceding numerical value

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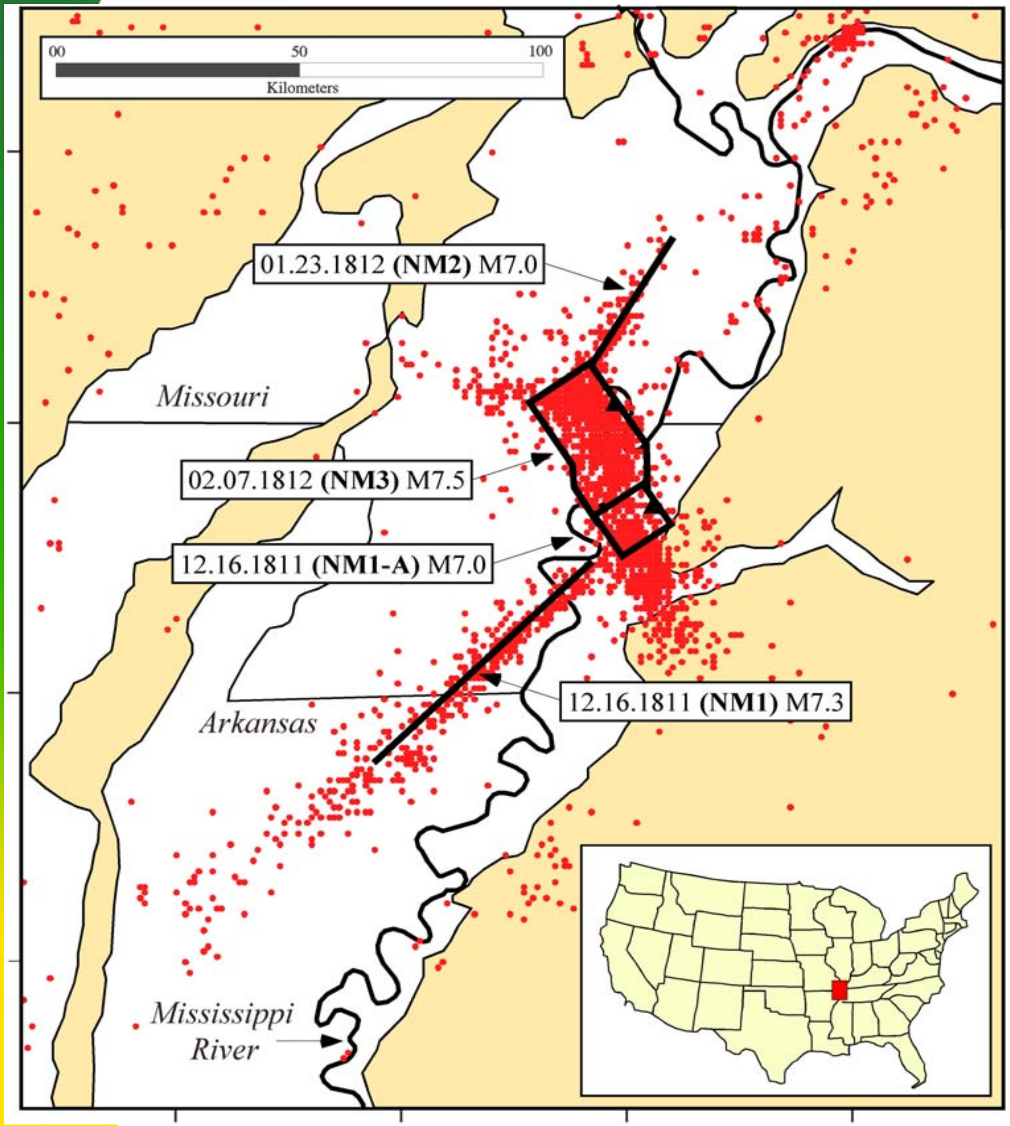
1811-12 Quakes



- A series of M_w 7.0 to 7.7 earthquakes occurred in southeast Missouri and northeast Arkansas between December 1811 and February 1812.
- Five significant events, about 2000 aftershocks

Revised Moment Magnitudes (M_W) for 1811-1812 Events

Event	Johnston (1996)	Hough *et al*. (2000)	Bakun and Hopper (2004)	
16 Dec 1811 (NM1)	8.0	7.2-7.3	7.6	(6.8-7.9)†
23 Jan 1812 (NM2)	7.8	7.0	7.5	(6.8-7.8)†
7 Feb 1812 (NM3)	7.9	7.4-7.5	7.8	(7.0-8.1)†

† 95% (±2s) range

- M_W 7.8 is best estimate of the largest M

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POST 1812 SEISMICITY in NEW MADRID SEISMIC ZONE

- M6.3 quake in Marked Tree, AR in 1843; did considerable damage to Memphis, 60-70 km east
- M6.6 quake in Charleston, MO in 1895; Felt in 23 states, 30 km of sand blows
- M5.4 in Wabash Valley (Dale, IL) in 1968; also felt in 23 states; light damage in St. Louis
- M5.0 in Wabash Valley west of Vincennes, IN (Olney, IL) in 1987
- M4.6 near Evansville, IN in 2002

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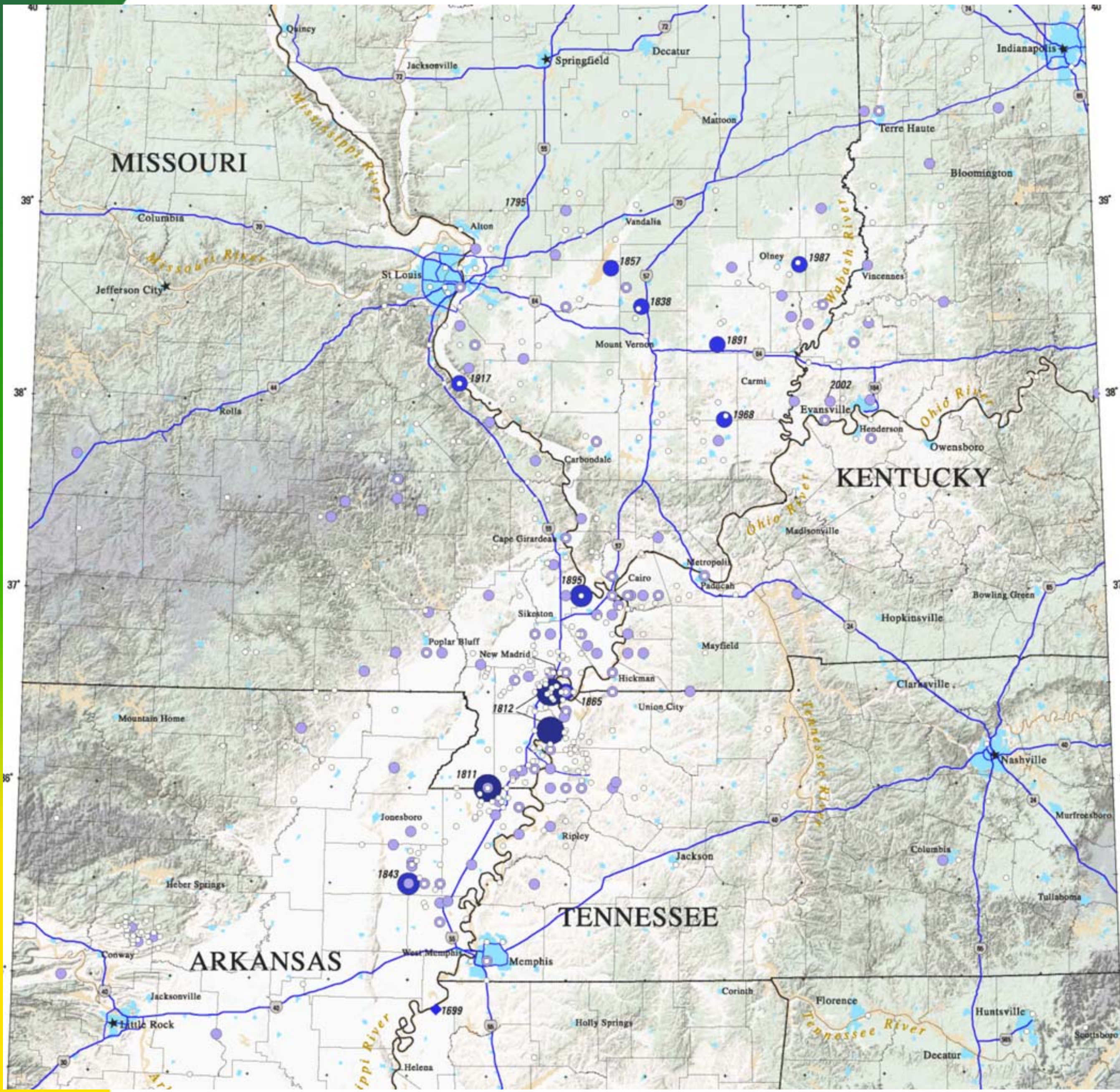
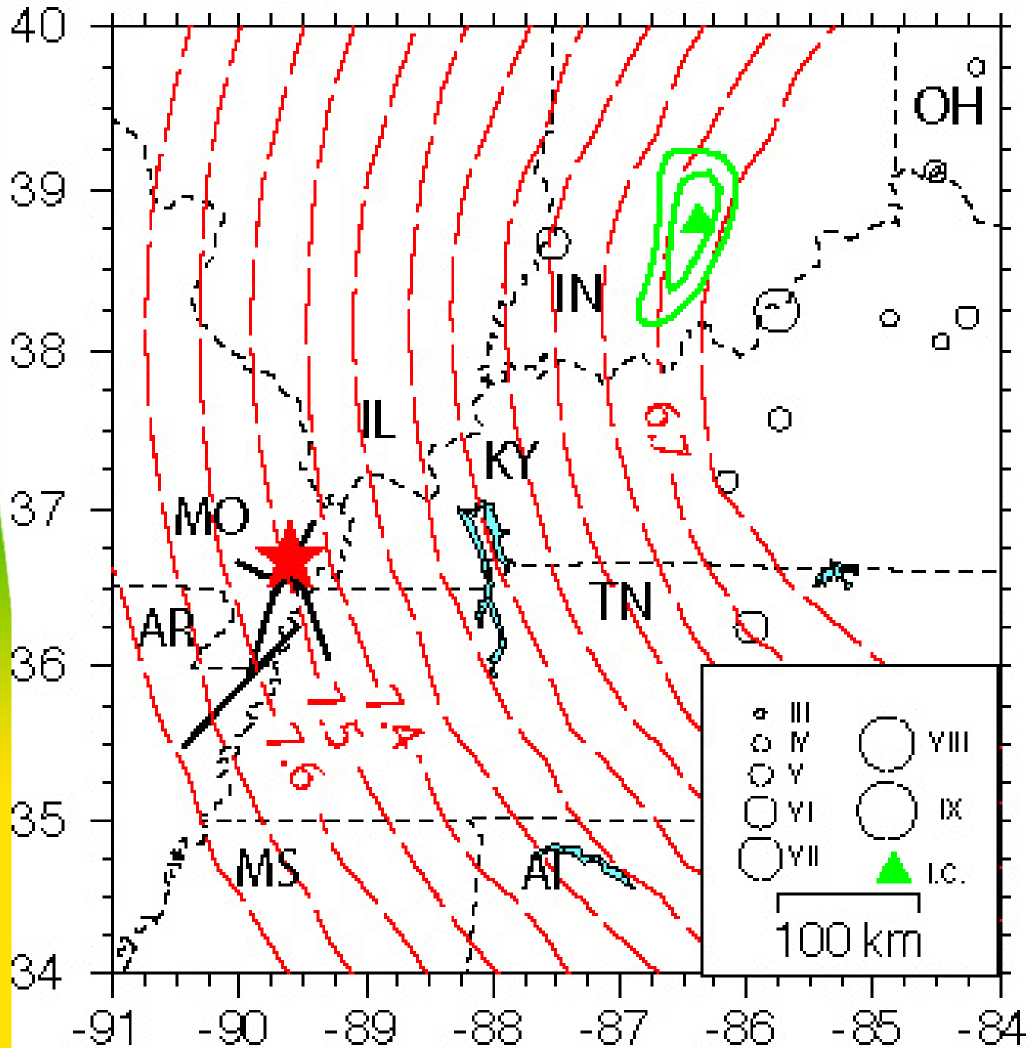


OTHER SEISMIC SOURCES

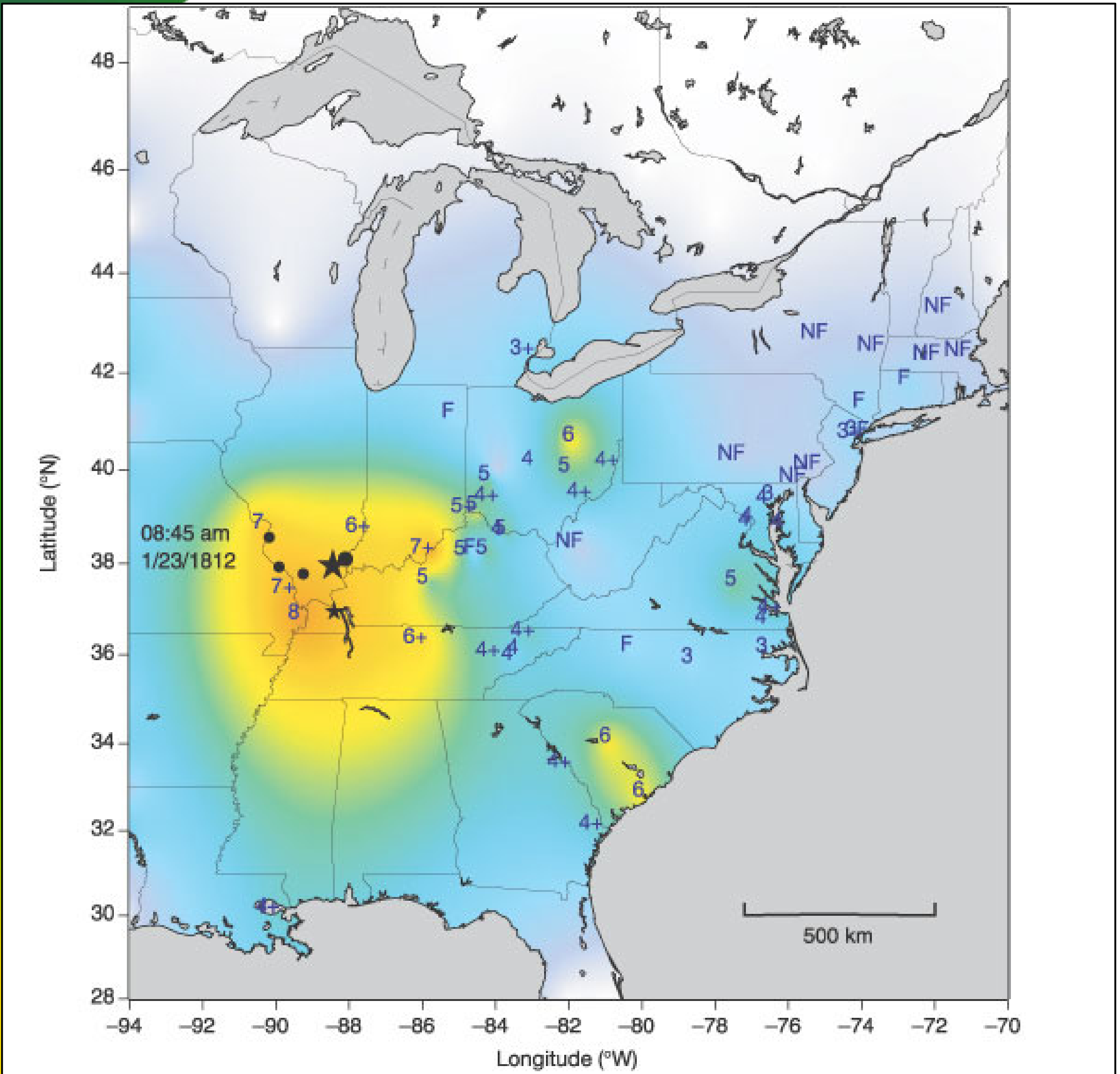
- Not all of the region's quakes emanate from the New Madrid Seismic Zone
- Wabash Valley Seismic Zone
- South Central Illinois

Triggered event in the Wabash Valley Seismic Zone?



- **23 January 1812 quake (NM2)**
- **Location: Assumed to be on the New Madrid North zone**
- **M_I =7.5**
- **M_W = 6.8-7.8 (±2s range)**
- **Possibly well north of NMSZ?**

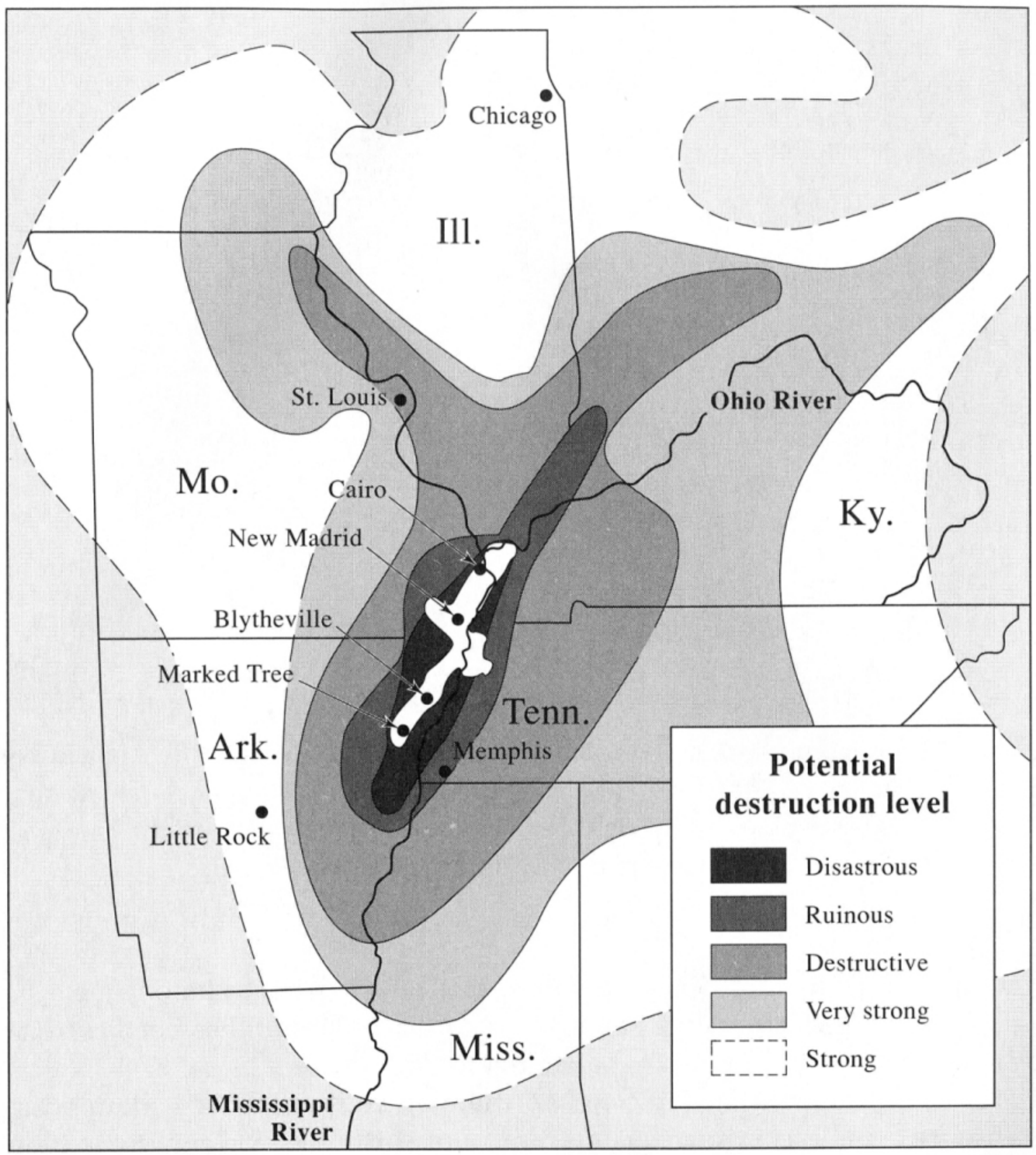
(Mueller, Hough, and Bilham, Nature, 2004)



Perceived shaking	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
Potential damage	None	None	None	Very light	Light	Moderate	Moderate/heavy	Heavy	Very heavy
Peak acceleration (% of *g*)	<0.17	0.17–1.4	1.4–3.9	3.9–9. 2	9.2–18	18–34	34–65	65–124	>124
Peak velocity (cm s^{-1})	<0. 1	0.1–1. 1	1.1–3. 4	3.4–8. 1	8.1–16	16–31	31–60	60–116	>116
Instrumental intensity	I	II–III	IV	V	VI	VII	VIII	IX	X+

- **Recently, the destructive effects of the 1811-12 New Madrid events has been attributed to site amplification effects, since most of the inhabited areas were in Holocene channels along major drainages.**
- **This is a revised map illustrating shaking severity for the January 23, 1812 event, thought to have been something between M_w6.8 and M_w 7.8**

DAMAGE POTENTIAL



Published damage predictions for the New Madrid Seismic Zone have focused on the near field area, in the upper Mississippi Valley

These are based on synthetic motion time histories with assumed soil cover; not on site specific characteristics or dynamic properties of structures.

EARTHQUAKE MECHANISMS THAT COMMONLY IMPACT STRUCTURES

- Surface fault rupture hazards
- Ground waves and fling effects
- Topographic enhancement of seismic energy
- Dynamic consolidation of soils
- Liquefaction and lateral spreading
- Site amplification effects
- Long period motion and resonant frequency effects
- Out-of-phase structural response

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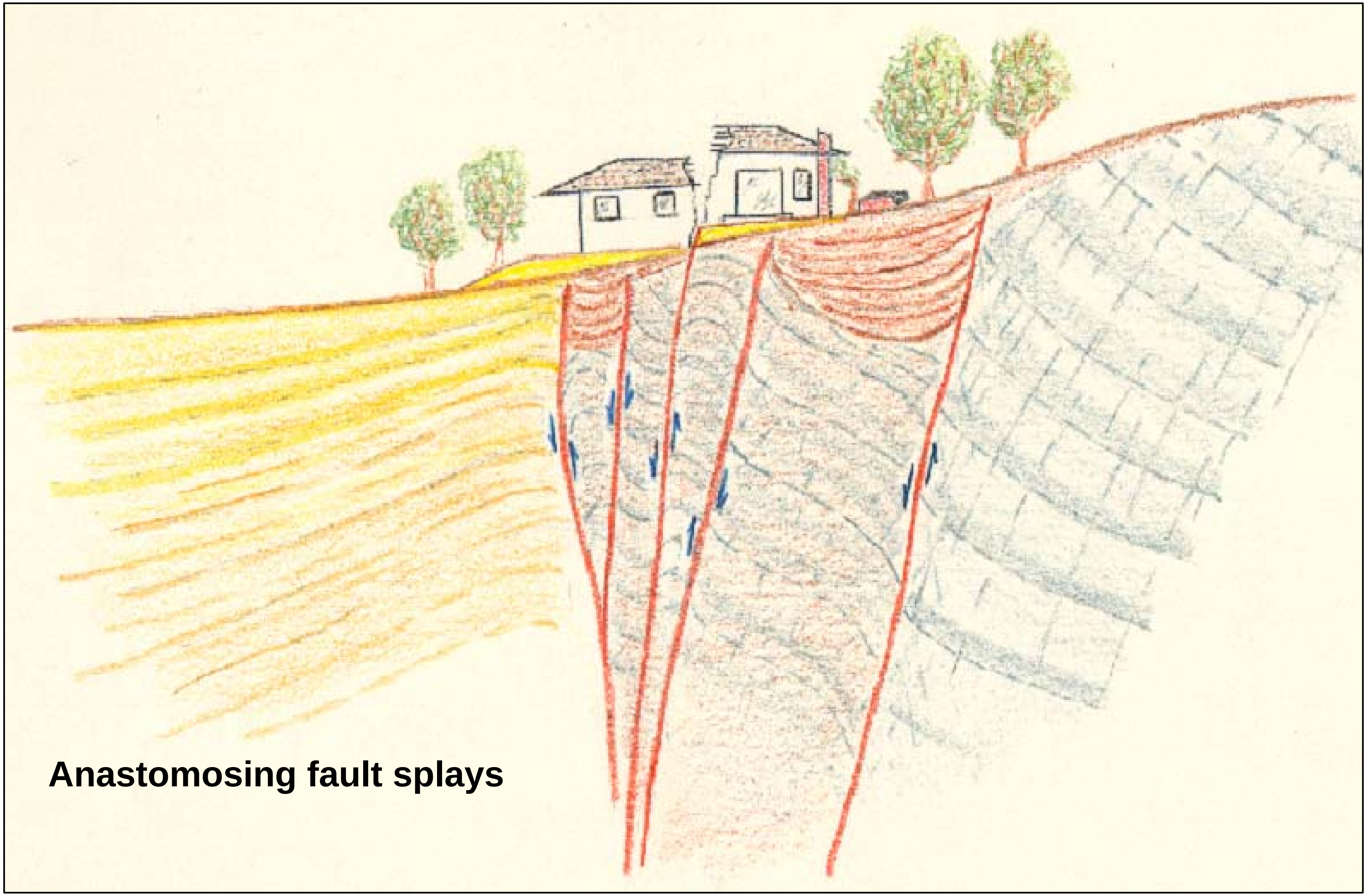
SURFACE FAULT RUPTURE HAZARDS

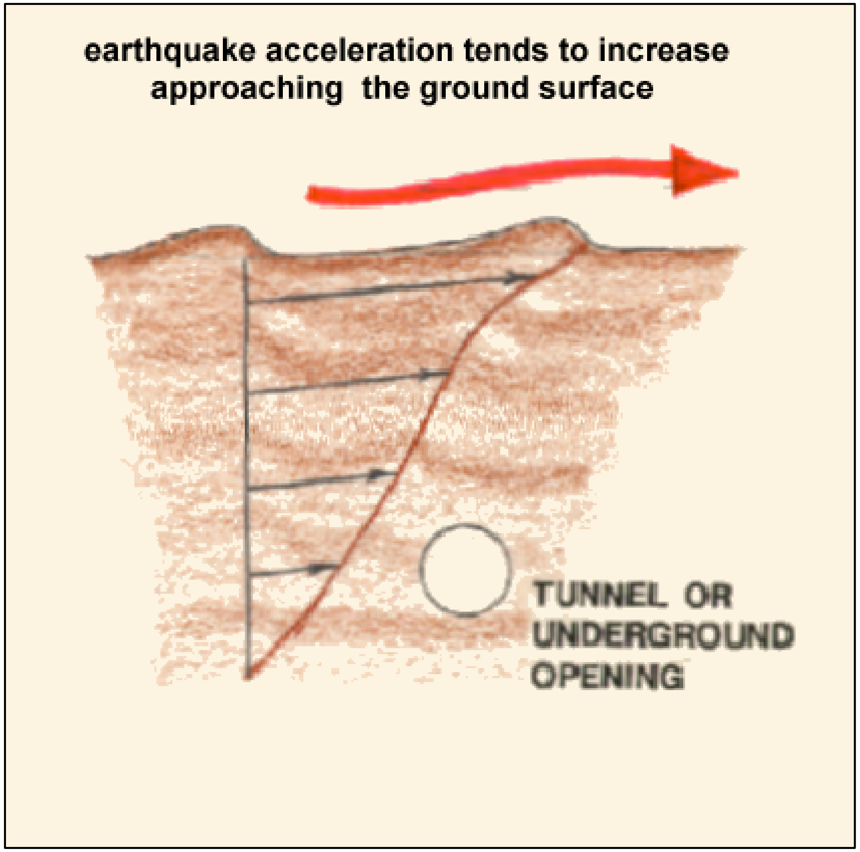


- **Major active faults usually extend up to the ground surface, where they can pose a threat to structures. Only about 2% of earthquake-induced structural damage is caused by surface fault rupture. Various fault strands identified near the ground surface may be active, dormant or ancient, as shown above.**

SURFACE RUPTURE

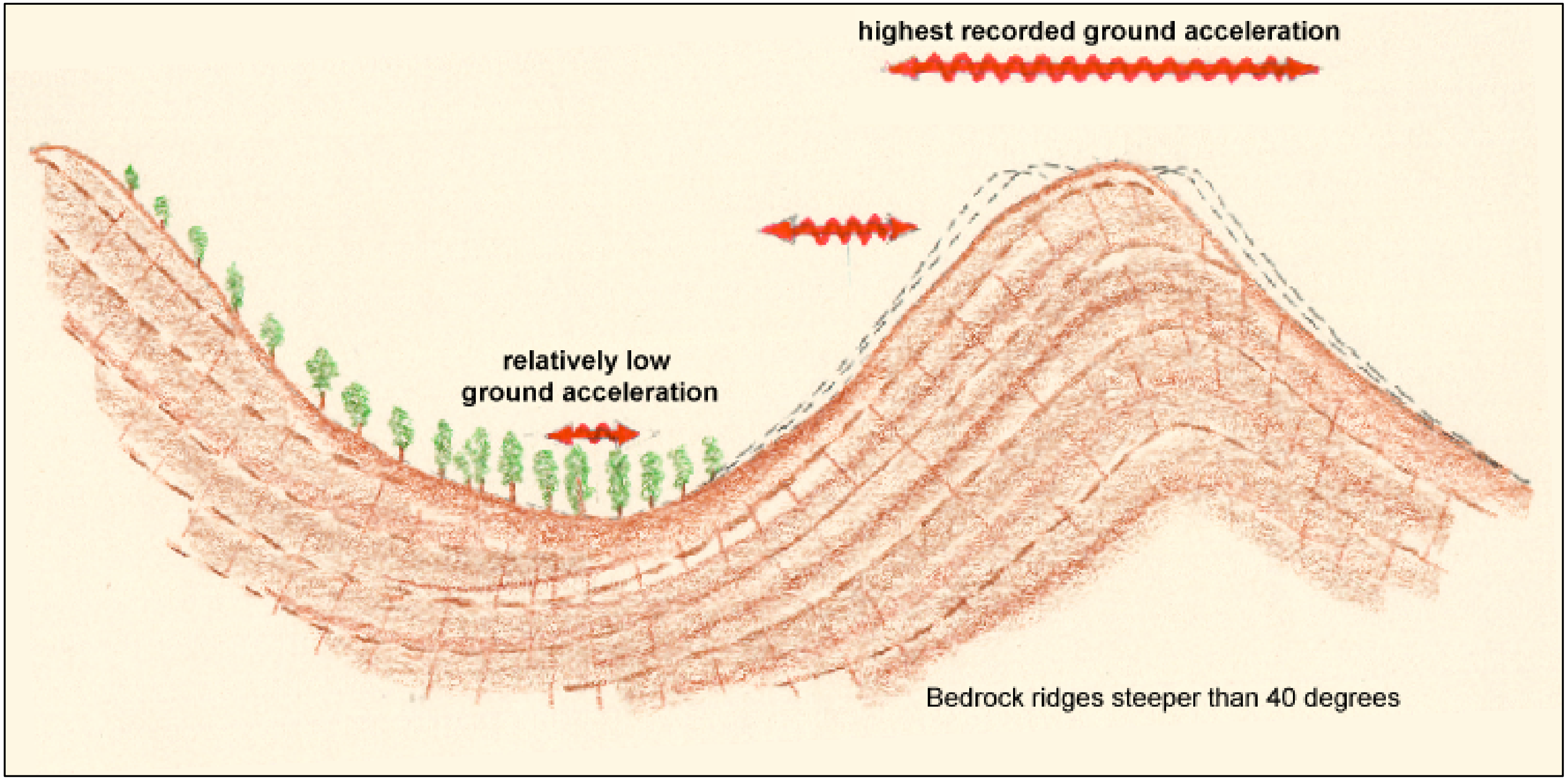
- Only a small percentage of earthquakes actually cause noticeable surface fault rupture
- Sometimes it is rather discrete (upper left)
- On other occasions it can be very abrupt and graphic (lower left)

FREE BOUNDARY/ GROUND WAVE EFFECT



- As the seismic wave train propagates upward and along the Earth's surface, the peak ground accelerations will tend to increase at the ground surface because there is no confinement. Tunnels and underground openings usually record much lower values of acceleration due to their increased confinement.

TOPOGRAPHIC INFLUENCE ON SITE RESPONSE



- Steep-sided bedrock ridges usually experience much higher accelerations during earthquakes because they are less laterally constrained. In the October 1989 Loma Prieta earthquake the PGA of 0.77g was recorded in the valley bottom at Corralitos. Estimates of PGA values for the adjoining ridges were in excess of 1.30g.

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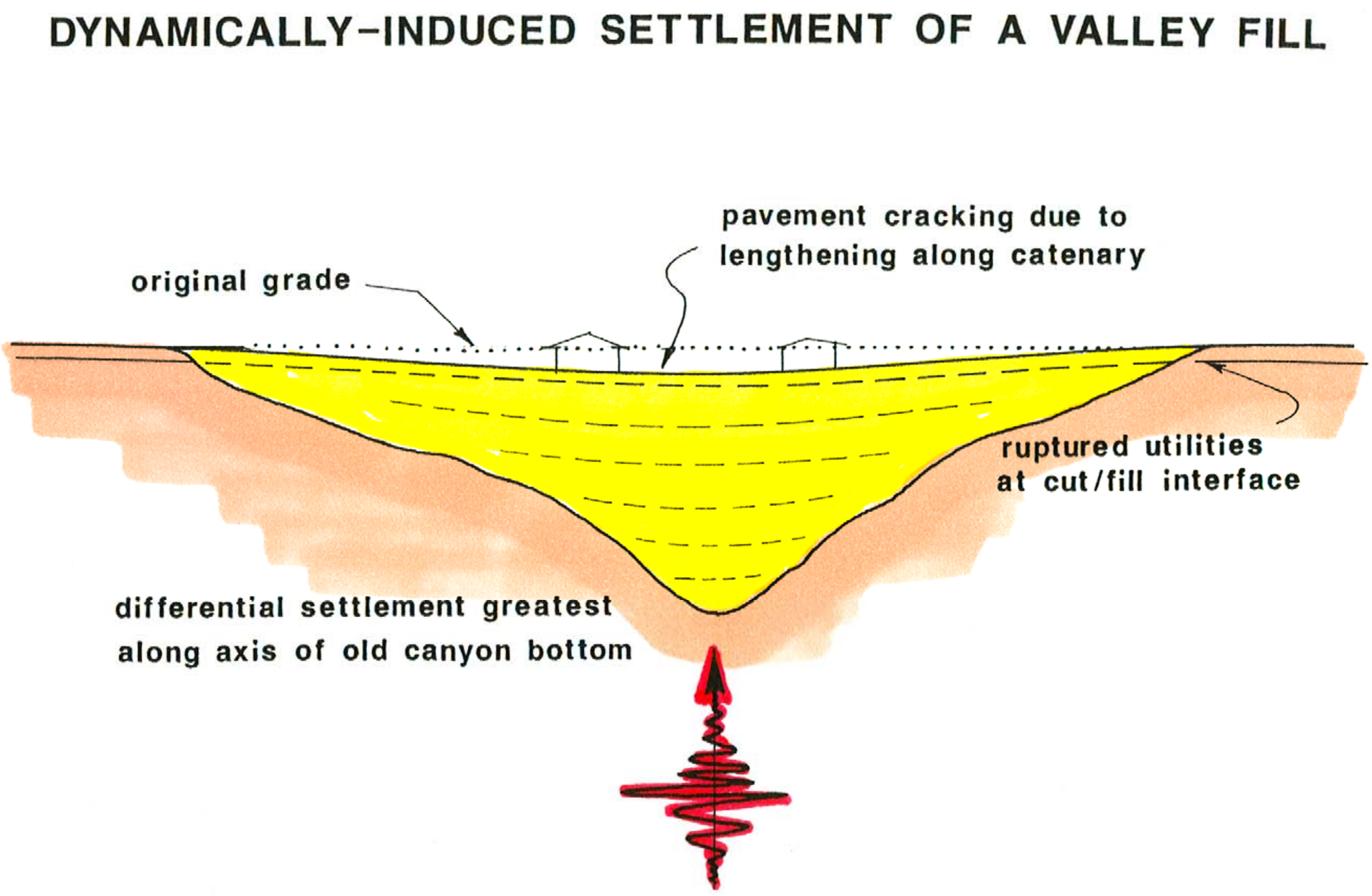
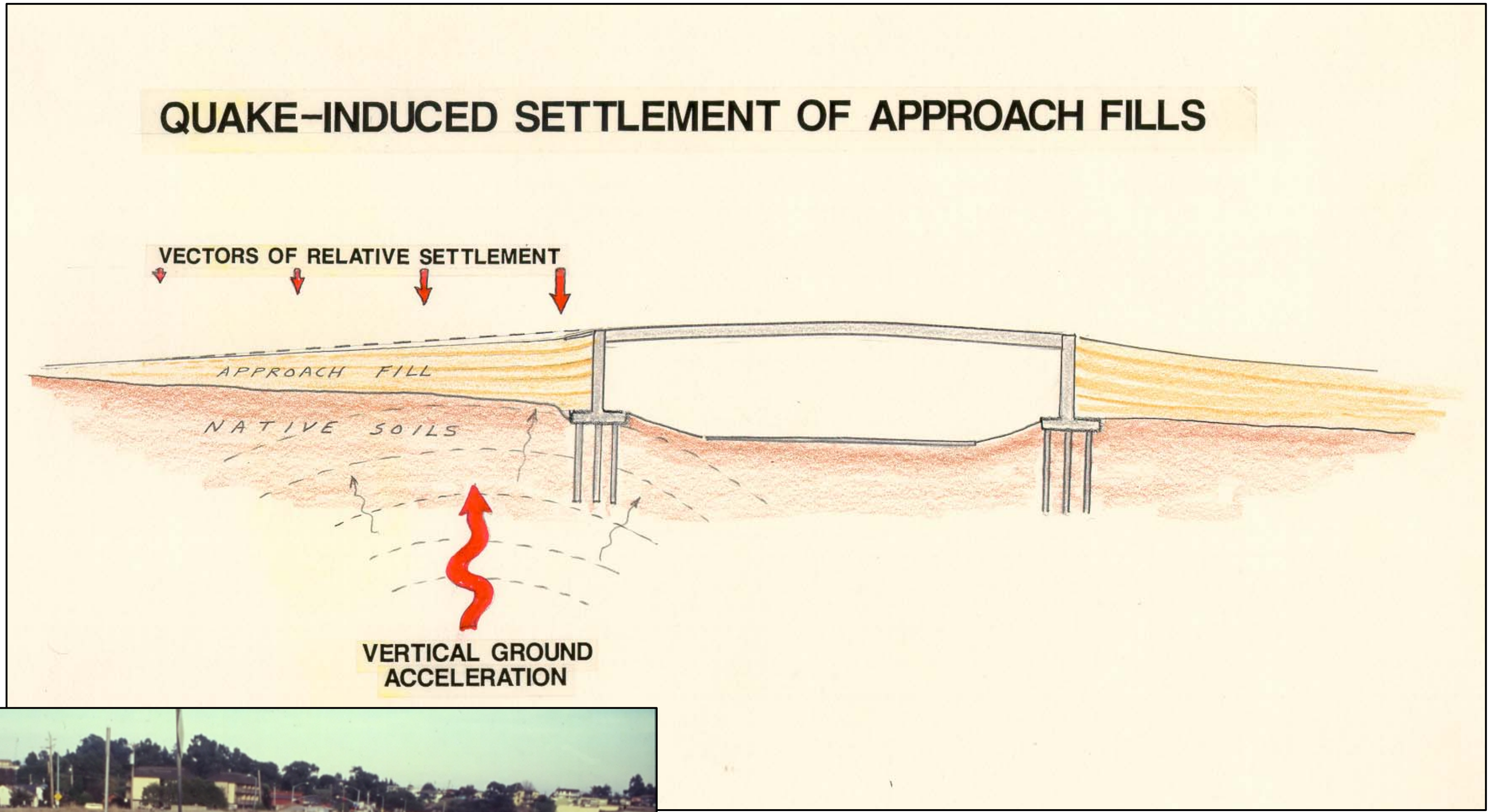
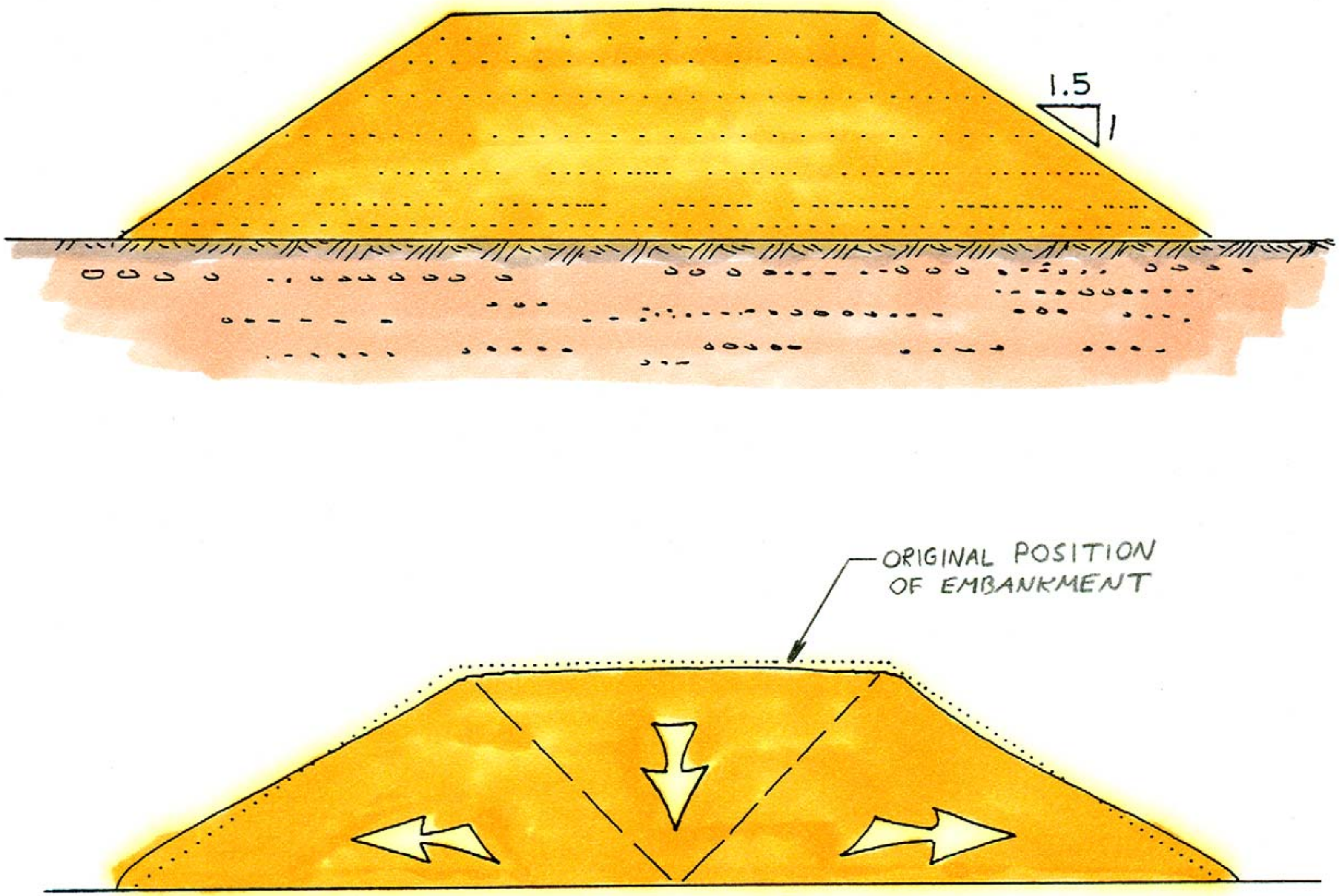


- **Fill embankments tend to consolidate and settle under dynamic loading in the near-field zone**



- **Regardless of the compactive effort engendered to filled ground during placement, these materials tend to compress during earthquake-induced shaking, often causing abrupt settlement of the approach fills at the abutments.**



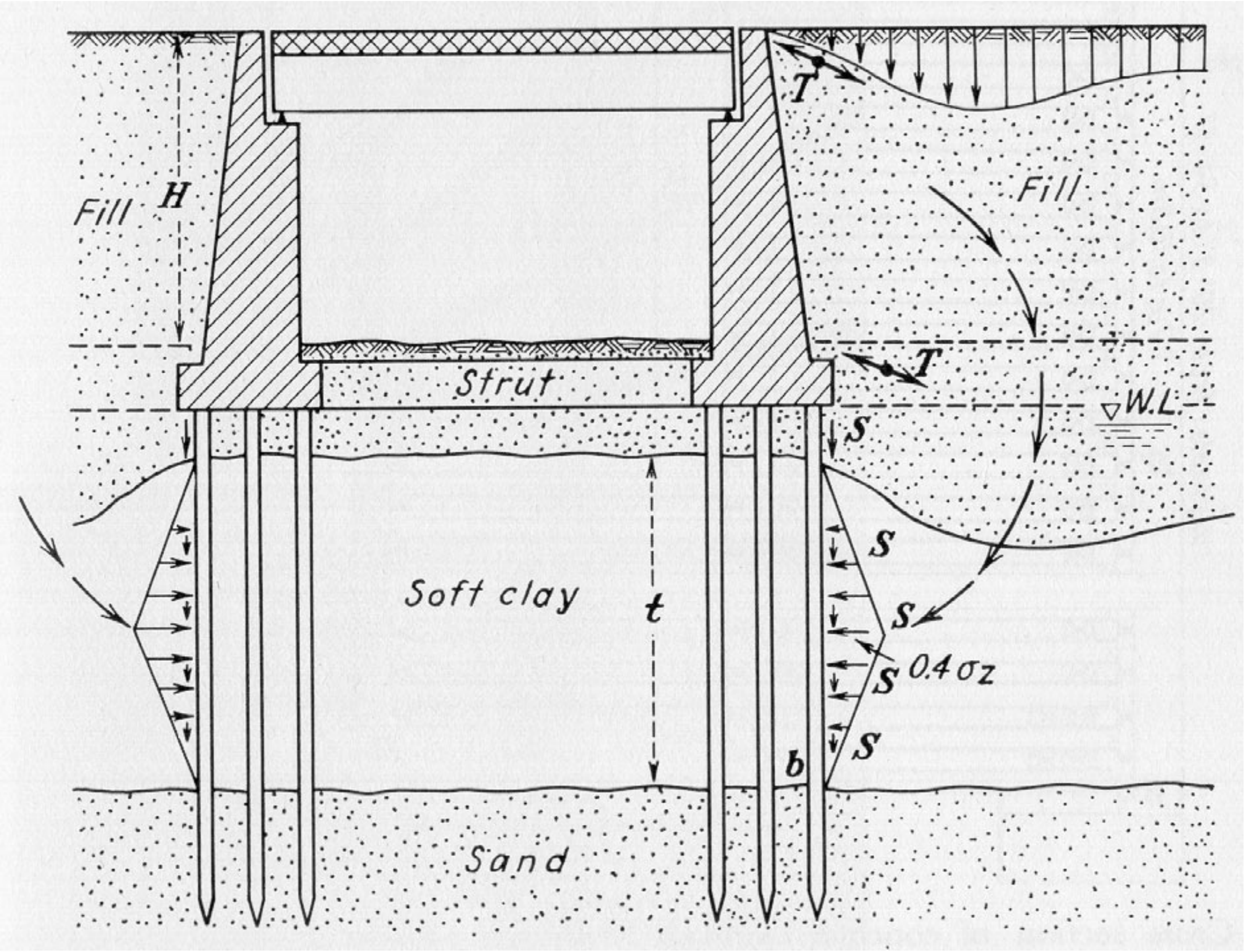
- **Mechanism of seismically-induced settlement of bridge approach fill prisms**

QUAKE-INDUCED SETTLEMENT

- Approach fills for pile supported bridges commonly exhibit grievous differential settlement
- Impacts traffic flow and any entrained utilities, like fire mains
- These examples are from Aug 1999 Chi Chi earthquake in Taiwan

APPROACH FILL SETTLEMENT

- Seismically-induced settlement and lurching of approach fills for the Cayumapa River Bridge near Valdivia, Chile, which occurred during the M9.5 May 1960 earthquake
- Replacement structure being constructed in lower view, using Geofoam



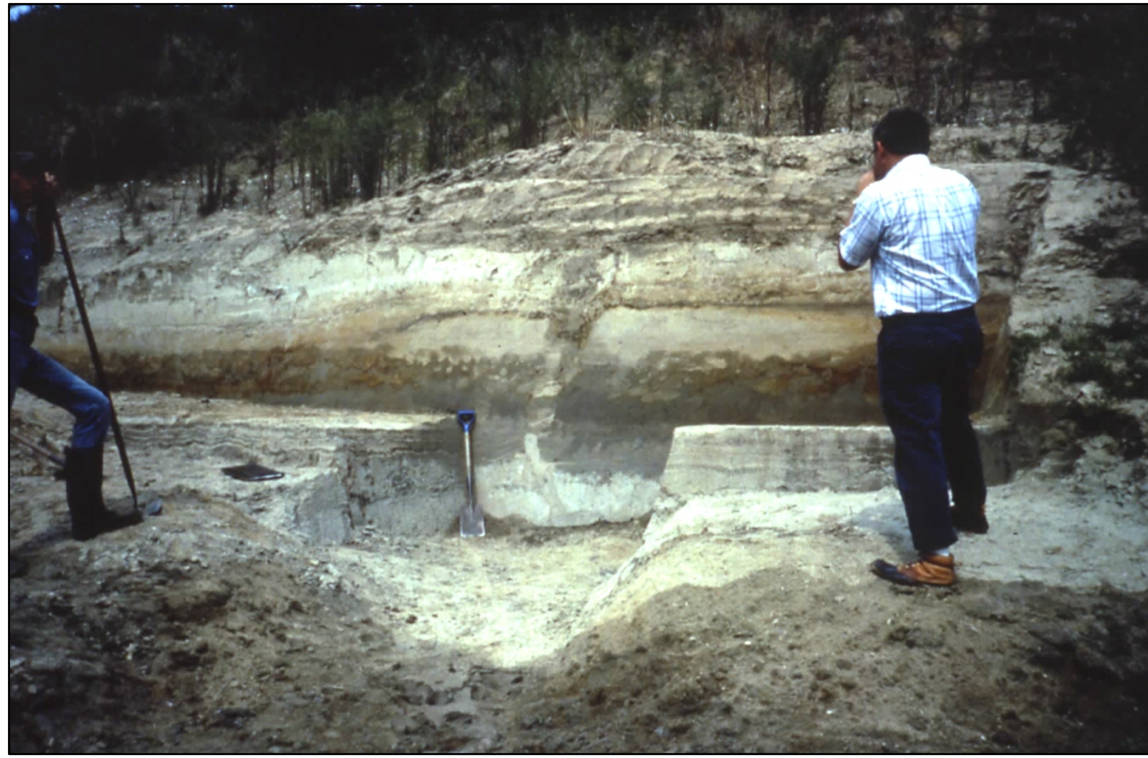
- **Tschebotarioff (1973) presented case studies of pile supported bridges that failed because of approach fill settlement.**

SETTLEMENT OF APPROACH FILL

- Crib wall supported approach fill for pile supported bridge. As fill consolidated, crib wall deformed and supporting piles deflected inward, towards channel. Taken from Tschetarioff (1973).

- **Farm lands west of Big Lake, AR reveal a series of linear fissures which disgorged liquefied sand from beneath a silt cover.**

PALEOLIQUEFACTION STUDIES



- C14 dating of organics caught in sand boils and dikes are used to date past earthquakes. Three M7.5 to M8 paleoevents have been conclusively dated: ~1450, ~900 and ~550 AD.

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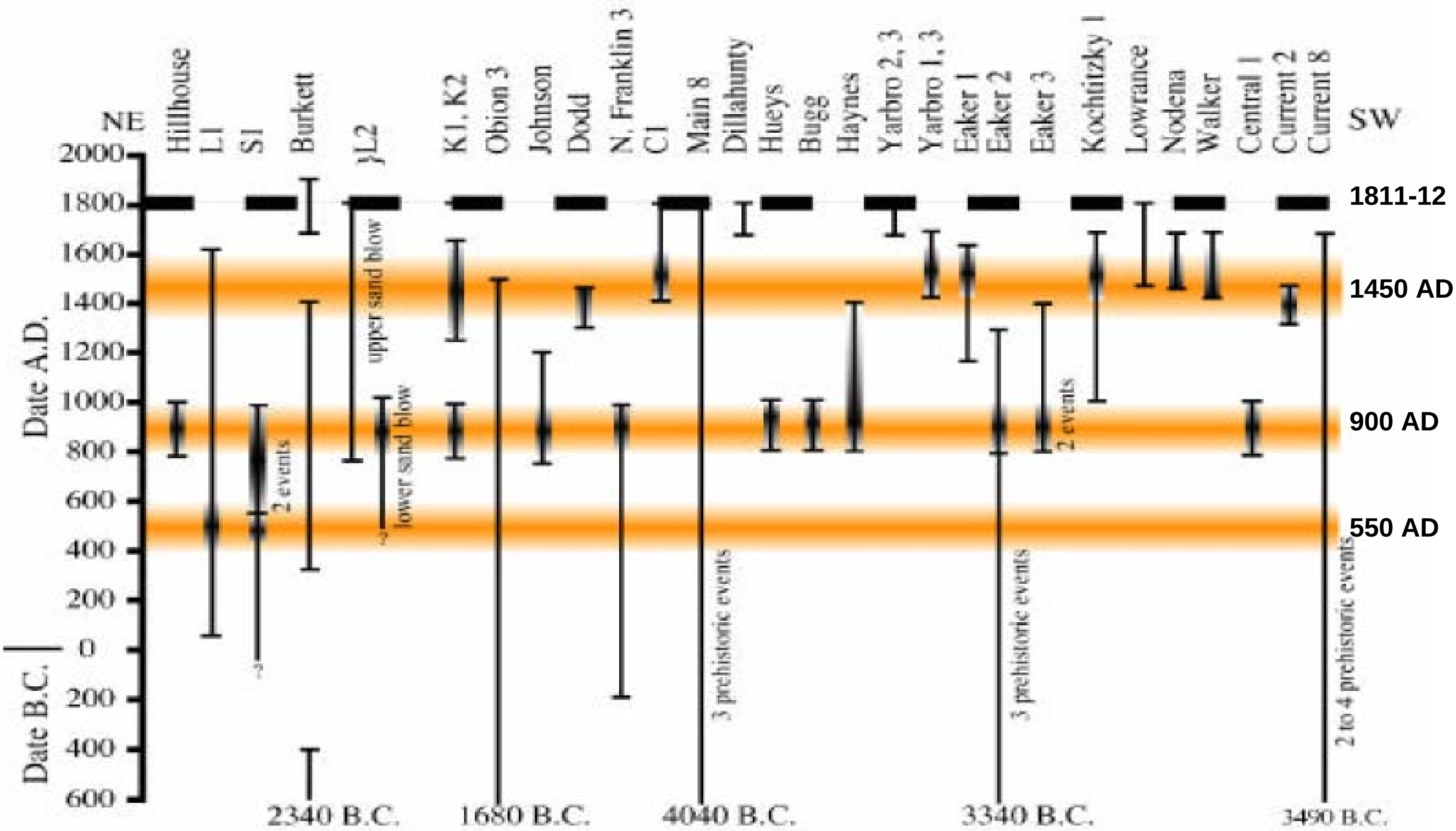
Paleoliquefaction Assessments



Shaded orange lines show most probable ages of major earthquakes in the NMSZ prior to 1811-12 (shown as dashed line)

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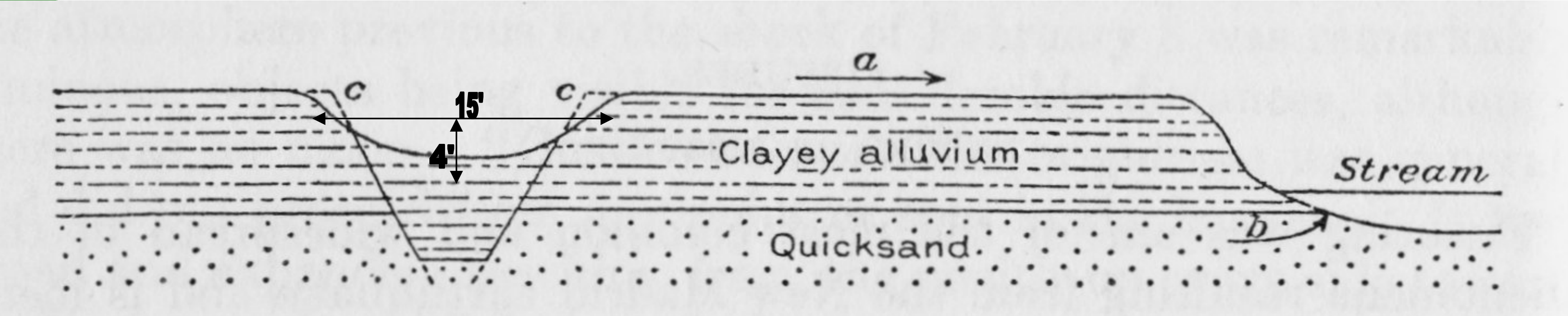
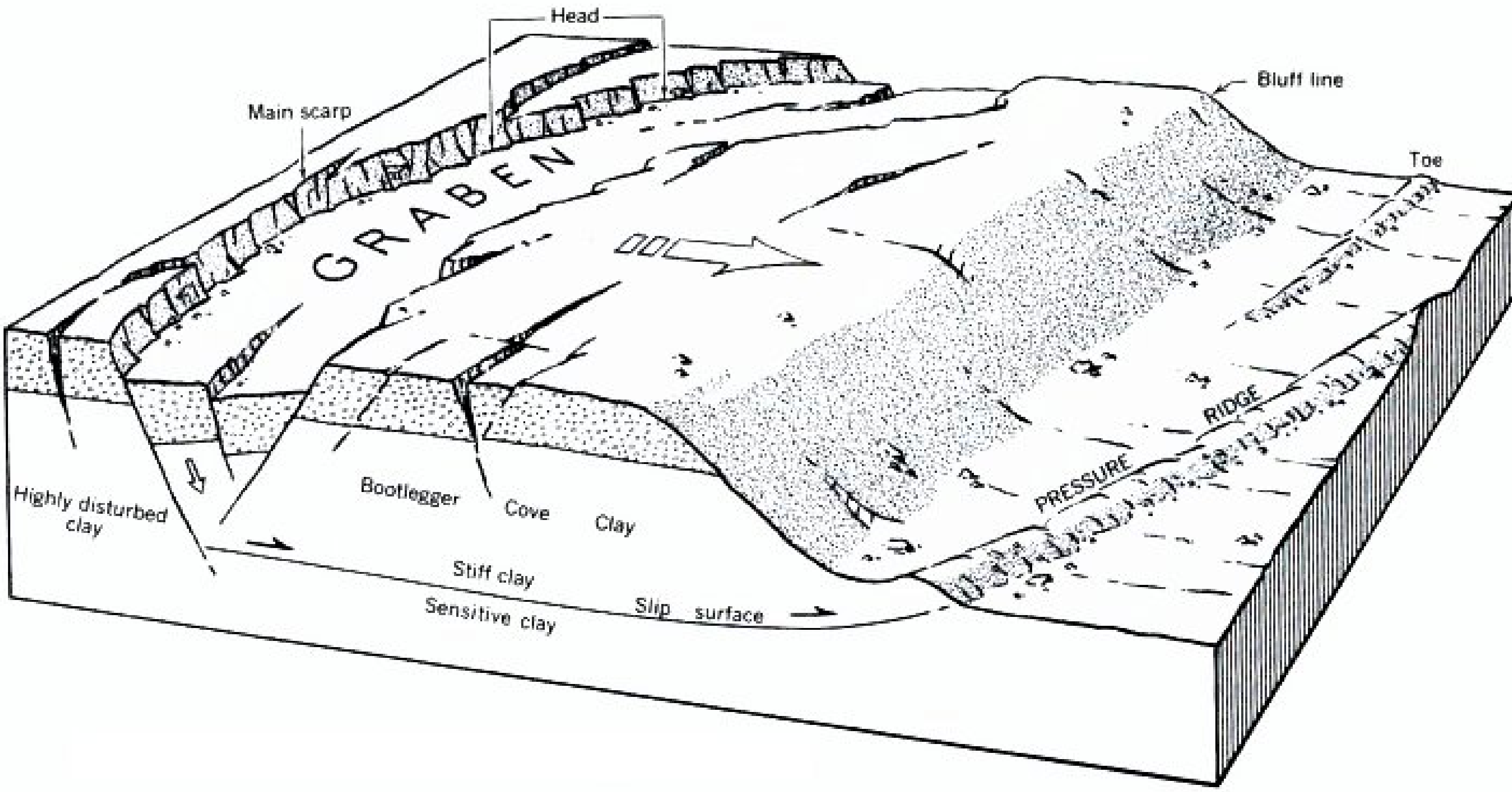
Liquefaction of Confined Horizons Causes Lateral Spreads



- **Lateral spreads** were initially recognized and identified by USGS geologist Myron Fuller while studying the effects of the 1811-12 New Madrid earthquakes between 1905-12. Fuller made the sketch above, noting that: ***"The depth of the openings was not usually very great, probably being in most cases limited to the hard clayey zone extending from the surface down to the quicksand which usually underlies the surface soil at depths of from 10 to 20 feet."***



Block diagram of a lateral spread which evolved from post-1964 earthquake evaluations in Alaska by Walt Hansen in USGS Professional Paper 542-A (1966)

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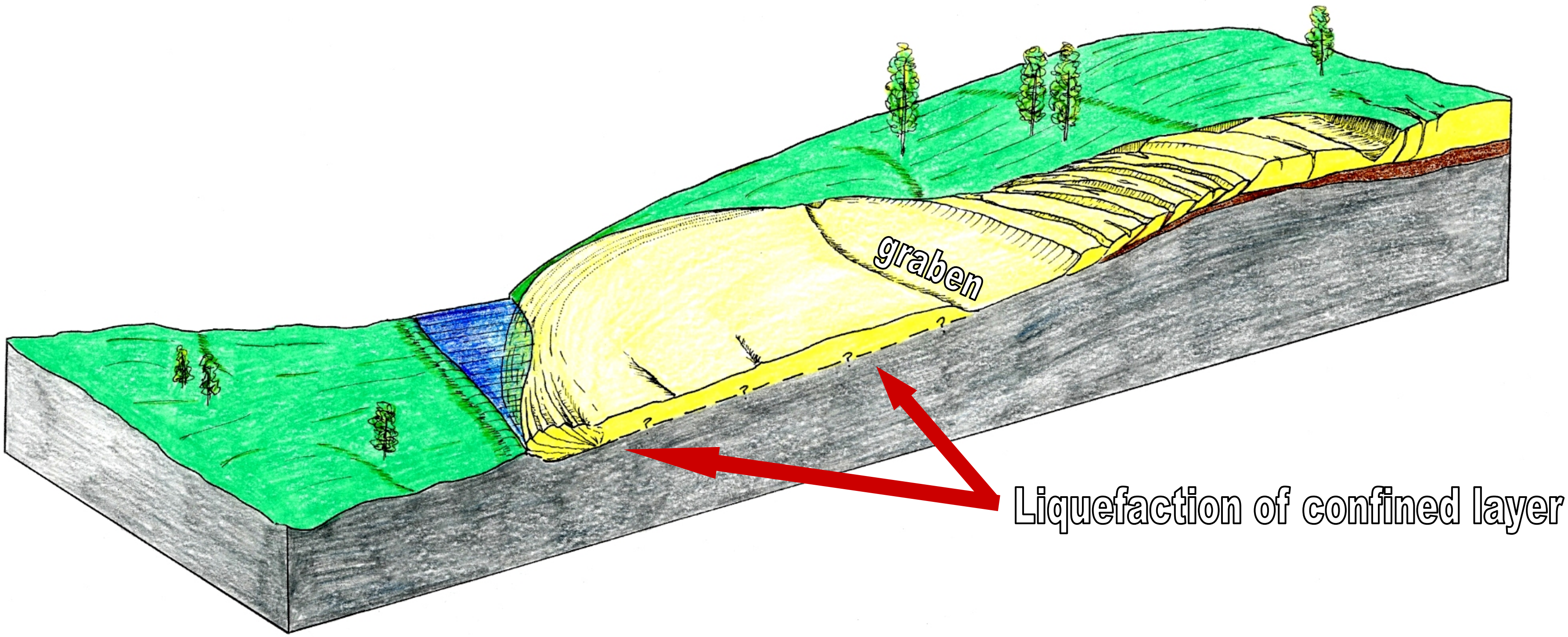
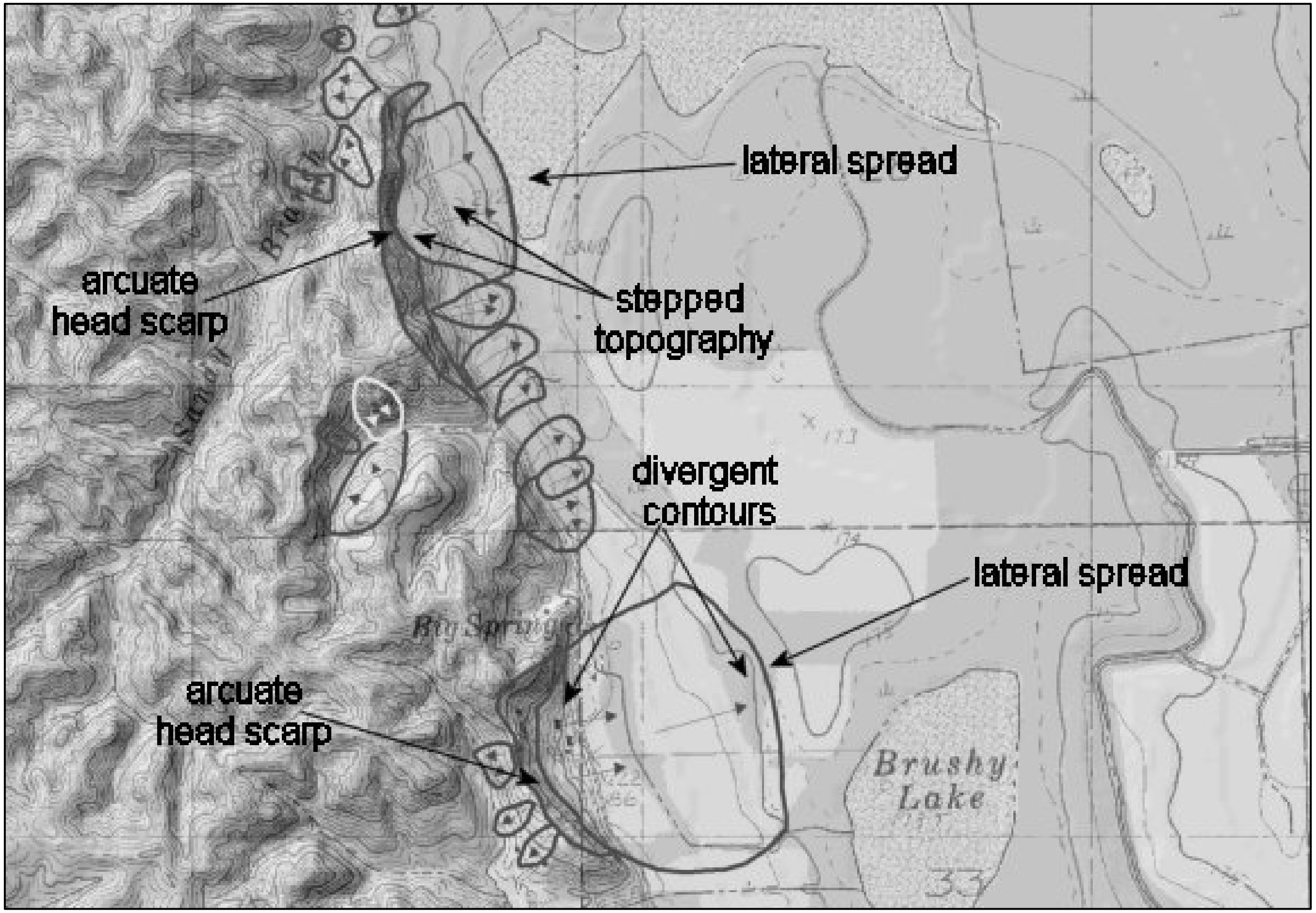
LATERAL SPREADING



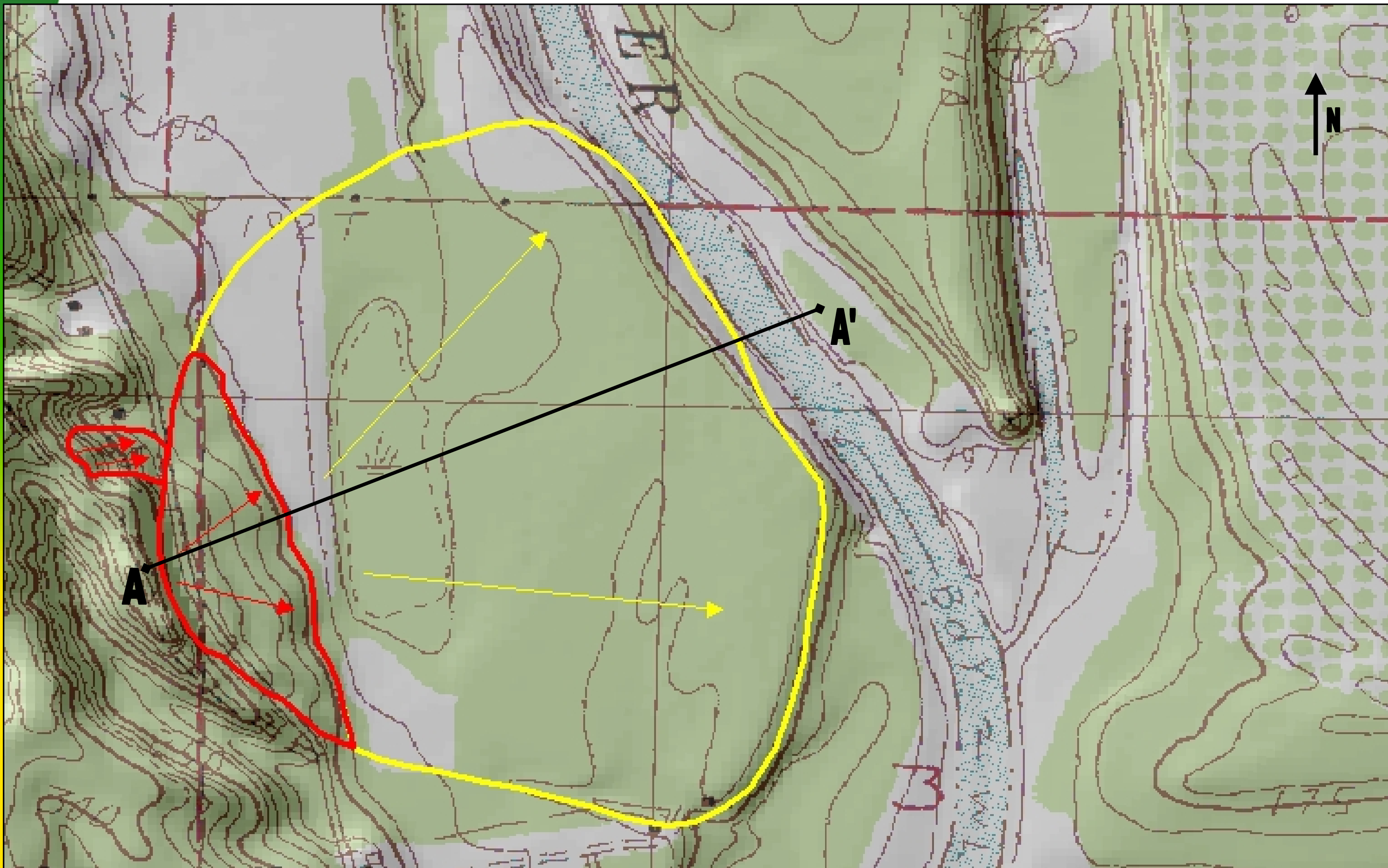
- **Lateral spreads can exhibit different length-to-depth ratios, depending on soil sensitivity. Liquefaction occurs along discrete horizons which are confined, allowing lateral translation of rafted material, usually towards open channels or depressions.**

Topographic Expression of Lateral Spreads Near Helena, Arkansas

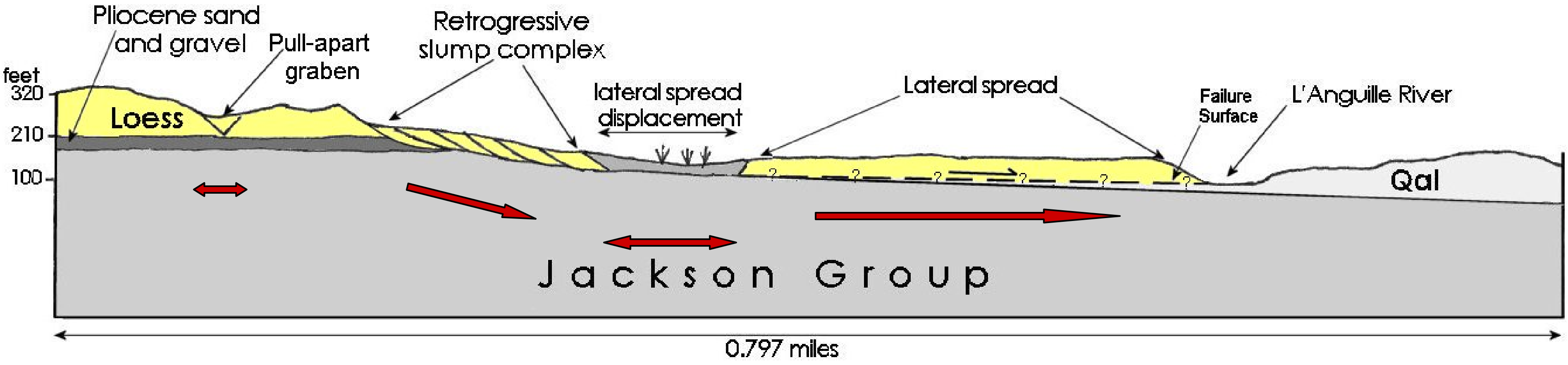
- Divergent contours
- Stepped topography
- Headscarp evacuation grabens
- Arcuate headscarps



Jeffersonville Lateral Spread Along Crowley's Ridge ~ 25 km north of Helena, Arkansas

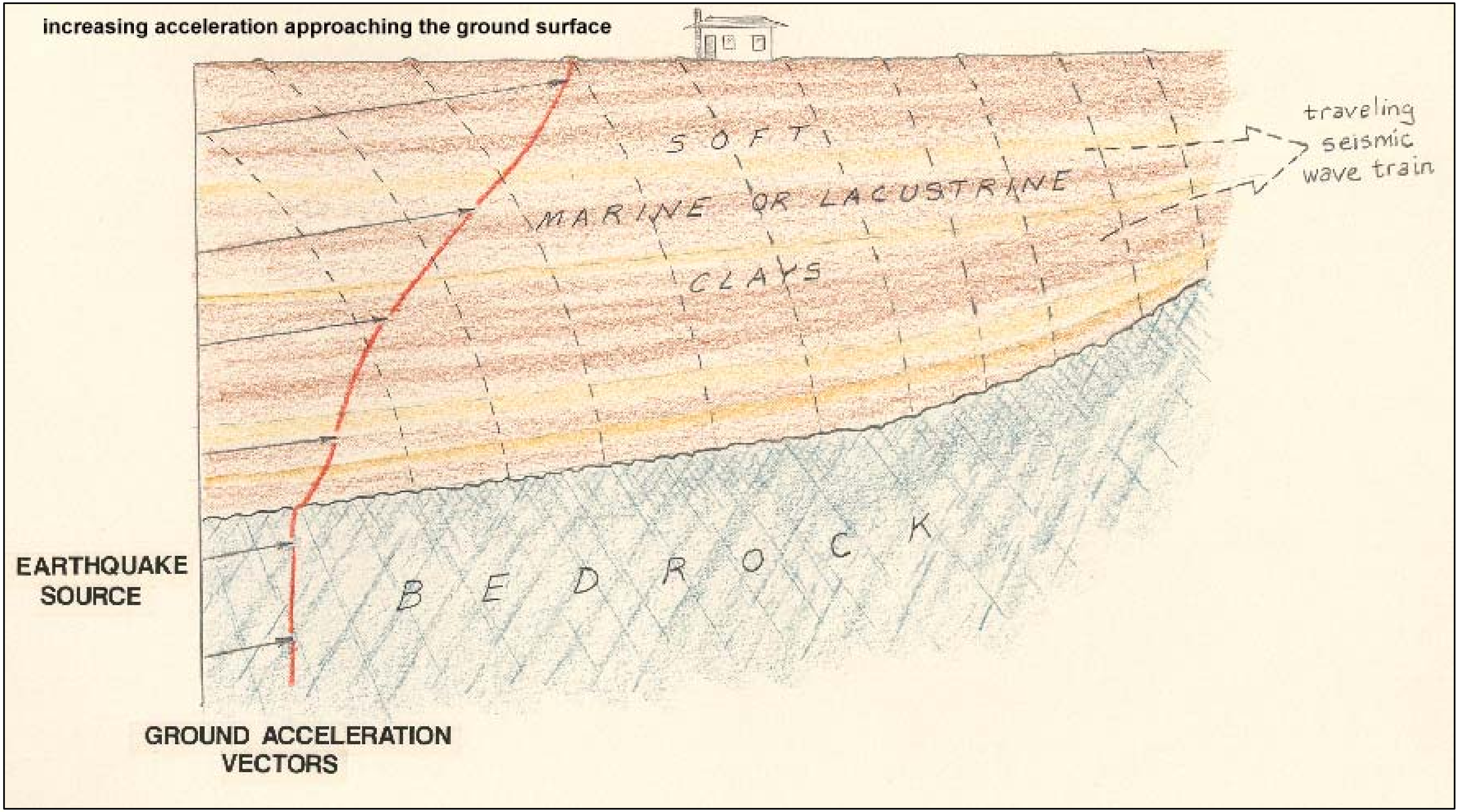


Cross-section through Jeffersonville Lateral Spread and Crowley's Ridge



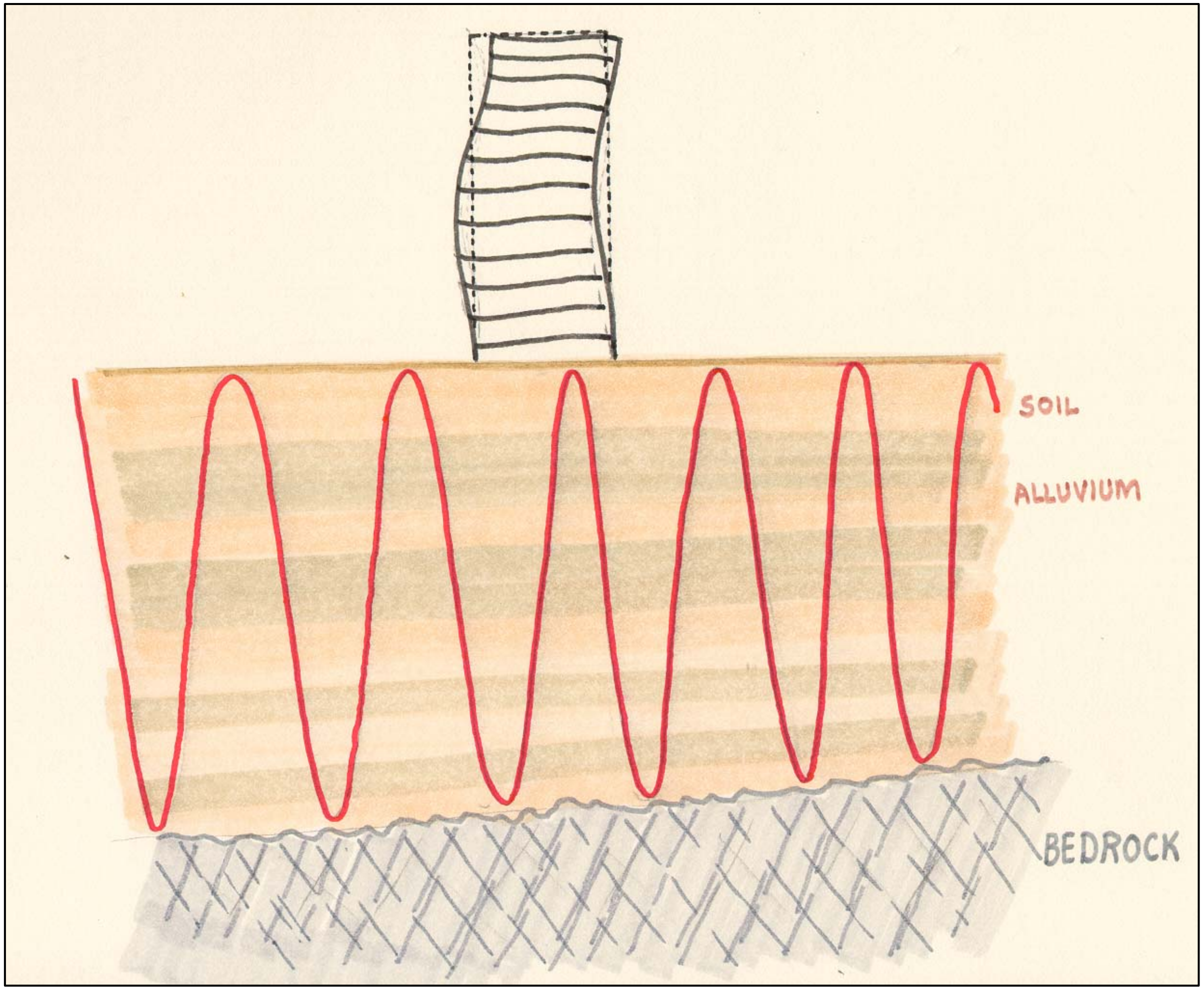
The Jeffersonville Lateral Spread feature appears to have been triggered by the 1811-12 New Madrid earthquake sequence, with the ground translating easterly into the L'Anguille River, near its mouth with the St. Francis River. The eastern escarpment of Crowley's Ridge is peppered with similar features.

WHAT IS SITE RESPONSE ?



- Site response is used to describe the fundamental period of vibration generated by a typical earthquake at any particular site. If soft unconsolidated sediments overlie resistant bedrock an impedance contrast develops at this boundary which causes incoming seismic energy to be absorbed at a rate faster than it can be transferred through the upper layers, causing significant amplification of ground motions.

SITE RESPONSE VERSUS STRUCTURAL RESPONSE



- **The fundamental period of vibration of any structure depends on its design and construction details. If the site period and structural period converge, a resonant frequency results which may be an order of magnitude greater than the natural site period, and the structure will be severely damaged or destroyed.**

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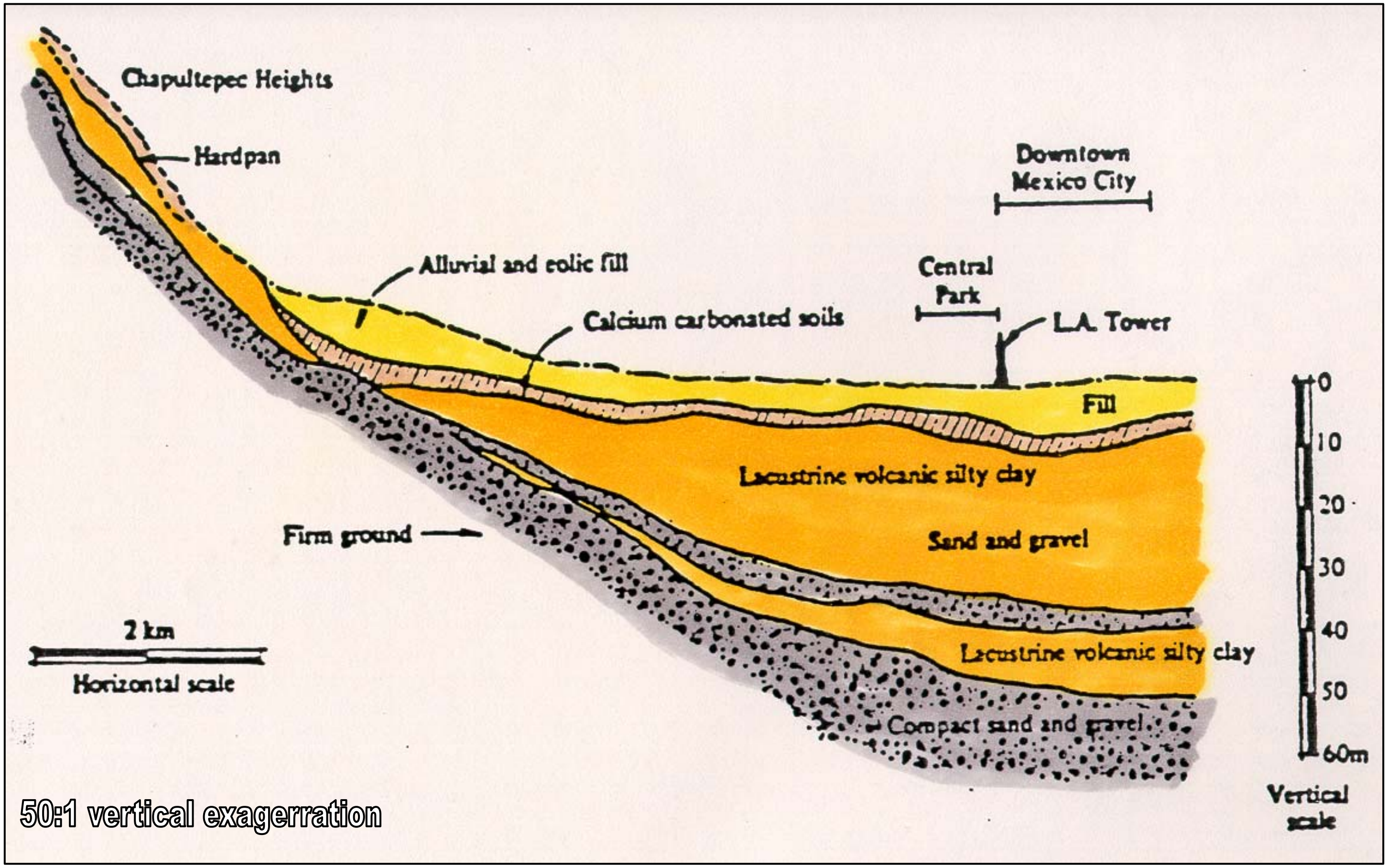
SOFT SEDIMENTS UNDERLYING MEXICO CITY



- **Generalized geologic cross section of the southern margins of the lacustrine basin underlying Mexico City. The lacustrine sediments were covered with fill as the city developed. These soft materials amplified the incoming seismic wave train from a M.8.1 earthquake located 52 km off the coast of Michoacan Province, some 350 km from Mexico City!**

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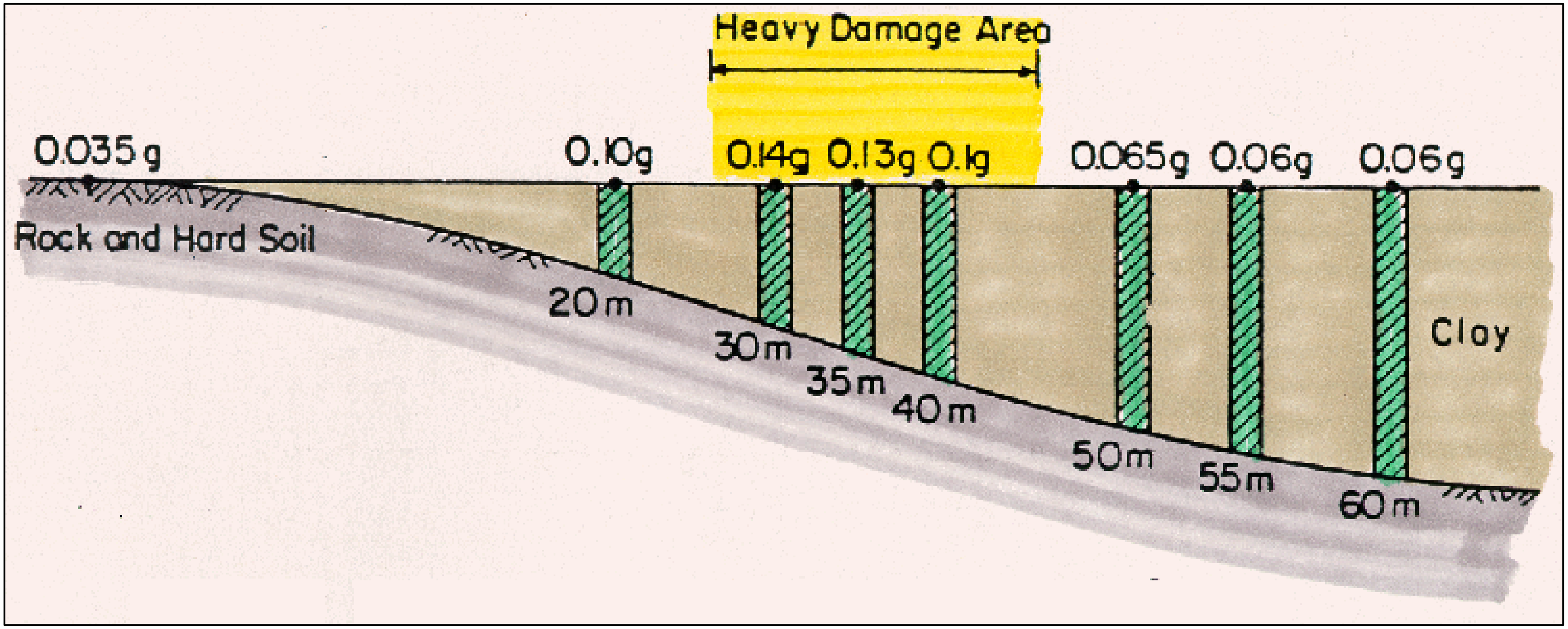
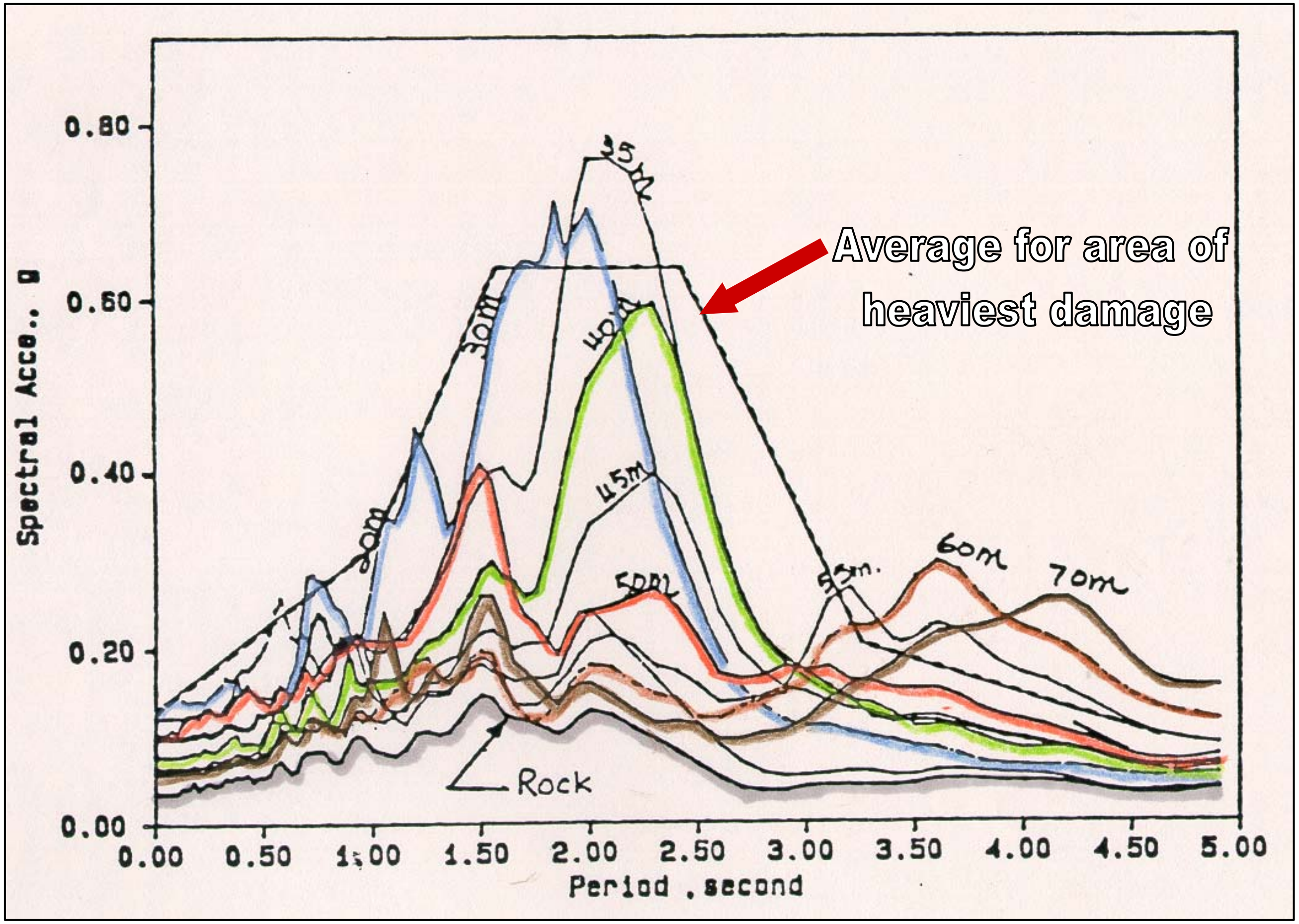
ZONE OF HEAVIEST DAMAGE DURING 1985 MEXICO CITY EARTHQUAKE



- **Computed distribution of peak ground surface accelerations for typical soil profiles in Mexico City, bounding the zone that experienced severe damage during the 1985 M. 8.1 Michoacan earthquake. The earthquake epicenter was 350 km from Mexico City and lasted close to 3 minutes. More than 500 buildings within the highlighted zone were severely damaged and 100 buildings between 6 and 22 stories high actually collapsed; killing 9,500, injuring 30,000 and leaving 100,000 homeless.**

VARIANCE OF RESPONSE SPECTRA WITH SEDIMENT THICKNESS IN MEXICO CITY



- **Response spectra calculated for different thicknesses of soft sediments in southern Mexico City, between downtown and Chapultepec Heights. Note impact of 30 to 45 m thickness.**

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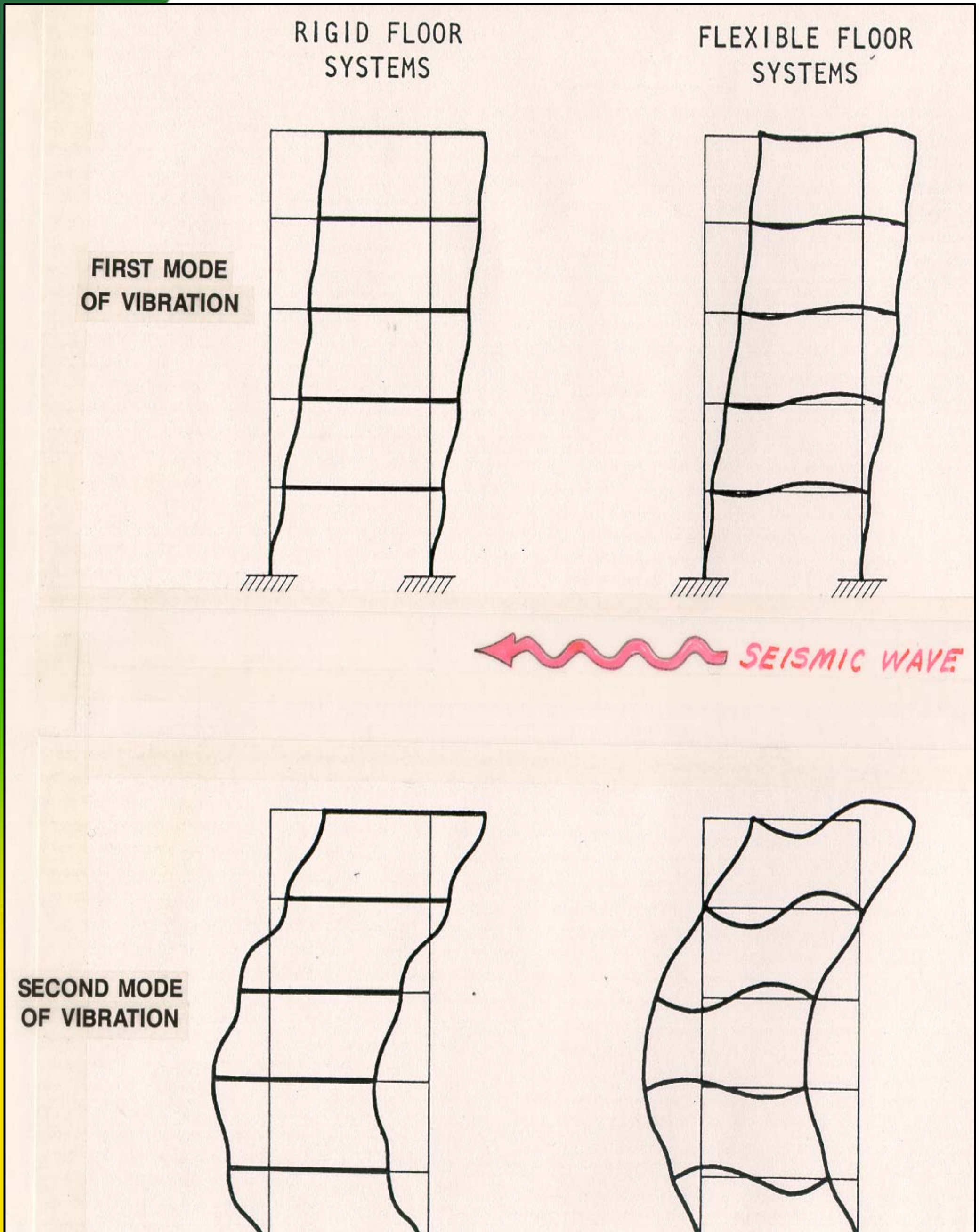
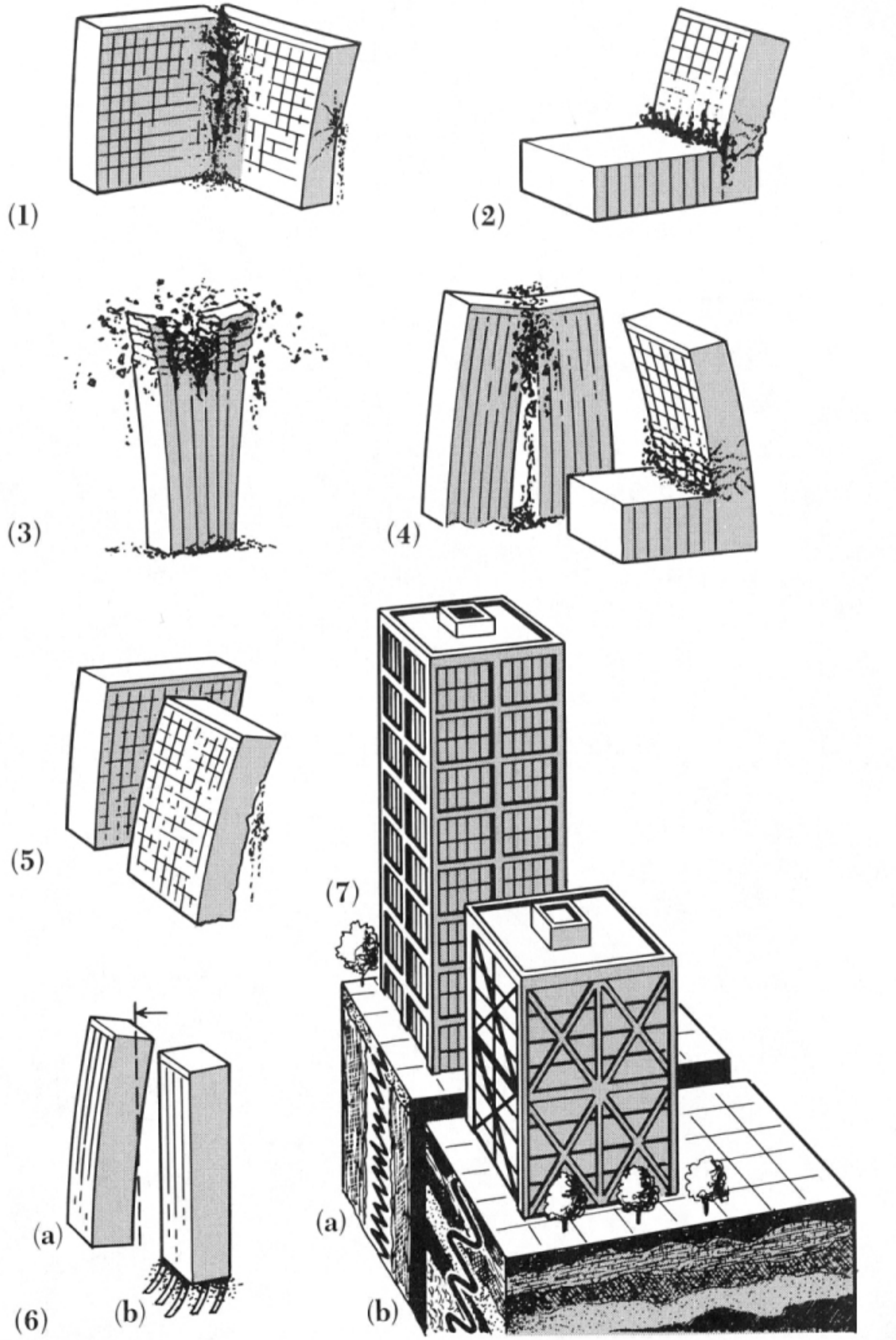
MODES OF VIBRATION



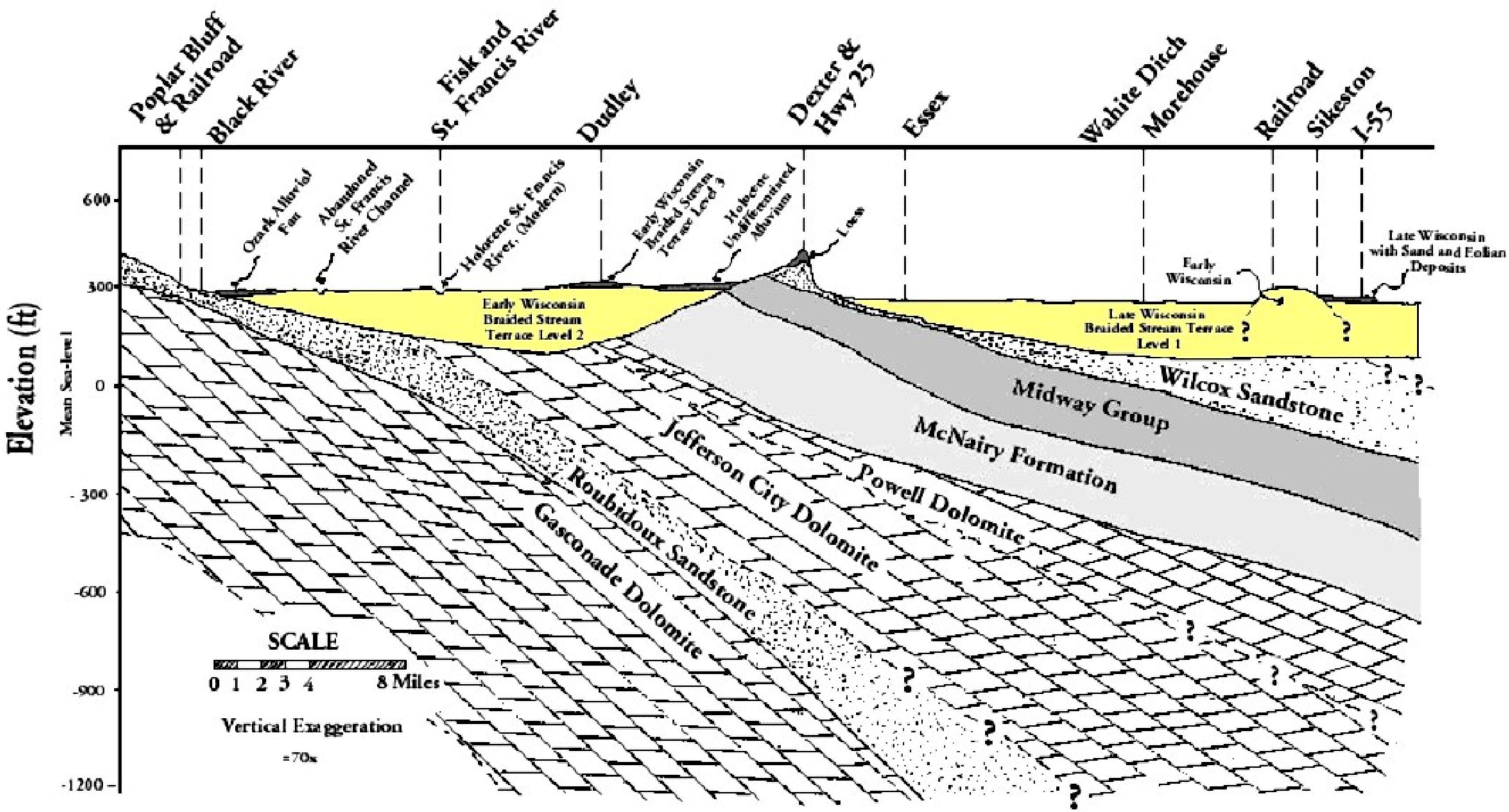
- **All structures posses fundamental modes of vibration which depend on their skeletal make-up: including material type, shear panels, connections, span distances and symmetry.**
- **This fundamental mode is known as the “first mode of vibration” and it generally controls the seismic design of most symmetrical structures.**
- **Secondary modes of vibration become increasingly important in complex structures with asymmetrical form or stiffness, or structures with damaged frames.**



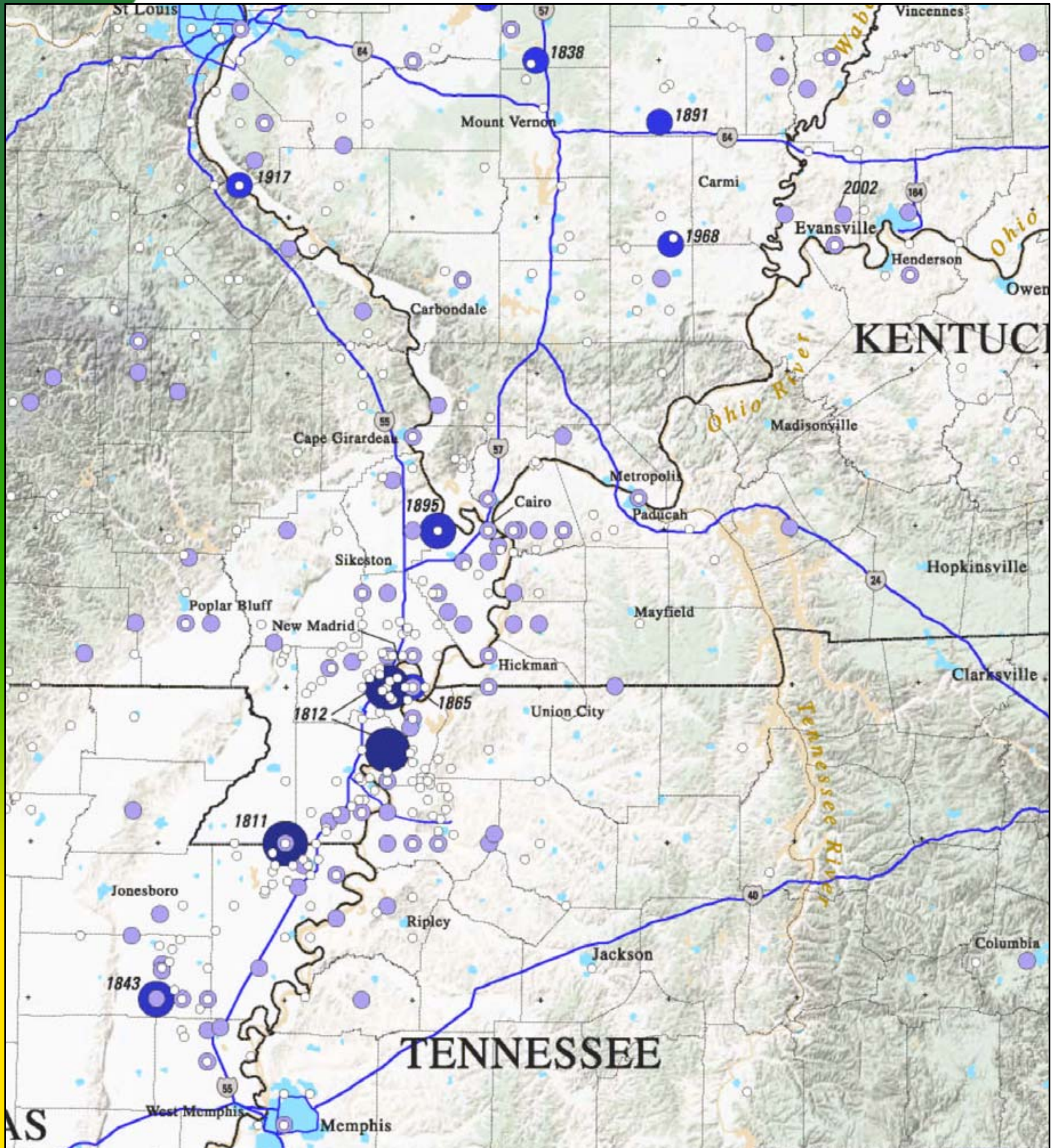
OUT-OF-PHASE MOTION

- **Adjacent structures can react differently to seismic excitation, depending on focal aspects of incoming energy, long period motion, site amplification, and degrading structural response as frames become damaged**

Geology Northern Mississippi Embayment



Impedance contrasts within the Wisconsin age river channels (yellow) likely pose the greatest seismic threat to highway infrastructure in the Midwest.



WHAT IS THE DESIGN EARTHQUAKE?

- >M7.5 in ~550
- >M7.5 in ~900
- >M7.5 in ~1450
- M7.5+ in 1811
- M8.0 in 1812
- M6.3 in 1843
- M6.6 in 1895
- M5.4 in 1968
- M5.0 in 1987
- M4.6 in 2002

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Recurrence Intervals for New Madrid Earthquake Events*

Magnitude	Recurrence Interval
4.0	14 Months
5.0	10 – 12 Years
6.0	70 – 90 Years
7.0	254 – 500 Years
8.0	550 – 1200 Years

* based on existing data; always subject to update and revision

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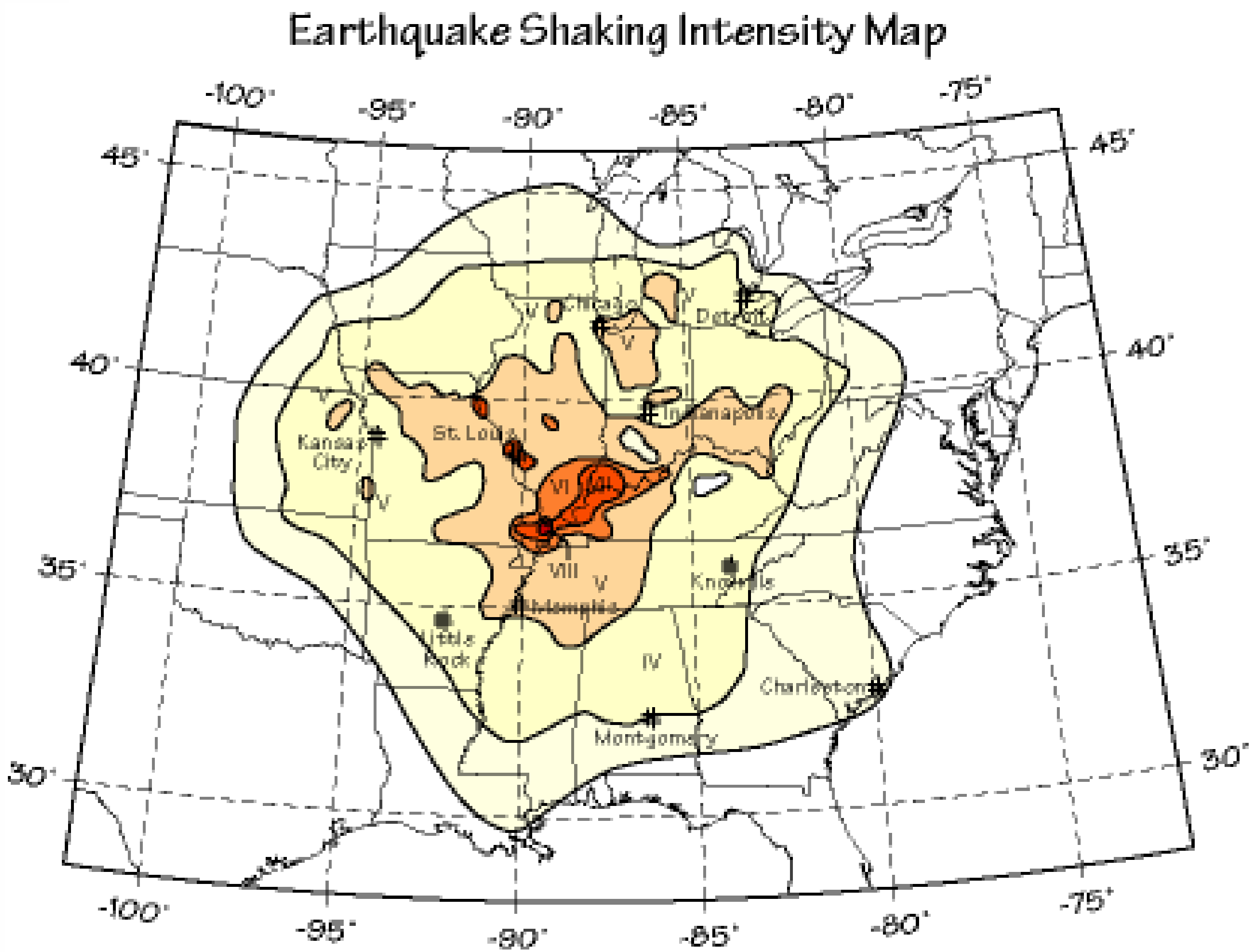

- **1895 M6.6 Charleston, MO earthquake**

1895 M6.6 Charleston, MO Quake

- October 31, 1895 Magnitude 6.6 Earthquake near Charleston Missouri. Modified Mercalli Intensity VIII
- Largest earthquake to occur in the Mississippi Valley region since the 1811-1812 New Madrid earthquake sequence. The estimated body-wave magnitude of this event is 5.9 and the surface-wave magnitude estimate is 6.7.
- People in 23 states felt this earthquake which caused extensive damage. to a number of structures in the Charleston region, including schools, churches, and homes. Structural damage and liquefaction were reported along a line from Bertrand, MO to Cairo, IL. The most severe damage occurred in Charleston, Puxico, and Taylor, Missouri; Alton, and Cairo, Illinois; Princeton, Indiana; and Paducah, Kentucky.
- The earthquake caused downed chimneys, cracked walls, shattered windows, and broken plaster to school buildings, churches, private houses, and to almost all the buildings in the commercial section of Charleston, MO.

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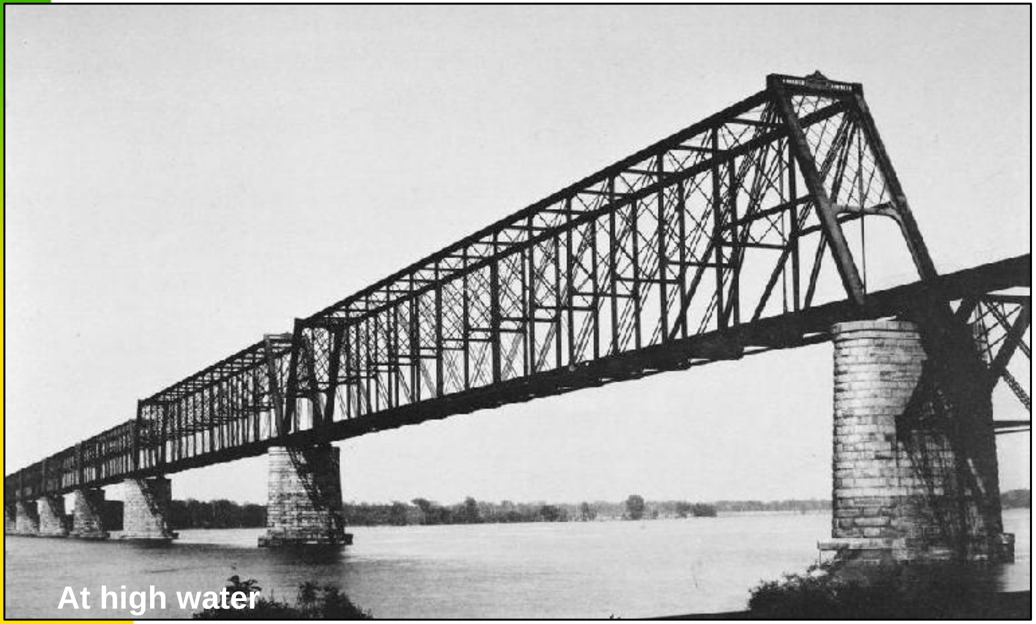
Illinois Central Bridge at Cairo, IL



- The Illinois Central Railroad bridge across the Ohio River at Cairo, IL was the longest iron or steel bridge in world when completed in 1889 (4 miles).
- One of its masonry bents was cracked and severely damaged during Oct 1895 Charleston, MO quake

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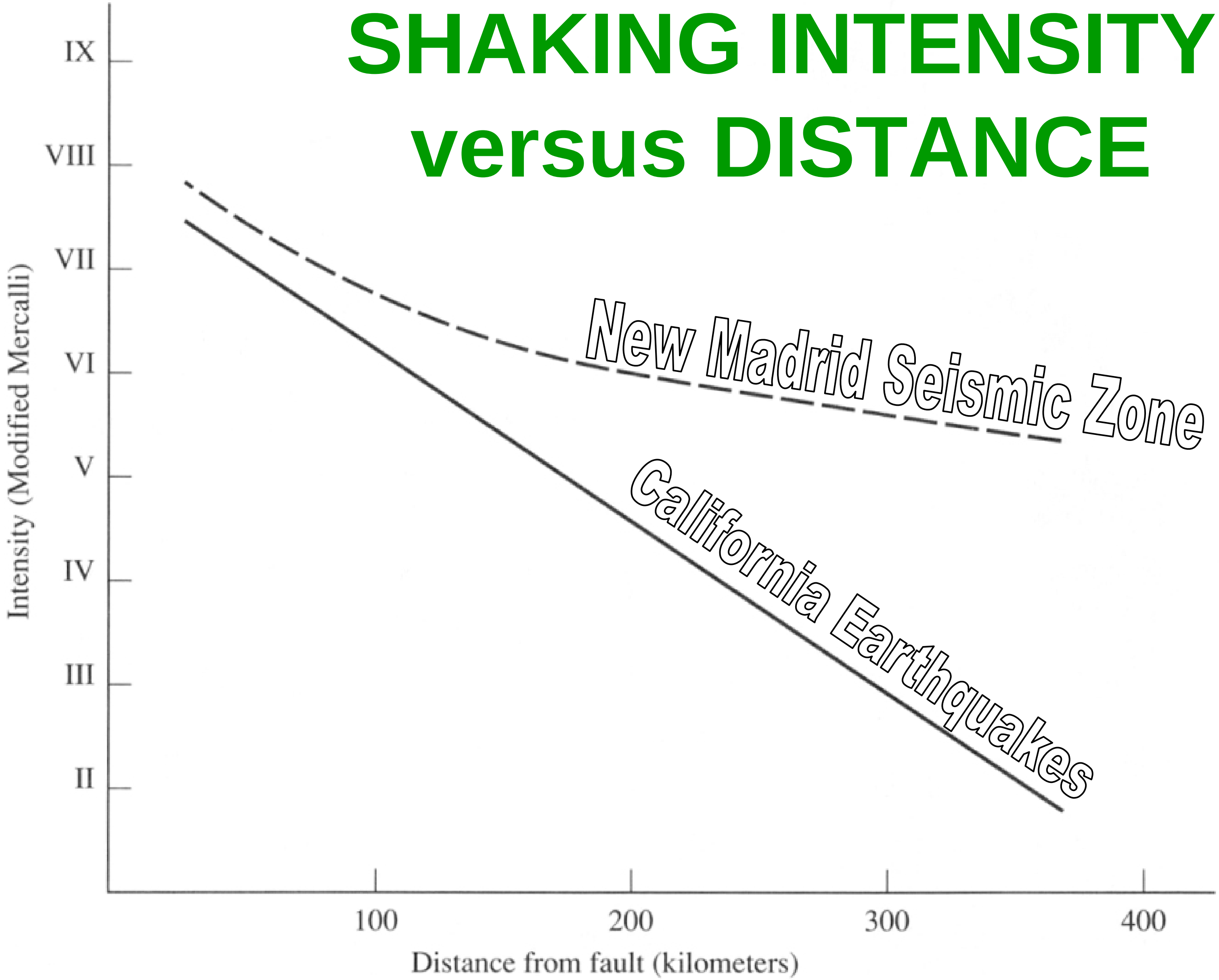
SHAKING INTENSITY versus DISTANCE



Midwest quakes are less frequent, but much more lethal than California quakes because there is <u>less damping</u> of seismic energy.

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MOST LIKELY QUAKE

- In our lifetimes, the most likely earthquake to impact St. Louis would be something similar to the Magnitude 6.6 Charleston, MO quake of 1895, which has a recurrence frequency of 70+/- 15 years (overdue since 1980).
- It could emanate from either the New Madrid Zone or the Wabash Valley Fault Zone, or even from south central Illinois

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