A PRIMER ON PALEOLIQUEFACTION INVERSE ANALYSIS AND ITS RESEARCH POTENTIAL IN CASCADIA

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University of Washington

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T236. CHARACTERIZING CASCADIA'S EARTHQUAKES—REEXAMINING OPEN QUESTIONS ABOUT CASCADIA SEISMIC AND TSUNAMI HAZARDS

OUTLINE

Motivation

Paleoliquefaction Inverse-Analysis

- Traditional Analytics
- State-of-the-Art Analytics
- Demonstration

Research Potential in Cascadia

Conclusions

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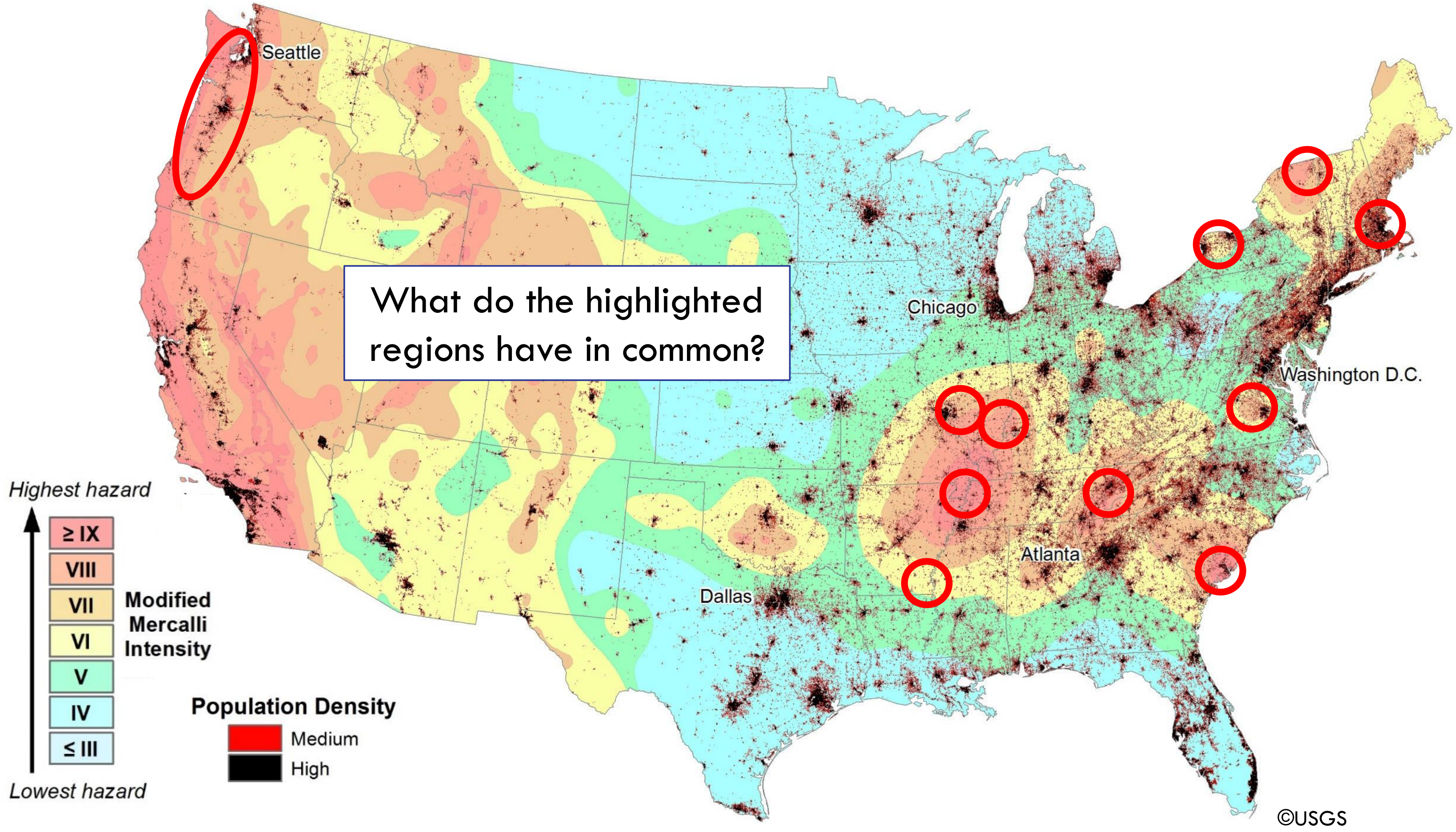
Seattle
Chicago
Washington D.C.
Atlanta
Dallas
What do the highlighted regions have in common?
Highest hazard
≥ IX
VIII
VII
VI
V
IV
≤ III
Lowest hazard
Modified Mercalli Intensity
Population Density
Medium
High
©USGS

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Phases of Paleoliquefaction Analysis

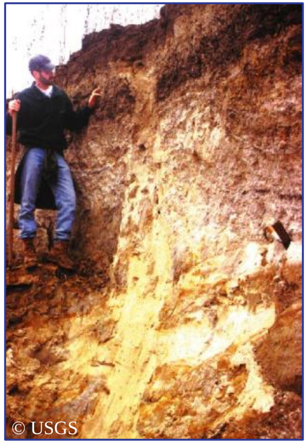
Phase 1: Field Interpretation

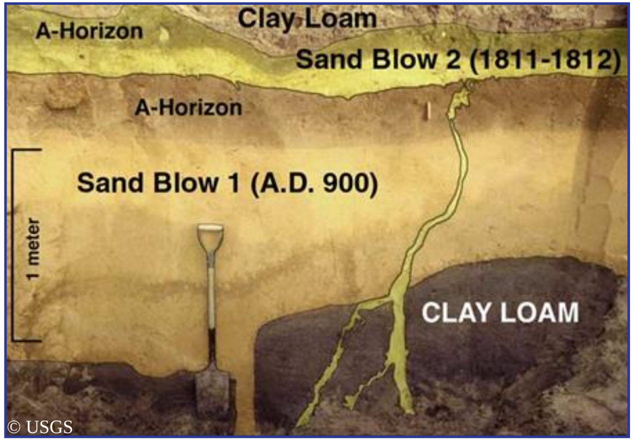
Liquefaction during 2010-2011 Canterbury Earthquakes

Phases of Paleoliquefaction Analysis

Phase 1: Field Interpretation

- Locate features
- Seismically induced?
- Date (e.g., C-14; OSL; stratigraphy) and tentatively group features





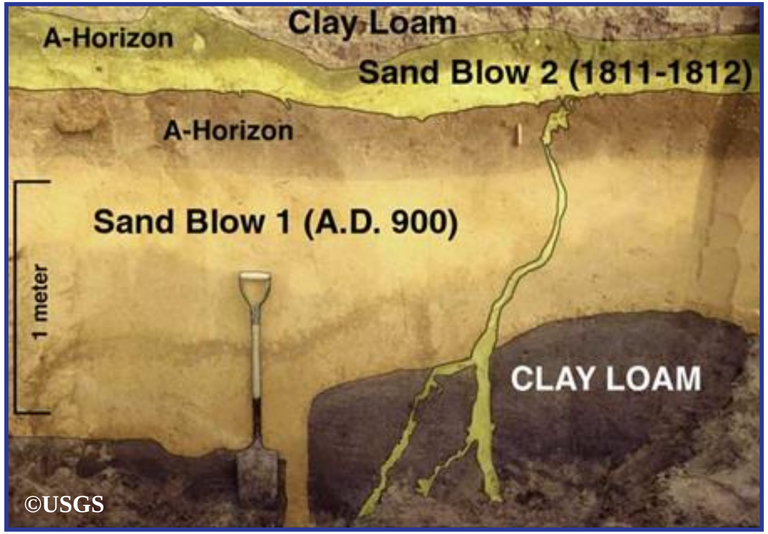
Phases of Paleoliquefaction Analysis

Phase 1: Field Interpretation

Trenching modern and paleo-liquefaction features in NZ

Phases of Paleoliquefaction Analysis

Phase 2: Inverse-analysis to compute seismic parameters



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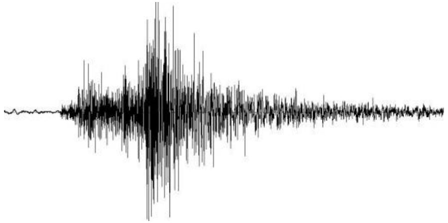

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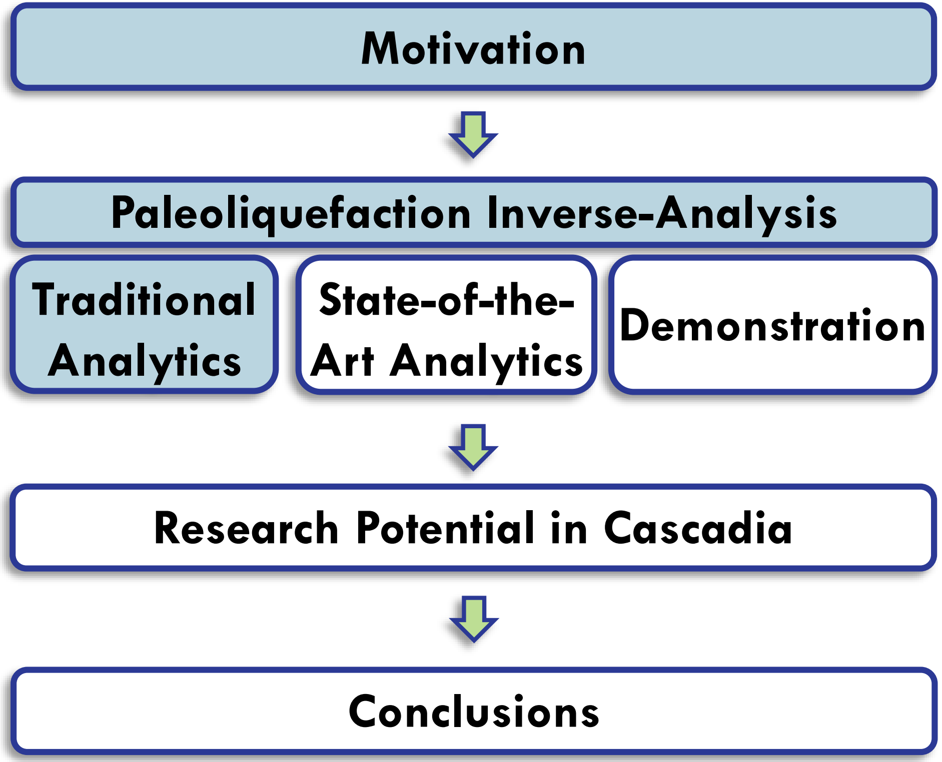
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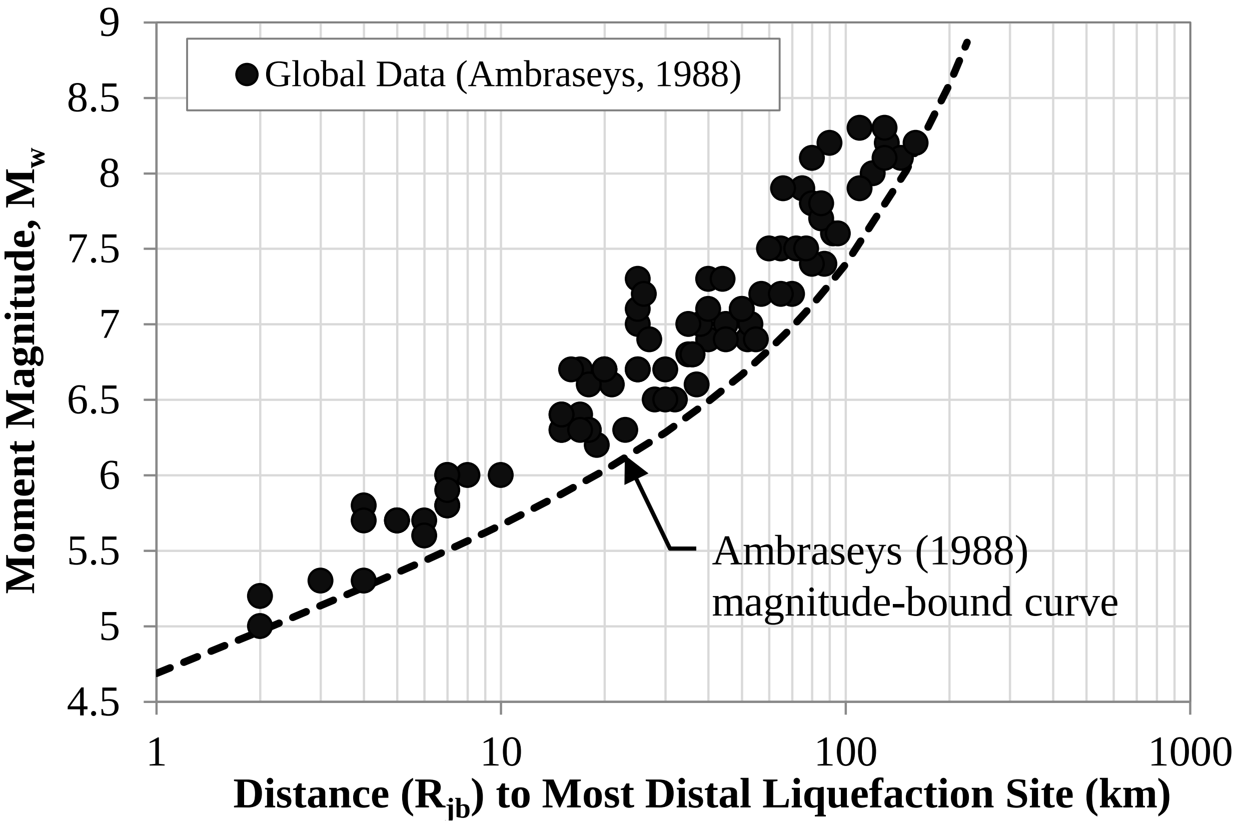
Traditional Paleoliquefaction Analytics: Magnitude Bound Approach

Magnitude-Bound Correlation



Traditional Paleoliquefaction Analytics: Magnitude Bound Approach

Magnitude-Bound Correlation

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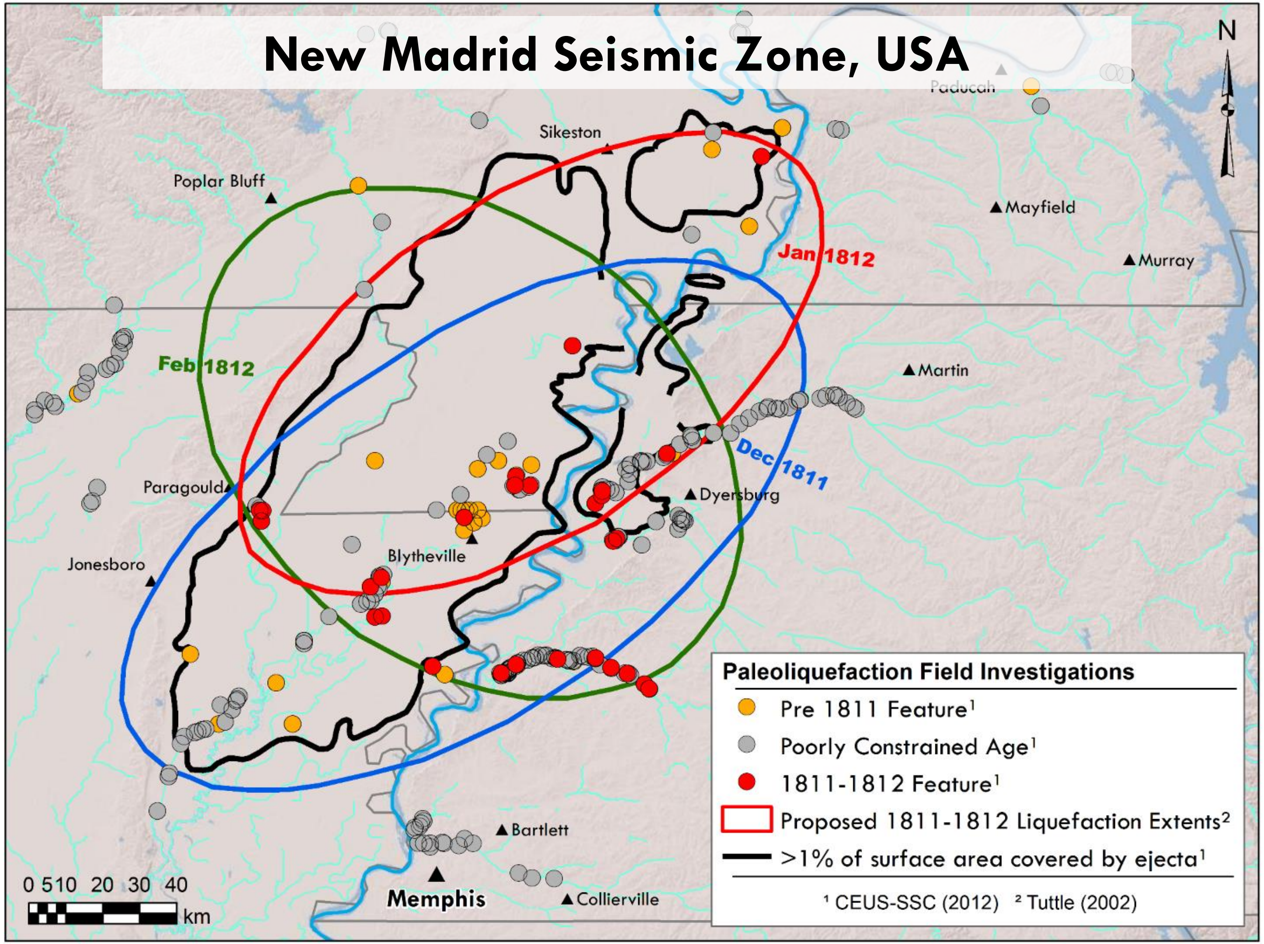
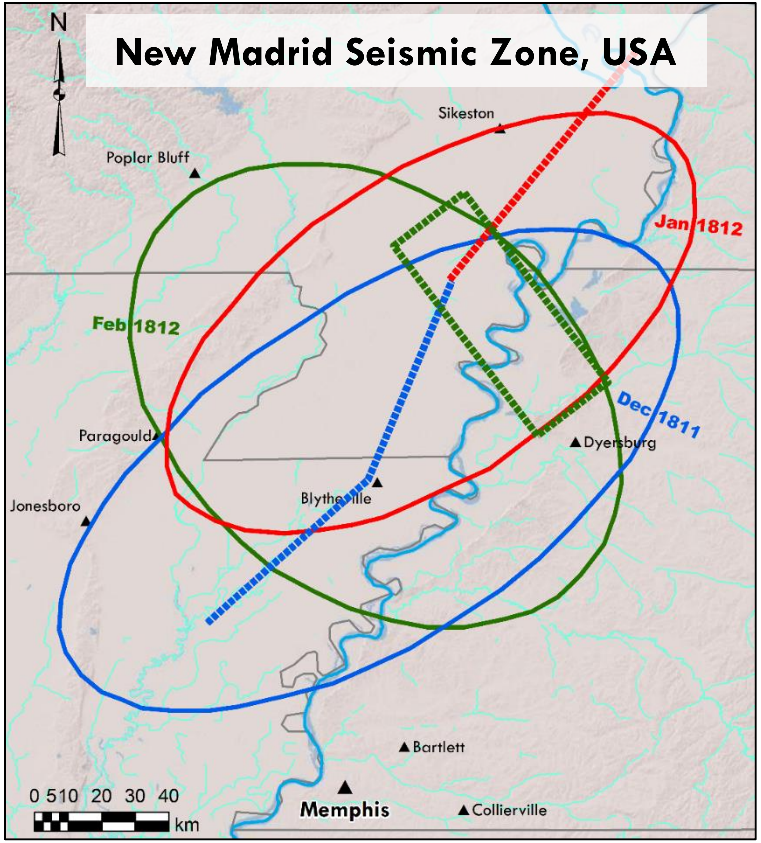
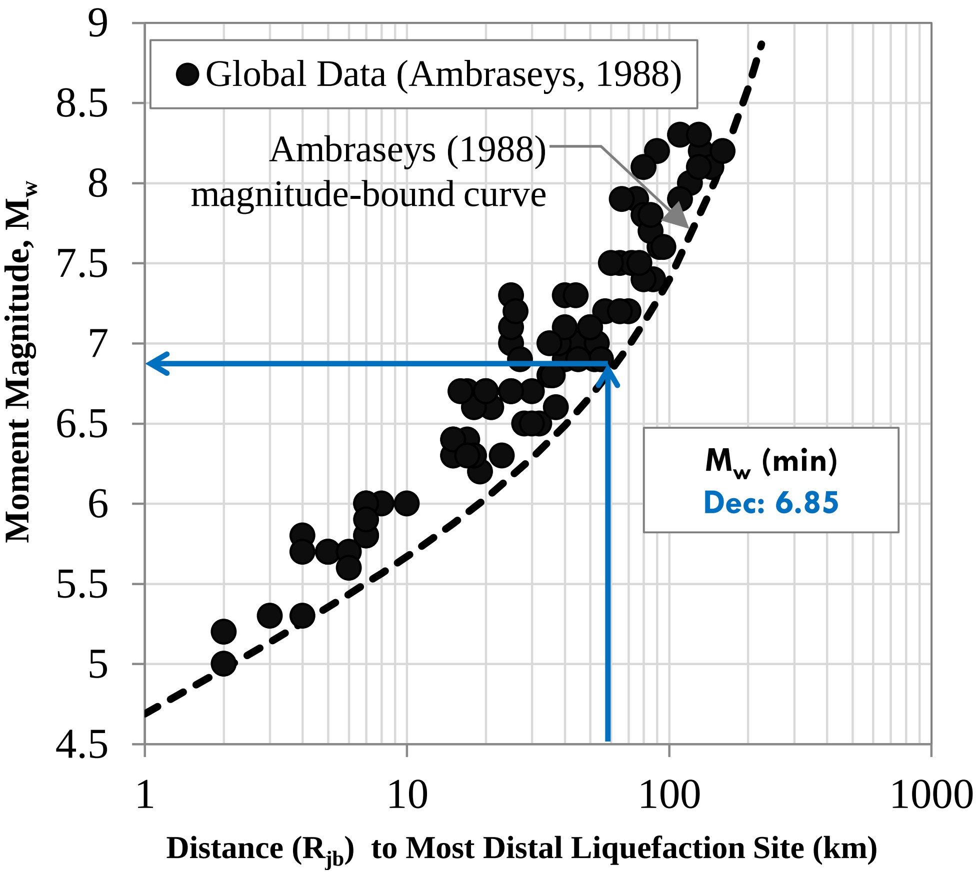
Application



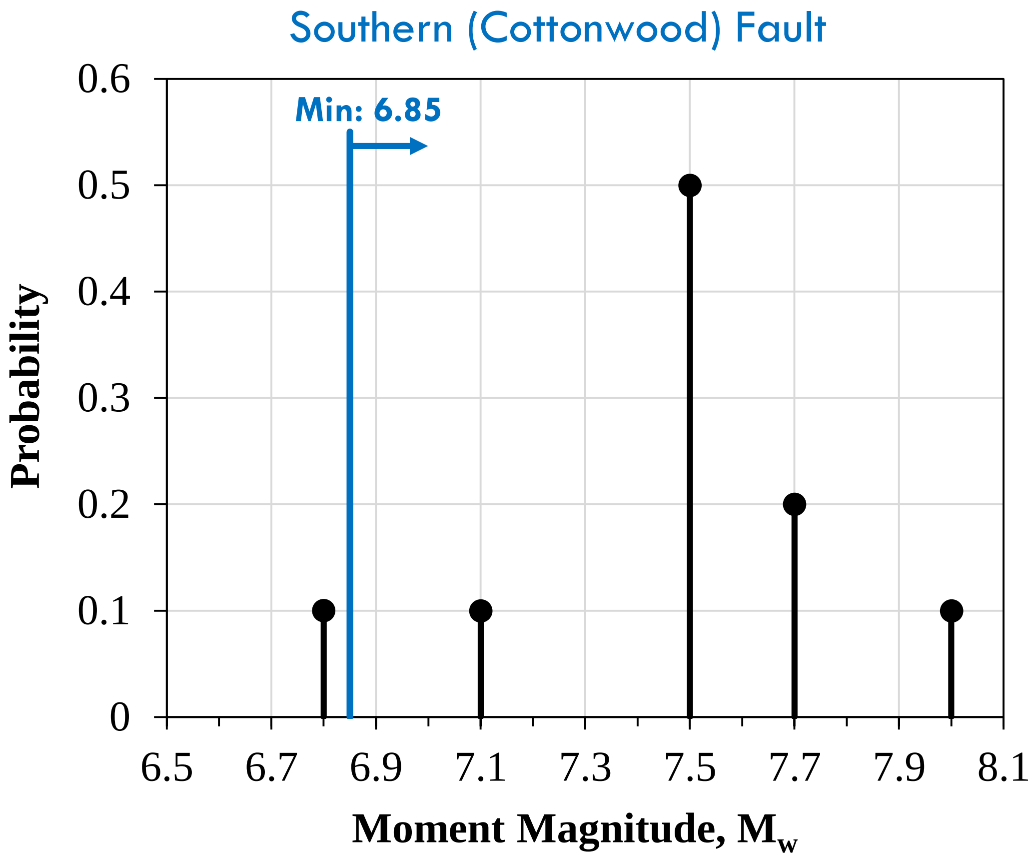
Traditional Paleoliquefaction Analytics: Magnitude Bound Approach



CEUS-SSC (2012) Preferred Rupture Scenario



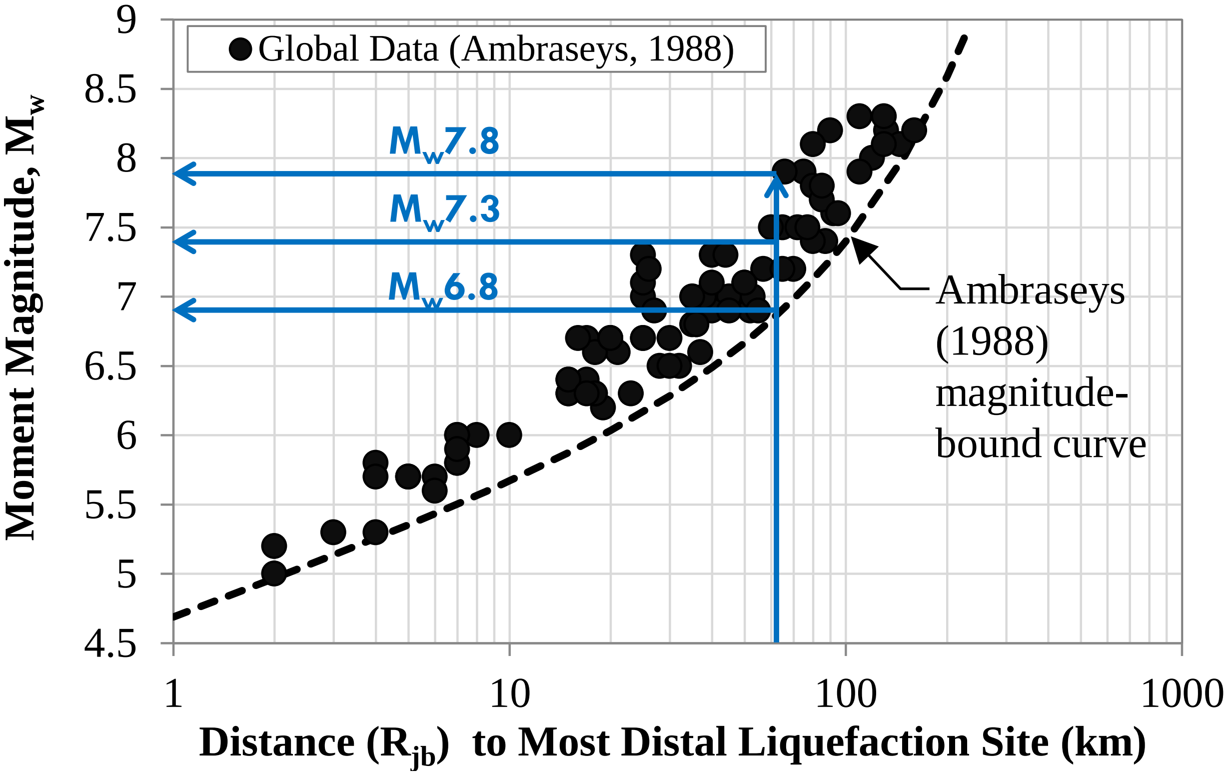
Traditional Paleoliquefaction Analytics: Magnitude Bound Approach



2014 USGS NSHMP Rupture Magnitude Probabilities

Traditional Paleoliquefaction Analytics: Magnitude Bound Approach

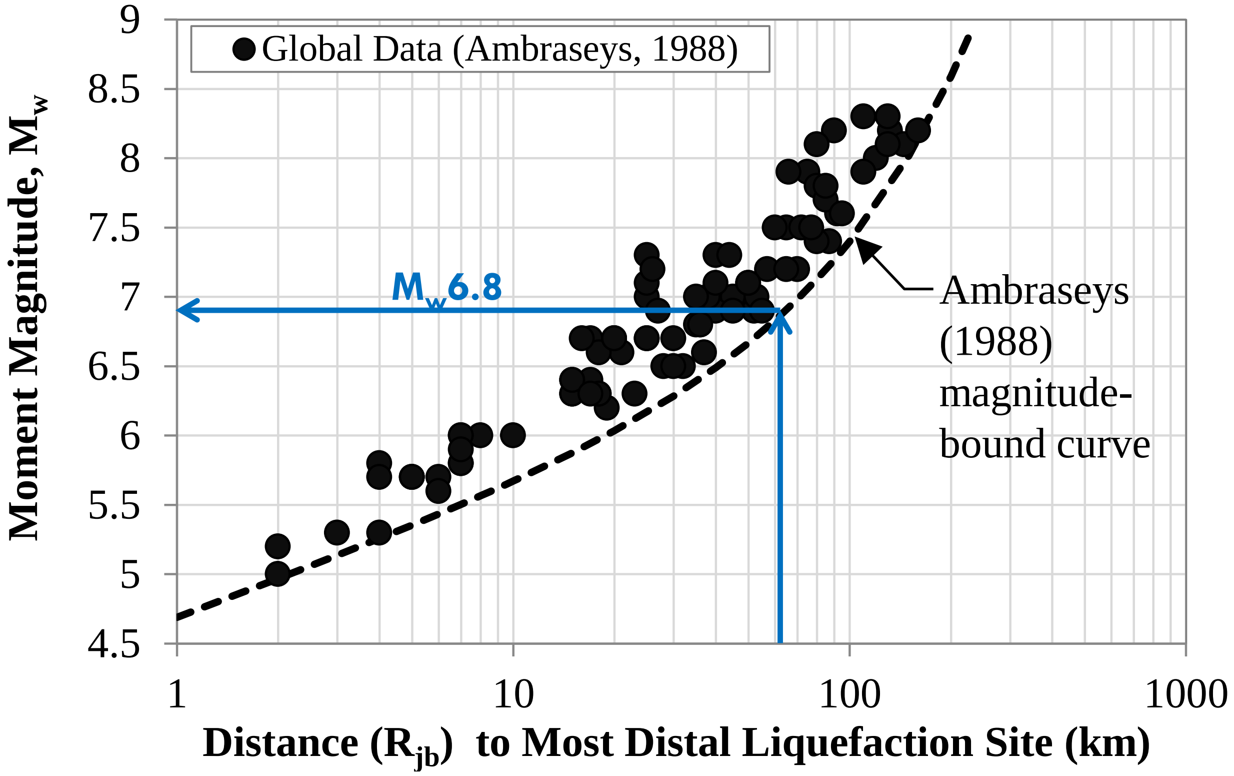
Limitation #1: Provides only a lower-bound estimate of magnitude



M_w6.8
or
M_w7.3
or
M_w7.8?

Traditional Paleoliquefaction Analytics: Magnitude Bound Approach

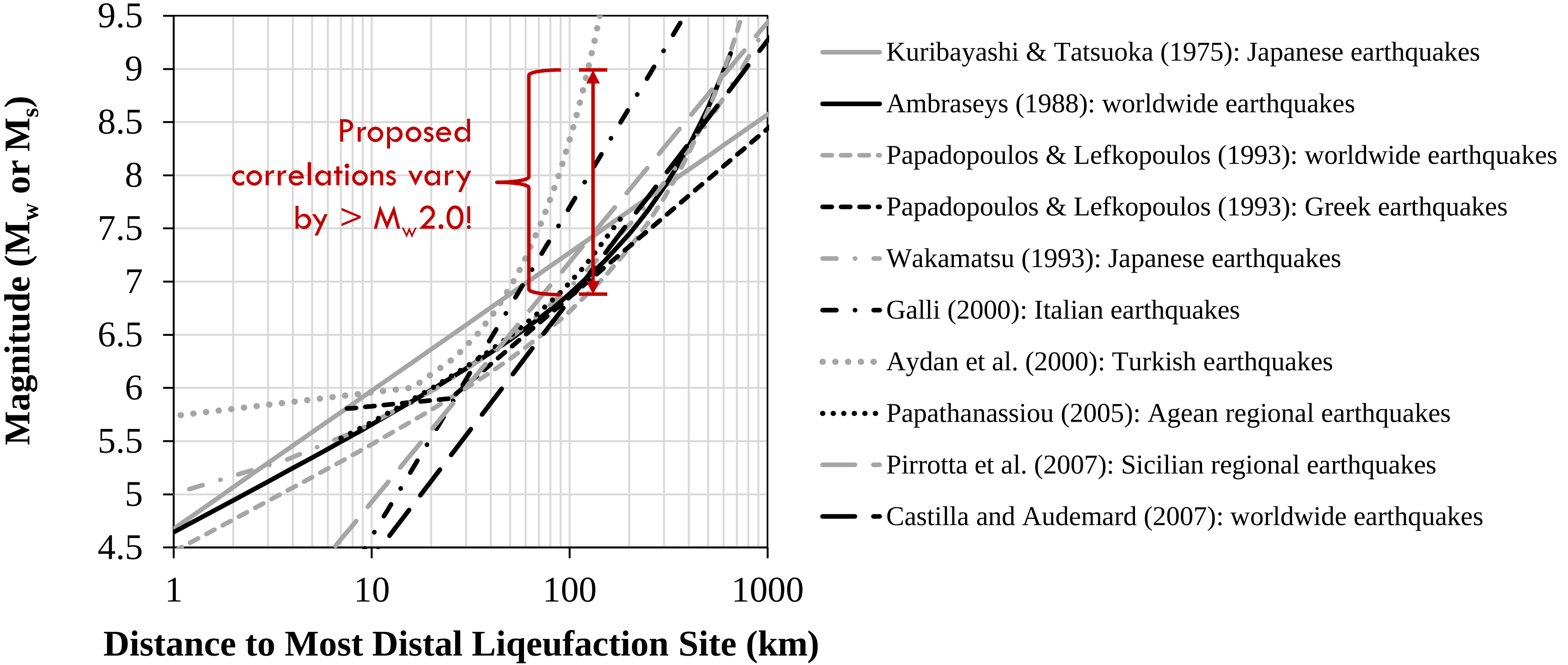
<u>Limitation #2</u>: Provides no quantification of uncertainty



What does "lower-bound" *really* mean?

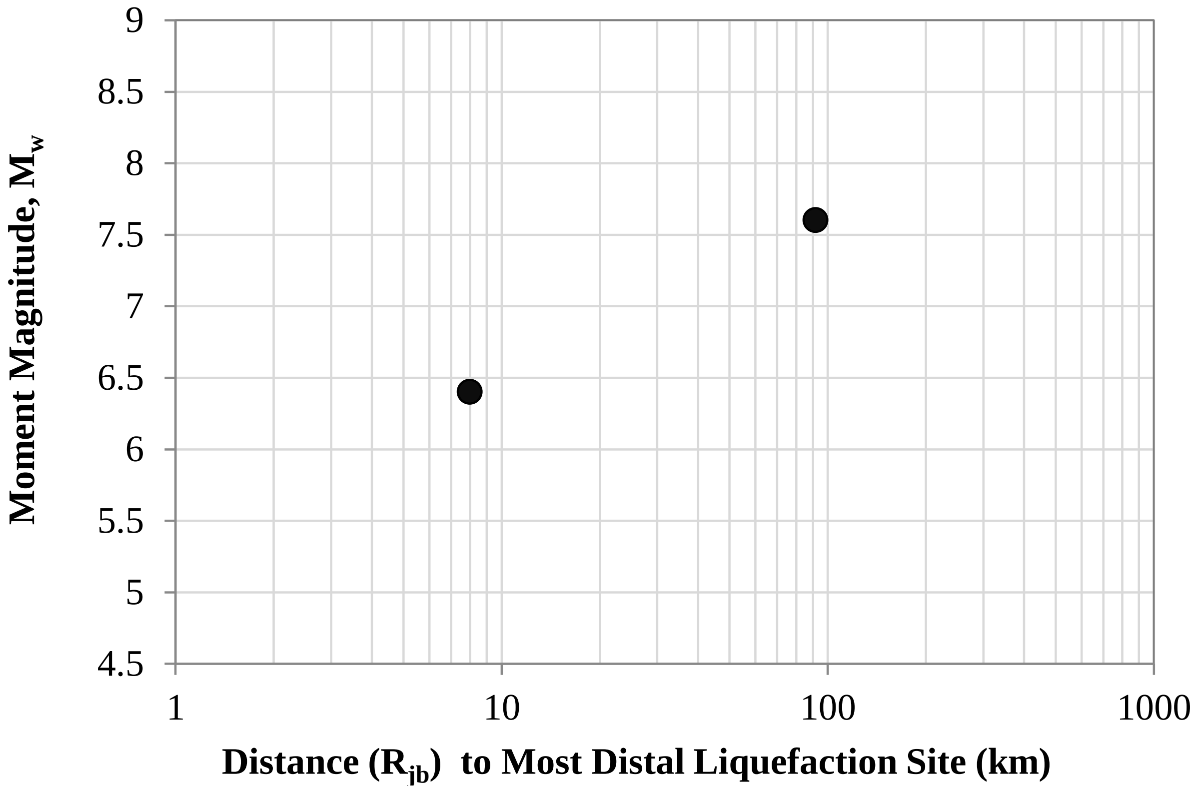
Traditional Paleoliquefaction Analytics: Magnitude Bound Approach

<u>Limitation #3</u>: Commonly relies on *global* correlations



Traditional Paleoliquefaction Analytics: Magnitude Bound Approach

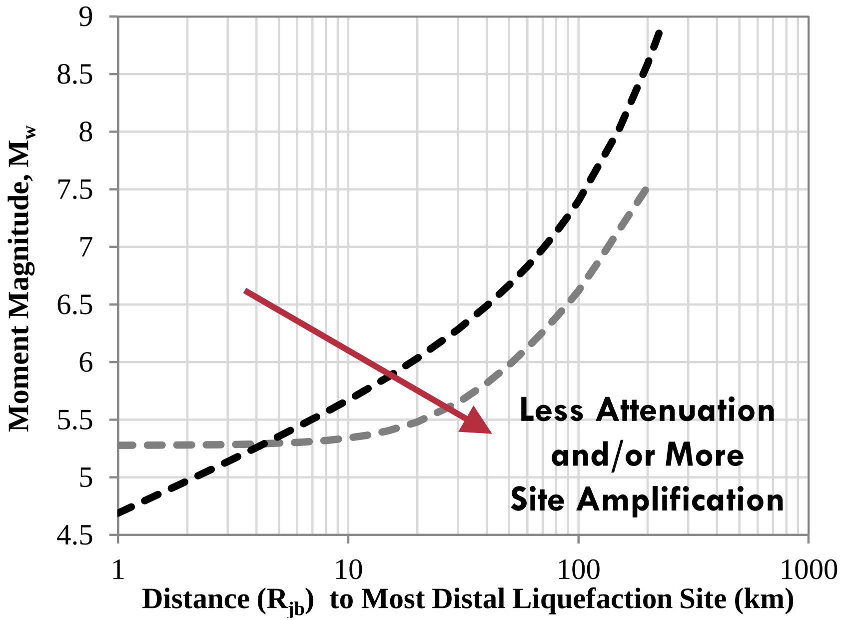
<u>Limitation #4</u>: Relies on field observations…what if earthquakes are too infrequent?



How do we develop a correlation from this data?

Traditional Paleoliquefaction Analytics: Magnitude Bound Approach

Can magnitude-bound correlations be developed without field observations?



Intuitively, we may deduce that:

The curve shape is a function of energy attenuation & site response

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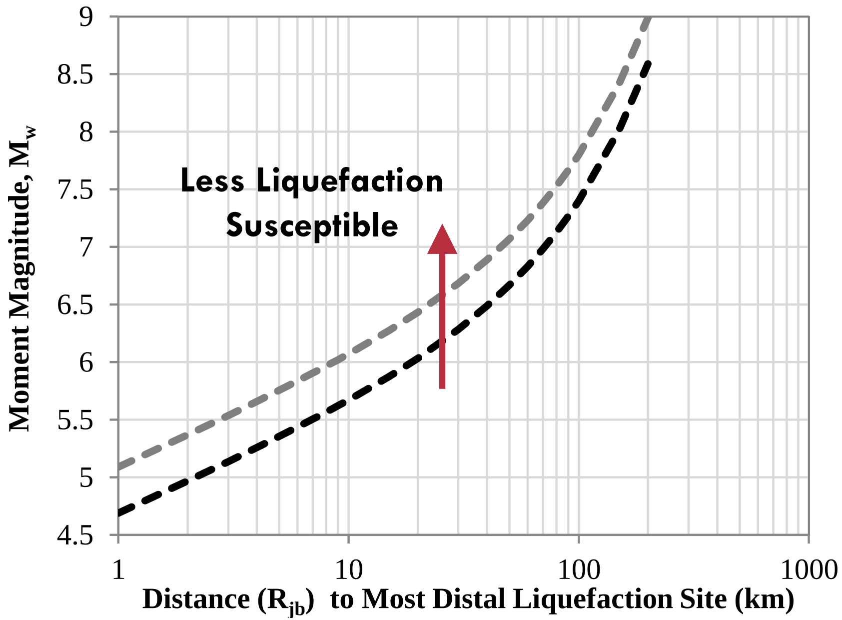

Intuitively, we may deduce that:

The curve shape is a function of energy attenuation & site response

The curve position is a function of liquefaction susceptibility

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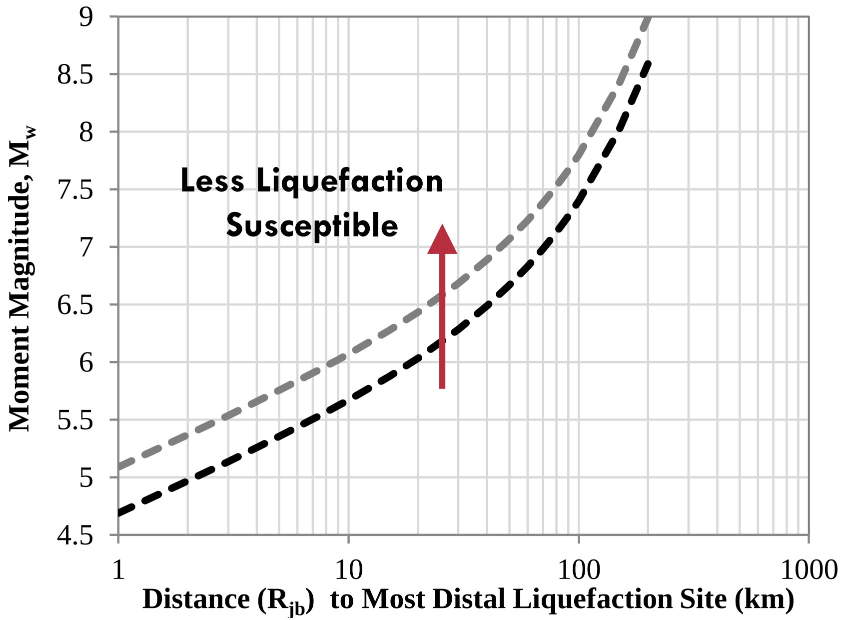

Intuitively, we may deduce that:

The curve shape is a function of energy attenuation & site response

The curve position is a function of liquefaction susceptibility

We know what factors control the curve. Can we compute curves without field observations?

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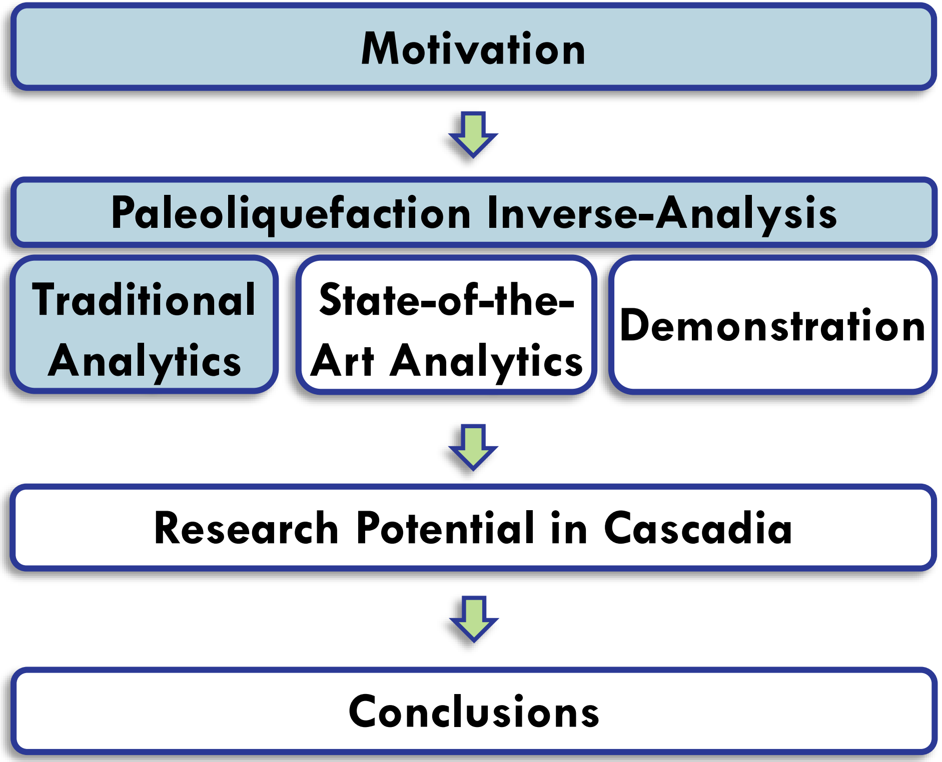
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Can magnitude-bound correlations be developed without field observations?

Using (1) liquefaction triggering mechanics; (2) ground motion prediction equations; and (3) the total probability theorem to integrate over model and parameter uncertainties:

The probability that a site liquefies, given magnitude (M) and site-to-source distance (R), is:

Using Stress-based liquefaction triggering mechanics:

$$P(\tau \geq \tau_t | \mathrm{EQK: M, R}) = \int_{a_{max}} \int_{r_d} P(\tau \geq \tau_t | a_{max}, r_d) \, f(a_{max}|M, R) \, f_{r_d}(r_d) \cdot dr_d \cdot da_{max}$$

Using Strain-based liquefaction triggering mechanics:

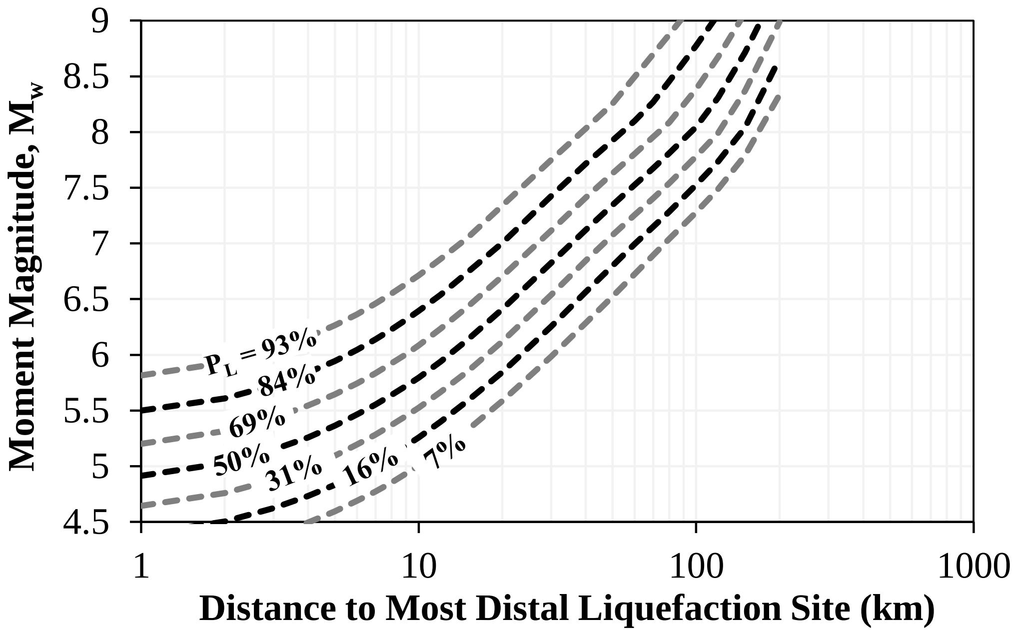
$$P(\gamma \geq \gamma_t | \mathrm{EQK: M, R}) = \int_{a_{max}} \int_{r_d} \int_{\frac{G}{G_{max}}} P\left(\gamma \geq \gamma_t \middle| a_{max}, r_d, \frac{G}{G_{max}}\right) f(a_{max}|M, R) \, f_{r_d}(r_d) \, f_{\frac{G}{G_{max}}}\left(\frac{G}{G_{max}}\right) d\frac{G}{G_{max}} \cdot dr_d \cdot da_{max}$$

Combining results from the stress- and strain-based frameworks…

Can magnitude-bound correlations be developed without field observations?

YES!

Developed for New Zealand



State-of-the-Art Paleoliquefaction Analytics

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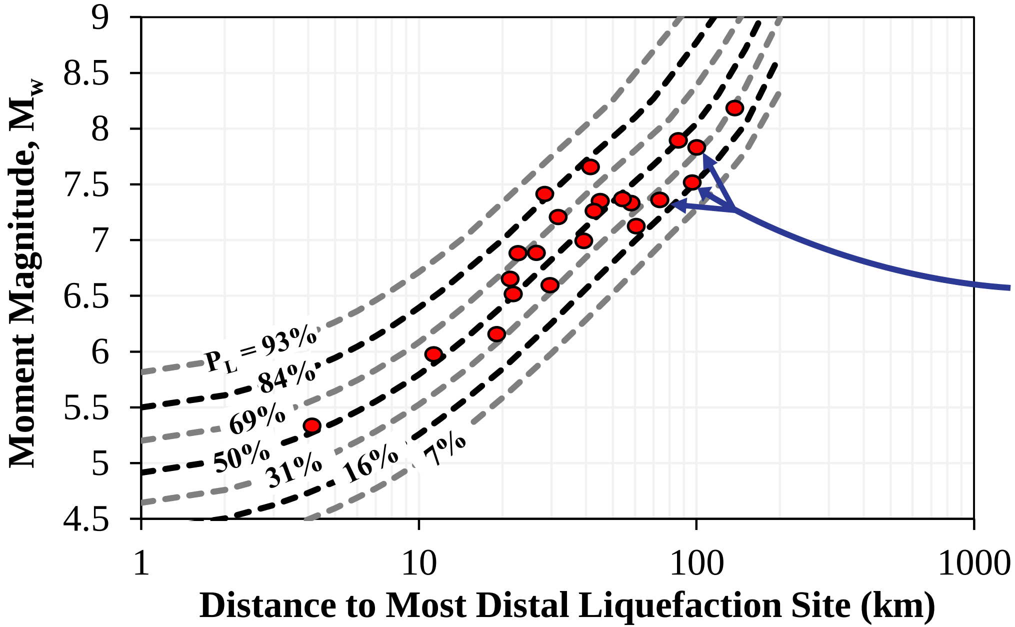
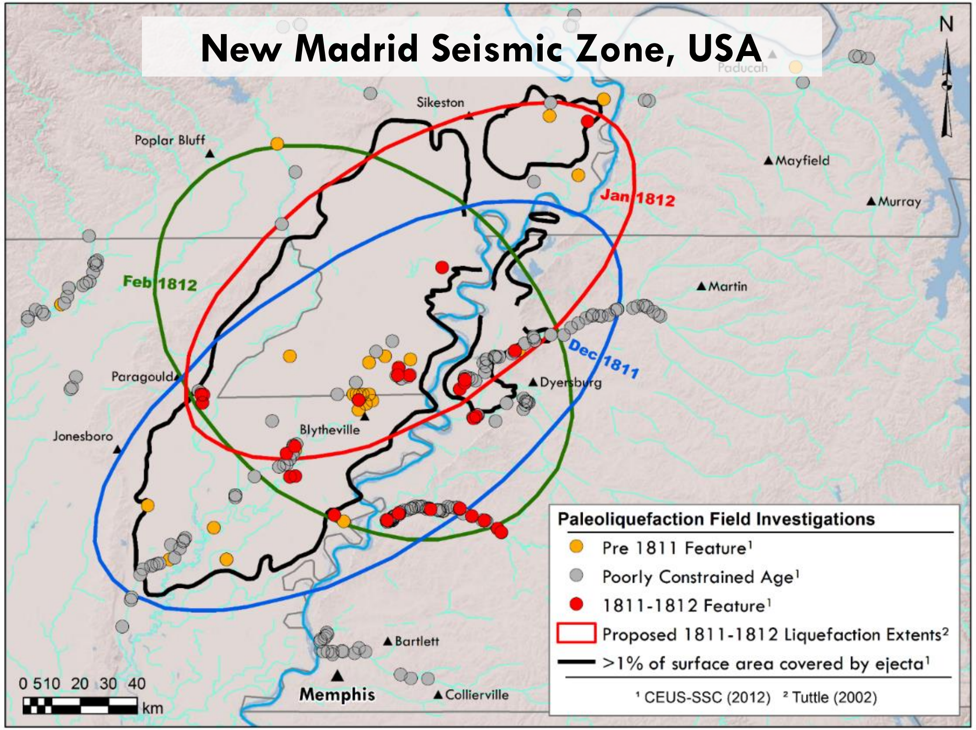
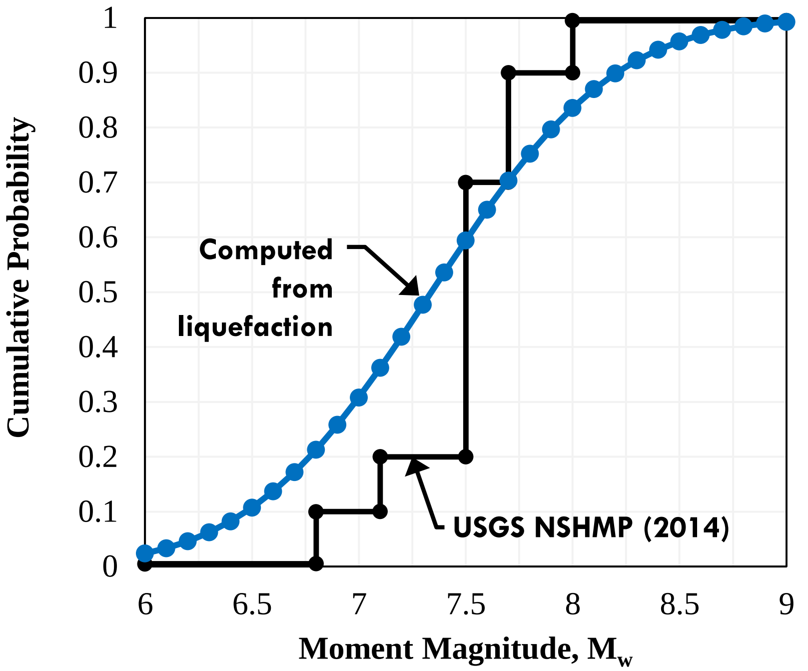


Empirical data from New Zealand…fits ±1σ mechanics-based prediction

State-of-the-Art Paleoliquefaction Analytics





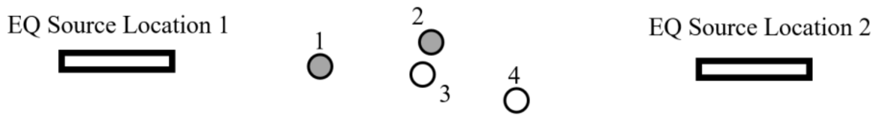
Much more informative, but still two problems:

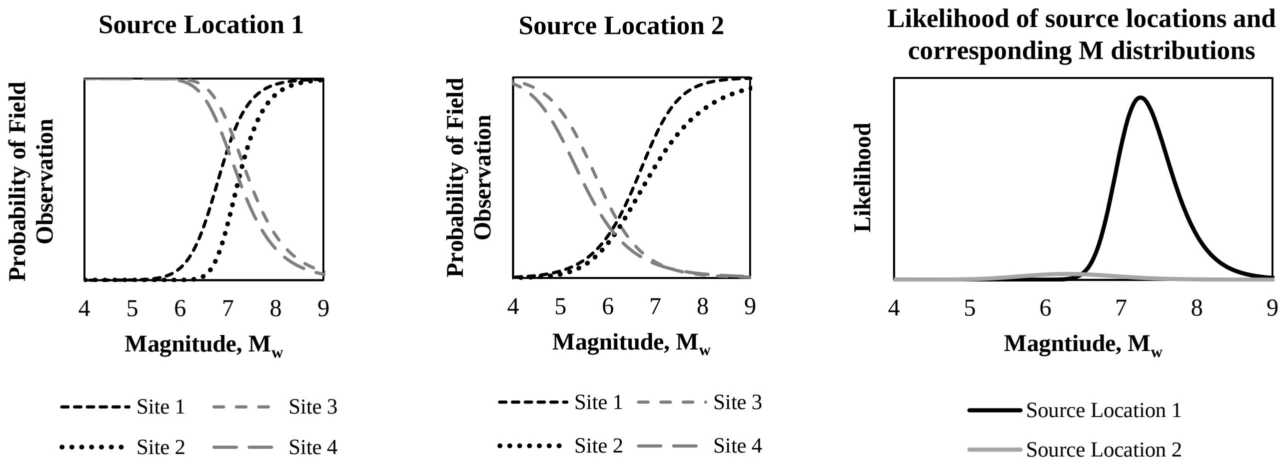
1) Not all field evidence is utilized (from mechanics standpoint)
2) Must know/assume source location…what if we don't know?

State-of-the-Art Paleoliquefaction Analytics

Combining <u>all field data</u>, we can compute the likelihood that an earthquake at a given location, having given magnitude, would produce a <u>series</u> of field observations:

$$L(M|x) = P(X = x|M) = \prod_{i=1}^{N} P(X_i = x_i|M)$$





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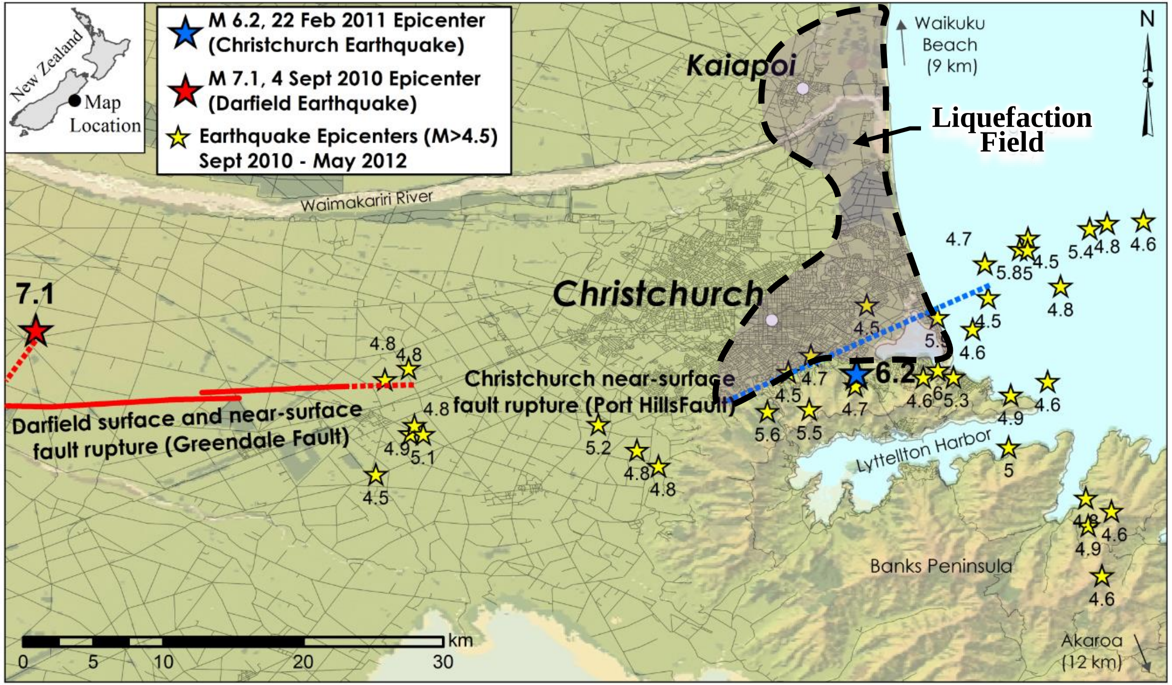
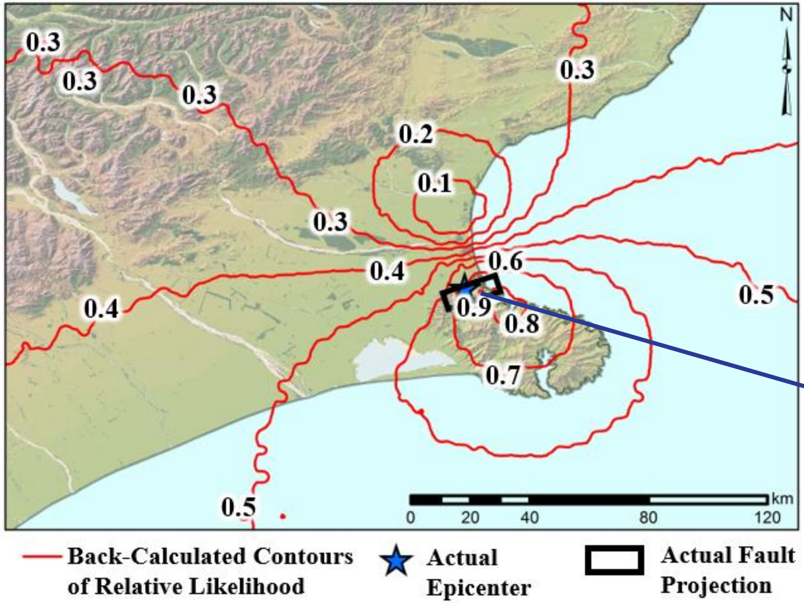
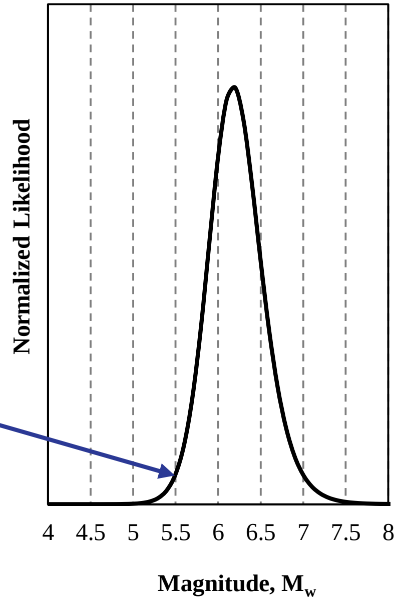
Proof-of-Concept: 2011 Christchurch, New Zealand, Earthquake



State-of-the-Art Paleoliquefaction Analytics

<u>Proof-of-Concept</u>: 2011 Christchurch, New Zealand, Earthquake





<u>Findings:</u>

1) Most likely source-location is within actual fault projection
2) Corresponding median magnitude (M6.25) is very close to actual (M6.2)

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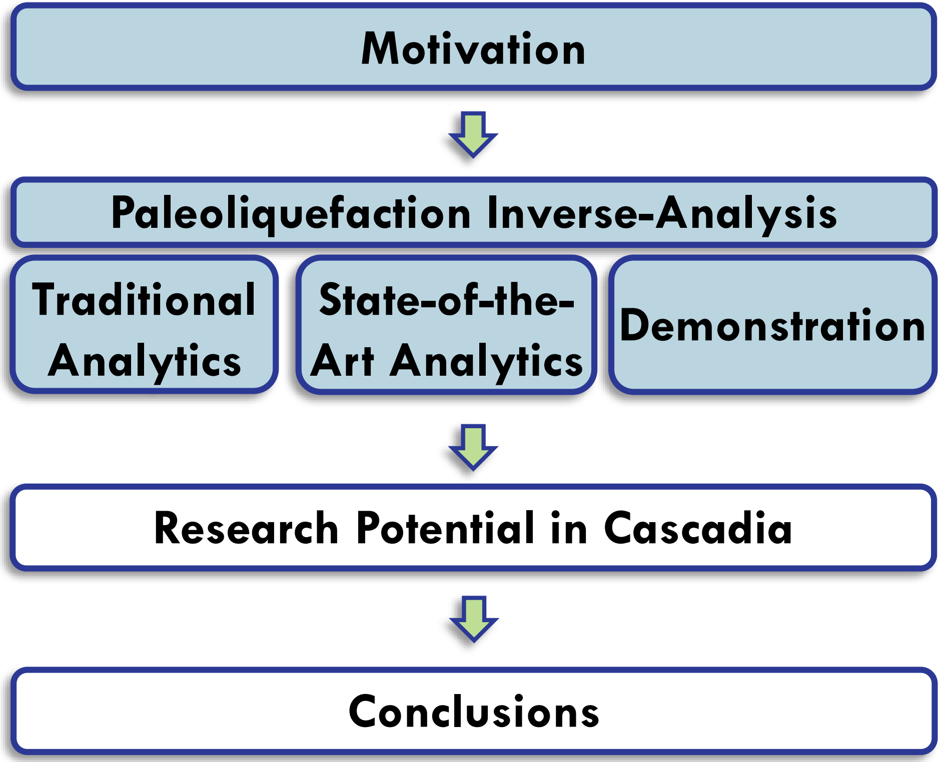
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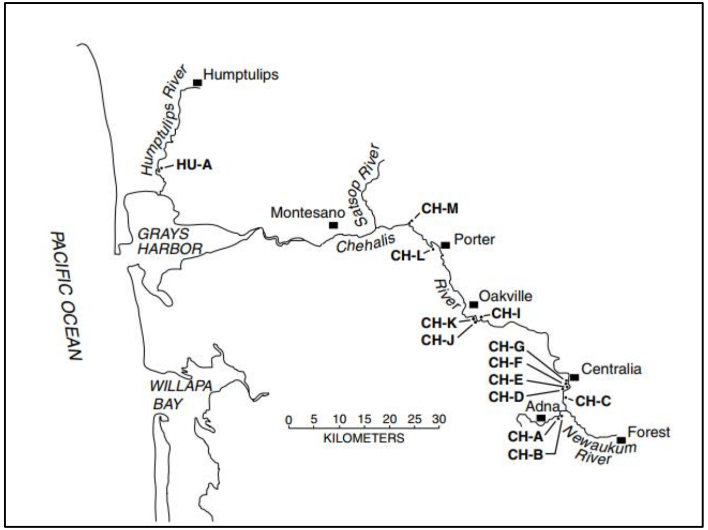
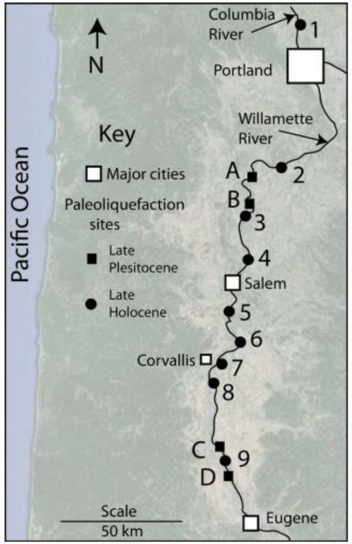
What is needed in the CSZ moving forward?

A public database compiling all paleoliquefaction data, to include

a. Location
b. Dating
c. In-situ geotechnical test data (very few known study-sites have this) = $



Obermeier and Dickenson (2000)



Peterson et al. (2014)

Where does paleoliquefaction fit in the Cascadia puzzle?

Type of Evidence	Earthquake Characteristics Obtainable From Evidence				
	Recurrence Rate	Ground Motions	Rupture Location	Magnitude	Other Source Traits
Dendrochronology					
Diatoms/Microfossils					
Other Subsidence Markers					
Tsunami Deposits/Impacts					
Turbidite Record					
On-Fault Evidence					
Landslides					
Liquefaction	Limited	Very Strong	Strong	Strong	?

Conclusions

- Multidisciplinary collaboration is needed to exploit the results of field studies.
  - Decades of work have too often ended in the use of very simple and debunked methods. This impacts our national seismic hazard maps.

- New paleoliquefaction analytics can probabilistically compute:
  - Causative ground motions at individual sites.
  - Source location and magnitude distribution from regional evidence.

- What is keeping up from applying these new analytics in the CSZ?
  - Existing data must be compiled from all researchers.
  - For most study-sites, in-situ geotechnical tests need to be performed.

References

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