Thoughts Concerning Earthquake Sources in the Northeastern U.S.

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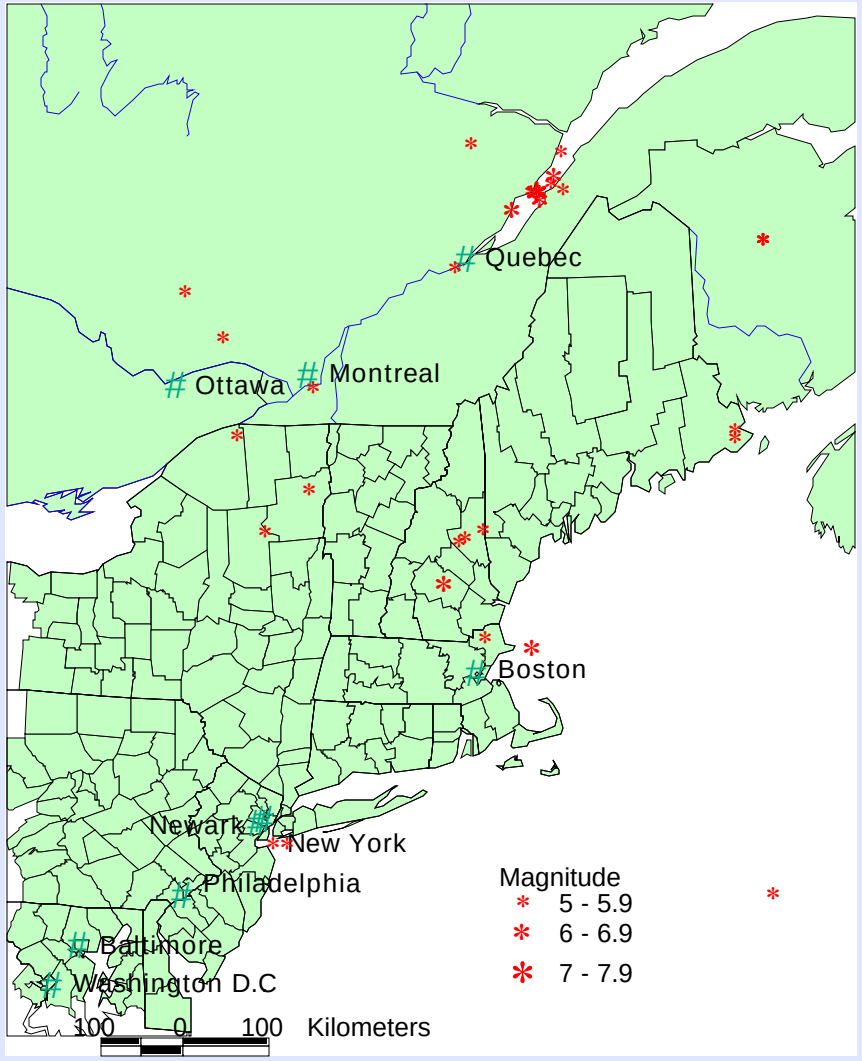
Major Earthquakes in the Northeastern U.S. and Southeastern Canada 1638-2006

These represent all the known or suspected earthquakes of magnitude 5.0 or greater in New England and vicinity.



Earthquake Completeness Thresholds

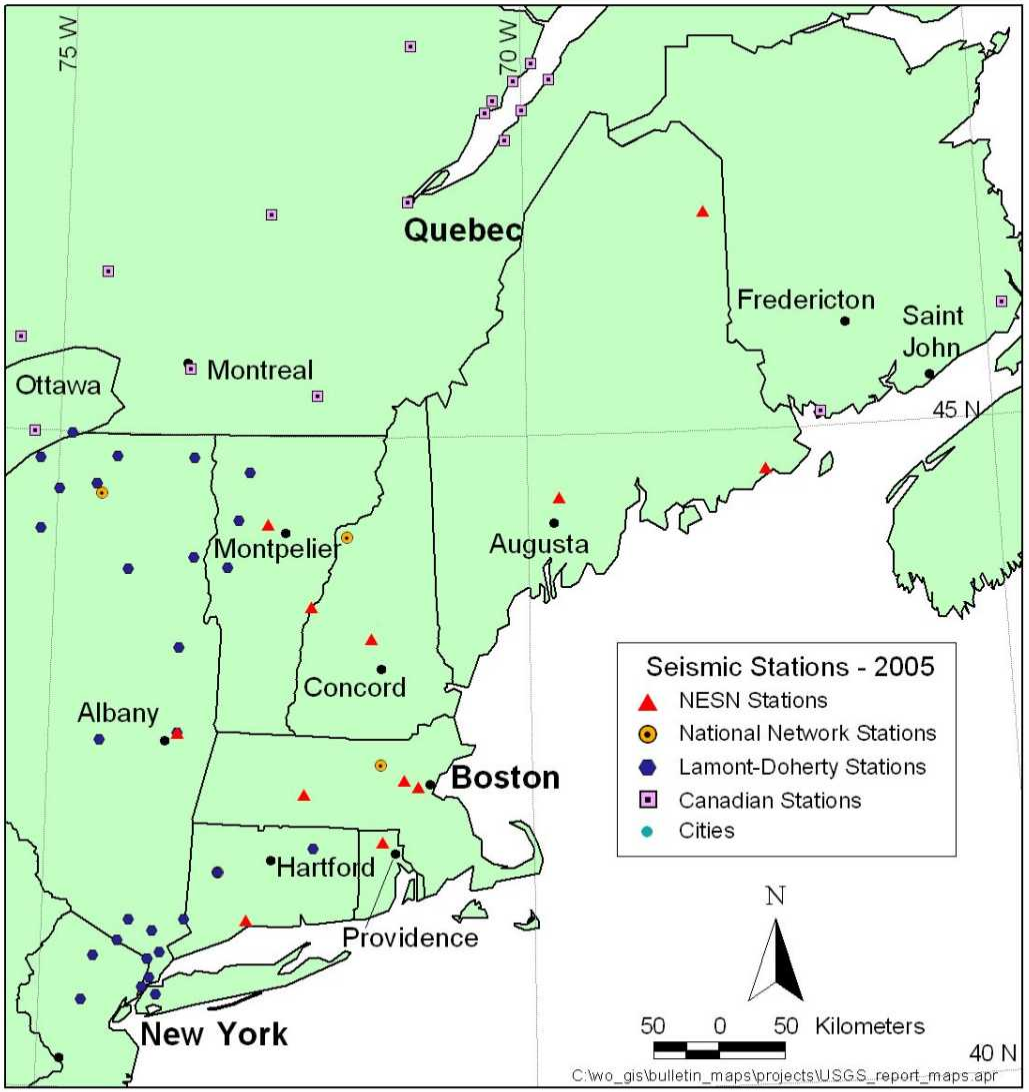
2004-present:
Northern New England - M2.5
Southern New England - M2.0

1992-2003:
Northern New England - M2.7
Southern New England - M2.5

1975-1991:
Northern New England - M2.0
Southern New England - M2.0

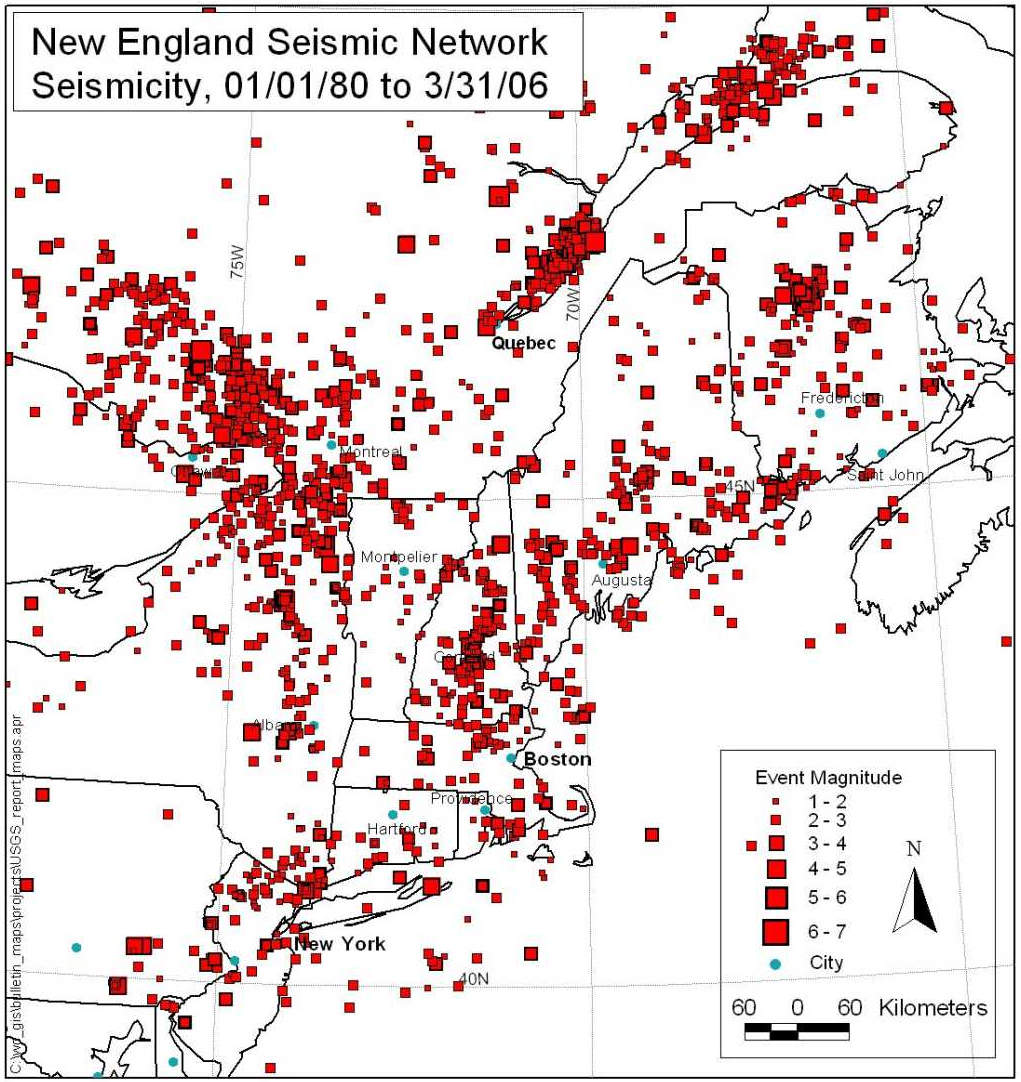
1935-1975:
New England - M2.7 to M3.0

Seismic Network



Seismicity Issues:

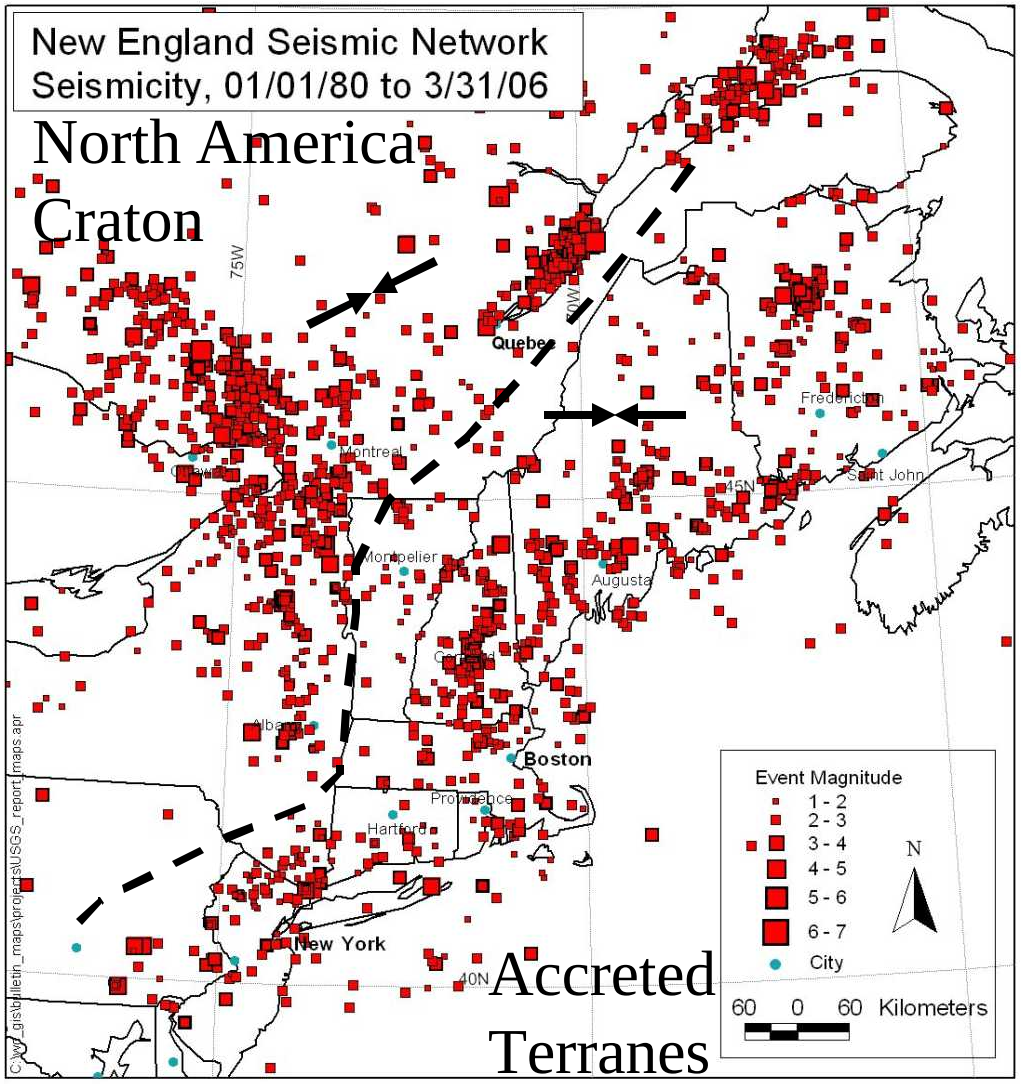
Earthquakes scattered broadly across region, with some areas of more concentrated seismicity and some areas with little or no seismicity



Seismicity Similarities and Differences

North America Craton:
-Steady seismicity rate
-Focal depths surface to 30 km
-Thrust earthquakes
-Average P axis NE-SW
(Charlevoix NW-SE)

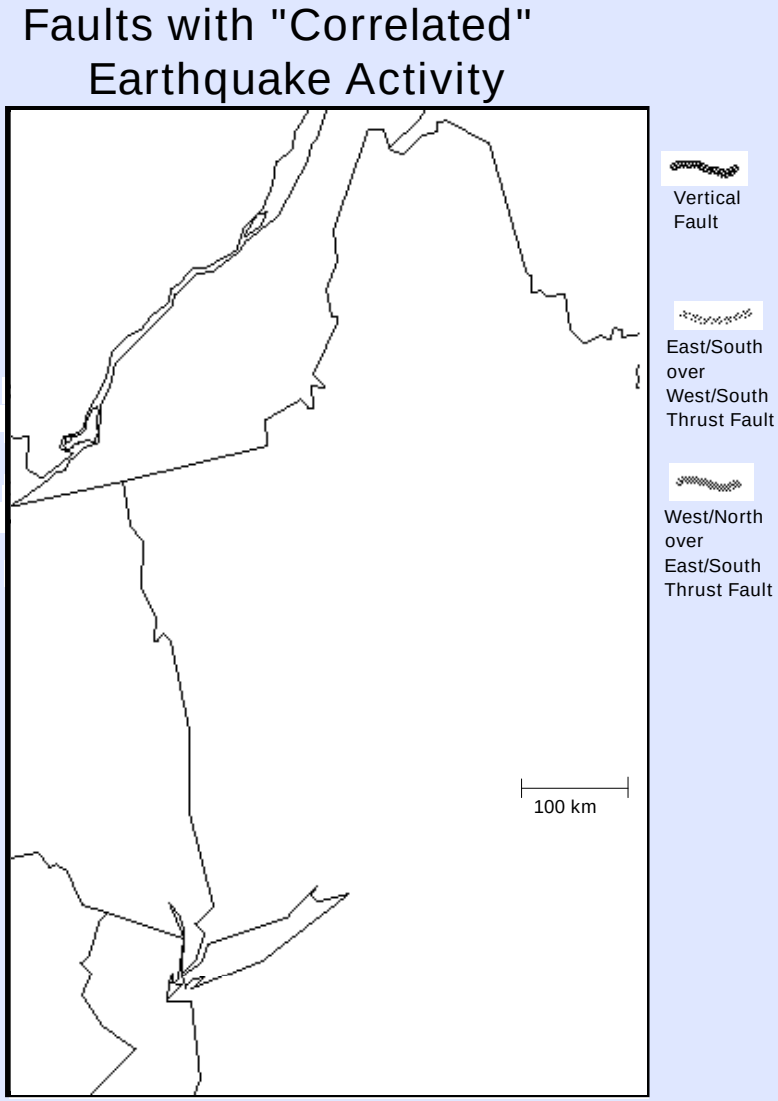
Accreted Terranes:
-Steady seismicity rate
-Focal depths surface to 12 km
(many less than 4 km)
-Thrust earthquakes
-Average P axis E-W



A belt of low seismicity separates the seismic activity of the craton from that of the accreted terranes.

Seismicity and Geologic Structures

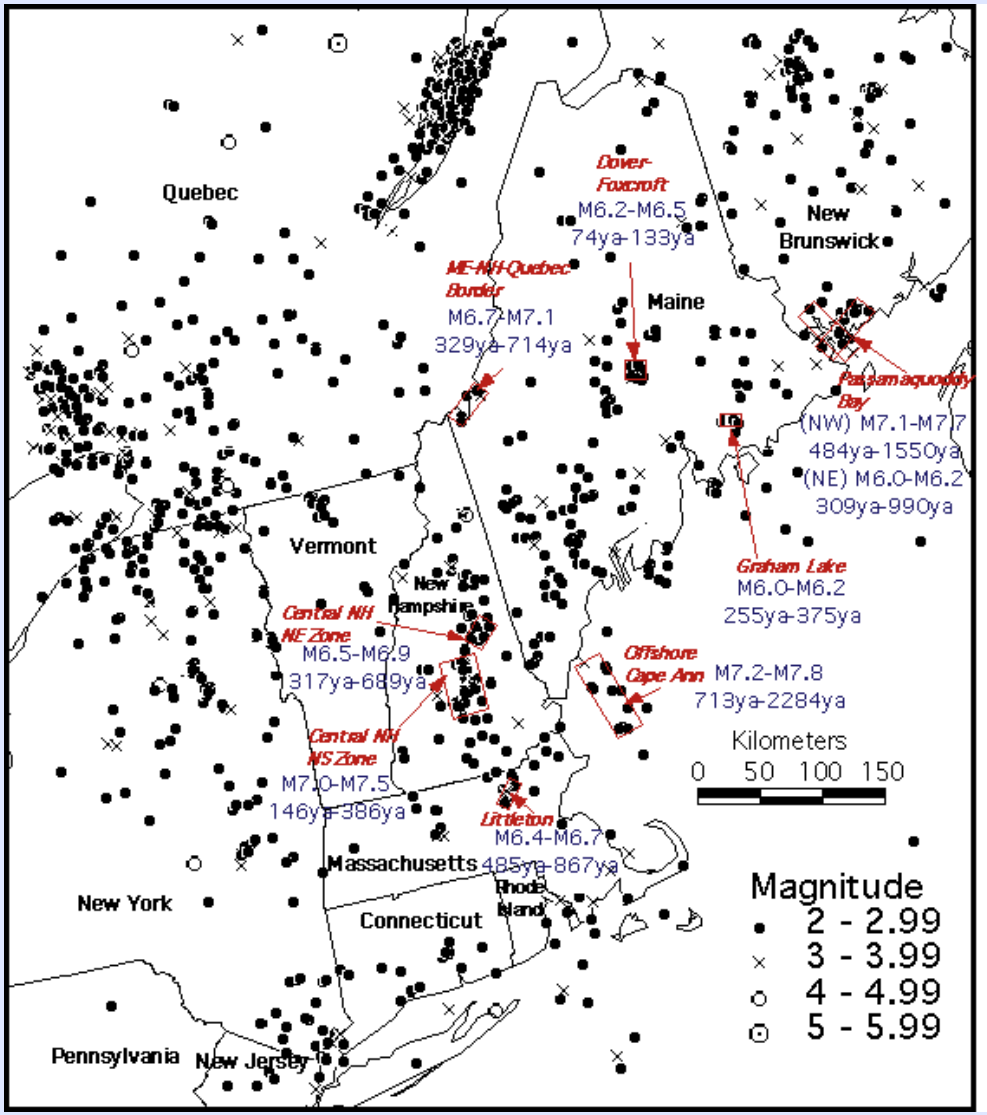
In New England, most earthquakes occur near faults or other structures that show evidence of activity during Mesozoic time (i.e., during the Mesozoic rifting of North America and Africa). Many are older faults that were reactivated at that time. Faults that were not active in the Mesozoic (such as the Taconic thrust faults) show little or no association with modern earthquake activity.



The above is modified from the unpublished Boston College B.S. thesis of Jim Spotila.

Many of the small earthquakes in our region may be very late aftershocks of strong earthquakes that took place hundreds or thousands of years ago.

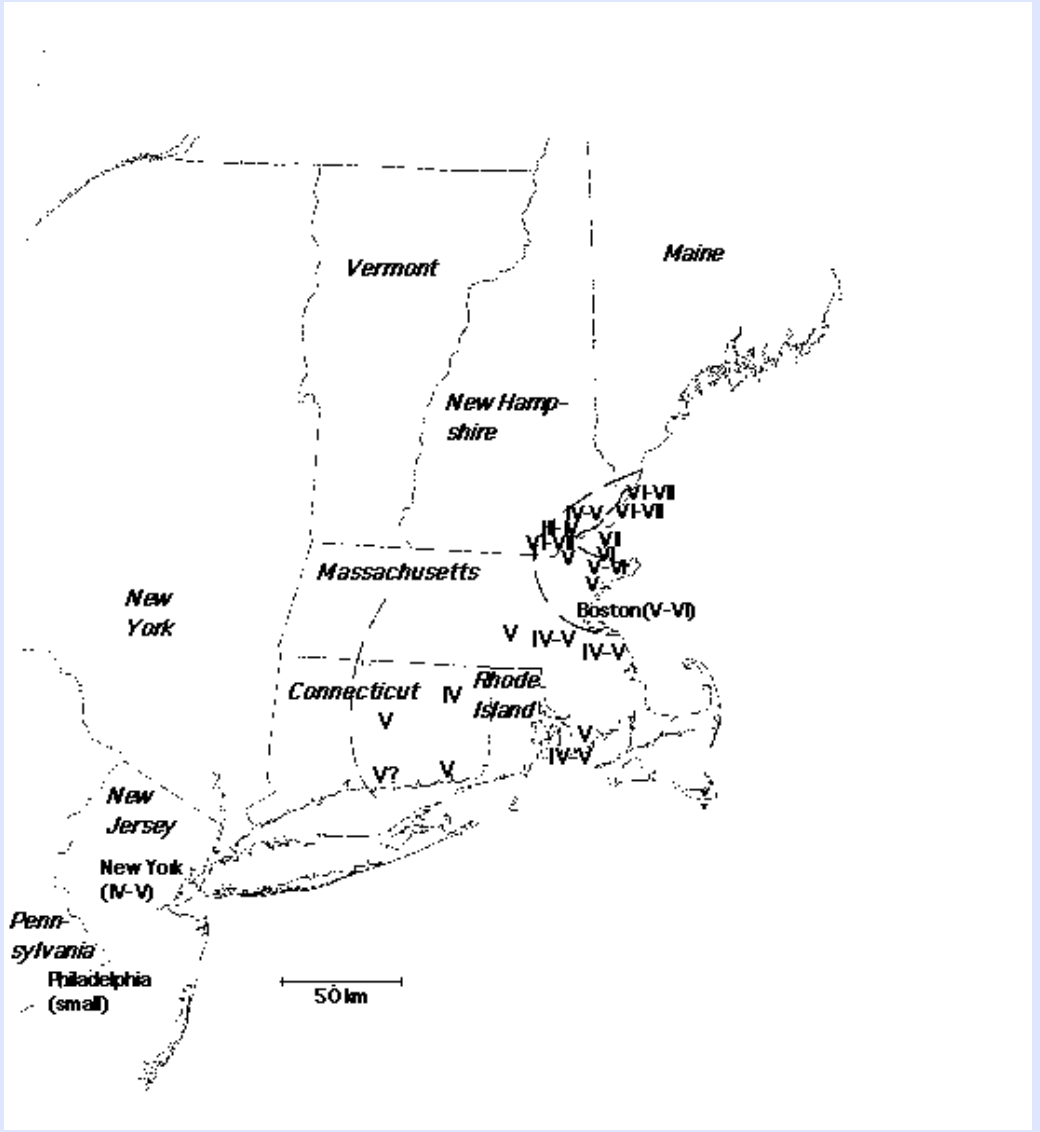
Under this "paleoseismicity" hypothesis, the spatial extents and activity rates of clusters of earthquakes can be used with magnitude-fault length scaling relations and with Omori's Law to estimate the magnitudes and times before present of past strong earthquakes (from *Ebel, Bonjer and Oncescu,* ***Seism. Res. Lett.,*** *2000*).



In 1727 there was a strong earthquake centered in northeastern Massachusetts.

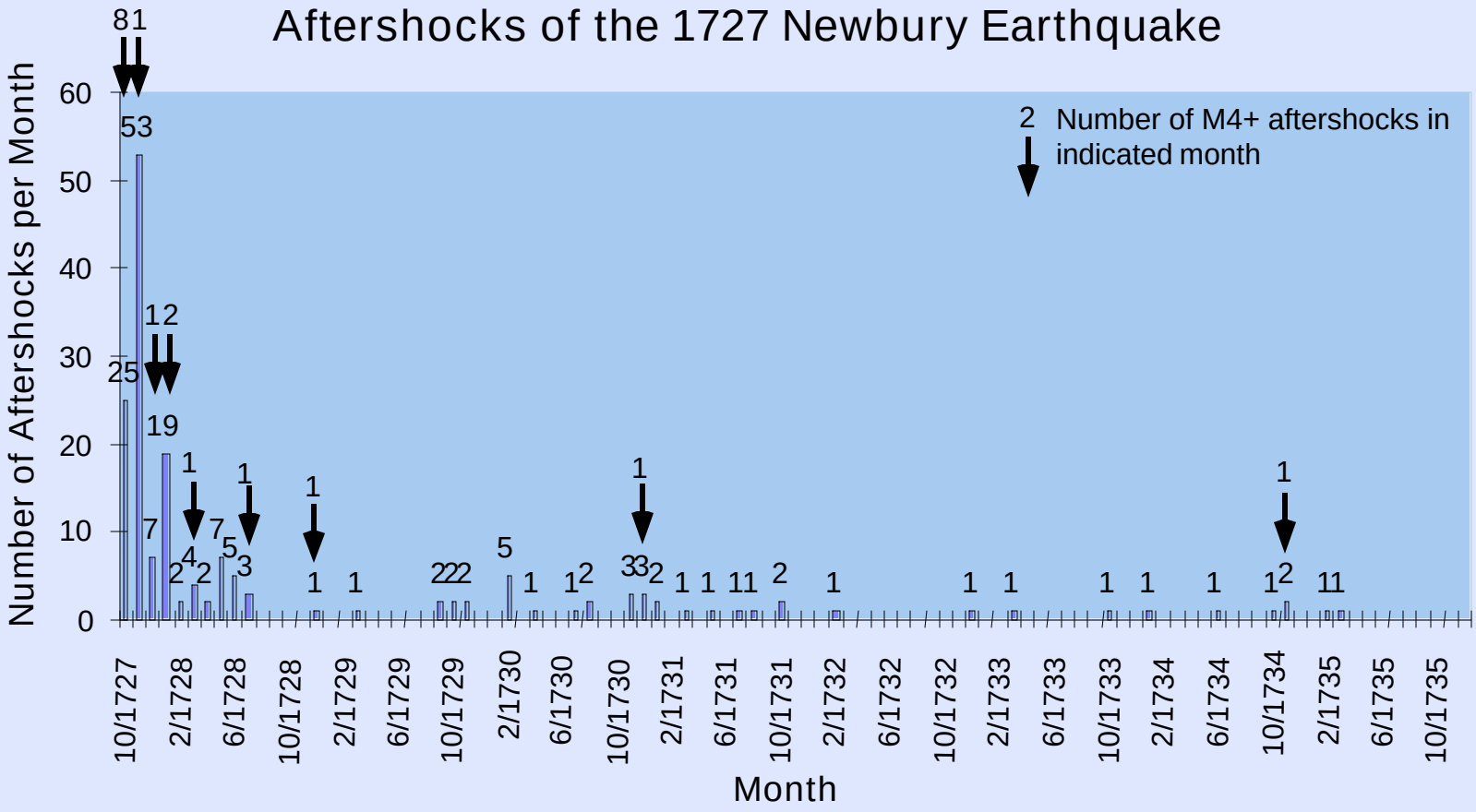
The earthquake damaged chimneys and stone walls in Newbury, Massachusetts and nearby towns. It was felt to Philadelphia and Casco Bay, Maine.

My estimated magnitude of this earthquake is 5.6.



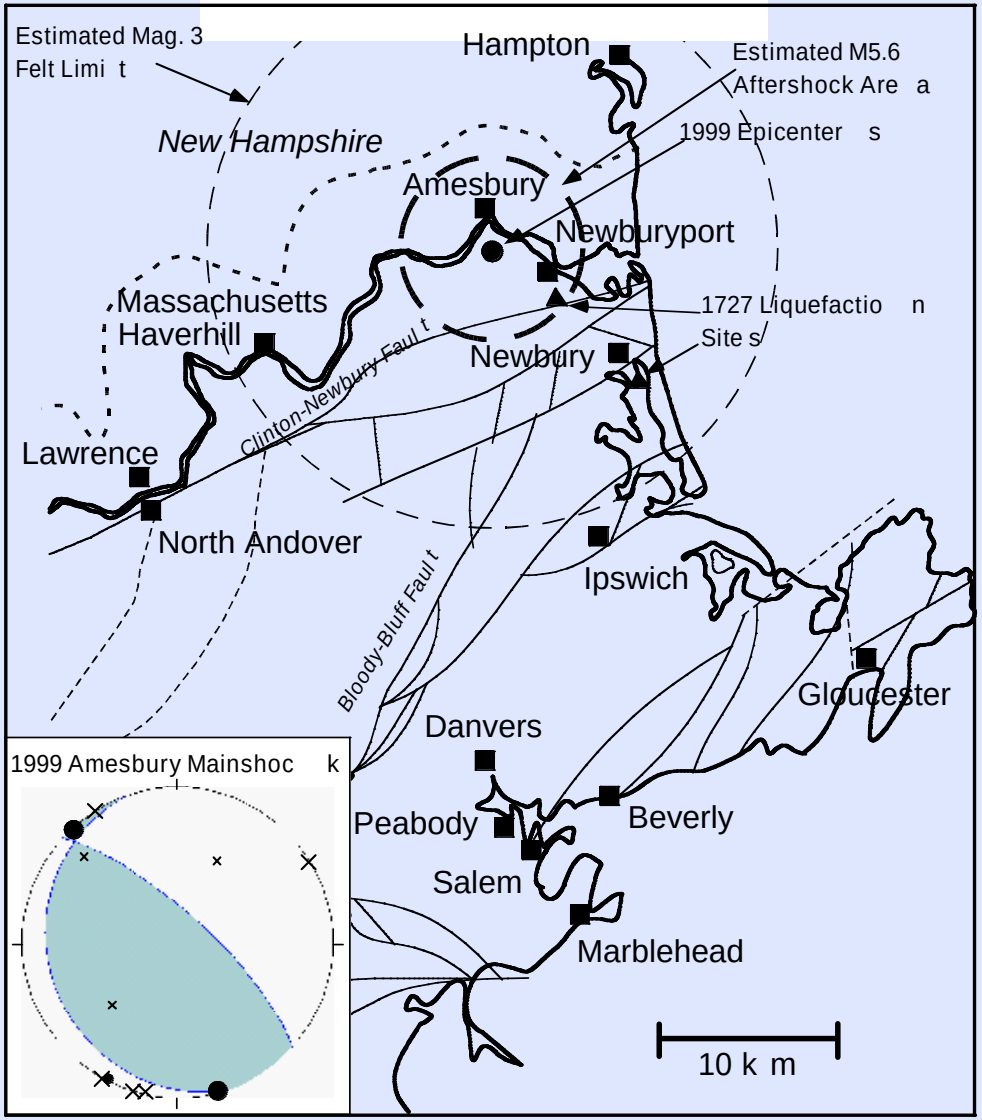
The Roman numerals on this plot are modified Mercalli intensities. MMI VI is minor damage, MMI VII is moderate damage, MMI VIII and higher is major damage.

The 1727 earthquake was followed by a vigorous and protracted sequence of aftershocks.



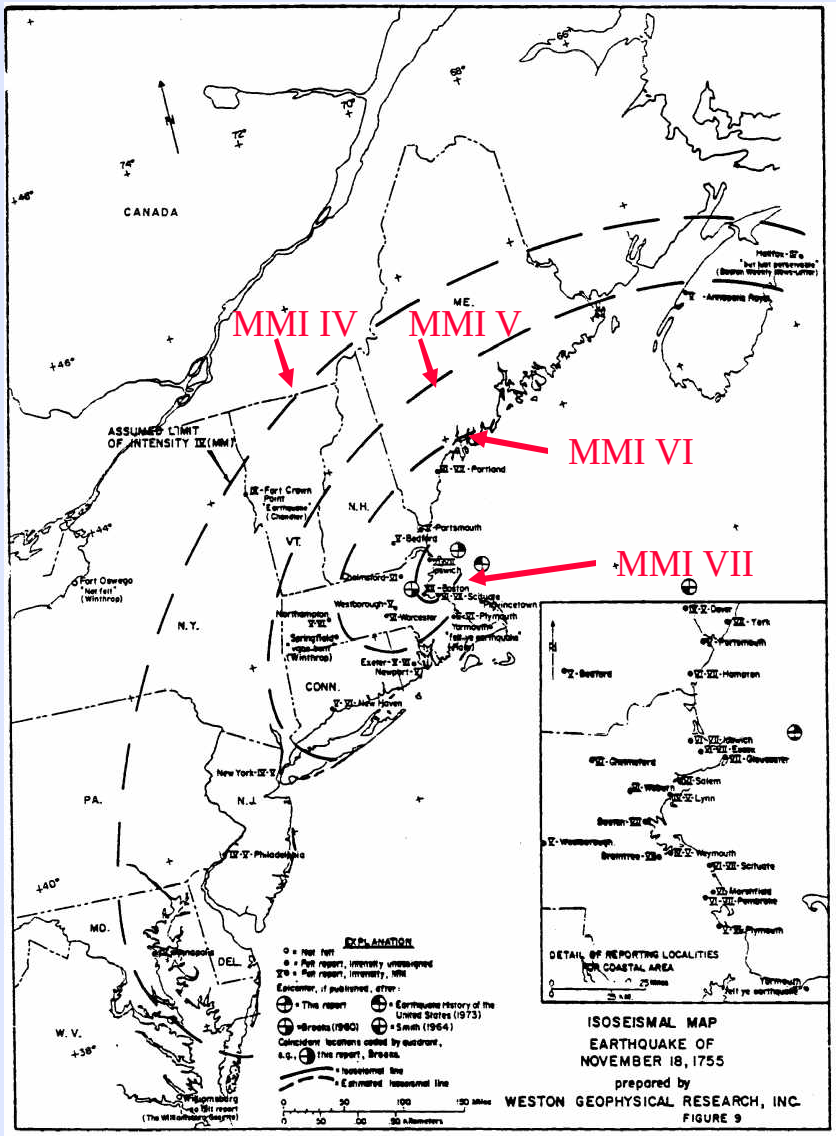
There were over 150 aftershocks documented for this earthquake, 17 of which were magnitude 4 or greater. The number of aftershocks per month followed a typical decay pattern with time (from *Ebel*, ***Seism. Res. Lett.,*** *2000*).

Four earthquakes, the largest M3.0, took place in the Newburyport area in January 1999. These may have been late aftershocks of the 1727 earthquake. The focal mechanism for the largest event shows thrust or reverse faulting on a NW-SE oriented fault plane. This trend is parallel to the local course of the Merrimack River, to some minor faults on the state bedrock map, and to an alignment of the 1727 liquefaction features (from *Ebel*, ***Seism. Res. Lett.,*** *2000*).



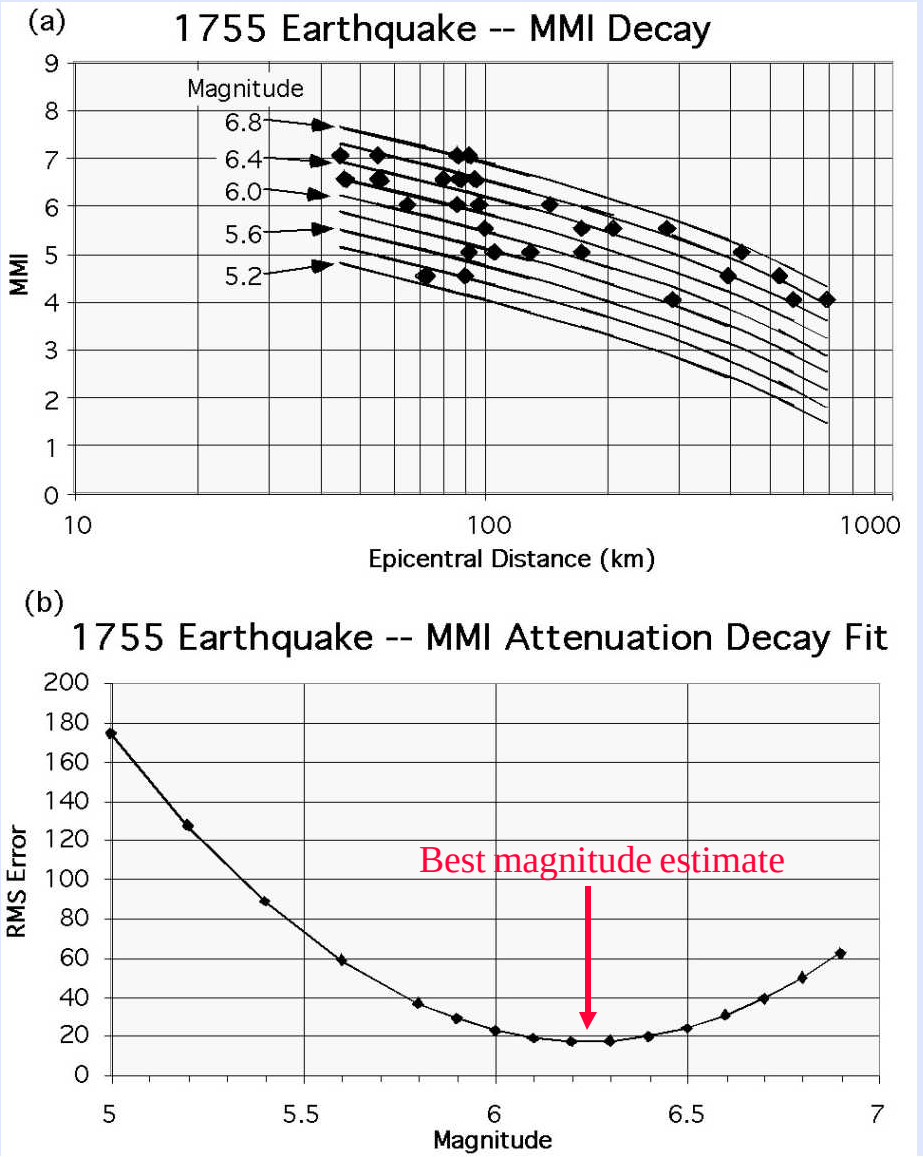
Isoseismals for the 1755 Cape Ann Earthquake

Modified Mercalli intensity isoseismals show that the greatest ground shaking was in northeastern Massachusetts, indicating source region somewhere near Cape Ann (hence the name of the earthquake).



Magnitude of the 1755 Earthquake

The decay of the modified Mercalli intensity values with distance from the hypothesized earthquake epicenter is most consistent with an earthquake of Lg-wave magnitude 6.2-6.3. (From *Ebel*, ***Seism. Res. Lett.,*** *2006*).



Modern Constraints on the 1755 Earthquake Source Location

Several lines of evidence from the historic records of aftershocks and mainshock felt effects suggest a source location north of Boston. The modern, instrumentally located earthquakes show a cluster of activity about 40-50 km offshore ENE of Cape Ann. This cluster may indicate the area where the 1755 faulting took place. (From *Ebel*, ***Seism. Res. Lett.,*** *2006*).

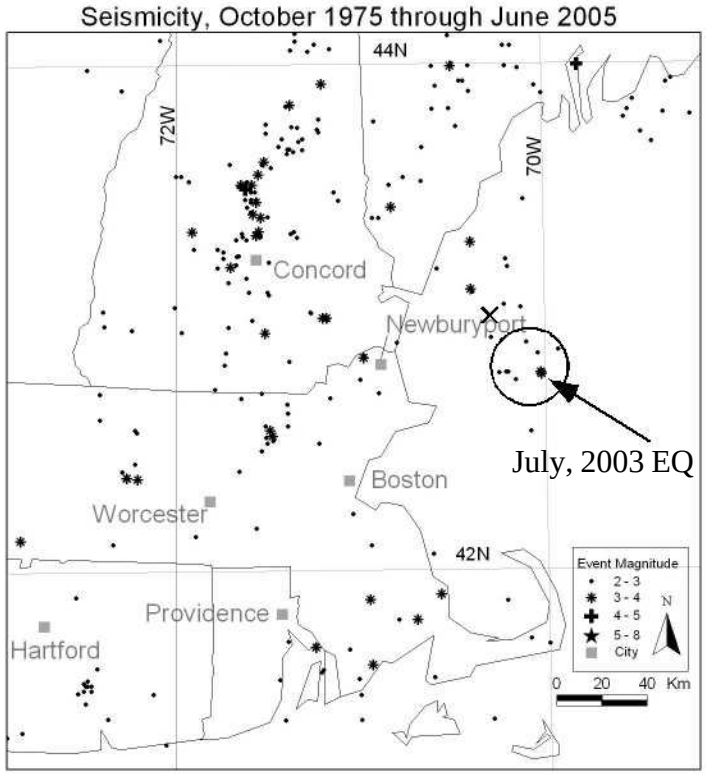


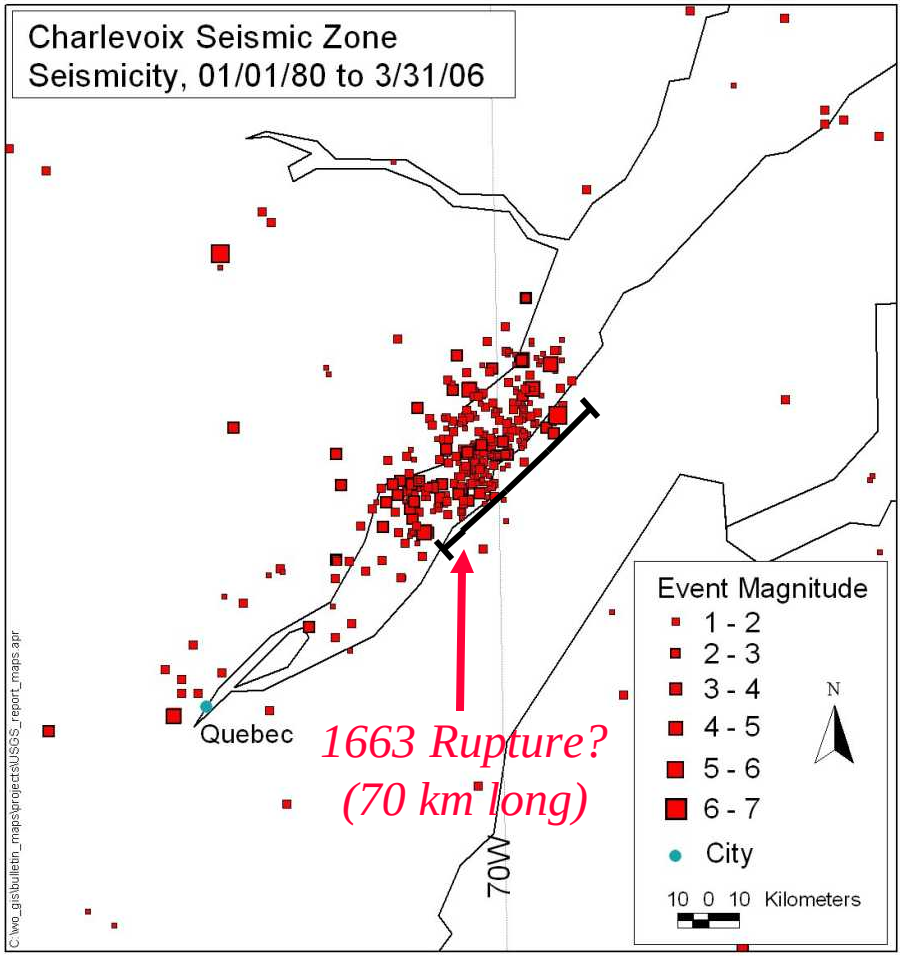
Table Summarizing Ground Motions at Several Different New England Towns in 1755

Town	Epicentral Distance (km)	MMI	Moderate Damage	Extensive Damage	pga	SA0.3
York, ME	55	7		50%? 20%?	0.23g? 0.10g?	0.27g? 0.20g?
Boston, MA	87	7	27-30%	2-3%	0.08-0.11g	0.18-0.21g
Braintree, MA	93	7		>1%	>0.03g	0.08g
Northampton, MA	208	5.5	>1%		>0.01g	>0.03g
New Haven, CT	281	5.5	>1%?		>0.01g?	>0.03g?
New York, NY	281	5.5	0%		<0.01g	<0.03g

Based on an analysis of chimney damage, the peak ground acceleration in Boston was about .08g to .11g and the SA0.3 was about .18g-.21g. This is comparable to the 5% in 50-year ground motions (once in 1000 years exceedence) from the USGS National Seismic Hazard Maps. (From *Ebel*, ***Seism. Res. Lett.,*** *2006*).

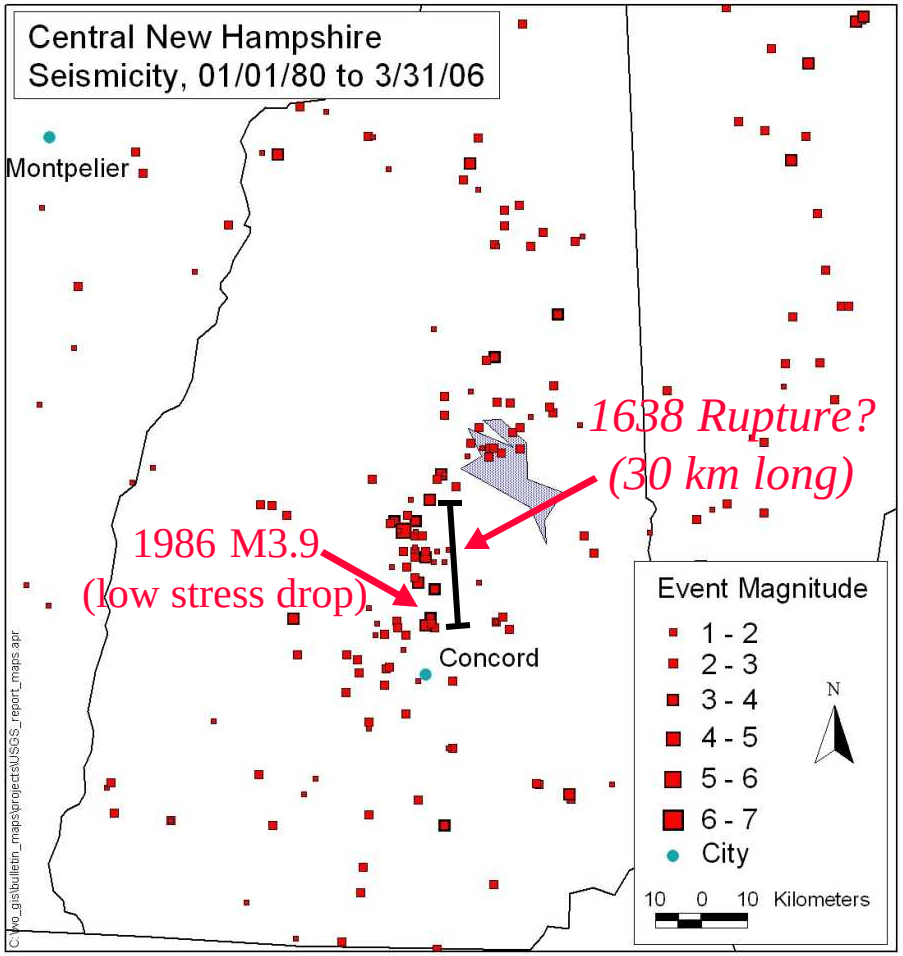
The 1663 Earthquake at Charlevoix, Quebec

This earthquake caused some minor chimney damage in Boston at a distance of 550 km. Several aftershocks were also were felt in Boston. If the modern seismicity is aftershocks of the 1663 event, then its rupture length must have been about 70 km. This suggests a magnitude approaching M7.5 (i.e., a New Madrid-size event). (See *Ebel*, ***Seism. Res. Lett.,*** *1996*).



Speculations on the 1638 Earthquake

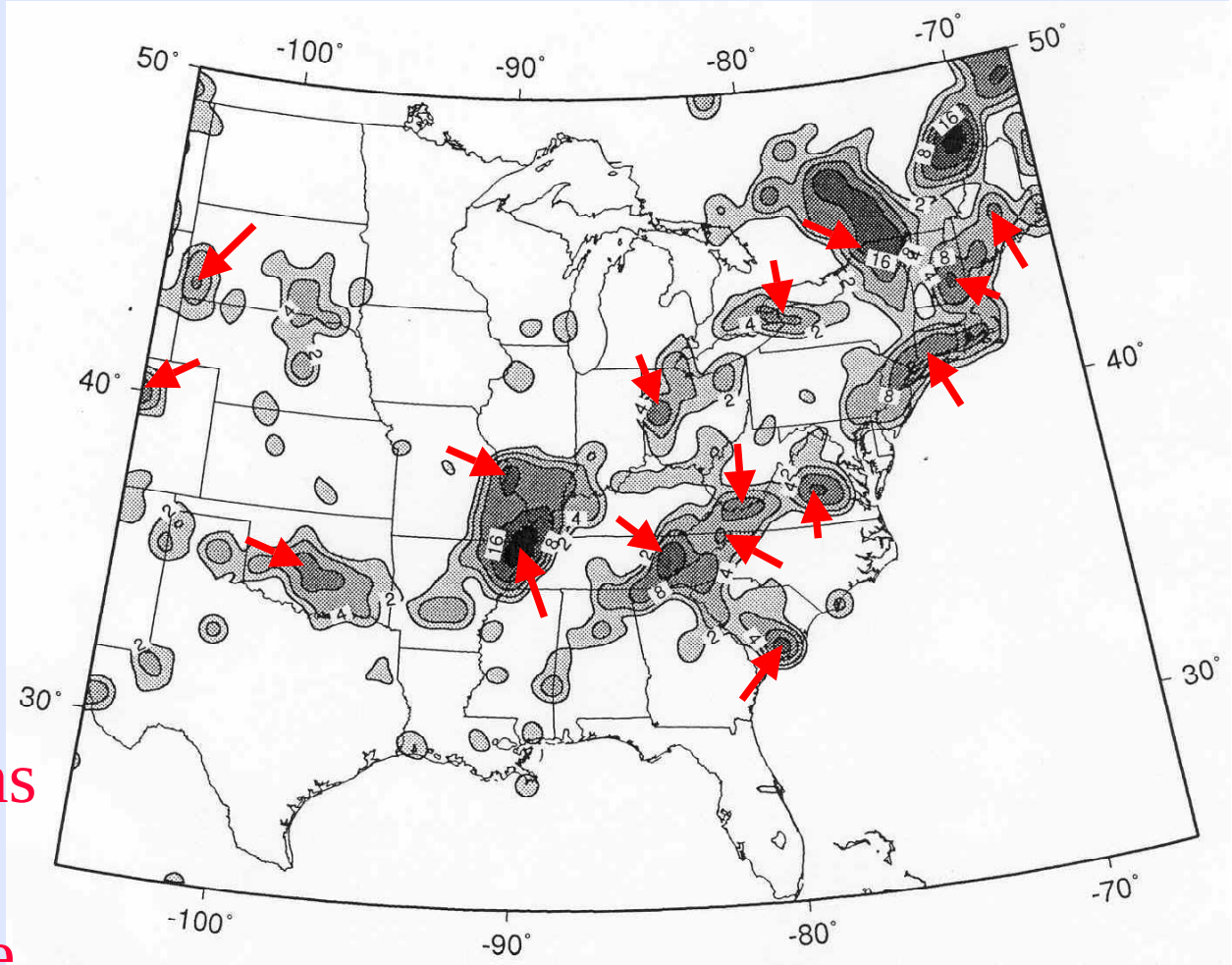
This earthquake was felt strongly in southeastern New England and at Trois-Rivieres in Quebec. Aftershocks were felt for 20 days in Boston. It is speculated here that this was a M6.5 to M7.0 earthquake centered near Concord, NH at the most seismically active locality in New England. (See *Ebel,* ***Seism. Res. Lett.,*** *1996*).



For the CEUS and for ENA, the observed rate of M>~7 earthquakes is greater than expected from extrapolations of the Gutenberg-Richter curves from the smaller earthquake activity in these regions (*Nishenko and Bollinger*, ***Science***, *1990*).

CEUS - Central and Eastern U.S.
ENA - Eastern North America

Building on the paleoseismicity idea that localized clusters of earthquakes in the CEUS delimit aftershock zones of past strong earthquakes, we can take the smaller earthquake activity and postulate locations where M>~7 earthquakes may have taken place in the past few thousand years.



The red arrows show areas of enhanced, localized seismicity rates (modified from *Frankel*, ***Seism. Res. Lett.,*** *1995*).

M>~7 Seismicity Rates Underestimated for the CEUS?

If all of the CEUS modern seismicity clusters show locations of M>~7 during the past 2000 or so years, then the rate of M>~7 earthquakes is approximately 2 to 3 times greater than that found from extrapolations of the smaller seismicity to larger magnitudes.

Paleoseismicity Cluster Analysis Results
Main shocks between M7.0 and M7.5 Have Equal Rates

Rate of M=0 Earthquakes in 60 Years	Time of Analysis (years)	Nishenko & Bollinger (1990) Relation 1 Recurrence Curve Prediction	Nishenko & Bollinger (1990) Relation 2 Recurrence Curve Prediction	Nishenko & Bollinger (1990) Relation 1 Cluster Analysis Prediction	Nishenko & Bollinger (1990) Relation 2 Cluster Analysis Prediction
16 or more	**1118**	**3.0**	**1.7**	**8**	**8**
8 or more	**2124**	**5.7**	**3.1**	**15**	**15**

Table 2b
Paleoseismicity Cluster Analysis Results
Main shocks between M7.0 and M7.5 Have Gutenberg-Richter Distribution

Rate of M=0 Earthquakes in 60 Years	Time of Analysis (years)	Nishenko & Bollinger (1990) Relation 1 Recurrence Curve Prediction	Nishenko & Bollinger (1990) Relation 2 Recurrence Curve Prediction	Nishenko & Bollinger (1990) Relation 1 Cluster Analysis Prediction	Nishenko & Bollinger (1990) Relation 2 Cluster Analysis Prediction
16 or more	**1118**	**3.0**	**1.7**	**6**	**4**
8 or more	**2124**	**5.7**	**3.1**	**13**	**7**

Gutenberg-Richter Extrapolation

Paleoseismicity Extrapolation

If the rate of M>~7 earthquakes in the CEUS is underestimated by a factor of 2 to 3, then the seismic hazard ground motions in much of the CEUS are underestimated by about 8% to 25%.

Probabilistic Peak Ground Accelerations (g) for Different Rates of M7.0 to 7.5 Earthquakes

Boston, MA

	10% in 50 Years	*5% in 50 Years*	*2% in 50 Years*
GR Rate for M7 to 7.5	**0.0588**	**0.1103**	**0.2316**
Double GR Rate for M7 to 7.5	**0.0653**	**0.1205**	**0.2504**
% Increase over GR Rate	**11.1%**	**9.3%**	**8.1%**
Triple GR Rate for M7 to 7.5	**0.0714**	**0.1305**	**0.2685**
% Increase over GR Rate	**21.4%**	**18.3%**	**15.9%**

Central, NH

	10% in 50 Years	*5% in 50 Years*	*2% in 50 Years*
GR Rate for M7 to 7.5	**0.0742**	**0.1359**	**0.2754**
Double GR Rate for M7 to 7.5	**0.0812**	**0.1472**	**0.2967**
% Increase over GR Rate	**9.4%**	**8.3%**	**7.8%**
Triple GR Rate for M7 to 7.5	**0.0879**	**0.1584**	**0.3169**
% Increase over GR Rate	**18.4%**	**16.6%**	**15.1%**

Western MA

	10% in 50 Years	*5% in 50 Years*	*2% in 50 Years*
GR Rate for M7 to 7.5	**0.0422**	**0.0689**	**0.1259**
Double GR Rate for M7 to 7.5	**0.0477**	**0.0776**	**0.1431**
% Increase over GR Rate	**13.0%**	**12.6%**	**13.6%**
Triple GR Rate for M7 to 7.5	**0.0529**	**0.0862**	**0.1597**
% Increase over GR Rate	**25.3%**	**25.0%**	**26.9%**

GR Rate – Rates of large earthquake from an extrapolation of the Gutenberg-Richter recurrence relation from the smaller magnitude seismicity.