The August 23, 2011
Earthquake in the Central Virginia Seismic Zone

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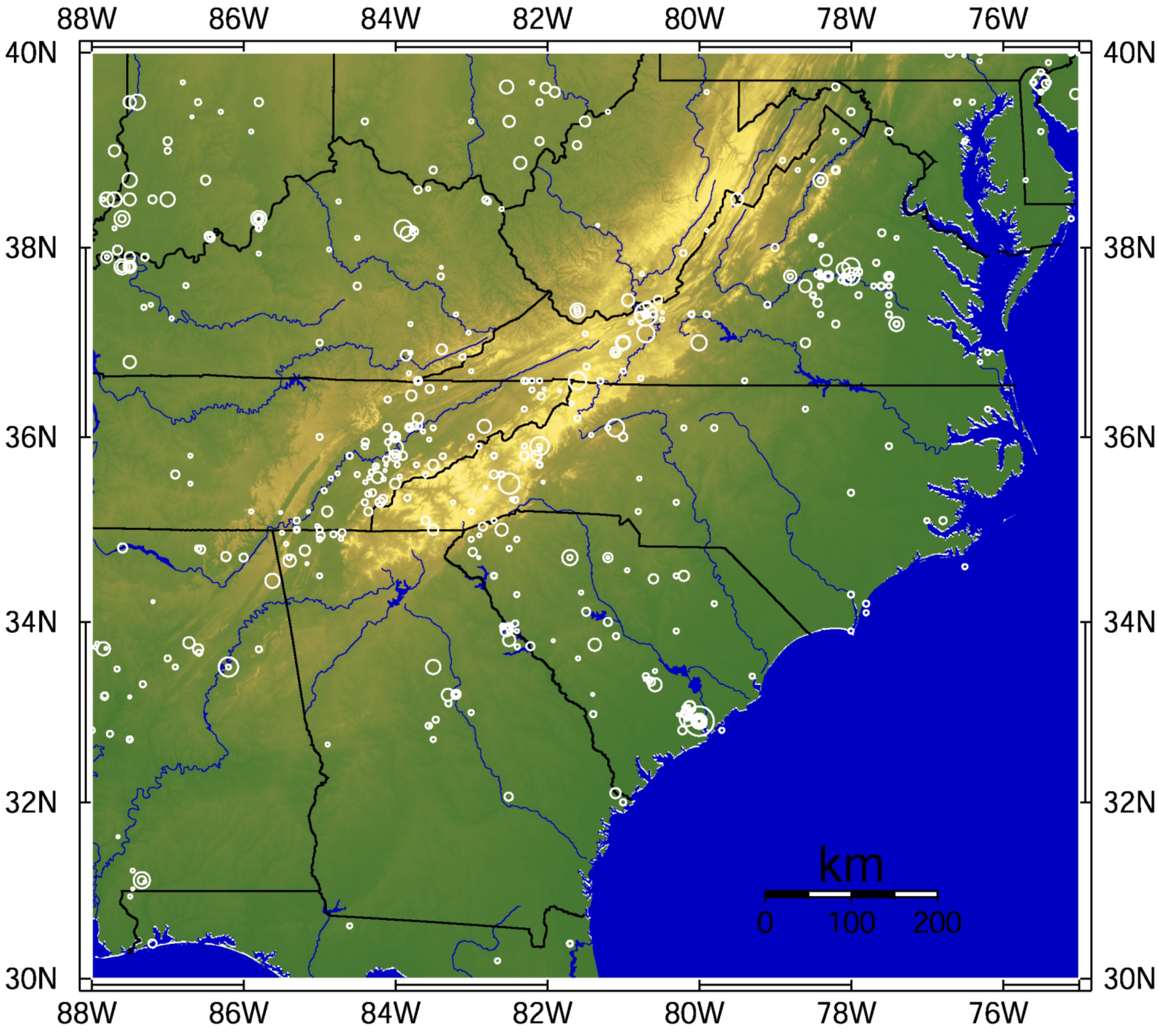
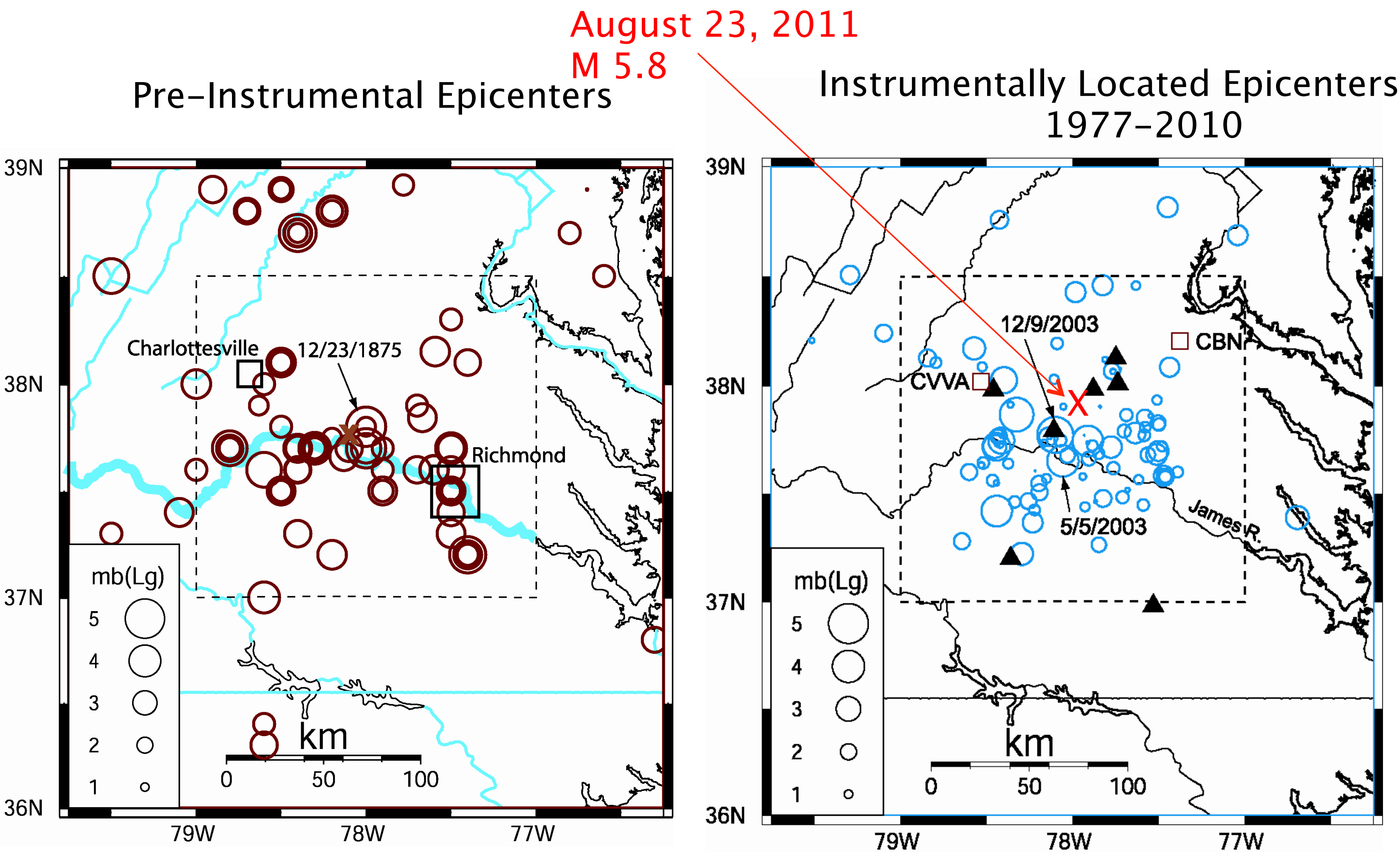
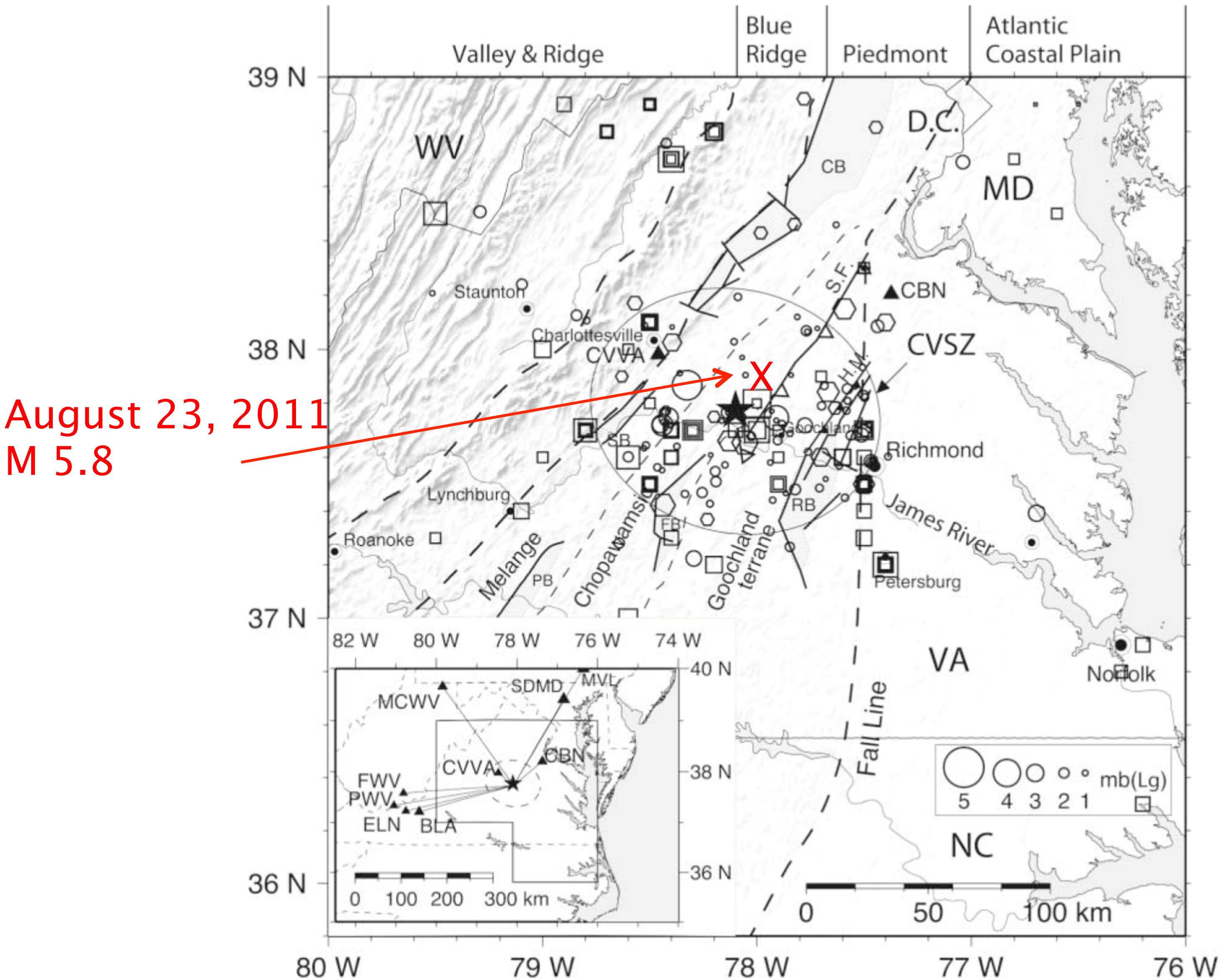
USGS National Seismic Hazard Mapping Workshop
University of Memphis
Memphis, Tennessee
February 22-23, 2012

Magnitude Greater Than 3.0, 1568 to Present

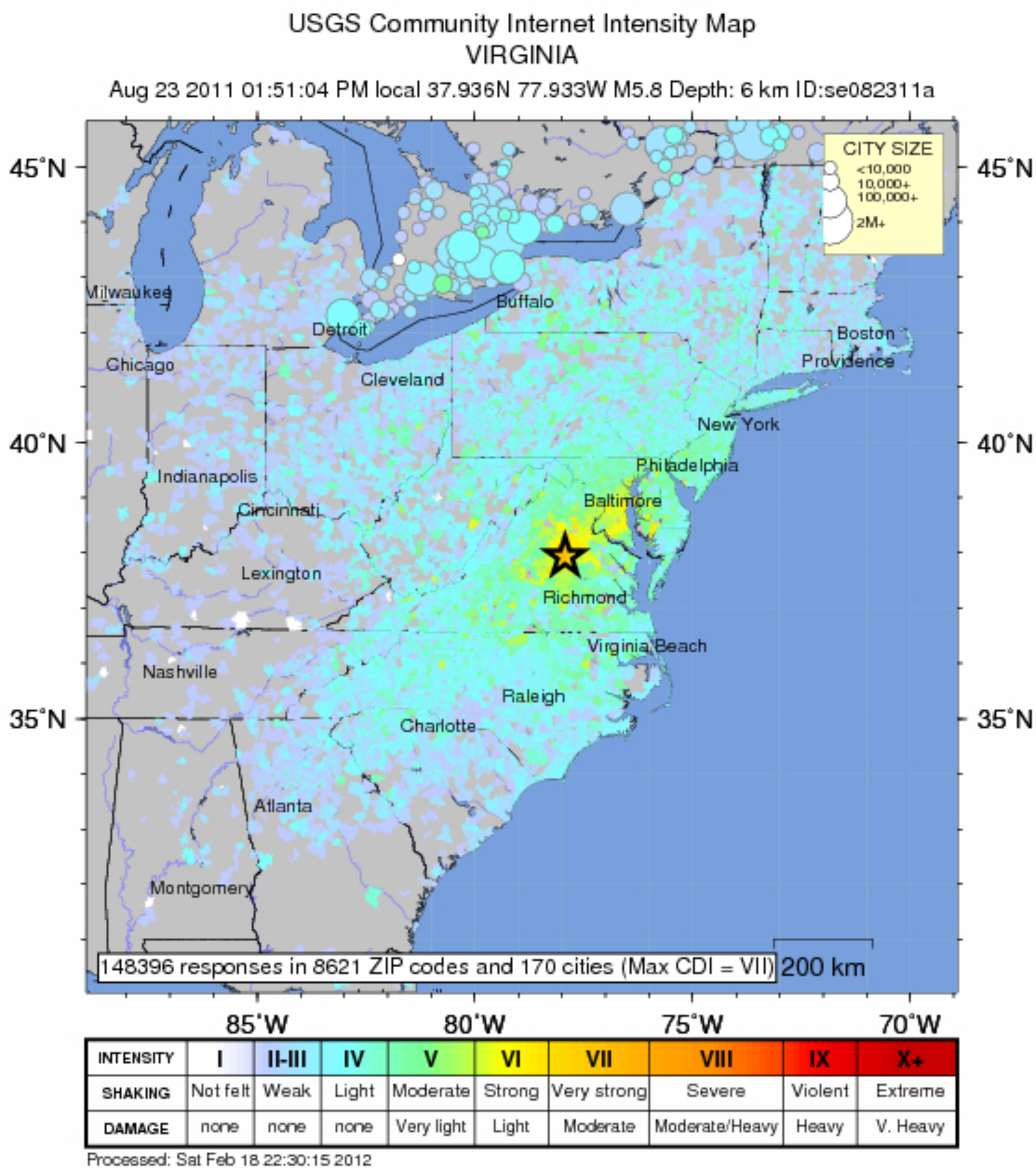




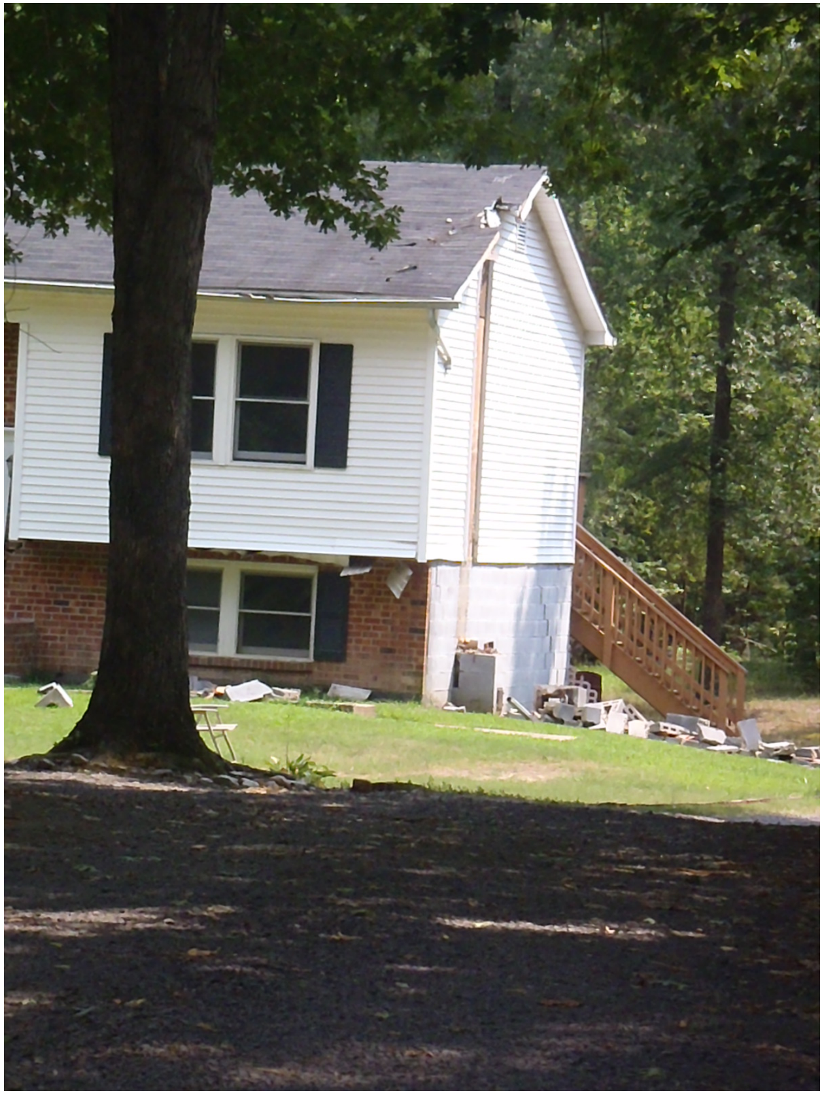
August 23, 2011
M 5.8
Pre-Instrumental Epicenters
Instrumentally Located Epicenters
1977-2010
39N
38N
37N
36N
79W
78W
77W
Charlottesville
12/23/1875
Richmond
mb(Lg)
5
4
3
2
1
km
0
50
100
12/9/2003
CVVA
CBN
5/5/2003
James R.



from : Kim, W.-Y. and M.C. Chapman (2005). The 9 December 2003 central Virginia earthquake sequence: a composite earthquake in the central Virginia seismic zone, BSSA, 95, 2428-2445

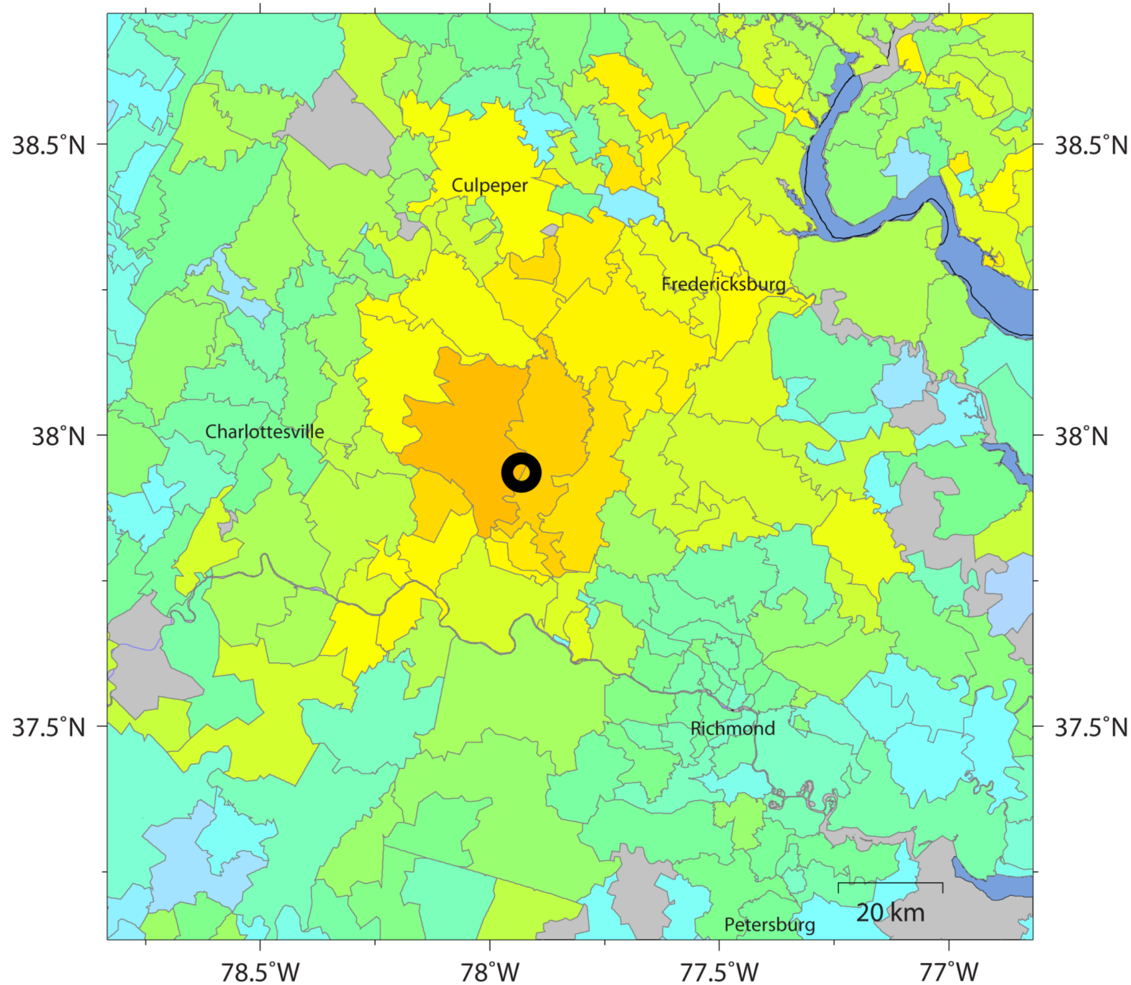

USGS Community Internet Intensity Map
VIRGINIA
Aug 23 2011 01:51:04 PM local 37.936N 77.933W M5.8 Depth: 6 km ID:se082311a
CITY SIZE
<10,000
10,000+
100,000+
2M+
45°N
40°N
35°N
85°W
80°W
75°W
70°W
Milwaukee
Chicago
Detroit
Buffalo
Cleveland
Boston
Providence
New York
Philadelphia
Baltimore
Indianapolis
Cincinnati
Lexington
Richmond
Virginia Beach
Nashville
Raleigh
Charlotte
Atlanta
Montgomery
148396 responses in 8621 ZIP codes and 170 cities (Max CDI = VII)
200 km
INTENSITY I II-III IV V VI VII VIII IX X+
SHAKING Not felt Weak Light Moderate Strong Very strong Severe Violent Extreme
DAMAGE none none none Very light Light Moderate Moderate/Heavy Heavy V. Heavy
Processed: Sat Feb 18 22:30:15 2012

Examples of damage, August 23, 2011



USGS internet intensity maps

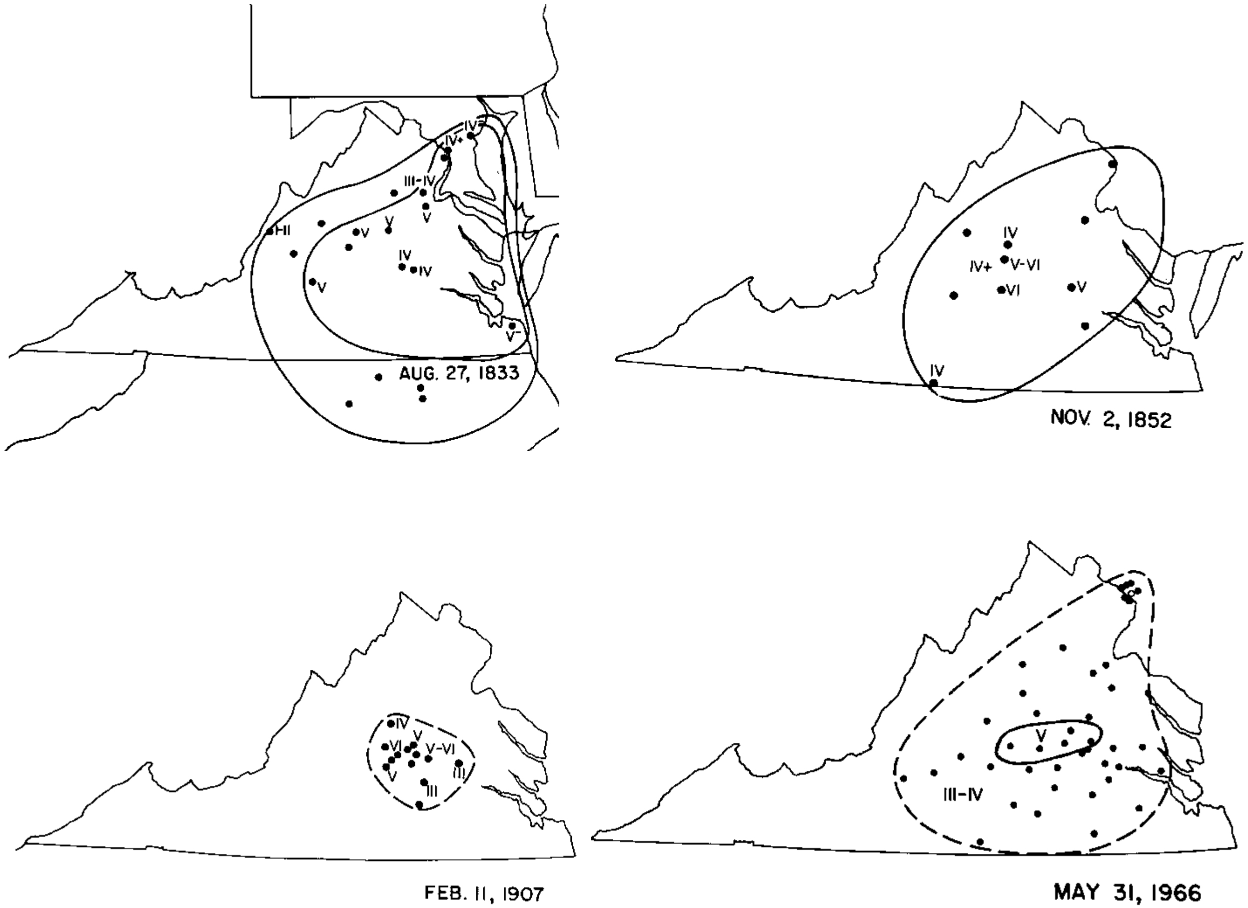
Note the stronger shaking reported to the North and Northeast of the epicenter



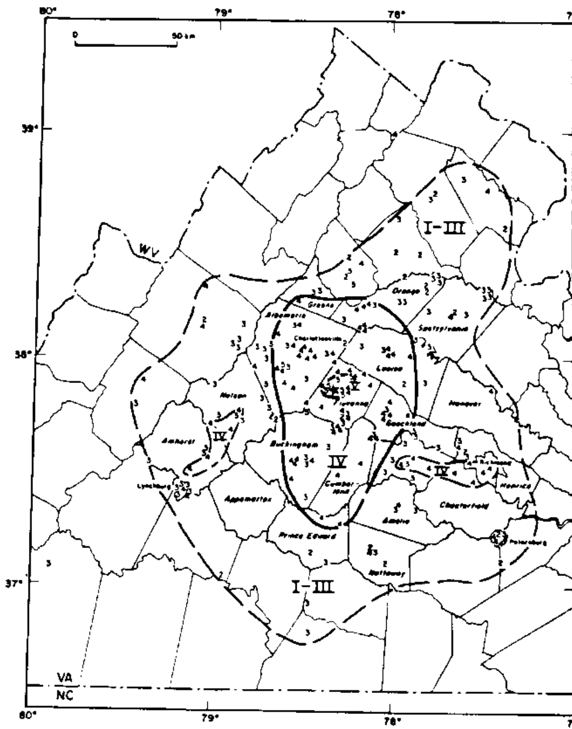
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy

http://earthquake.usgs.gov/earthquakes/dyfi/events/se/082311a/us/index.html

Some Other Central Virginia Shocks



Isoseismals from Hopper and Bollinger, 1971

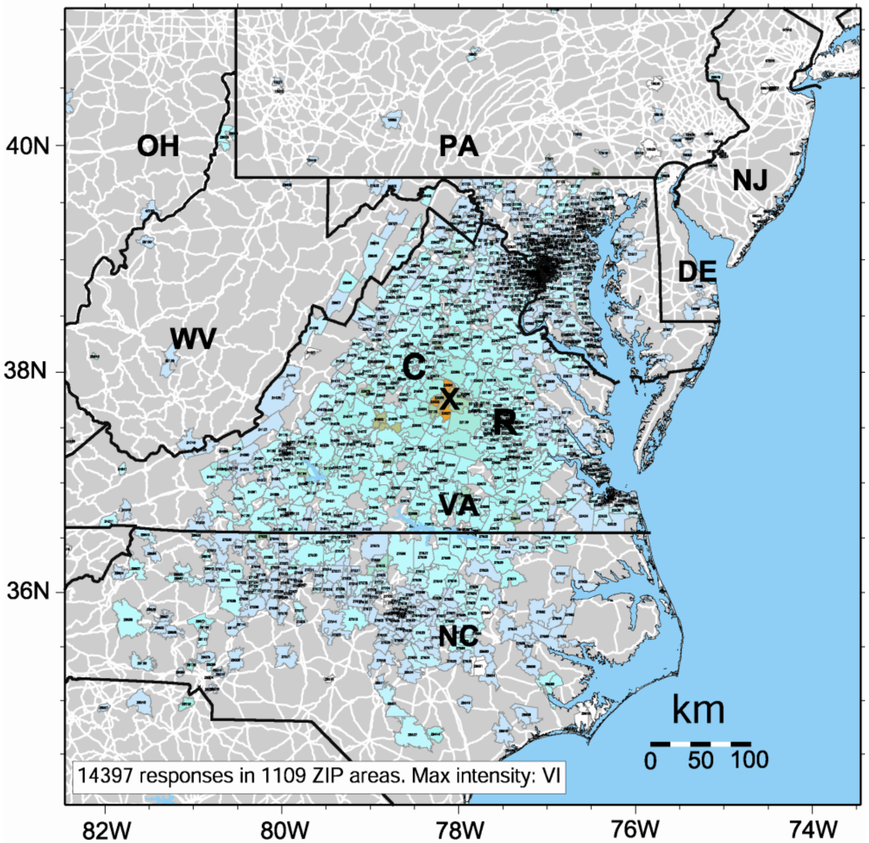


August 17, 1984, m_{bLg} = 4.0

from Tsoflias et al. 1991

The two largest central Virginia events prior to 2011

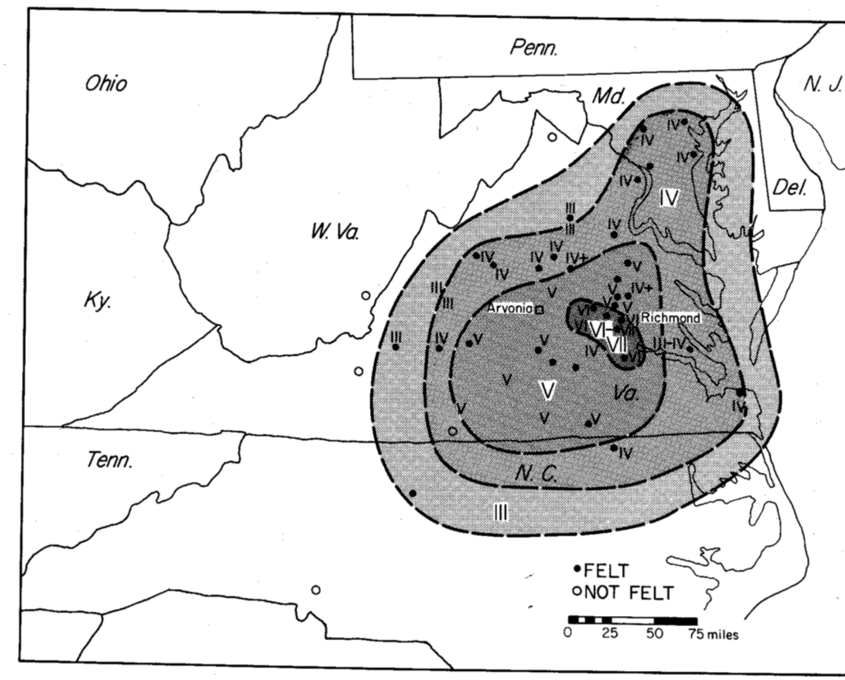
December 9, 2003, M 4.5 compound event



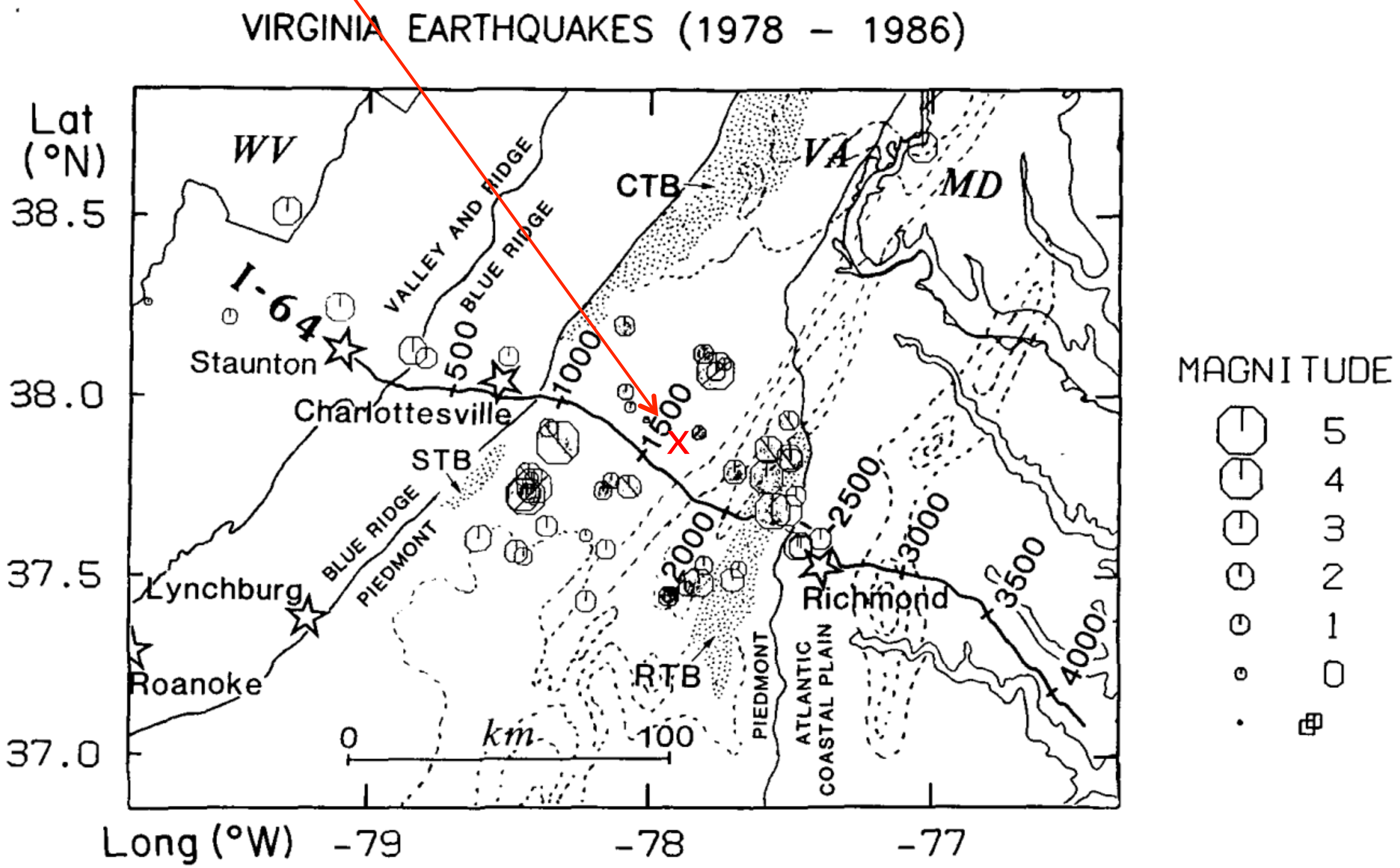
INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy

USGS internet intensity map

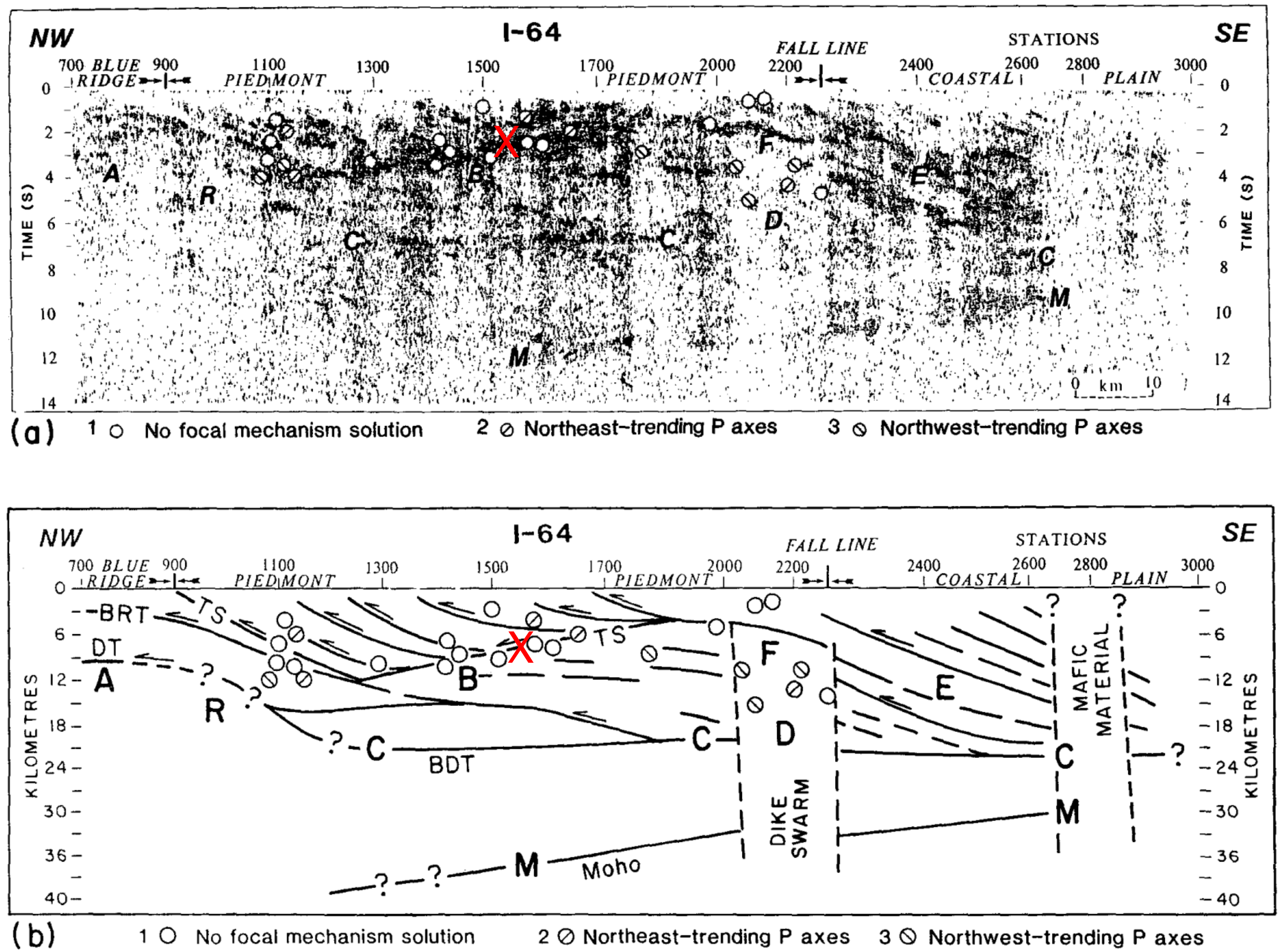
December 22, 1875



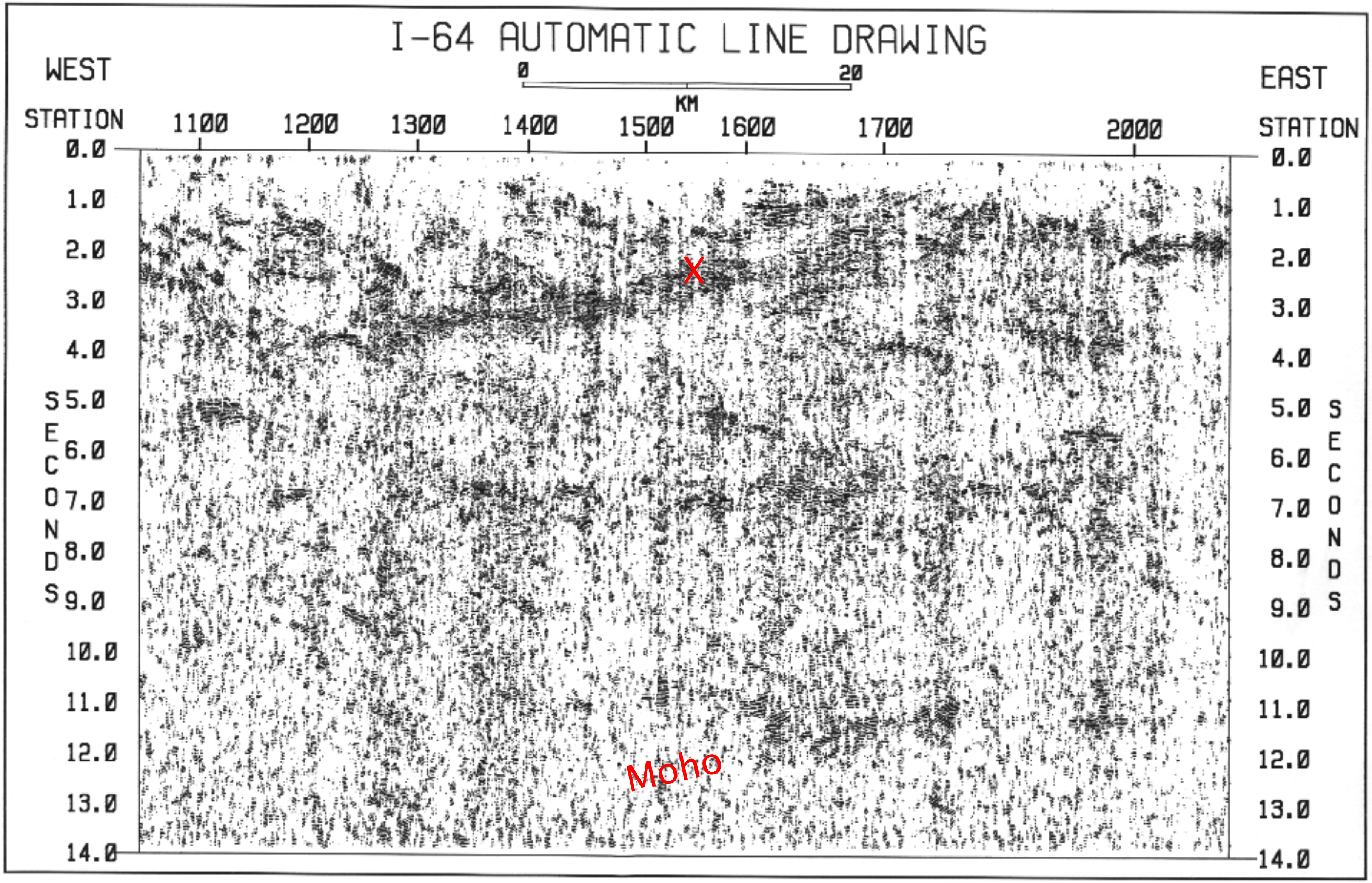
August 23, 2011 earthquake



from: Coruh, C., G.A. Bollinger and J.K. Costain (1988). Seismogenic structures in the central Virginia seismic zone, Geology, 16, 748-751.

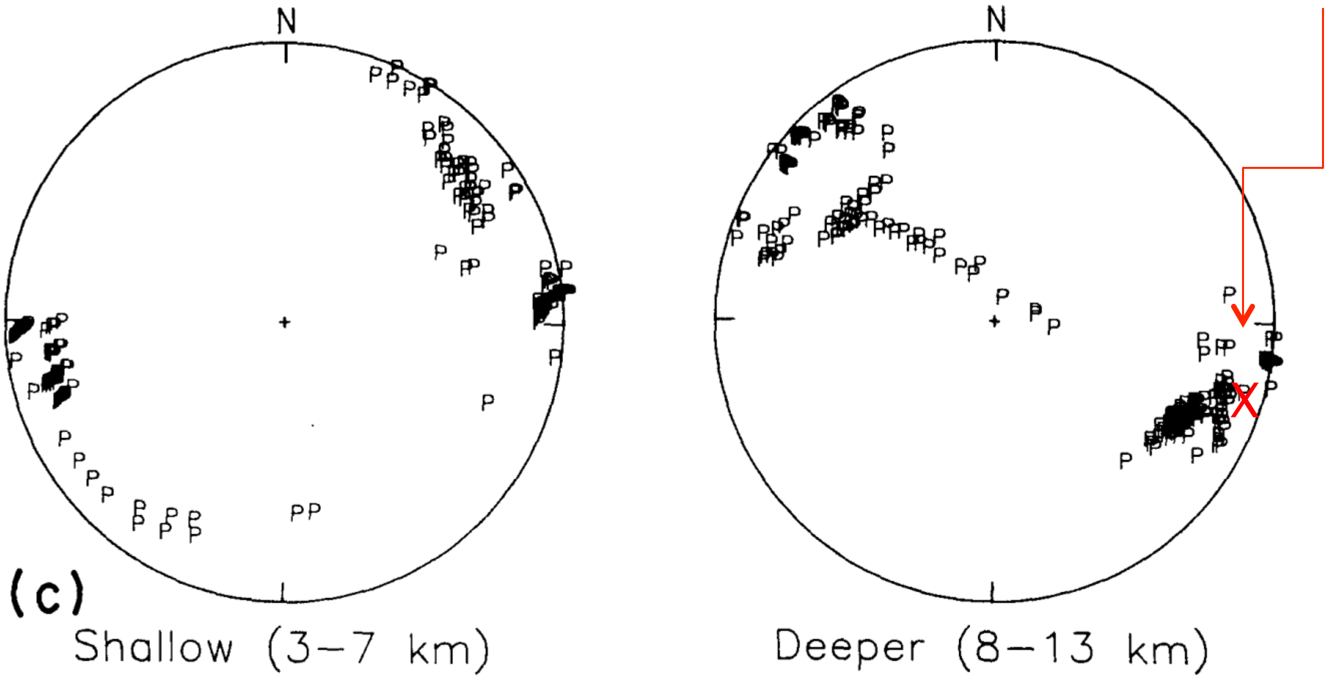


from: Coruh, C., G.A. Bollinger and J.K. Costain (1988). Seismogenic structures in the central Virginia seismic zone, Geology, 16, 748-751.


I-64 AUTOMATIC LINE DRAWING
WEST
EAST
0
20
KM
STATION
1100
1200
1300
1400
1500
1600
1700
2000
STATION
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
SECONDS
X
Moho

Focal mechanisms in Central Virginia are compressional (P axis is sub-horizontal) but the azimuth of the P axis ranges from Northeast to Southeast, and may depend on depth.

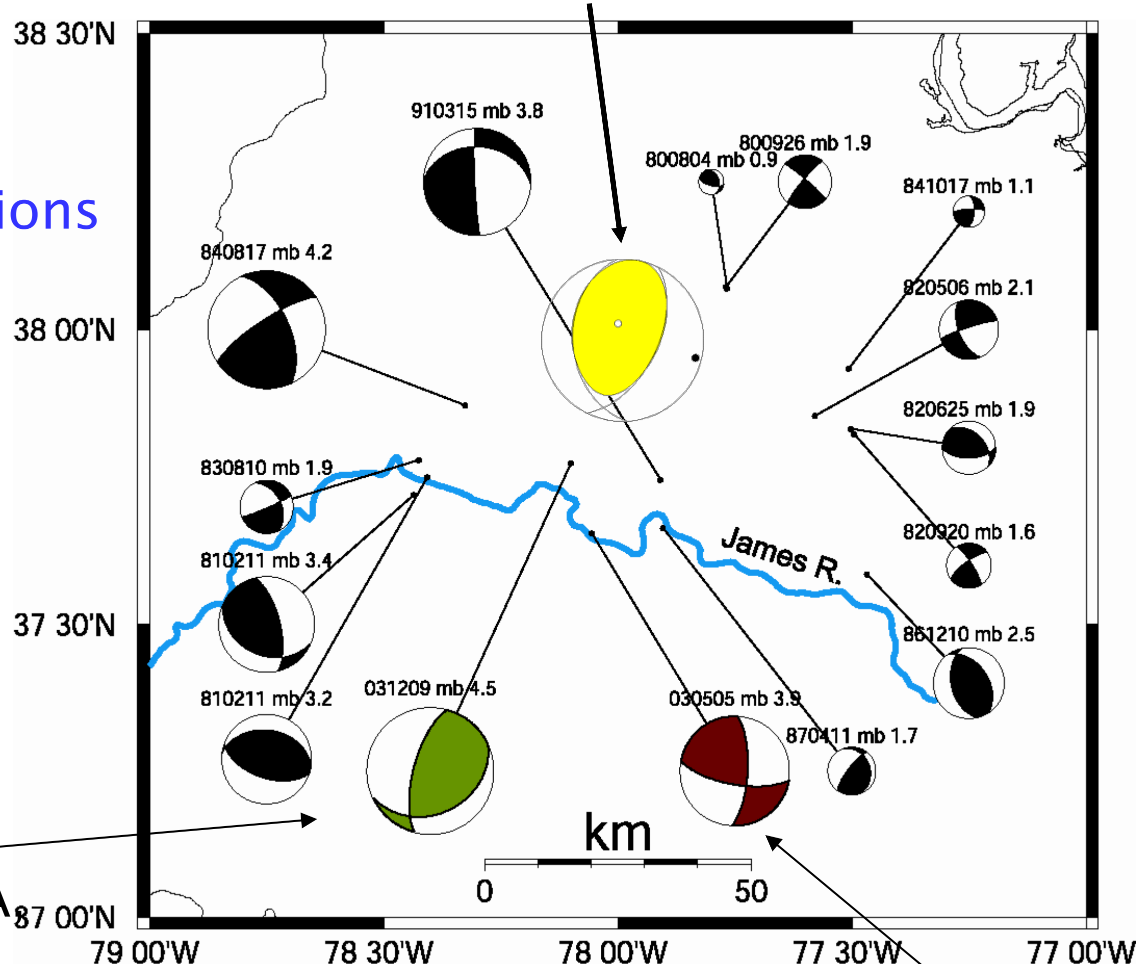
The P axis trend and plunge for the 2011 event is N102E, 3 degrees (R.B. Herrmann)



from: Coruh, C., G.A. Bollinger and J.K. Costain (1988). Seismogenic structures in the central Virginia seismic zone, Geology, 16, 748-751.

August 23, 2011 M 5.8
mechanism by Bob Herrmann

Focal Mechanism Solutions, Lower Hemisphere projections



Dec. 9, 2003, M 4.5
Kim and Chapman, BSSA, vol. 95, no. 6, 2005.

March 5, 2005, M 3.9
Bob Herrmann

Table 1
Significant Earthquakes that Occurred in the Central Virginia Seismic Zone*

Date (yyyy-mm-dd)	Origin Time (hh:mm:sec)	Latitude (° N)	Longitude (° W)	Depth (km)	Mag. m_b (*Lg*)	I_{max}	Felt Area (km^2)	Reference
1774-02-21	19:11	37.2	77.4		4.6			(1, 6)
1833-08-27	11:00	37.7	78.0		4.6	VI	130,000	(7)
1852-11-02	23:35	37.6	78.6		4.4			(6)
1875-12-23	04:45	37.8	78.0		4.9	VII	120,000	(1)
1885-10-10	04:35	37.7	78.8		4.4	VI	51,000	(6)
1907-02-11	13:22	37.7	78.3		4.0	VI	5,100	(6)
1918-04-10	01:09:12	38.7	78.4		4.7	VI	153,000	(8)
1981-02-11	13:44:16.4	37.720	78.435	6	3.4			(2)
1981-02-11	13:50:31.5	37.750	78.407	10	3.2			(2)
1981-02-11	13:51:38.6	37.721	78.450	7	2.9			(2)
1984-08-17	18:05:46.9	37.868	78.324	8	4.2	V–VI	60,000	(3)
1998-10-21	05:56:46.9	37.422	78.439	13	3.8			(4)
2003-05-05	16:32:32.7	37.755	78.072	5	3.9	V		(4)
2003-12-09	20:59:14.6	37.607	77.963	5	4.5	VI	160,000	(5)
2003-12-09	20:59:18.7	37.774	78.100	10	4.25 M_w			(9)
2003-12-09	20:59:18.72	37.7753	78.0997	10.03	4.05 M_w	subevent 1		hypoDD
2003-12-09	20:59:30.68	37.7727	78.1003	9.97	4.05 M_w	subevent 2		hypoDD

*Mag, magnitude: I_{max}, maximum Modified Mercali intensity; (1) Stover and Coffman (1993), Bollinger and Hopper (1971), Oaks and Bollinger (1986); (2) Sibol and Bollinger (1981); (3) Davison *et al.* (1984); (4) Virginia Tech Seismological Observatory data archives, USGS Preliminary Determination of Epicenter reports; (5) Quick Epicenter Determinations (QED), National Earthquake Information Center USGS; (6) Bollinger (1969); (7) Mac-Carthy (1958); (8) Watson (1918); (9) this study.

8 M 4.0 and greater events since 1875
Log N = 2.766 –(1)M
return period: M 4.0 17.1 years
M 5.0 171 years
M 5.8 1,081 years

6 M 3.4 and greater events since 1981
Log N = 2.687 – (1) M
return period: M 4.0 20.6 years
M 5.0 206 years
M 5.8 1,297 years

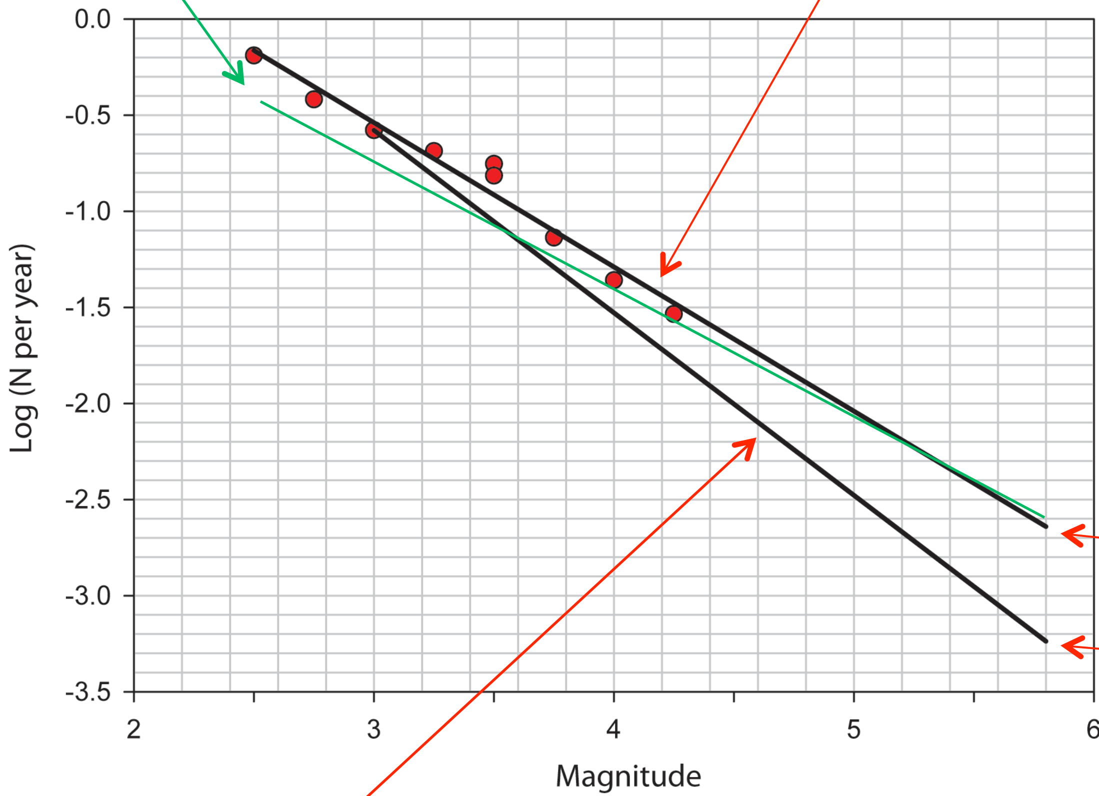
The long-term rates agree with the instrumentally based rates

But is the b value in the central Virginia seismic zone close to 1 ????

probably not

Bollinger et al. (1989)
central Virginia recurrence

Chapman's 2012 fit to central Virginia
seismic zone catalog:
Log (N) = 1.72 – 0.75 M

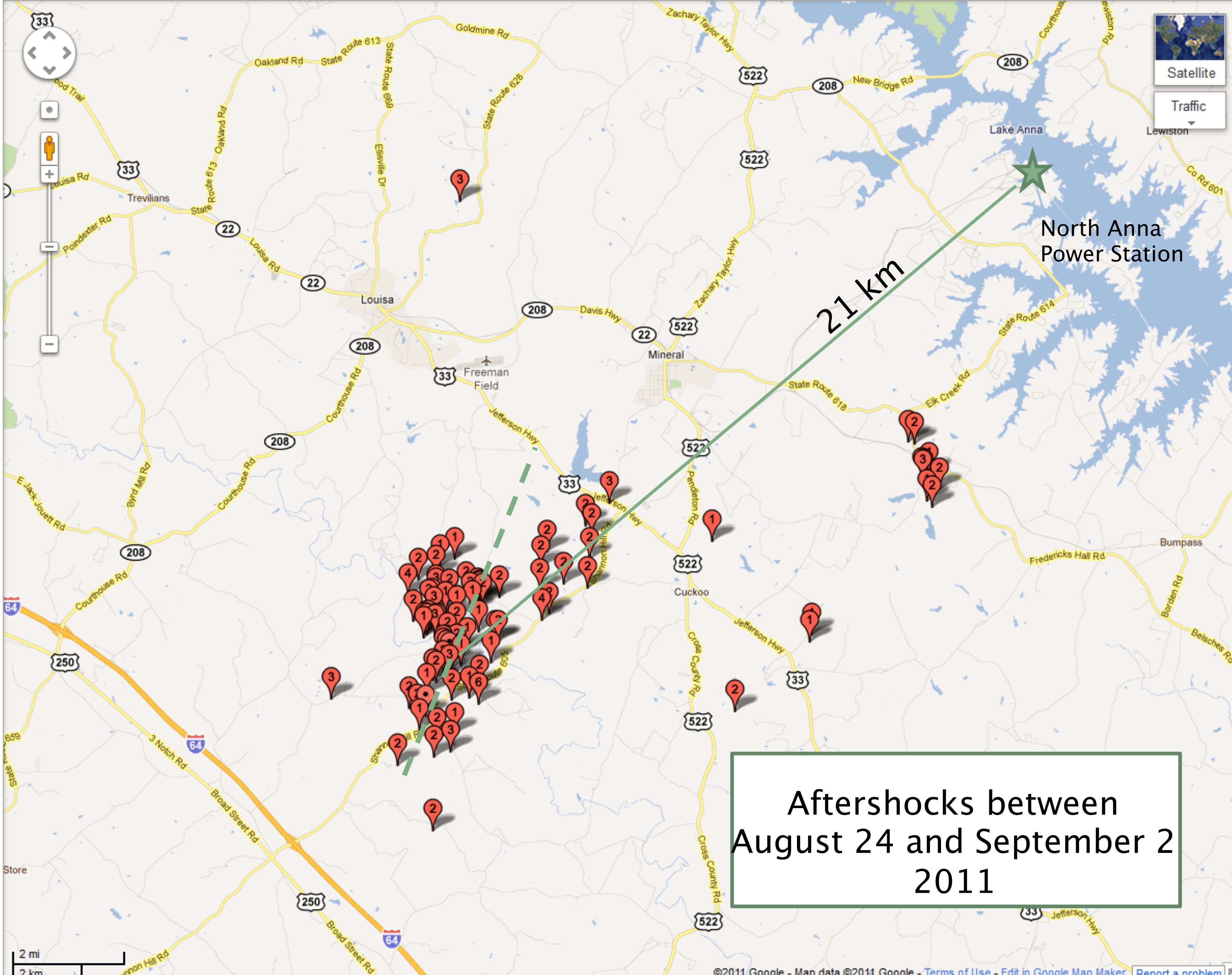


Return period M 5.8: 437

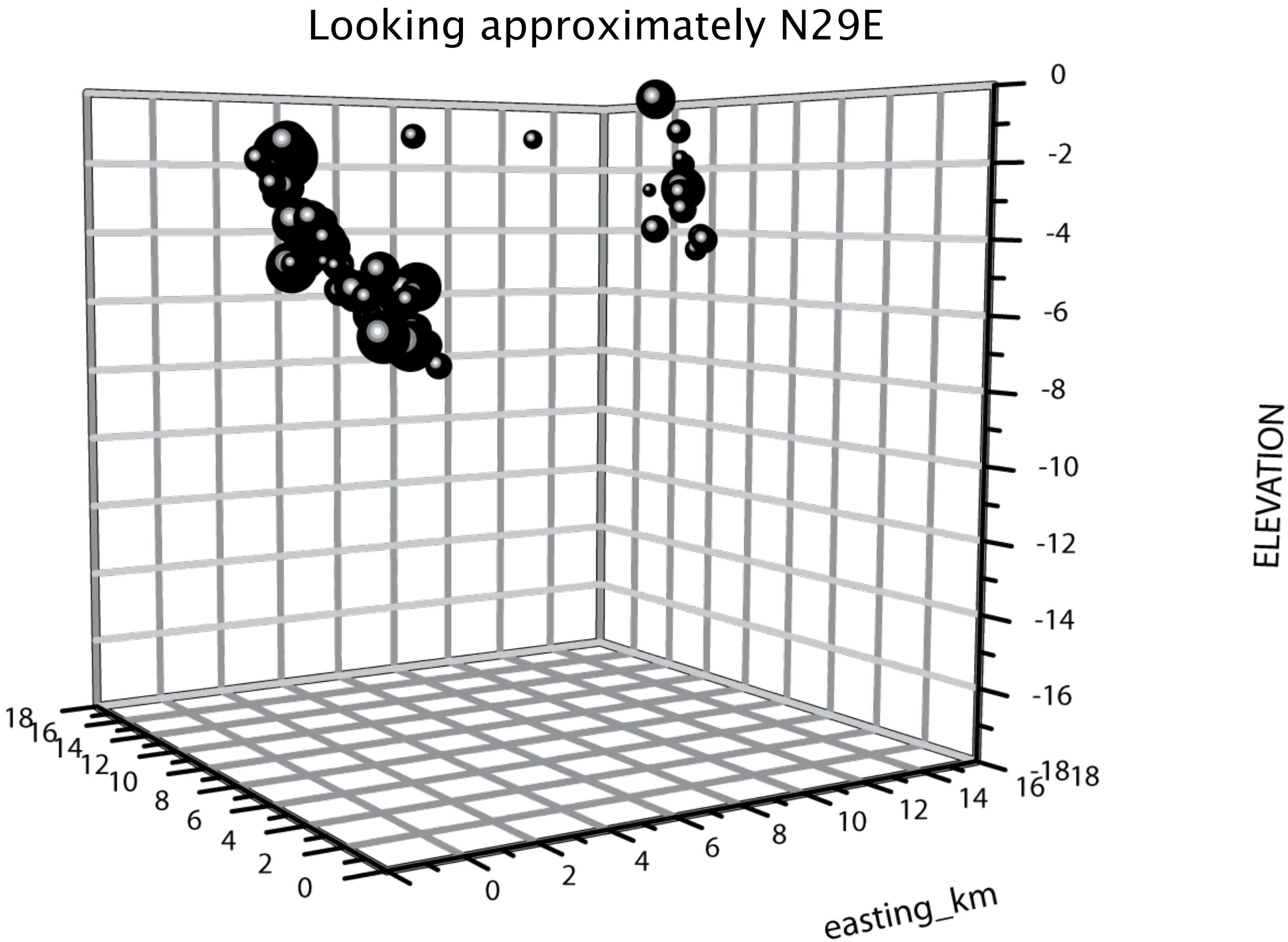
Return period M5.8: 1,72

recurrence based on N (M=3.0 since 1976) with b = 0.95

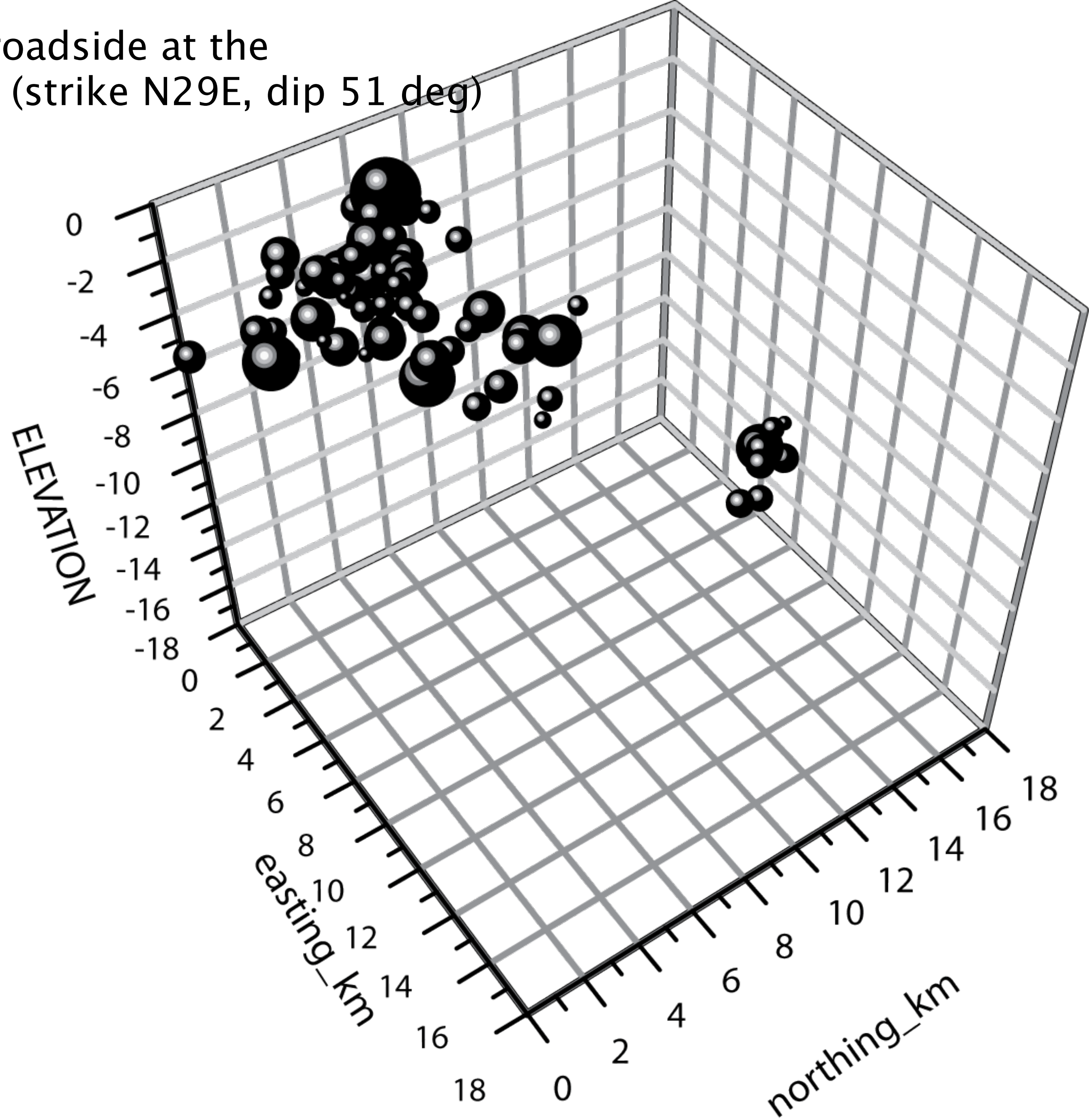
Bollinger, G.A. Davison, F.C., M.S. Sibol and J.B. Birch (1989). Magnitude recurrence relations for the southeastern United States and its subdivisions, JGR, 94, B3, 2857-2873


North Anna
Power Station
21 km
Aftershocks between
August 24 and September 2
2011
Lake Anna
Louisa
Mineral
Freeman Field
Cuckoo
Trevilians
Bumpass
Satellite
Traffic
2 mi
2 km
©2011 Google - Map data ©2011 Google - Terms of Use - Edit in Google Map Maker
Report a problem

Aftershock hypocenters, Aug. 24 – Sept. 2, 2011



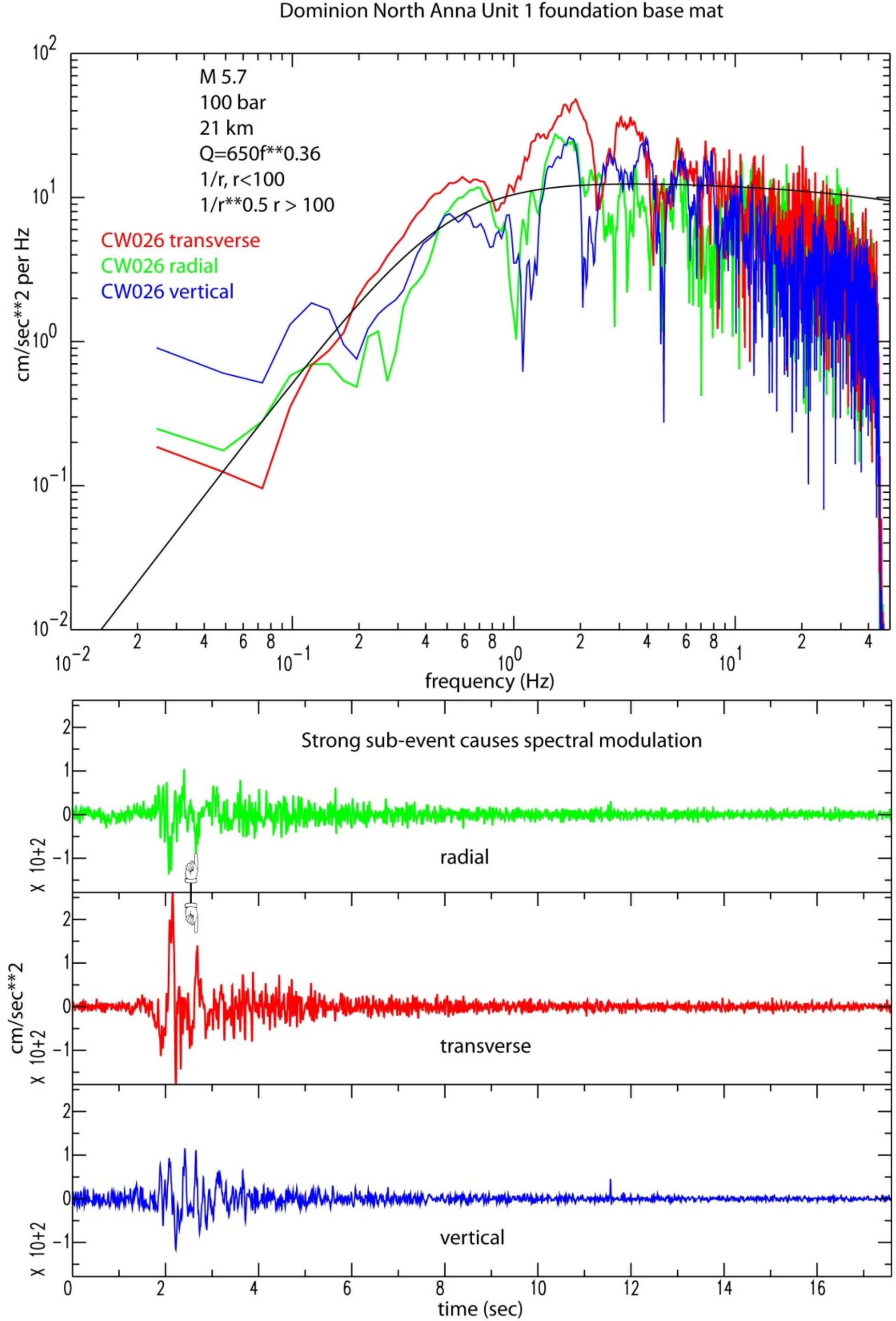
Looking broadside at the
fault plane (strike N29E, dip 51 deg)

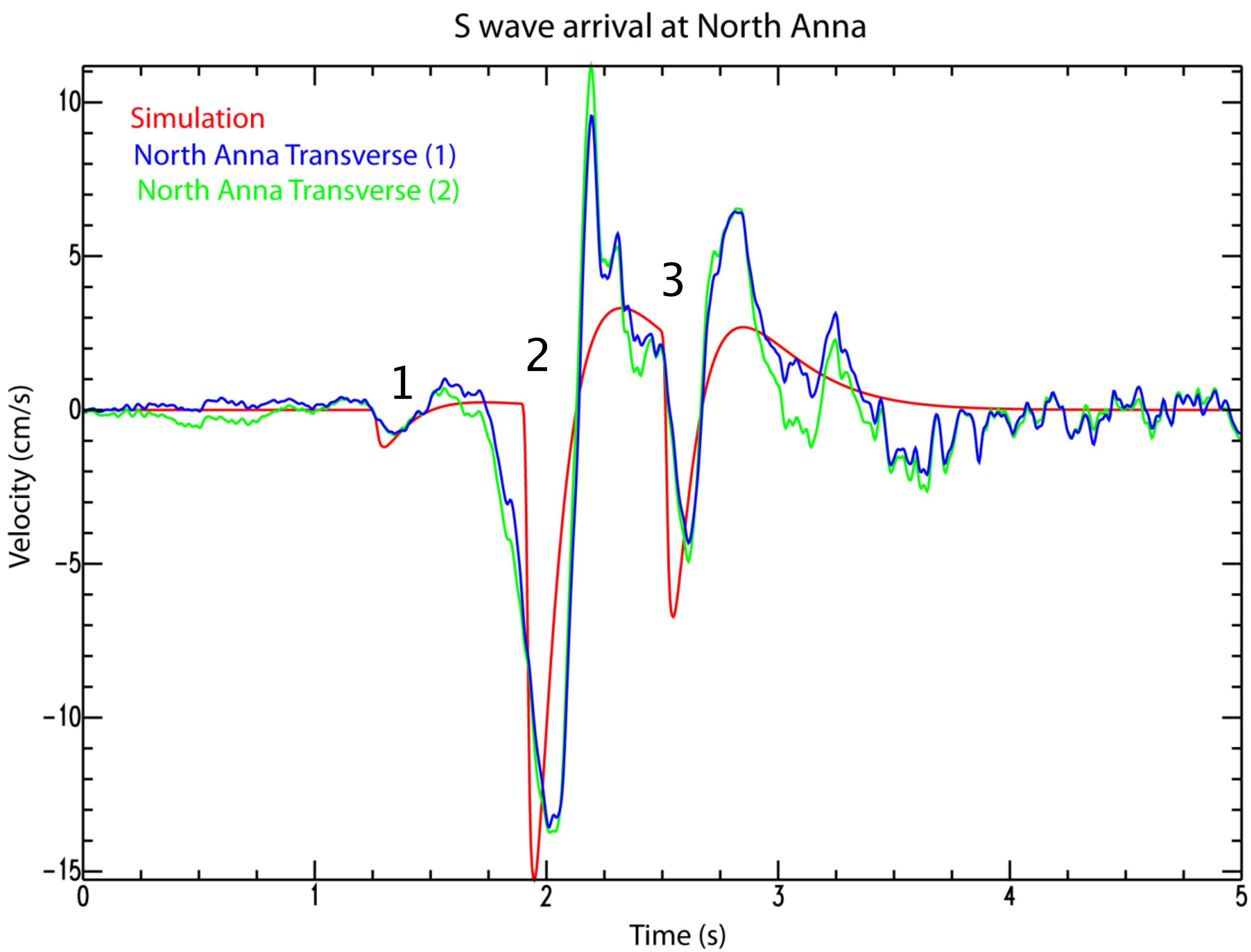


Strong motion recordings
on the foundation base mat
of the unit 1 containment structure
at North Anna.

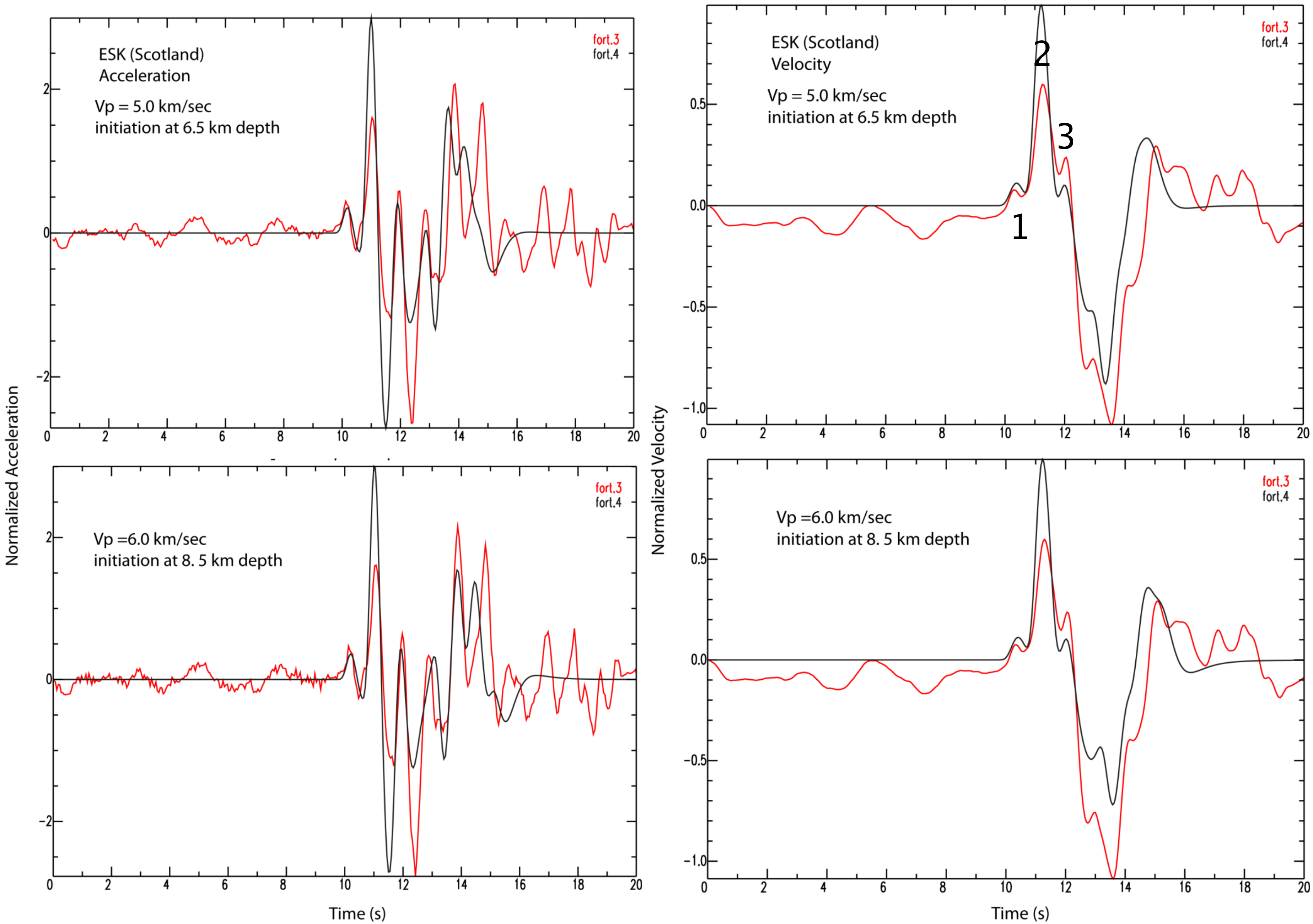
The records are remarkable for the very short duration, and pulse-like character of the largest motion---the S wave(s).

Note the modulated character of the Fourier amplitude spectra, due to two strong pulses in the S-wave train.



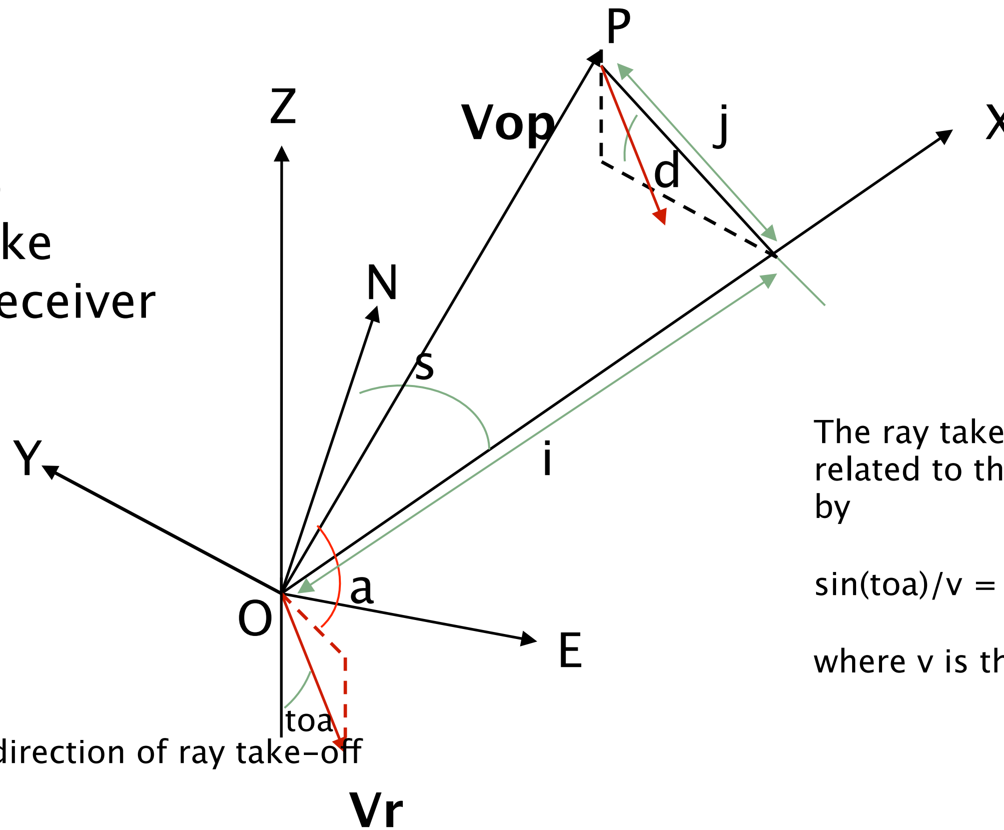

S wave arrival at North Anna
Simulation
North Anna Transverse (1)
North Anna Transverse (2)
1
2
3
Velocity (cm/s)
Time (s)
10
5
0
-5
-10
-15
0
1
2
3
4
5

Sub-events are visible on teleseismic recordings




ALE
KIEV
ESK
GRFO
DLBC
YKW3
PAB
LLLB
PNT
EDM
PGC
B05D
K22A
W18A
MSTX
DBIC
PLCA

d = fault dip
s = fault strike
a = source receiver azimuth



Vr unit vector in direction of ray take-off

Vop position vector of point P

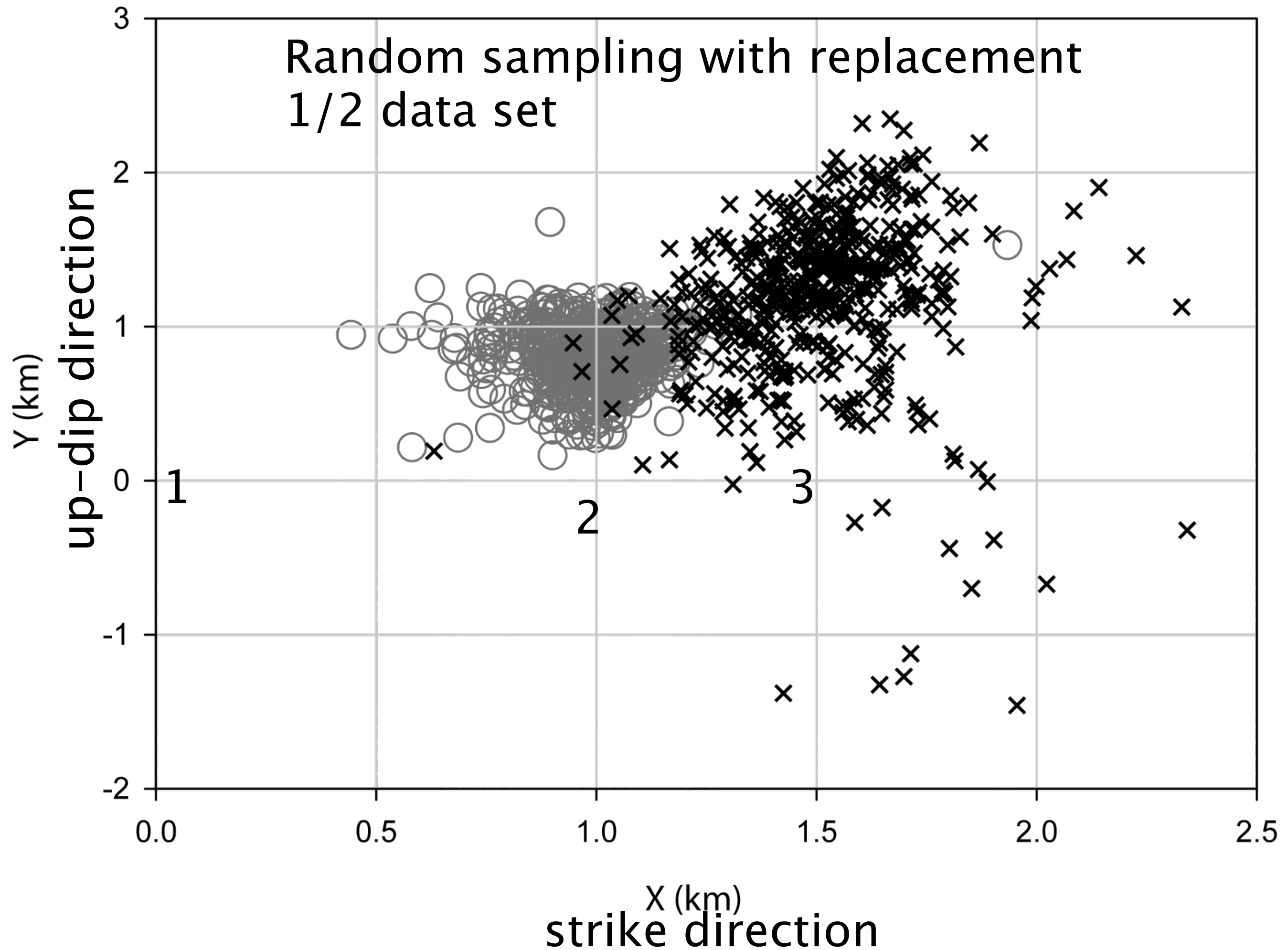
The ray take-off angle, toa, is related to the ray parameter P by

sin(toa)/v = P

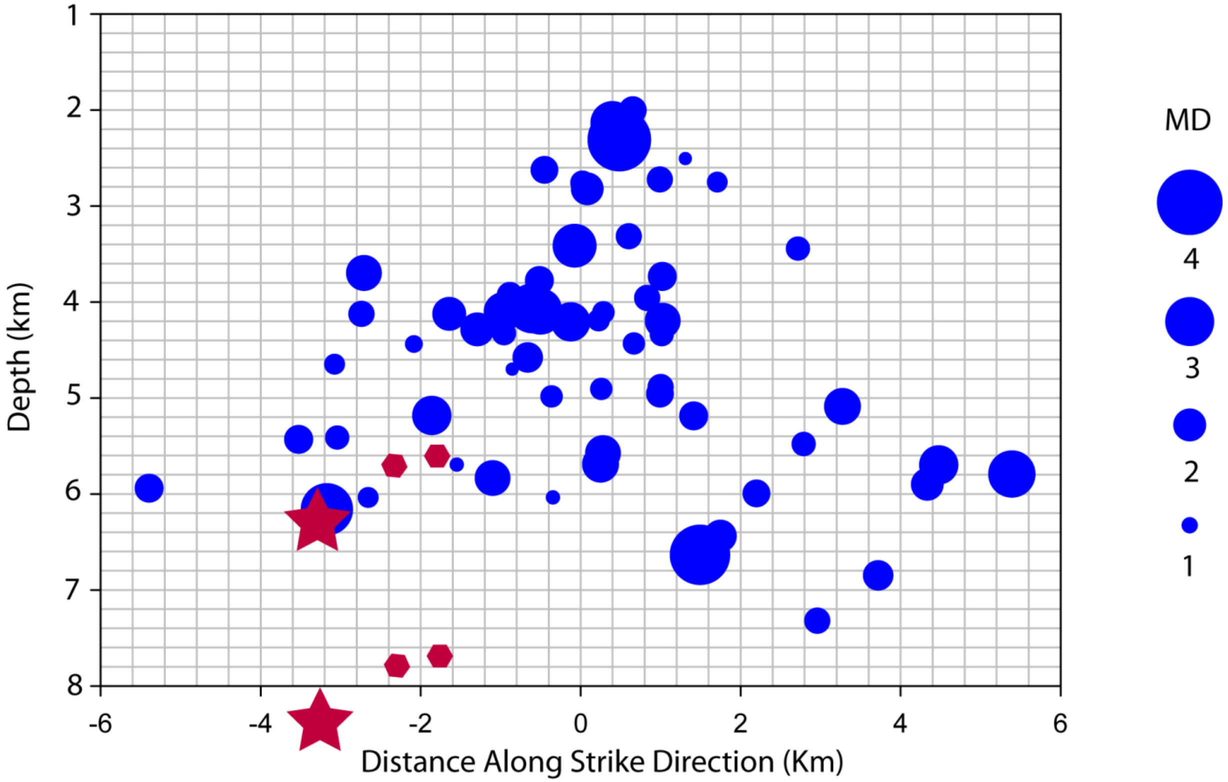
where v is the local seismic velocity

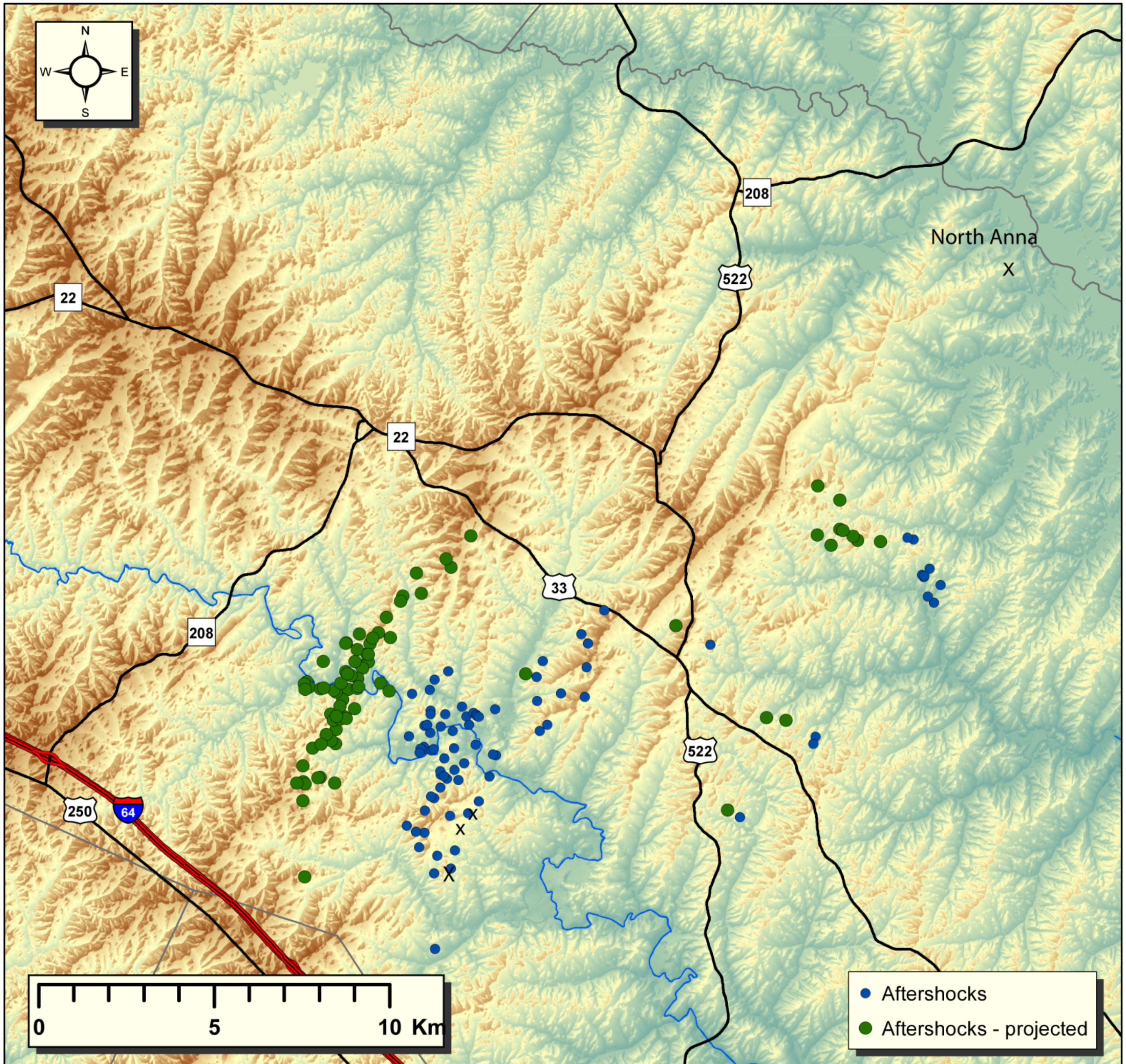
Consider two different sources, at points O and P in the plane of the fault. Define point O to be the origin of a local Cartesian coordinate system in the horizontal plane, with X axis in the strike direction.

Results of locating sub-events 2 and 3 relative to event 1 under the assumption that they are on a single fault plane using teleseismic and local data. The rupture velocity was apparently about 1.5 km/s.



Early aftershocks and main shock subevents




N
W
E
S
208
North Anna
X
522
22
22
33
208
522
250
64
0
5
10 Km
Aftershocks
Aftershocks - projected

Thank you for your Attention!