Youngstown Earthquake on 24 December 2011 and 31 December 2011

Summary (January 2, 2012)[1]

The locations of the December 24th and 31st, 2011 Youngstown, Ohio earthquakes are determined by using *P*- and *S*-wave arrival times at four seismographic stations deployed around the Youngstown since December 1st, 2011 (Table 1). The epicenters are fairly well determined by the data with the nearest station located at 1.9 km (=1.2 miles) and the station coverage with an azimuthal gap of about 120º. The epicenters and the seismographic stations used are plotted in Figure 1.

The focal depths are 3.55 and 3.68 km (=2.2 – 2.3 miles) with their 95% confidence error ellipsoids extending 0.86 km (=0.54 miles) of major axis in vertical direction. The epicentral distances of the two nearest stations are less than the focal depths, and hence the solution from the location program is reliable. Additional uncertainty in the focal depth may be due to the velocity model used to locate the events. We used virtually two-layered crustal model that consists of the top layer with *P*-wave velocity of 4.5 km/s and thickness of 2.7 km, and a 7.3 km thick crystalline rock layer with *P*-wave velocity of 6.12 km/s. The *S*-wave velocities are considered to be Vp/√3.

The two events located close to each other, and the 12/31 shock occurred about 100 m (~330 feet) east from the 12/24 shock (Figure 1). The error ellipses around the epicenters indicate that the ellipses have a 95% chance of containing the ***true*** epicenters.

The duration magnitude, Mc, of the 12/24 event determined by measuring signal durations from six stations is Mc 2.7. For 12/31 shock which USGS assigned the magnitude 4.0, we determined its seismic moment, focal mechanism and focal depth by modeling observed seismic records at permanent seismographic stations around Ohio. Waveform modeling is an advanced method of seismic data analysis which yields very useful information about the quakes.

The results of the waveform modeling indicate that the focal mechanism for the 12/31 shock is predominantly strike-slip faulting along steeply dipping nodal planes (see Figure 2). At the moment, we do not know which one is the fault plane. The seismic moment of the 12/31 shock is 8.3e+21 dyne-cm which corresponds to the moment magnitude Mw 3.9.

Table 1. Source parameters of the December 24th and 31st, 2011 Youngstown, Ohio earthquakes*

Date (year-mo-dy)	Time (UTC) (hh:mm:sec)	Latitude (ºN)	Longitude (ºW)	Depth (km)	Magnitude (M)	RMS (s)	Erh (km)	Erz (km)
2011-12-24	06:24:57.98	41.1186	80.6936	3.55	2.7	0.012	0.43	0.86
2011-12-31	20:05:00.01	41.1182	80.6926	3.68	4.0	0.010	0.41	0.86

* RMS=travel time residuals (observed-calculated) in seconds; Erh= horizontal error in km for 95% confidence level, Erz=vertical error in km for 95% confidence level.

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The best fit waveforms are produced for the focal depth of about 3-4 km, consistent with the location results. The focal mechanism also reveals regional tectonic stress field around the epicentral region. The P-axis of the focal mechanism trends NE-SW and plunges at very shallow angle (5°), which is consistent with a broad regional stress field – E-W trending horizontal compression, in the eastern United States.

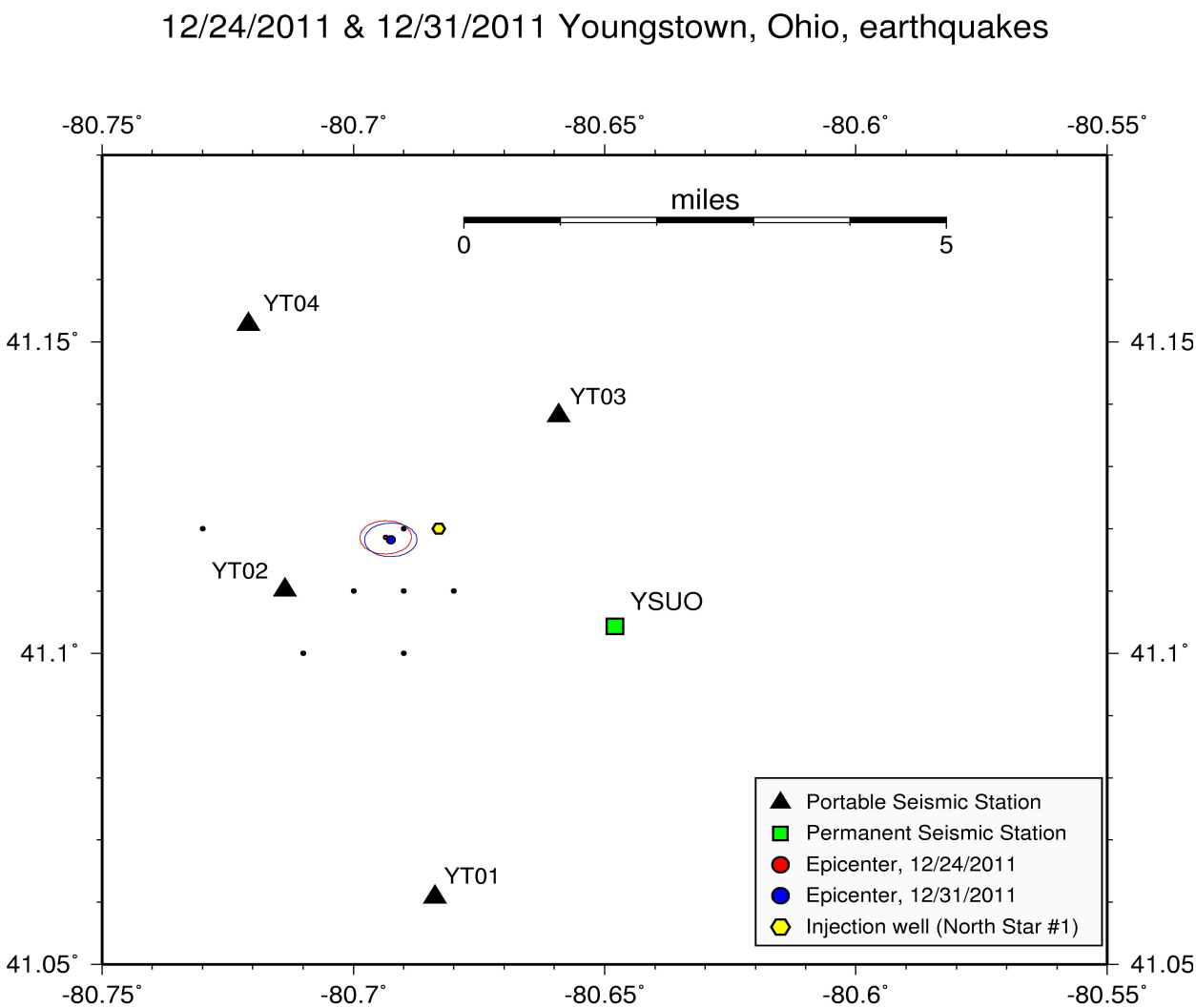

Figure 1. Locations of the M 2.7 earthquake on 12/24/2011 (red filled circle) and M 4.0 earthquake on 12/31/2011 (blue filled circle) in Youngstown, Ohio. Nine earthquakes that occurred between March – November 2011 in the region are plotted with small filled dots. Four portable seismographic stations around the region deployed by the Lamont-Doherty Earth Observatory of Columbia University and the Ohio Geological Survey, ODNR since 12/01/2011 and a permanent seismographic station YSUO (Youngstown State University) of the Ohio Seismic Network (green square) are plotted for reference. These epicenters are determined by using *P*- and *S*-wave readings from four portable seismographic stations located within 2-6.5 km (1.3-4.0 miles) from the earthquake source area. The ellipse around the epicenter is the 95% confidence error ellipse indicating that the ellipse has a 95% chance of containing the ***true*** epicenter.

```
PROGRAM HYPINV (version 1.3 - JUNE 1978) run on 28 Dec  2011 at 01:23:43
stations
   center 41. 07.45  80. 40.60  dlyaz=  999.00 dlywd=  0.00
  i  name ---lat---- ----lon---- pdly1 sdly1 pdly2 sdly2 fmc xmc wt mdl cal per typ
  1 YT01  41. 03.65  80. 41.03w  0.00  0.00  0.00  0.00 0.0 0.0 1  1   0.0 0.2  0 0.0
  2 YT02  41. 06.61  80. 42.82w  0.00  0.00  0.00  0.00 0.0 0.0 1  1   0.0 0.2  0 0.0
  3 YT03  41. 08.29  80. 39.55w  0.00  0.00  0.00  0.00 0.0 0.0 1  1   0.0 0.2  0 0.0
  4 YT04  41. 09.17  80. 43.25w  0.00  0.00  0.00  0.00 0.0 0.0 1  1   0.0 0.2  0 0.0
  5 YSUO  41. 06.26  80. 38.88w  0.00  0.00  0.00  0.00 0.0 0.0 1  1   0.0 0.2  0 0.0

 crust
 model:        1                      2                      3
 layer vel   depth  thick     vel   depth  thick     vel   depth  thick
   1  4.500  0.000  2.700    3.700  0.000  1.000    5.980  0.000  7.000
   2  6.120  2.700  7.300    5.400  1.000  2.100    6.620  7.000 28.000
   3  6.620 10.000 31.000    6.100  3.100 11.900    8.100 35.000999.000
   4  8.250 41.000999.000    6.700 15.000999.000    0.000  0.000  0.000

 test parameters
-iteration and convergence- -weighting, errors, trial depth- -duration mag constants-
   20=itrlim    0.90=damp    50.00=discut   0.50=rmscut  -1.70=fma1    -1.27=fma2
0.005=dquit   0.0001=drqt     1.00=disw1    2.00=rmsw1    2.21=fmb1     2.00=fmb2
 7.00=dxfix    0.012=eigtol   3.00=disw2    8.00=rmsw2    0.00=fmz1     0.00=fmz2
 7.00=dzmax     0.02=rback    1.00=swt      0.05=rderr    0.00=fmd1     0.00=fmd2
 0.50=dzair     0.60=bacfac   2.50=ztr      1.00=ercof   500.0=fmbrk    1.73=pos

1 24 dec 11,  6:24  event no.   1
                                                        adjustments (km)
  i origin   lat n    lon w     z  nwr  rms   dt    dlat   dlon    dz    rr nf
  1 177.86 41  7.28  80 41.48  4.41  8 0.06 0.017 -0.236  0.276  0.000 0.363 3
 focal depth freed
  2 177.88 41  7.15  80 41.68  4.41  8 0.05 0.104 -0.087 -0.079 -0.803 0.811 4
  3 177.98 41  7.11  80 41.62  3.61  8 0.02-0.004  0.012 -0.009 -0.061 0.063 4
  4 177.98 41  7.11  80 41.61  3.55  8 0.01 0.001  0.002 -0.005 -0.006 0.008 4
  5 177.98 41  7.11  80 41.61  3.54  8 0.01-0.001 -0.009 -0.002 -0.004 0.010 4
  6 177.98 41  7.11  80 41.61  3.54  8 0.01-0.001  0.009  0.005  0.016 0.020 4
  7 177.98 41  7.11  80 41.61  3.55  8 0.01 0.000 -0.007 -0.005  0.000 0.008 4

          eigenvalues
    (2.8720.4210.3050.141)                                      #error ellipse
  eigenvectors of adjustment        covariance           errors #  serr az dip
 ot (-.995-.0110.0270.097)(  0.002 -0.001 -0.002 -0.013)  0.040 #  0.36 289 78
 lat(0.003-.997-.030-.067)( -0.001  0.015  0.001  0.008)  0.124 #  0.17  89 10
 lon(0.009-.0170.982-.188)( -0.002  0.001  0.032  0.019)  0.179 #  0.12 180  4
 z  (-.1010.070-.184-.975)( -0.013  0.008  0.019  0.128)  0.358 #
-------------------------------------------------------------------------------
year mo da origin time lat n     lon w    depth  rms   erh   erz gap xmag fmag
2011-12-24 06:24:57.98 41 07.11  80 41.61  3.55  0.012 0.17  0.36 119      2.7

 rmswt dmin itr nfm nwr nws remk tq sq dq    lat    lon
  0.01  1.9   7   4   8   4  aa  b  a  b     41.1186 -80.6936

  sta dist azm  an p/s w   sec+ccor  (tobs -tcal -dly  =res)  wt  xmg fmg  info

YT02   1.9 242 144 ipd   58.826 0.00 0.850 0.837 0.00  0.013 1.14         0.293
                    s  1 59.423 0.00 1.447 1.448 0.00 -0.001 0.86         0.719
YT03   3.6  53 121 ipd 1 59.031 0.00 1.055 1.040 0.00  0.015 1.14         0.418
                    s  1 59.760 0.00 1.784 1.799 0.00 -0.015 0.86         0.668
YSUO   4.1 112 116 ipu 4 58.116 0.00 0.140 1.115 0.00 -0.975 0.00         0.000
YT04   4.4 329 113 ipu   59.132 0.00 1.156 1.159 0.00 -0.003 1.14         0.521
                    s  1 59.971 0.00 1.995 2.006 0.00 -0.010 0.86         0.427
YT01   6.5 172 102 ipu   59.460 0.00 1.484 1.482 0.00  0.002 1.14         0.520
                    s  1 60.517 0.00 2.541 2.564 0.00 -0.023 0.86         0.430
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PROGRAM HYPINV (version 1.3 - JUNE 1978) run on  2 Jan  2012 at 23:02:31

 stations
   center 41.  7.45   80. 40.60  dlyaz=  999.00 dlywd=  0.00
i  name ---lat---- ----lon---- pdly1 sdly1 pdly2 sdly2 fmc xmc wt mdl cal per typ
1 YT01 41.  3.65   80. 41.03w  0.00  0.00  0.00  0.00 0.0 0.0 1  1   0.0 0.2  0 0.0
2 YT02 41.  6.61   80. 42.82w  0.00  0.00  0.00  0.00 0.0 0.0 1  1   0.0 0.2  0 0.0
3 YT03 41.  8.29   80. 39.55w  0.00  0.00  0.00  0.00 0.0 0.0 1  1   0.0 0.2  0 0.0
4 YT04 41.  9.17   80. 43.25w  0.00  0.00  0.00  0.00 0.0 0.0 1  1   0.0 0.2  0 0.0
5 YSUO 41.  6.26   80. 38.88w  0.00  0.00  0.00  0.00 0.0 0.0 1  1   0.0 0.2  0 0.0

 crust
 model:        1                      2                      3
 layer vel   depth  thick     vel   depth  thick     vel   depth  thick
   1  4.500  0.00   2.700    3.700  0.00   1.000    5.980  0.00   7.000
   2  6.120  2.70   7.300    5.400  1.00   2.100    6.620  7.00  28.000
   3  6.620 10.00  31.000    6.100  3.10  11.900    8.100 35.00 999.000
   4  8.250 41.00 999.000    6.700 15.00 999.000    0.000  0.00   0.000

 test parameters
-iteration and convergence- -weighting, errors, trial depth-  -duration mag constants-
   20=itrlim     0.900=damp     50.00=discut    0.50=rmscut  -1.700=fma1    -1.270=fma2
0.005=dquit     0.0001=drqt      1.00=disw1     2.00=rmsw1     2.21=fmb1      2.00=fmb2
7.000=dxfix     0.0120=eigtol    3.00=disw2     8.00=rmsw2     0.00=fmz1      0.00=fmz2
7.000=dzmax     0.0200=rback     1.00=swt       0.05=rderr     0.00=fmd1      0.00=fmd2
0.500=dzair     0.6000=bacfac    2.50=ztr       1.00=ercof   500.00=fmbrk     1.73=pos

1 31 dec 11, 20: 4  event no.   1

                                                        adjustments (km)
 i origin   lat n    lon w     z  nwr  rms   dt    dlat   dlon    dz    rr nf
 1  60.01 41  7.09  80 41.56  3.68  8 0.01 0.004  0.000 -0.003  0.000 0.003 3
 focal depth freed
 2  60.01 41  7.09  80 41.56  3.68  8 0.01 0.000  0.001 -0.003  0.004 0.005 4
 3  60.01 41  7.09  80 41.56  3.68  8 0.01 0.000  0.001 -0.003  0.000 0.003 4

          eigenvalues
    (2.8730.4170.2950.139)                                     #error ellipse
  eigenvectors of adjustment        covariance           errors #  serr az dip
 ot (-.994-.014-.030-.101)(  0.002 -0.001 -0.002 -0.013)  0.041 #  0.36 293 78
 lat(0.005-.9970.0290.077)( -0.001  0.016  0.001  0.009)  0.125 #  0.17  89 10
 lon(0.012-.015-.9840.177)( -0.002  0.001  0.033  0.018)  0.182 #  0.12 180  4
 z  (-.1060.0800.1730.976)( -0.013  0.009  0.018  0.129)  0.359 #

 ------------------------------------------------------------------------------
 yr mo da   origin     lat n     lon w    depth  rms   erh   erz gap xmag fmag
 11-12-31 20:05:00.01  41 07.09  80 41.56  3.68  0.010 0.17  0.36 122     4.0

 rmswt dmin itr nfm nwr nws remk tq sq dq    lat    lon
  0.01  2.0   3   4   8   4  ab  b  a  b     41.1182 -80.6926

  sta dist azm  an p/s w   sec+ccor  (tobs -tcal -dly  =res)  wt  xmg fmg  info
YT02   2.0 245 144 ipd   60.887 0.00 0.873 0.860 0.00  0.013 1.14         0.285
                    s  1 61.501 0.00 1.487 1.488 0.00 -0.001 0.86         0.720
YT03   3.5  51 123 ipd   61.071 0.00 1.057 1.046 0.00  0.011 1.14         0.421
                    s  1 61.812 0.00 1.798 1.809 0.00 -0.011 0.86         0.674
YSUO   4.0 112 119 ipu 4 59.914 0.00-0.100 1.110 0.00 -1.210 0.00         0.000
                    s  4 60.900 0.00 0.886 1.920 0.00 -1.034 0.00         0.000
YT04   4.5 329 115 ipu   61.190 0.00 1.176 1.180 0.00 -0.004 1.14         0.524
                    s  1 62.045 0.00 2.031 2.041 0.00 -0.010 0.86         0.418
YT01   6.4 173 104 ipu   61.494 0.00 1.480 1.478 0.00  0.002 1.14         0.523
                    s  1 62.555 0.00 2.541 2.556 0.00 -0.016 0.86         0.432
```

A preliminary LCSN moment tensor solution for the event located at Youngstown, Ohio, (41.12N, 80.68W, h= 3.0 km, LDEO) on 12/31/2011 at 20:05:01 UTC. Mw 3.9 and depth of 3 km were obtained from long-period waves recorded by stations of the LCSN, USNSN, CNSN, USArray, PennState and other seismic networks around Ohio.

```
          LCSN Moment Tensor Solution

Event Date/Time:12/31/2011 20:05:01.0 (Preliminary)

Best Fitting Double-Couple:
   Mo = 8.30E+21 Dyne-cm
   Mw = 3.88
   h  =   3 km
   Plane   Strike   Dip    Rake
    NP1      265     72      12
    NP2      171     79     162
Principal Axes:
   Axis  Azimuth  Plunge      Value
     P       219       5  -0.10E+24
     N       321      69   0.66E+20
     T       127      20   0.10E+24
Moment Tensor: Scale = 10**23 Dyne-cm
   Component   Value
 Mxx=-0.29 Mxy=-0.91 Mxz=-0.13
 Myy= 0.18 Myz= 0.31 Mzz= 0.12
```

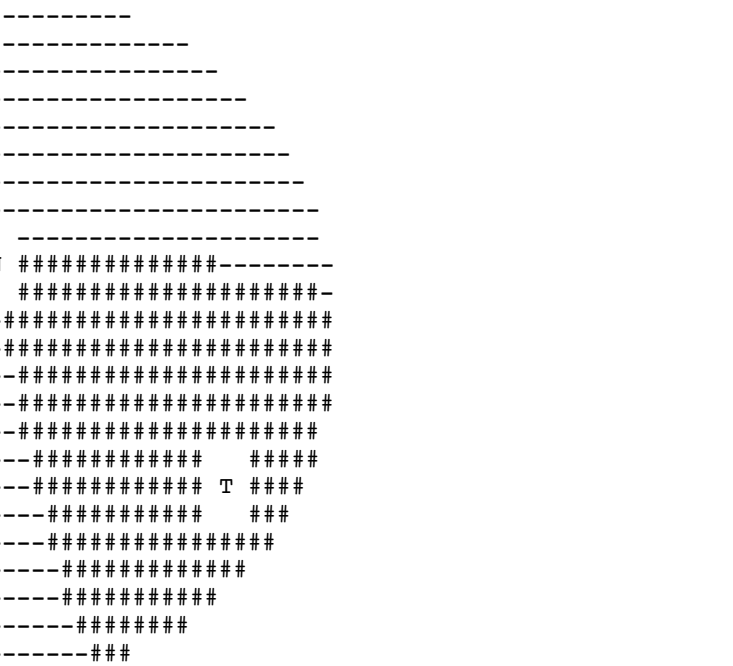

Figure 2. The focal mechanism of the 12/31 shock is represented as a *beachball* which indicates that the earthquake occurred as predominantly strike-slip faulting along steeply dipping nodal planes. Orientation of the nodal planes, P- and T-axis, elements of the moment tensor, Mxx etc. are indicated.