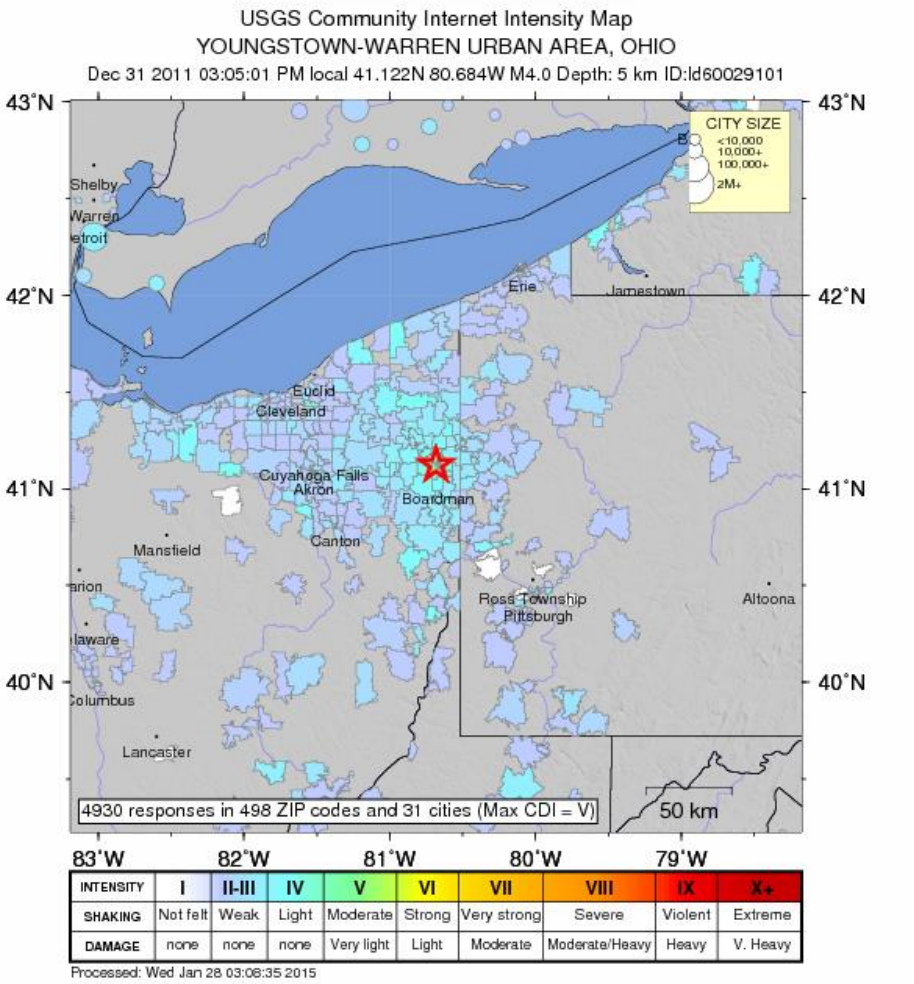
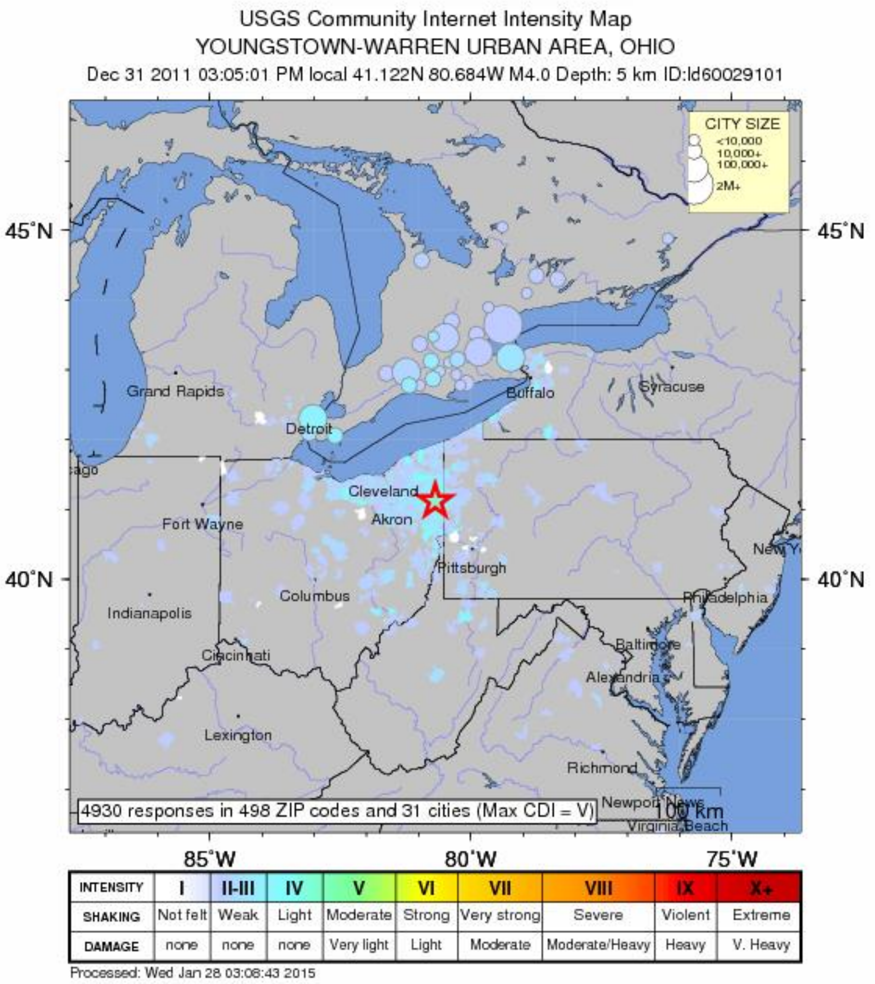
Induced Seismicity From a Regulator's Perspective

Richard Simmers, Chief
Division of Oil and Gas Resources Management

Northstar #1 – December 31, 2011





Timeline

2011
- Youngstown area seismicity

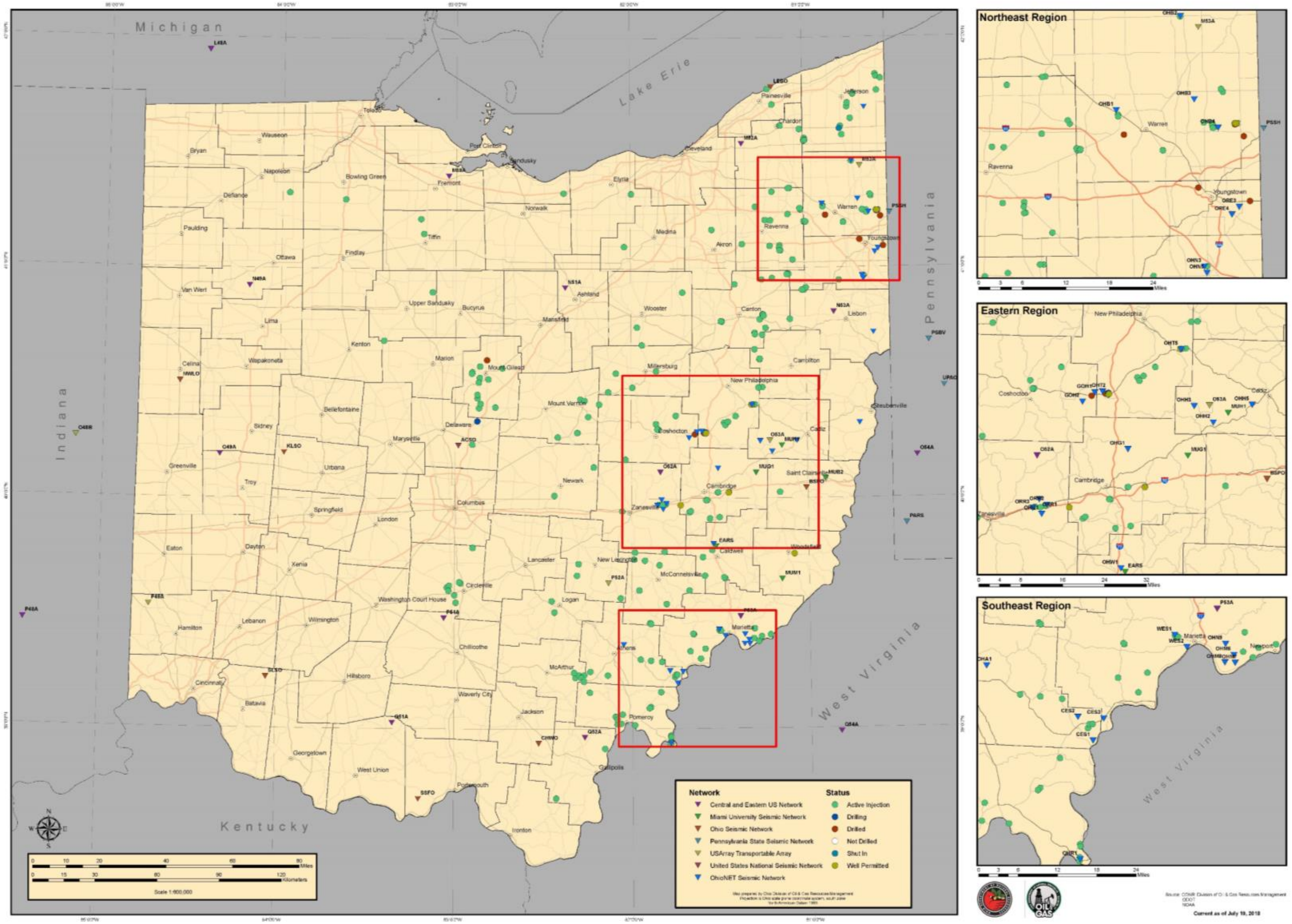
2012
- Senate Bill 315 signed into law; new statute for injection wells
- Deployment of 3-component stations to monitor seismicity in eastern Ohio

2014
- Seismic event associated with well completion

2015
- Established time correlation between completions pumping and events

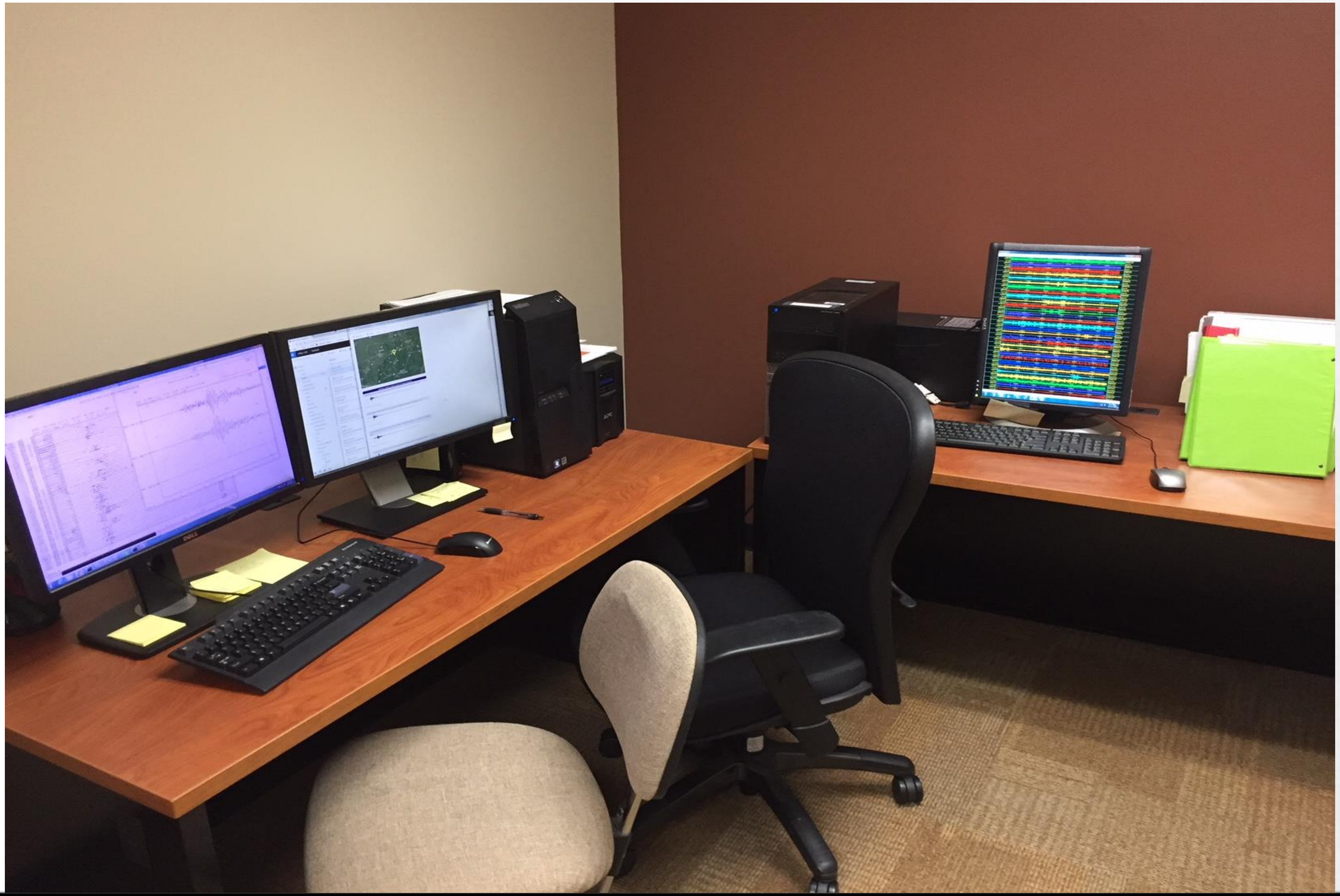
Ohio Department of Natural Resources: Division of Oil & Gas Resources Management OhioNET Seismic Network

by S. Dade



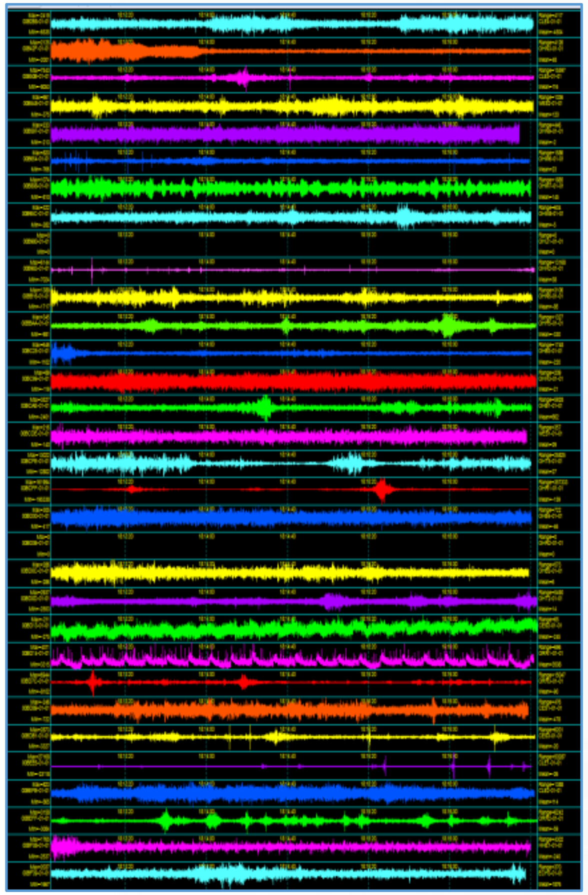
OhioNET Seismic Monitoring System

- OhioNET's capabilities allow data to be transmitted to the Division's Central Office



OhioNET Seismic Monitoring System

- 24/7, 365 day real-time continuous seismic monitoring by a lead geophysicist, two seismologists and a geo technician.
- OhioNET receives data from over 60 seismic stations



Ref Tek Network Monitor (4.0.8.0 - 2015Jun15) - List View

Acquisition	Temp.	Input	Backup	Delay(s)	RAM(Kb)	Disk1(Mb)	Disk2(Mb)	GPS(h)
Start On	21°C	12.9V	3.3V	1	0%(6400)	0%(7621)	76%(3806)	U-Sleep (0.3)
Start On	23.4°C	12.7V	3.3V	1	0%(6400)	100%(7621)	26%(3806)	U-Sleep (0.3)
Start On	21.5°C	12.7V	3.3V	1	0%(6400)	67%(7621)	0%(3813)	U-Sleep (0.3)
Start On	21.3°C	12.5V	3.3V	1	0%(14592)	N/A	N/A	U-Sleep (0.3)
Start On	21.5°C	12.5V	3.3V	1	0%(14592)	N/A	N/A	U-Sleep (0.3)
Start On	22°C	12.7V	3.3V	1	13%(6400)	N/A	N/A	U-Sleep (0.3)
Start On	21.5°C	11.8V	3.3V	1	0%(14592)	N/A	N/A	U-Sleep (0.3)
Start On	22.4°C	12.9V	3.3V	3190	1%(6400)	N/A	N/A	U-Sleep (0.4)
Start On	20.3°C	12.6V	3.3V	0	0%(6400)	N/A	N/A	L-Awake
Start On	22.4°C	13.7V	3.3V	8814	0%(6400)	N/A	N/A	L-Awake
Start On	21°C	12.9V	3.3V	0	0%(6400)	N/A	N/A	L-Awake
Start On	20°C	12.6V	0.4V	3190	0%(6400)	N/A	N/A	L-Awake
Start On	25°C	12.8V	3.3V	568	0%(6400)	N/A	N/A	L-Awake
Start On	25°C	12.9V	3.3V	3815	0%(14592)	N/A	N/A	L-Awake
Start On	21.4°C	12.8V	0.4V	1	3%(6400)	100%(1873)	36%(1873)	L-Awake
Start On	21.3°C	12.8V	0.4V	0	14%(6400)	60%(15250)	0%(1873)	L-Awake
Start On	20.8°C	12.8V	0.4V	1	5%(6400)	60%(15250)	0%(1950)	L-Awake
Start On	20°C	12.9V	3.3V	1	0%(6400)	N/A	N/A	L-Awake
Start On	16.5°C	12.7V	3.3V	0	0%(6400)	N/A	N/A	L-Awake
Start On	23°C	12.8V	0.4V	2	1%(6400)	0%(1873)	62%(15250)	L-Awake
Start On	21.4°C	12.7V	3.3V	0	17%(6400)	100%(15250)	14%(15250)	L-Awake
Start On	21.4°C	12.7V	3.3V	0	15%(6400)	0%(3806)	58%(7621)	L-Awake
Start On	22.5°C	12.6V	3.3V	0	0%(6400)	N/A	N/A	L-Awake
Start On	18.9°C	12.6V	3.1V	0	13%(6400)	0%(1950)	87%(15250)	L-Awake
Start On	21°C	12.5V	3.3V	1	0%(6400)	N/A	N/A	U-Sleep (0.3)
Start On	21.5°C	12.7V	3.3V	1	0%(14592)	N/A	N/A	U-Sleep (0.3)
Start On	20.8°C	12.6V	3.3V	1	0%(6400)	N/A	N/A	U-Sleep (0.3)
Start On	21.5°C	12.9V	3.3V	0	9%(6400)	64%(7621)	0%(3806)	L-Awake
Start On	23°C	12.6V	0.4V	1	0%(6400)	N/A	N/A	L-Awake

OhioNET Seismic Monitoring System

In-Ground

- 75% underground
- Tiered shelving
- L22 Sensor: Placed at the bottom of the vault

Pros:
- Most concealed

Cons:
- Collects water
- Maintenance accessibility

OhioNET Seismic Monitoring System

Elevated

- Borehole Sensor: Within 10 feet of station
- All other equipment on pole

Pros:

- Ventilation/Temperature control
- Easiest maintenance
- Sensor stays level
- Layout: Most organized

Cons:

- Wasps/hornets on panels

Earthworm Alert – Harrison Co. during Hydraulic Fracturing Operation

Ohio DNR EW Automated Preliminary Earthquake Location: Please note that earthquake data may be preliminary and subject to change. - EW Event ID: 7298

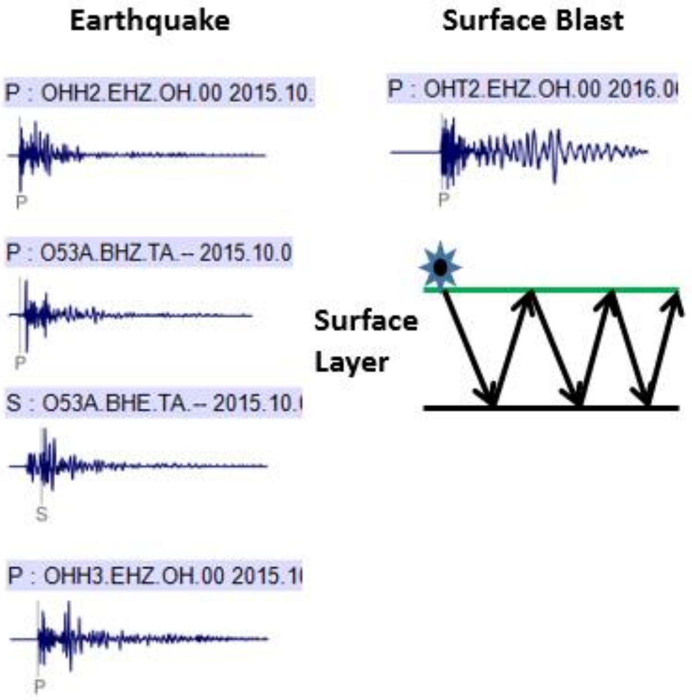
OhioNET@dnr.state.oh.us

Sent: Thu 10/1/2015 3:29 AM

To: Rush, David

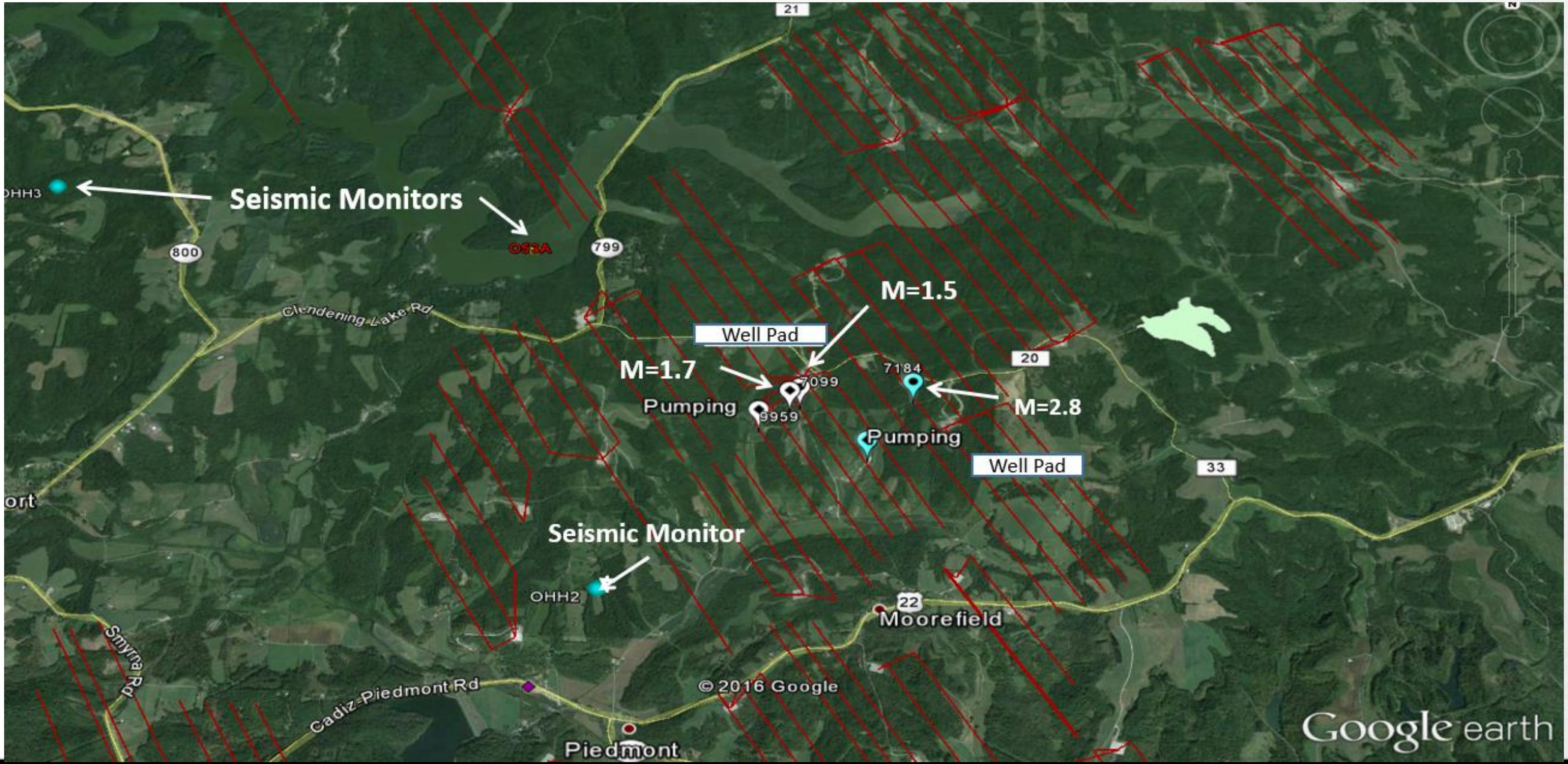
Recalculated depth places event at top of basement

EW Event ID: 7298	
Origin time:	2015.10.01 08:25:33 !!
Latitude:	40.2270
Longitude:	-81.1902
Depth:	0.8 km **2.7 km (8860')**
Coda Magnitude:	1.5 Md nobs=5
Local Magnitude:	1.7 ±0.6 ML nobs=68
RMS Error:	0.08 s
Horizontal Error:	0.48 km
Depth Error:	0.22 km
Azimuthal Gap:	130 Degrees
Total Phases:	26
Total Phases Used:	13
Num S Phases Used:	4
Quality:	B

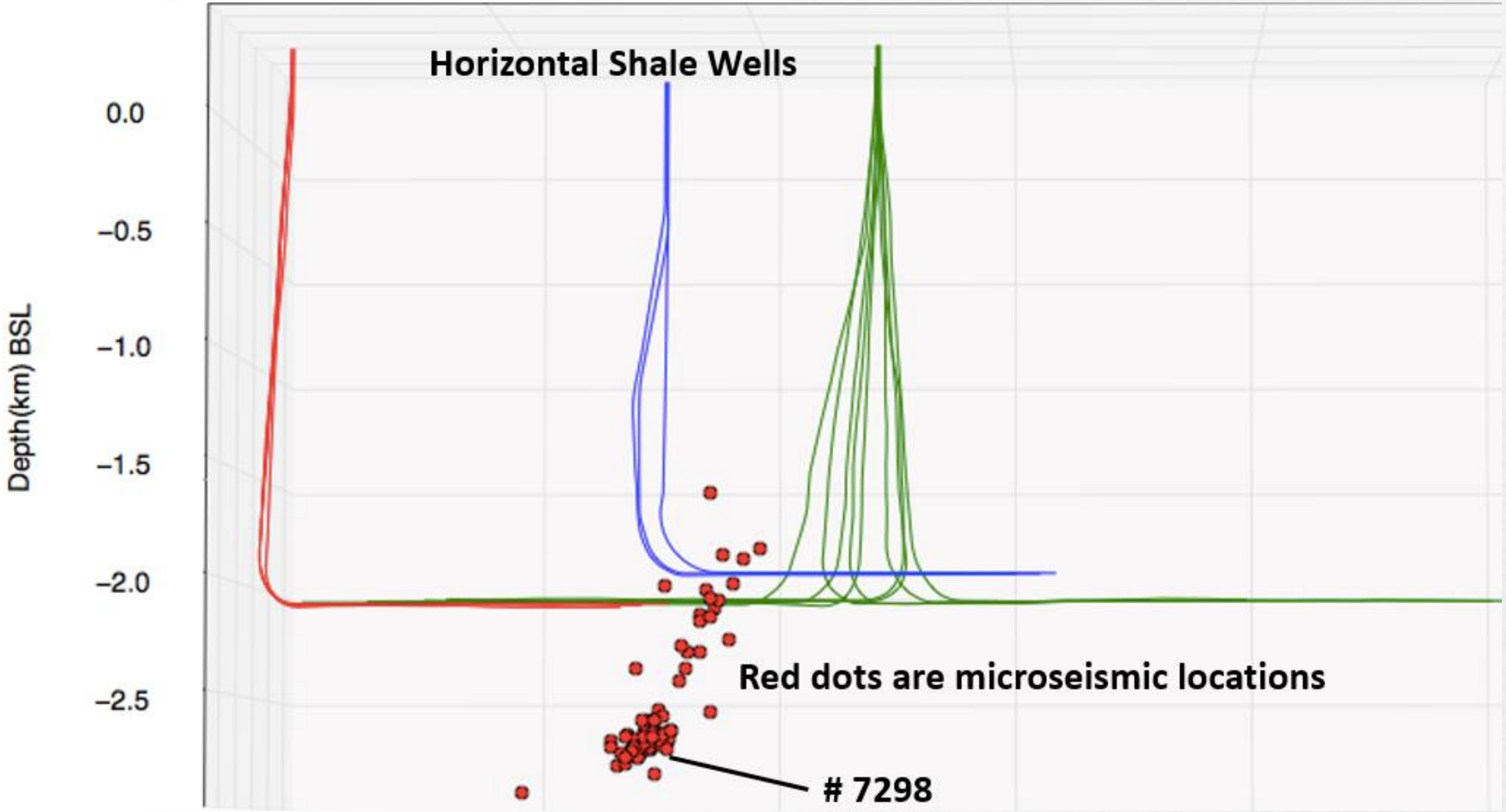


Harrison County, October 2015

- Timing of seismic events coincide with pumping

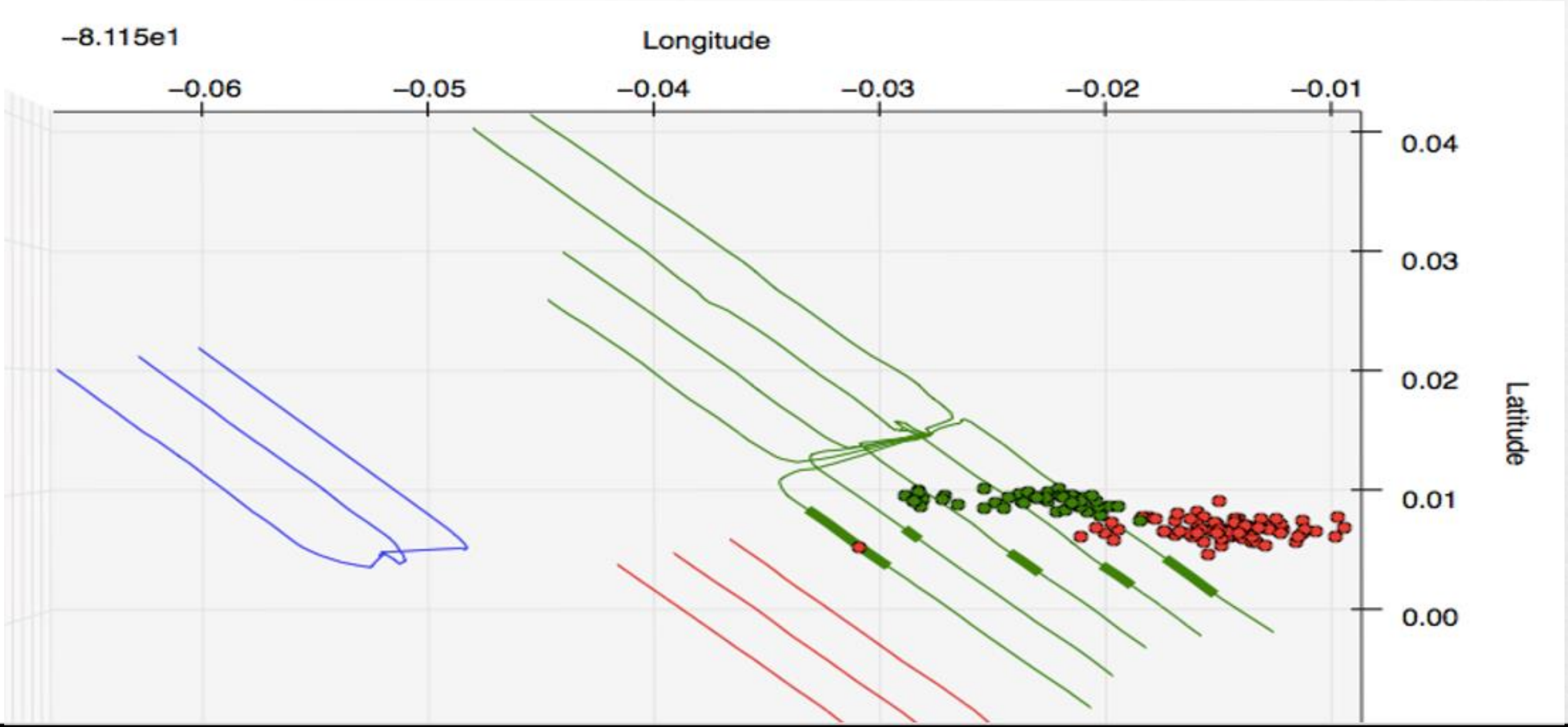


Depth View of Seismic Events



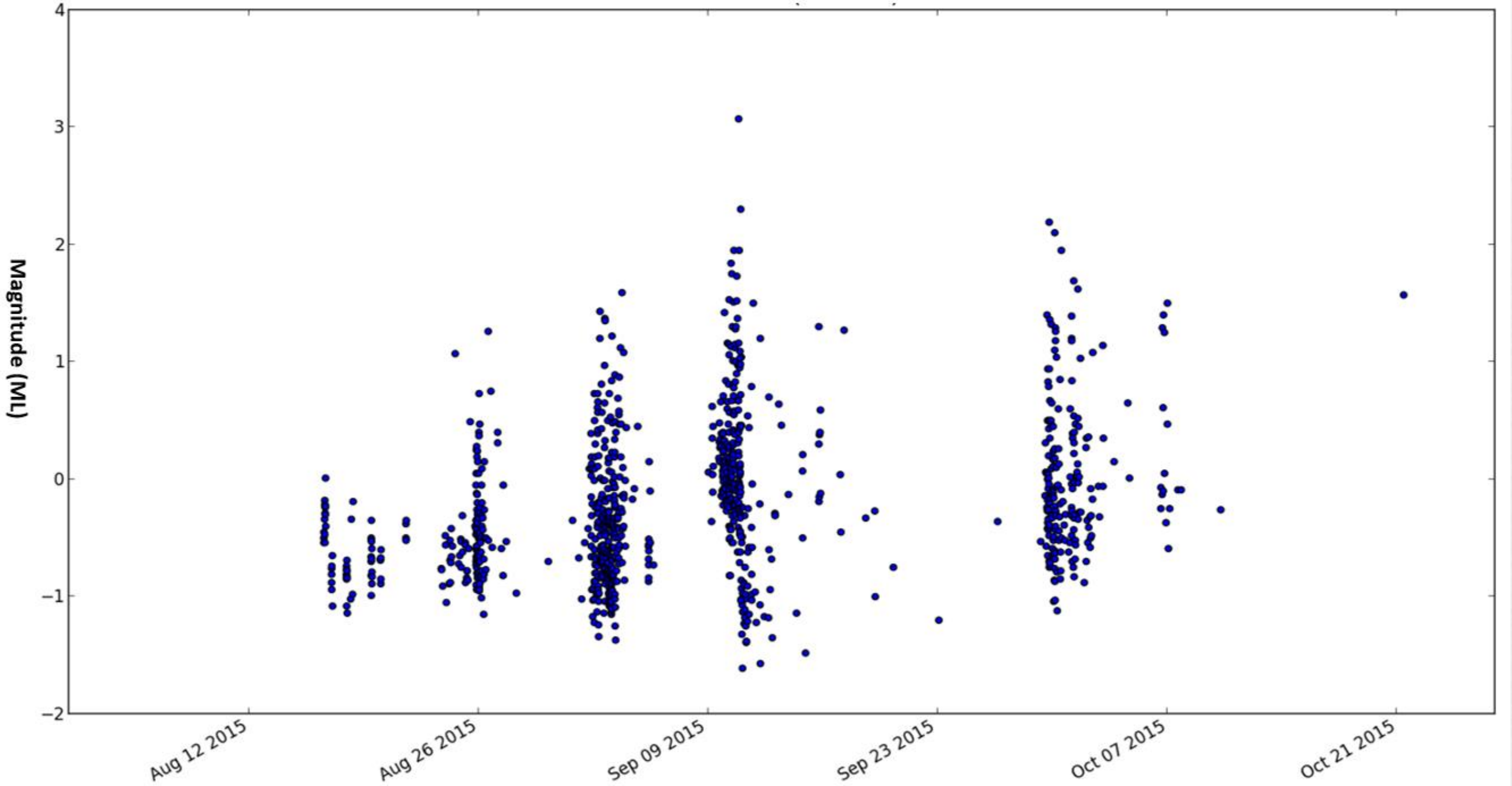
Source: Paul Friberg, ISTI

Map View of Earthquakes, Harrison County



Source: Paul Friberg, ISTI

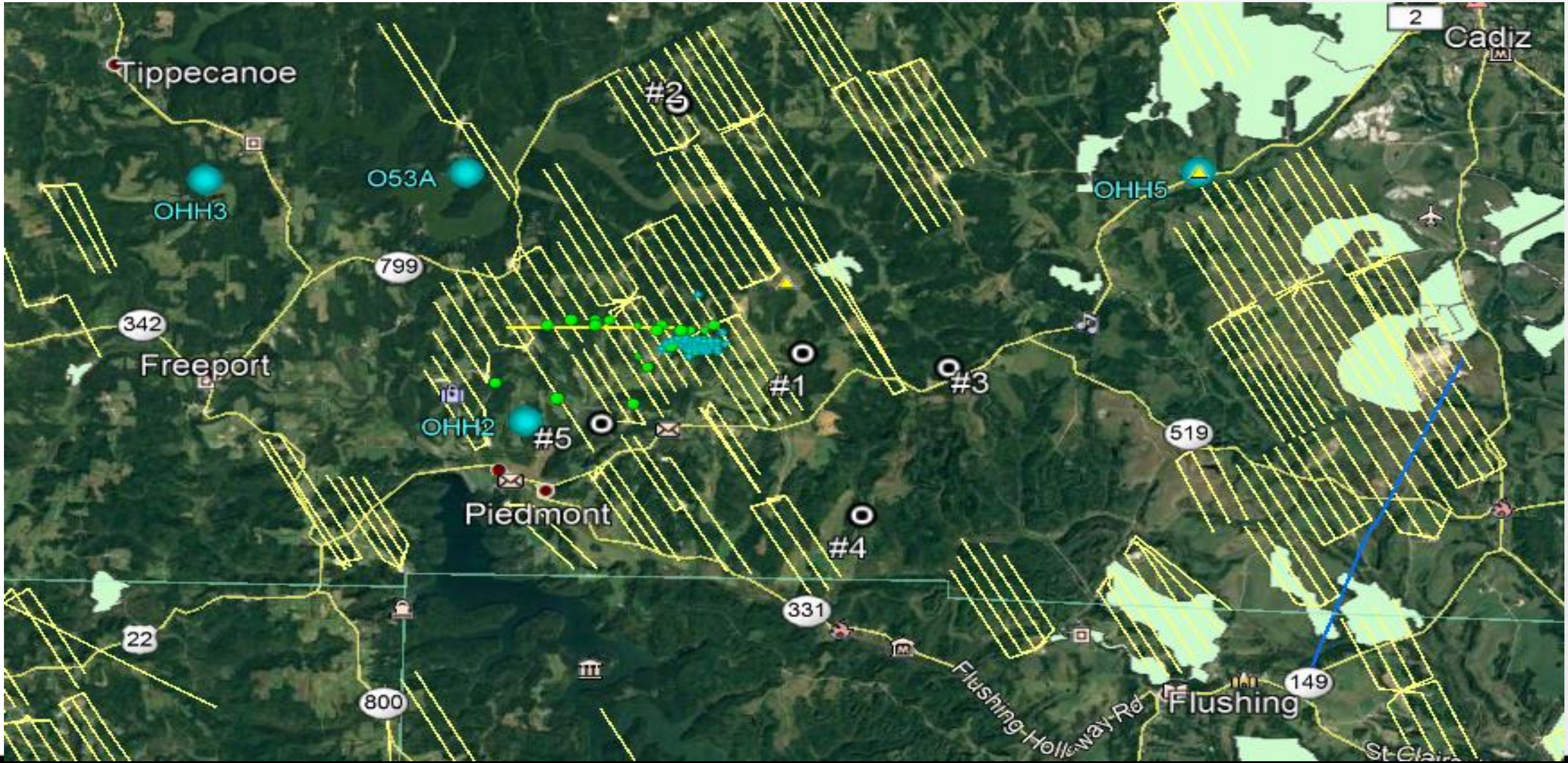
Plot of Microseismic Events at Well Completion Pad, Harrison County



Ohio Department of
NATURAL RESOURCES

Source: Paul Friberg, ISTI

Harrison County Operator Stations

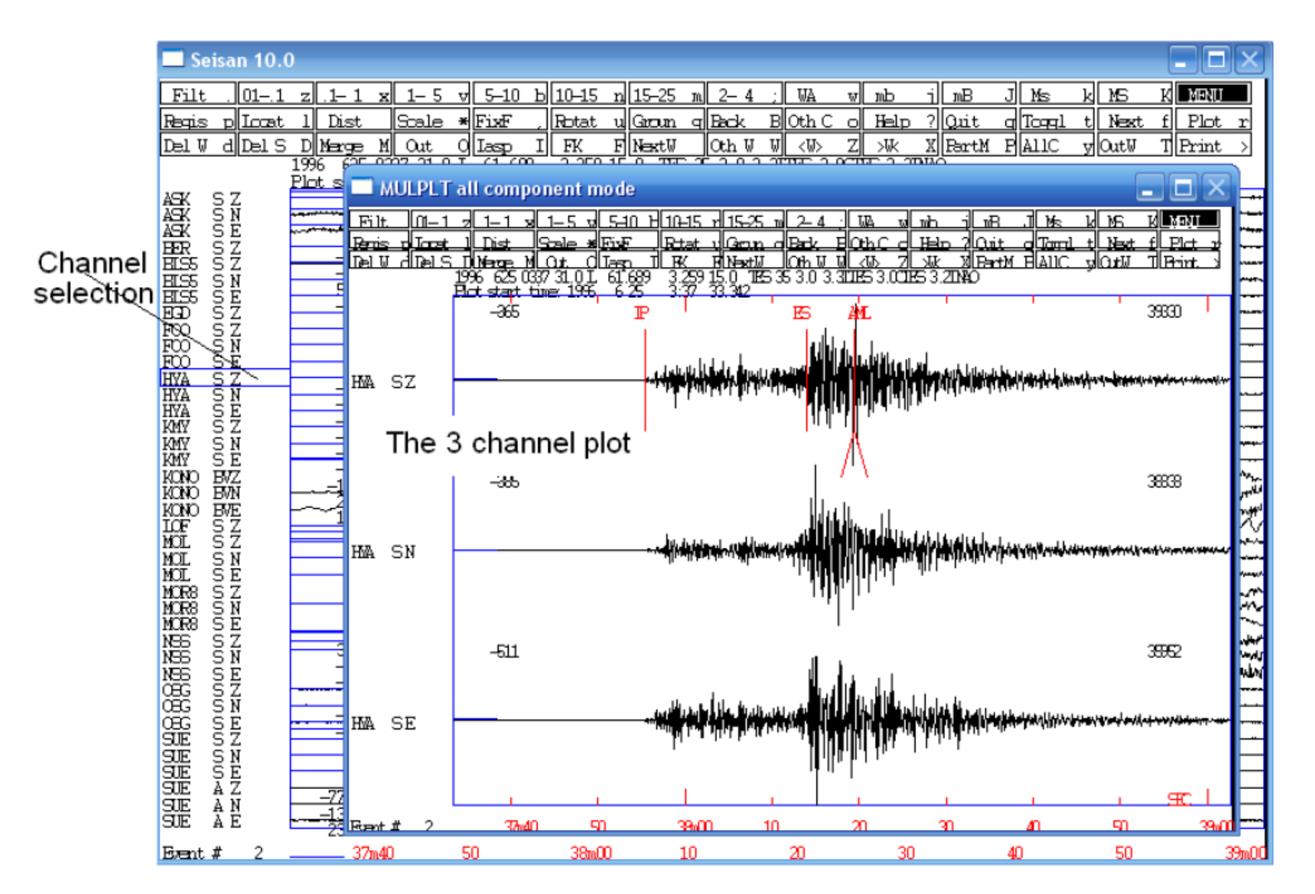


Monroe County Operator Stations

Error Ellipsoid and 3 mile buffer

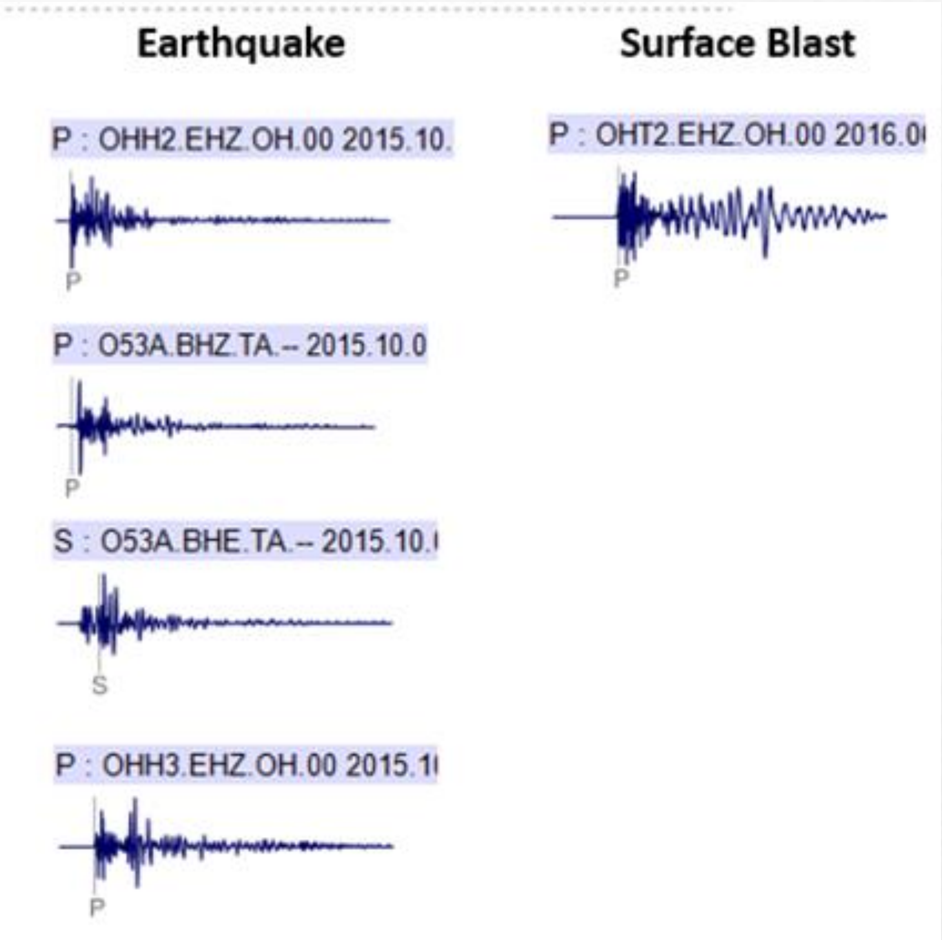
P-S Wave Separation

- Subsurface seismic velocity and P-S wave separation indicate distance from station



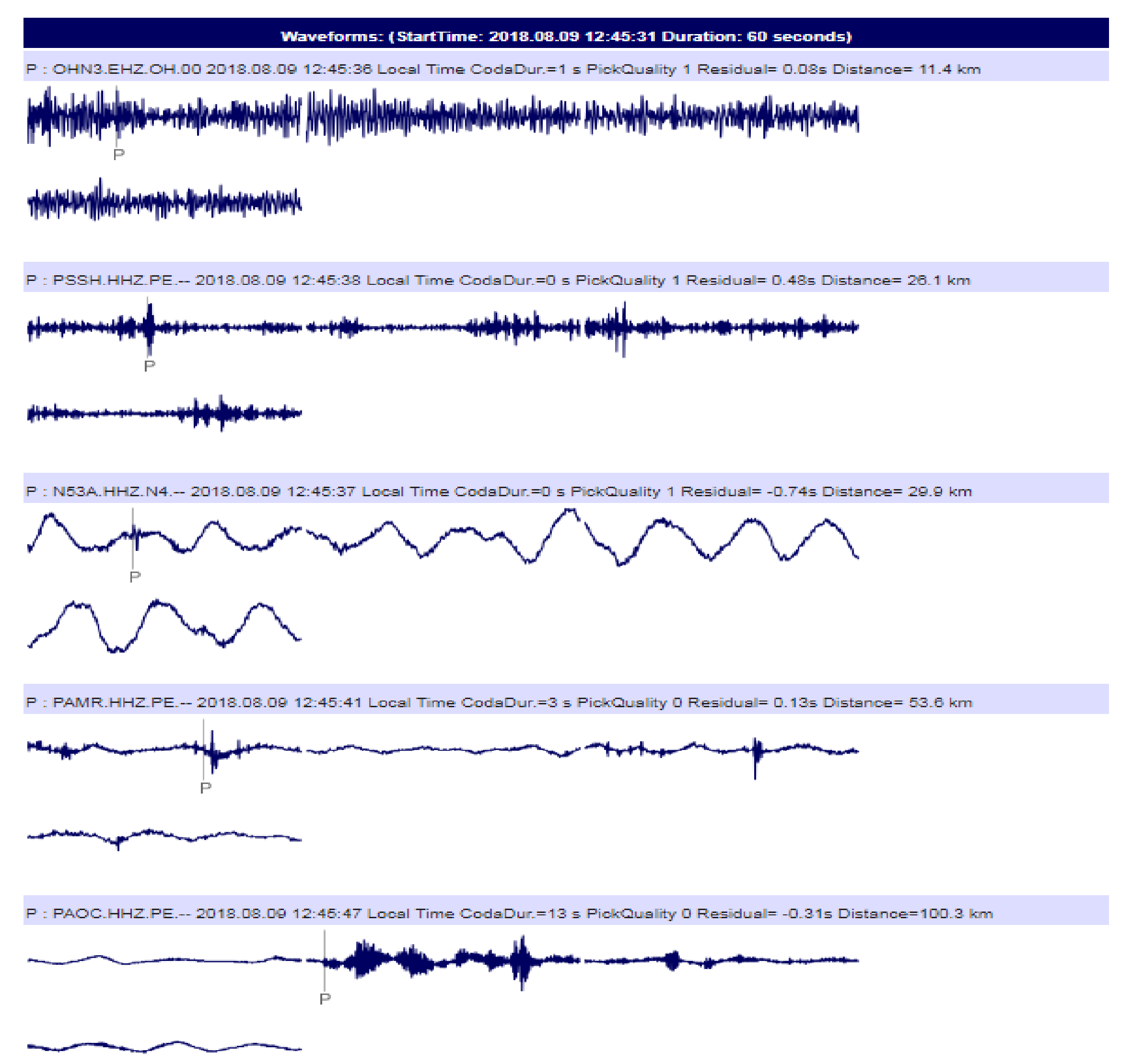
Determining Signal Source

- Use characteristics in the seismic signal to help determine the source
  - Seek clarity of P-wave and S-wave arrivals
  - Seek signal at many stations
  - Greater distance from seismic station to signal source may increase difficulty



Random Noise

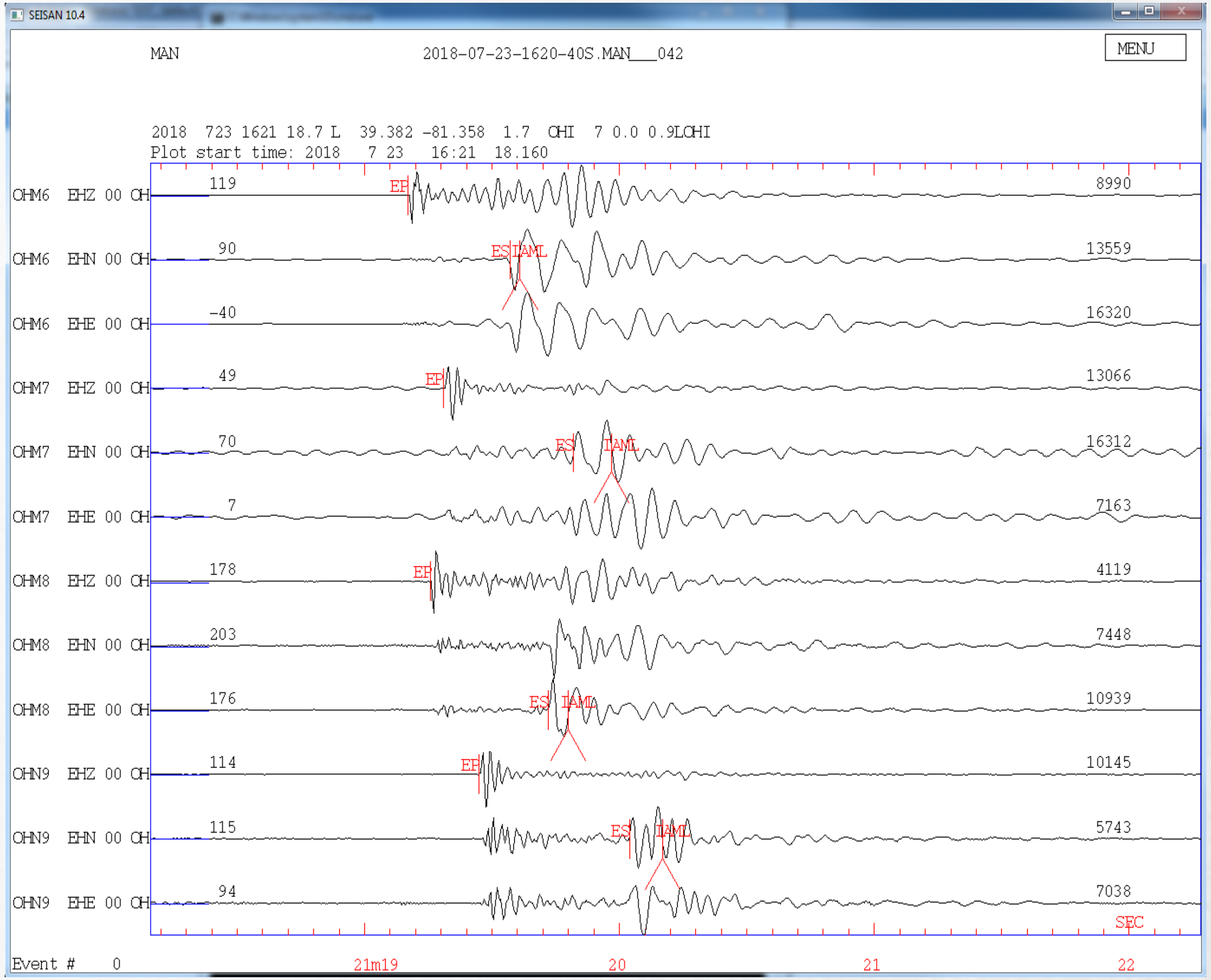
- Little to no time agreement in the signal from multiple stations
- Apparent arrivals may appear gradual or abrupt



Manual Location

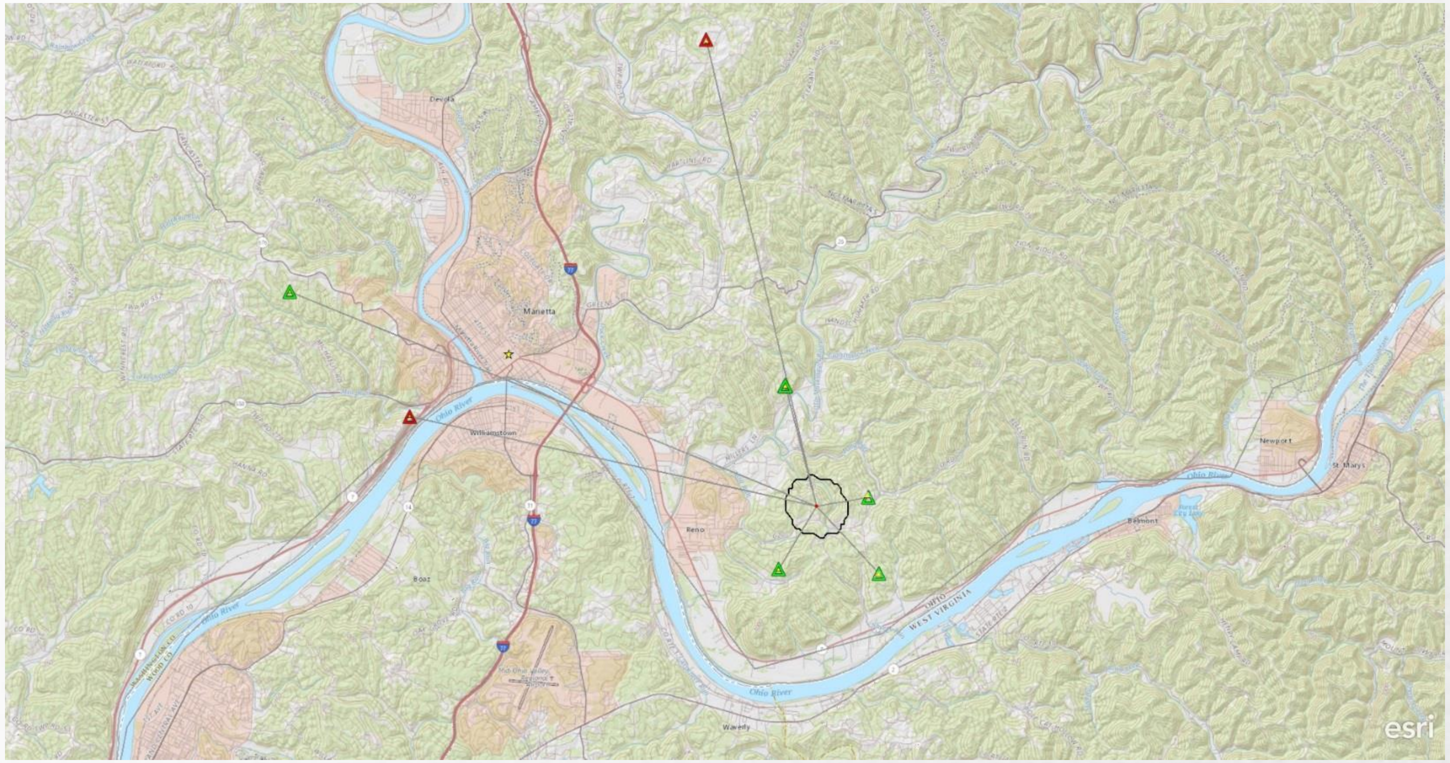
- When an alert is suspected to be caused by an actual earthquake, further investigation occurs

- Refine the P-wave and S-wave arrival times for the location



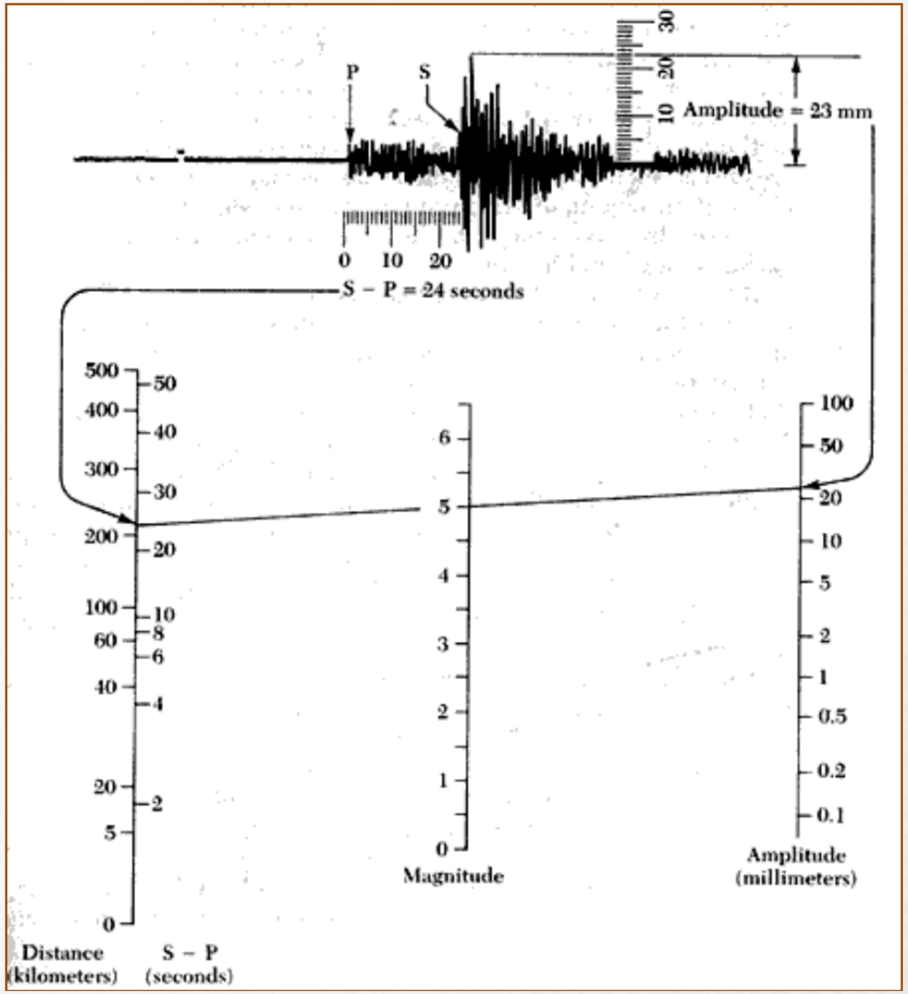
Map Earthquake Location

- The triangles represent seismic stations involved in calculation
- The red dot is the location
- The circle around the location represents the maximum location error



Graphical Magnitude

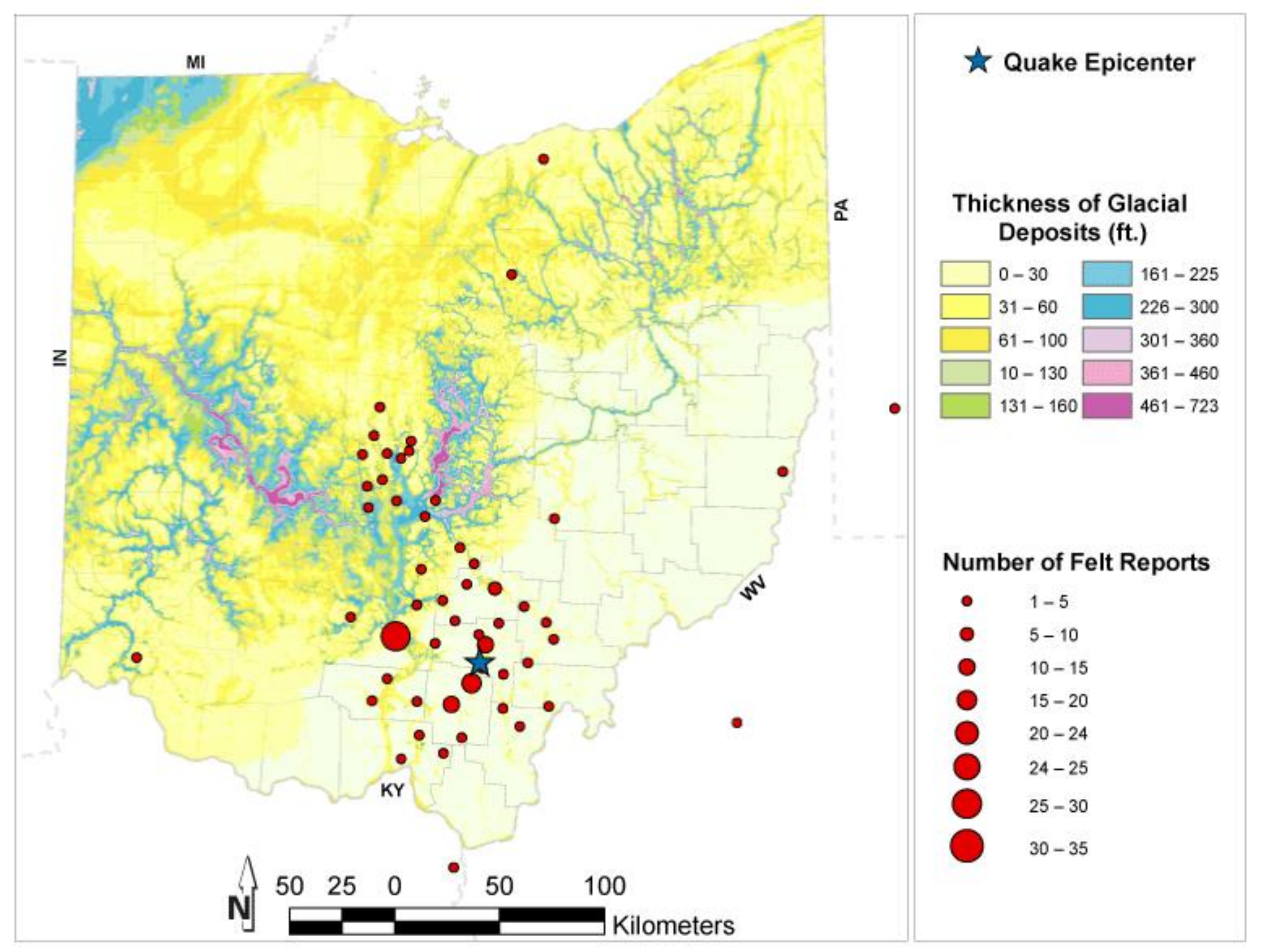
- Procedure
  - Determine distance from earthquake (left vertical axis)
  - Measure signal strength (right vertical axis)
  - Connect the dots
- Measure of size of earthquake, not impact on structures



Ruff, (2002)

Site Amplification

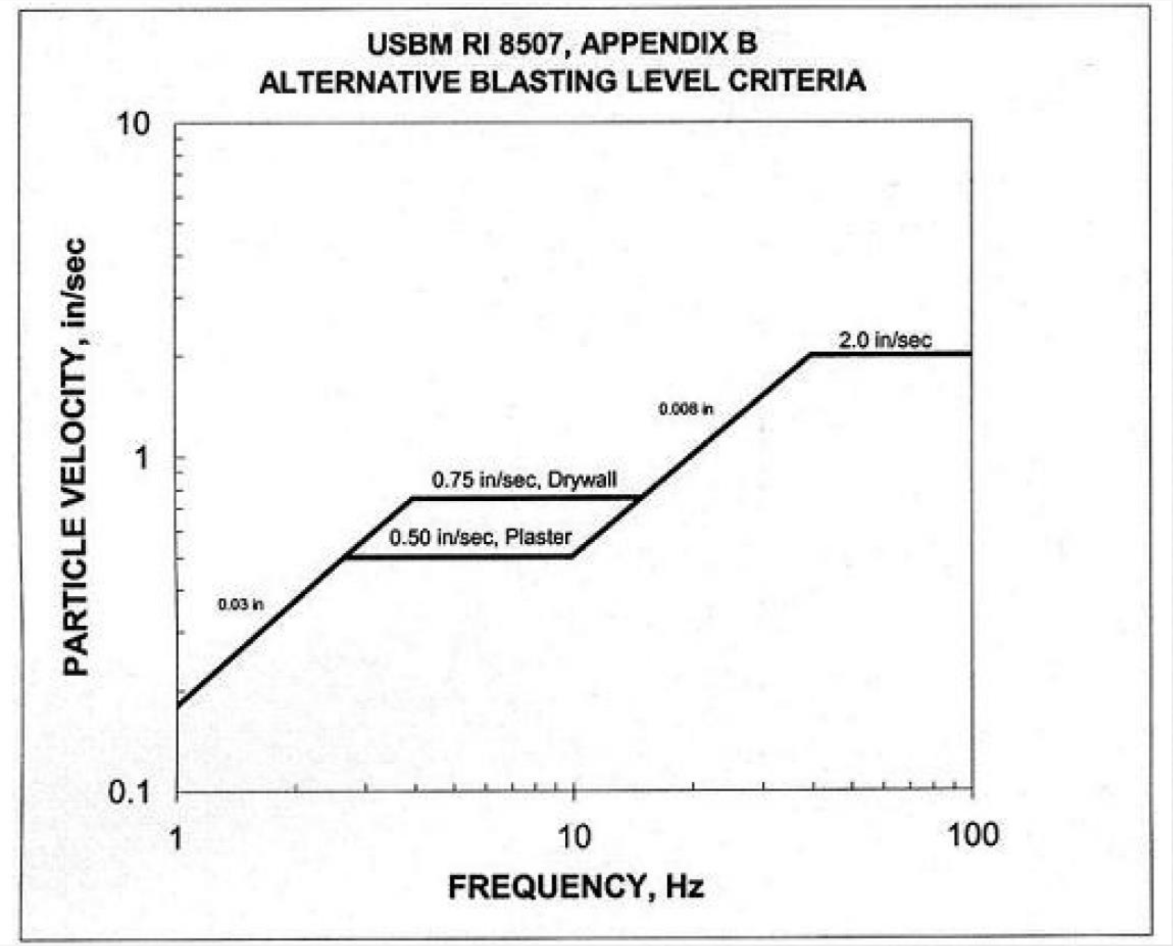
- Greater bedrock depths are more likely to amplify the signal and may increase potential for damage
- 3.8 magnitude event in 2017
- Felt reports from an earthquake in Ohio are around sites where depth to bedrock is greatest



Blake (2017)

Site Amplification

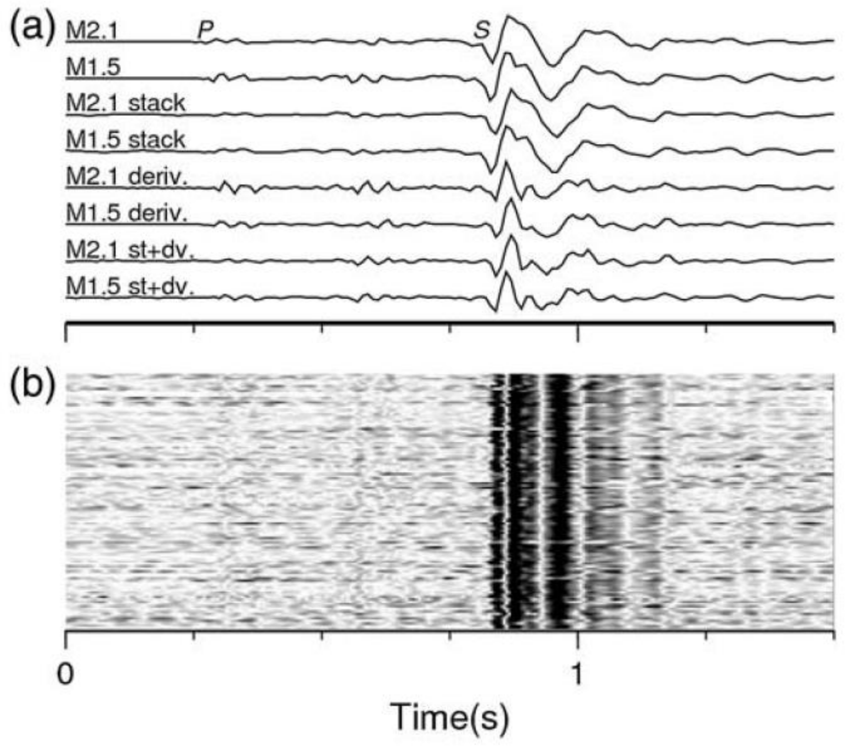
- ODNR adopted blasting criteria that avoids structural damage due to mining explosives
- Instruments can be used to determine the ground motion at a point
- Similarly, ground motion may be used to determine damage due to earthquakes



OAC 1501: 13-9-06(F)(8)

Waveform Correlation

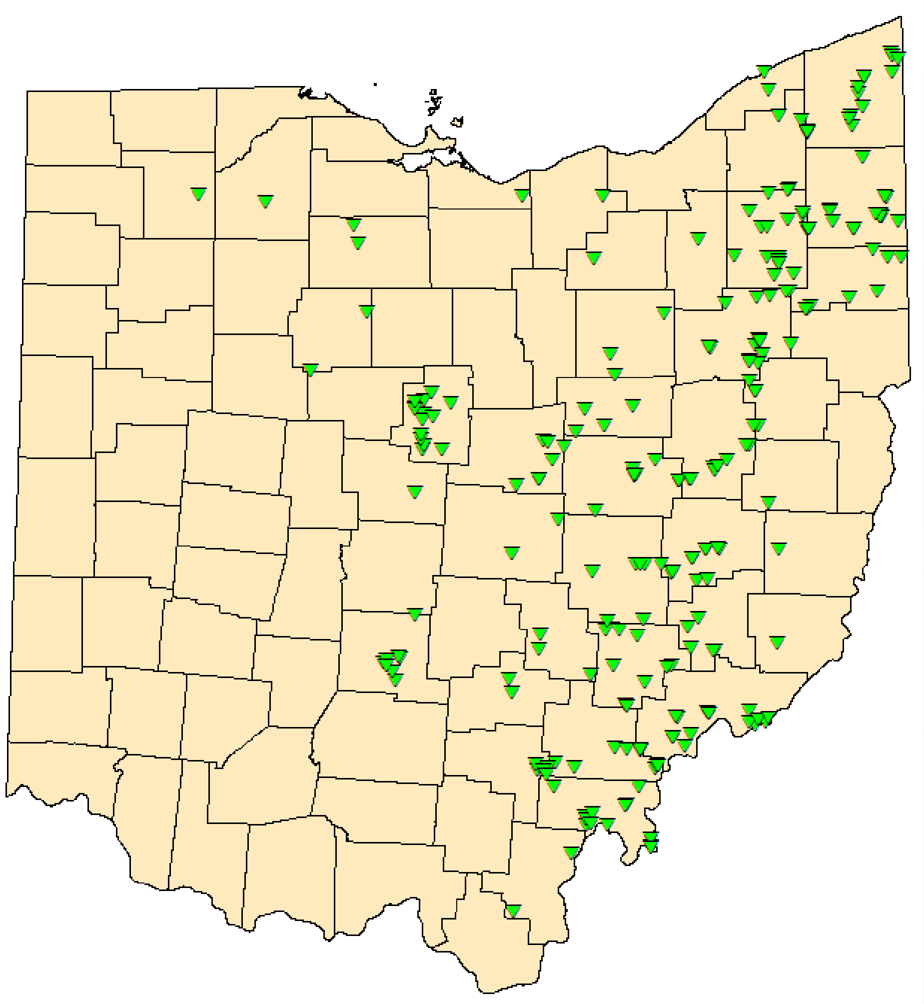
- Well correlated waveforms are very similar to each other
- Indication of a similar earthquake source
- This method helps with identifying smaller events which is useful for mapping faults



▲ **Figure 2.** Normalized *P* and *S* waveforms recorded on the BHE component of AWM4. (a) Template waveforms from the 31 August 2014 M_L 2.1 and 28 July 2014 M_L 1.5 earthquakes, as well as the stacks of events they matched with, derivatives of the template waveforms, and derivatives of the stacks. (b) Waveform amplitudes of the 108 matched events.

Skoumal et. al. (2015)

Class II Brine Disposal Wells in Ohio



Active Injection
215

Drilled
13

Drilling
3

Shut In
1

Permitted
7

Class II Brine Disposal Wells in Ohio

Recent Per Year Totals

2012 Totals
Brine: 14,157,885 barrels
Active Wells: 146

2013 Totals
Brine: 16,383,043 barrels
Active Wells: 164

2014 Totals
Brine: 24,704,481 barrels
Active Wells: 185

2015 Totals
Brine: 32,023,496 barrels
Active Wells: 212

2016 Totals
Brine: 32,253,109 barrels
Active Wells: 216

2017 Totals
Brine: 38,528,794 barrels
Active Wells: 217

Class II Brine Disposal Wells in Ohio

- Northstar #1 4.0 induced seismic event, New Year's Eve, 2011
  - Northstar #1 was drilled 200 feet into the Precambrian layer at a depth of 9,184 feet and began injecting in December 2010
  - A 2.7-magnitude event was recorded on Dec. 24, 2011 and this information was presented to ODNR on Dec. 29
  - On Dec. 30, the injection well was shut down
  - On Dec. 31, the area experienced a 4.0-magnitude seismic event

- A moratorium was placed on permitting additional injection wells until September of 2012

- Executive Order 2012-09K lead to the emergency amendment of rules regarding the injection of brine

Permit Conditions

- ORC 1509.06(F) "…provide that where the chief finds that terms or conditions to the permit can reasonably be expected to prevent such violations, the chief shall issue the permit subject to those terms and conditions…"

- **Injection wells** – 60 days of monitoring prior to injection; requirement of real-time continuous monitoring after injection commences

- **Horizontal wells** that intersect a known fault or lies within an area of seismic activity – 2 weeks of monitoring prior to the commencement of hydraulic fracturing

Mitigation Techniques

- Direct communication with the operator is essential
  - Discussion of seismic events and stages of the operation in real-time
  - Spatial analysis and time correlation with completion data during operation

- Modifying zipper fracturing to stack fracturing
- Reducing maximum pressure and overall job volume
- Reducing frac sand / proppant size and associated volumes
- Skipping stages as necessary

Mitigation Techniques

Restrictions via permit conditions may be placed on wells drilled near faults or areas of known seismic activity, in which seismic monitors must be installed for a specified time period prior to completion operations.

ML ≥ 1.5	Direct communication starts between operator and Division
ML = 2.0-2.4	Work with operator to modify operation
ML ≥ 2.5	Temporary halt completions on lateral
ML ≥ 3.0	Completion on pad suspended until an approved plan is submitted by operator

Summary

- Shale oil and natural gas development, along with brine disposal in Ohio, will continue to increase for the foreseeable future
- Real-time continuous monitoring is mandatory when trying to mitigate the risk of induced seismicity
- Having an aggressive stance and staying proactive has helped decrease induced seismicity occurrences in Ohio
- Proper policies and regulation have helped guarantee safe and proper extraction of oil and gas while offering less shutdown times for operators
- In the event of induced seismicity, direct communication with operators is essential for mitigation, along with modifying pad operations
- Sharing information with other states and the local community helps assist in tackling the problem of induced seismicity and aids in public confidence of their states regulatory agency

OhioNET Seismic Monitoring Staff

Dave Rush
Seismic Program Manager
ODNR-DOGRM
David.Rush@dnr.state.oh.us
614-265-6916

Steven Dade
Geologist 2
ODNR-DOGRM
Steven.Dade@dnr.state.oh.us
614-265-6946

James Gonsiewski
Geologist 3
ODNR-DOGRM
James.Gonsiewski@dnr.state.oh.us
614-265-6900

Jacqueline Mills
Geology Technician
ODNR-DOGRM
Jacqueline.Mills@dnr.state.oh.us
614-265-6925