



**MEWBOURNE**  
COLLEGE OF EARTH & ENERGY  
THE UNIVERSITY OF OKLAHOMA



# Potential Case of Induced Seismicity from a Water Disposal Well in South- Central Oklahoma

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# Introduction

- On September 17, 2013, a swarm of earthquakes began in Love County, Oklahoma, north of Marietta.
- These earthquakes began occurring about two weeks after injection began at a nearby disposal well (LCD #1).
  - Injection well was placed in “yellow light” rate and injection pressure limited
- The largest earthquake was a magnitude 3.4.
- Local residents consistently feel magnitude 1.8 earthquakes
  - Barely detectable by regional monitoring
- The earthquakes are occurring at shallow depths (~2 km) consistent with injection depths of the nearby disposal well.

# Damage summary from the magnitude 3.4 Sep. 23, 2013

## Damage to Homes

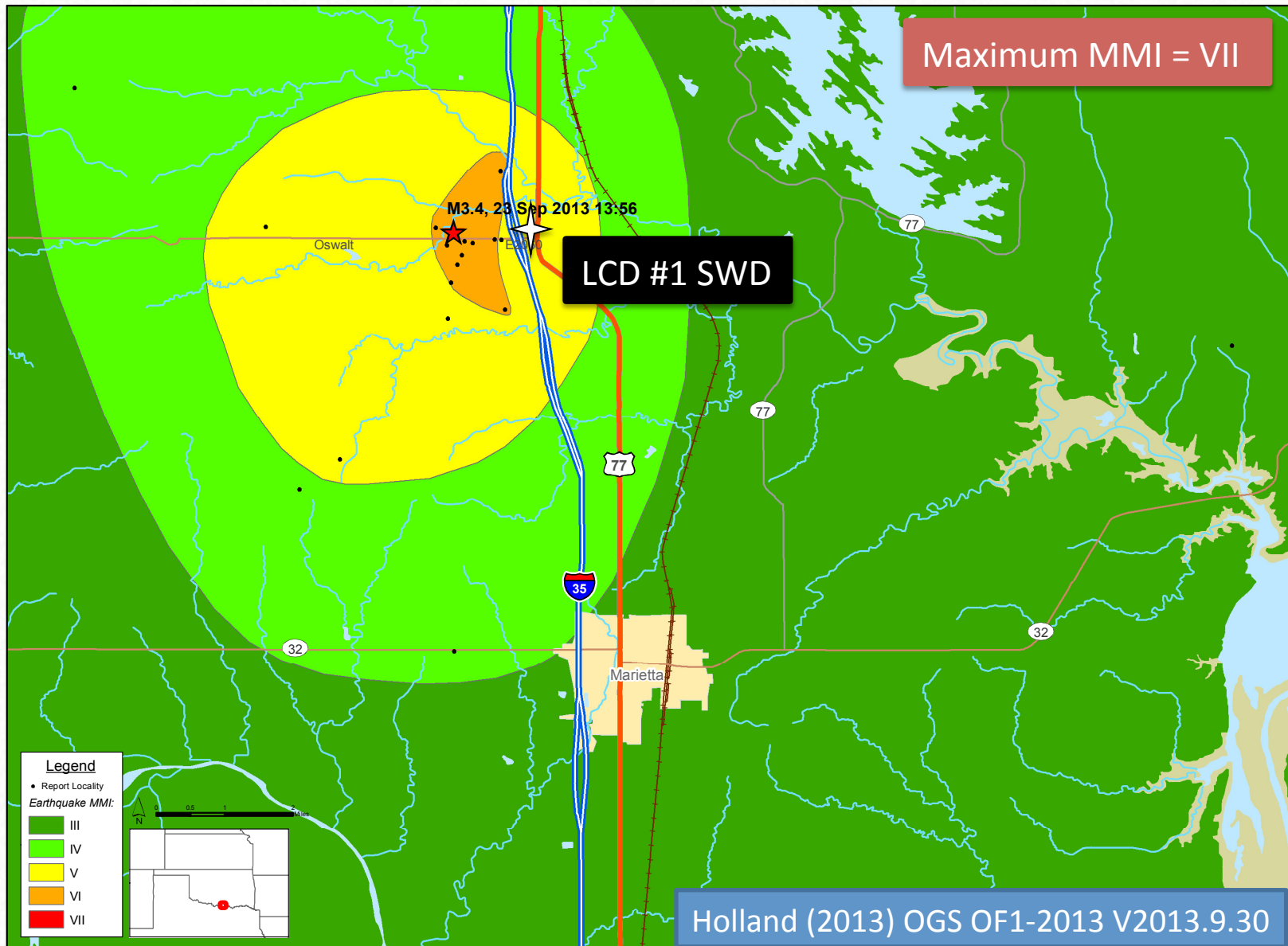
- Collapsed Chimney (1)
- Shattered Window (1)
- Damaged brick façade (~5)
- Doors and frames crooked (~5)
- Cracked foundations
  - Difficult to distinguish from normal OK soil effects
- Cracked drywall and cosmetic damage (~15-20)
- Fallen objects and strong shaking (>20)



Photo courtesy of Rhonda Lumry



# Felt Reports to Modified Mercalli Intensity



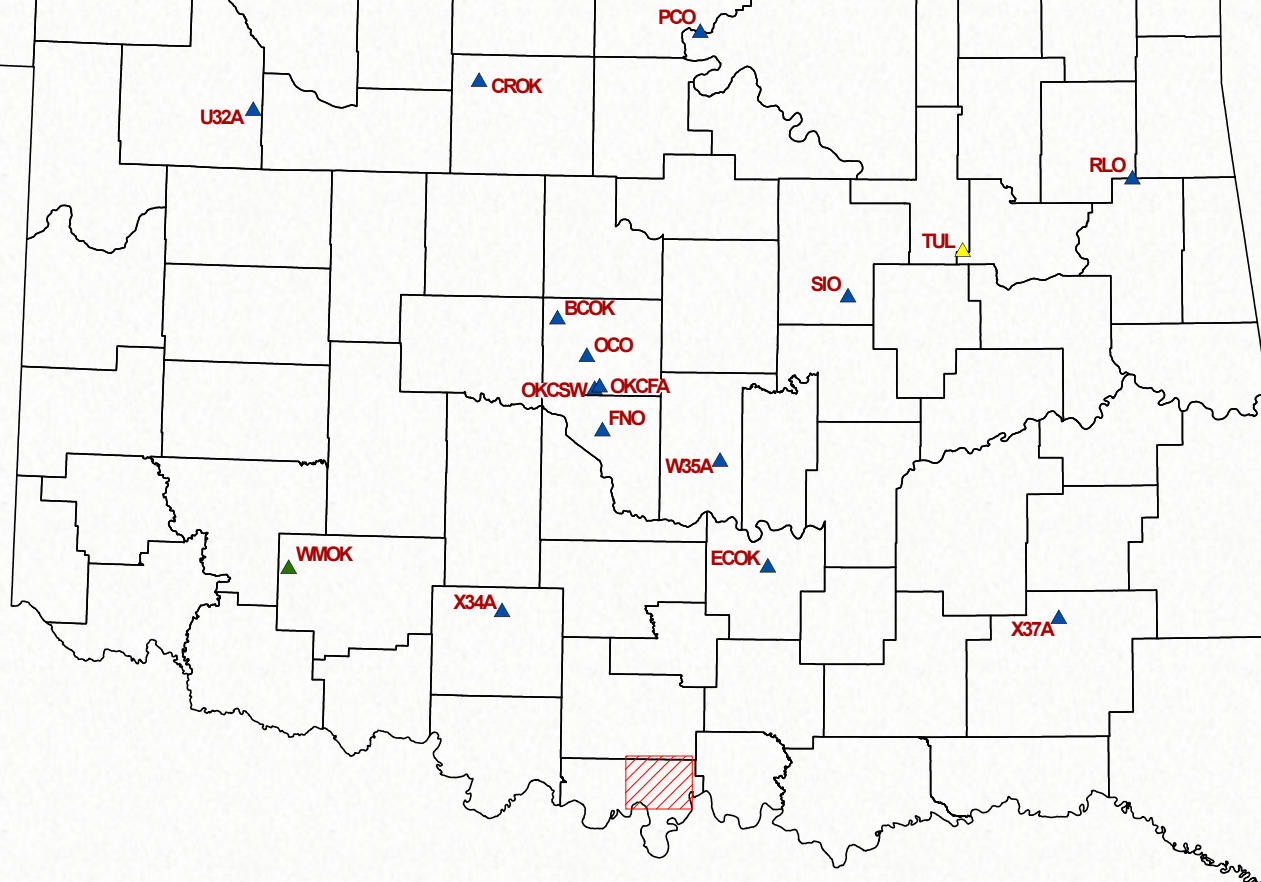


# Regional Seismic Stations

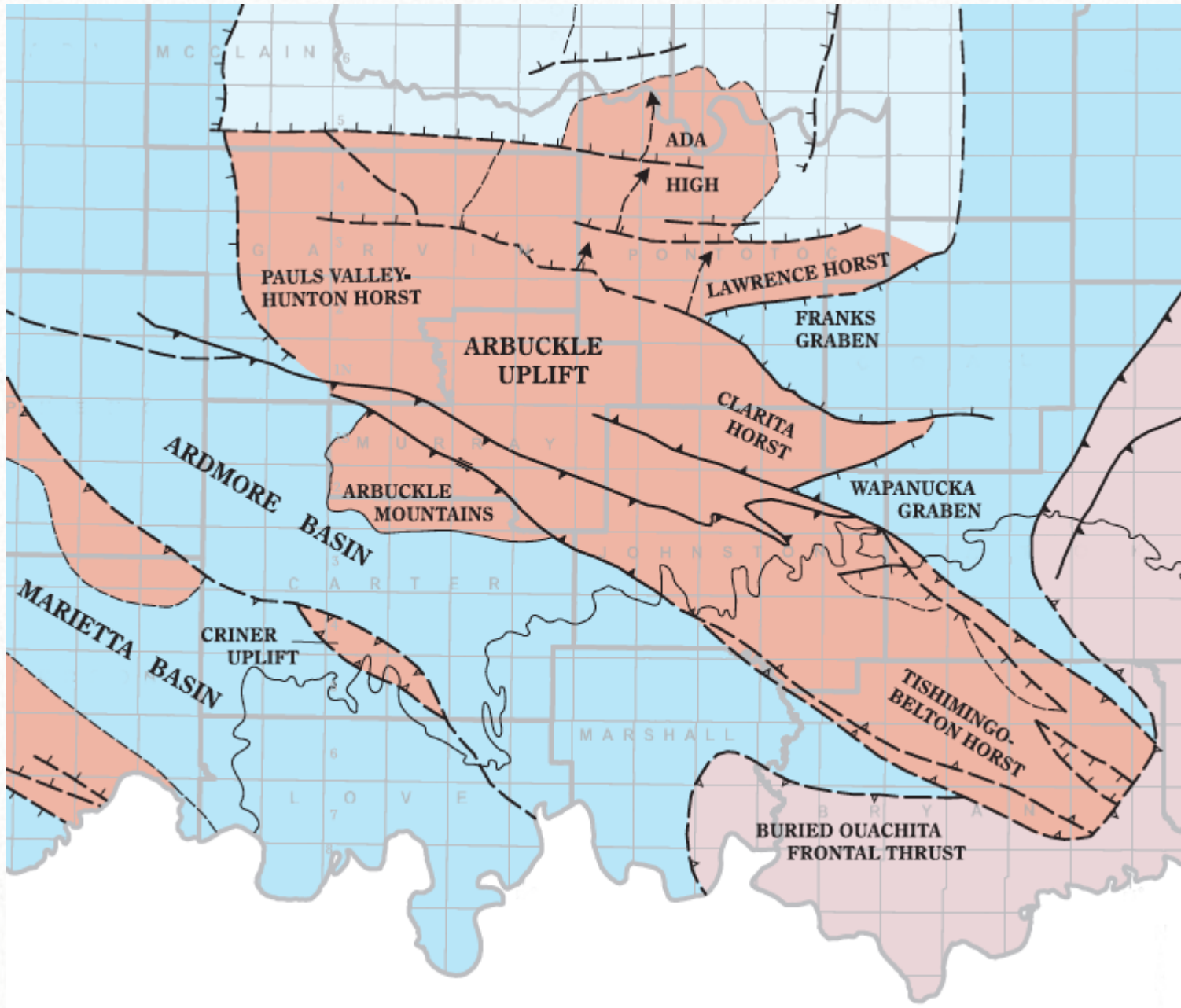
## Oklahoma Seismic Stations

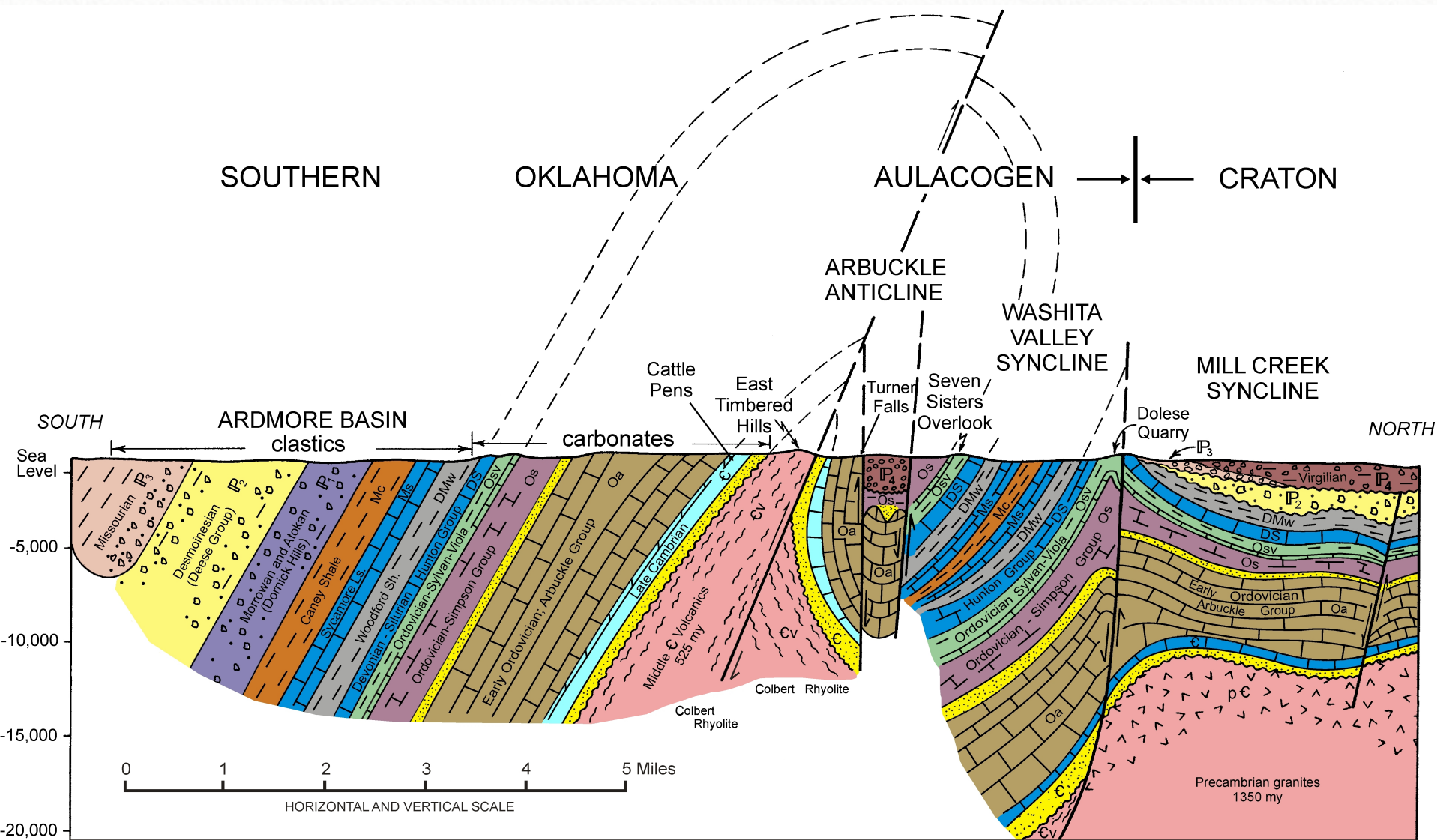
### Network

- ▲ Leonard Observatory
- ▲ OGS
- ▲ USGS



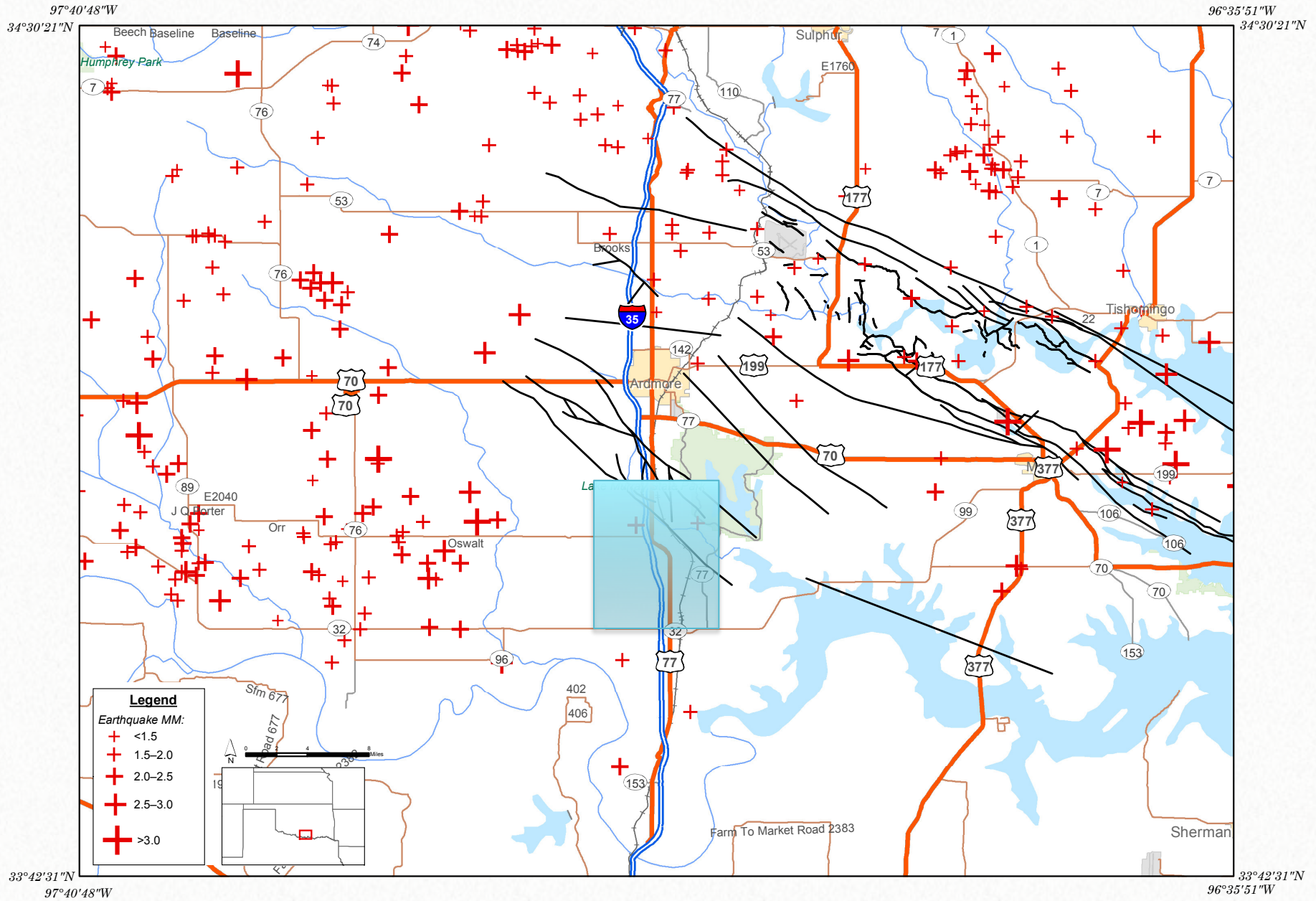
# Arbuckle Uplift





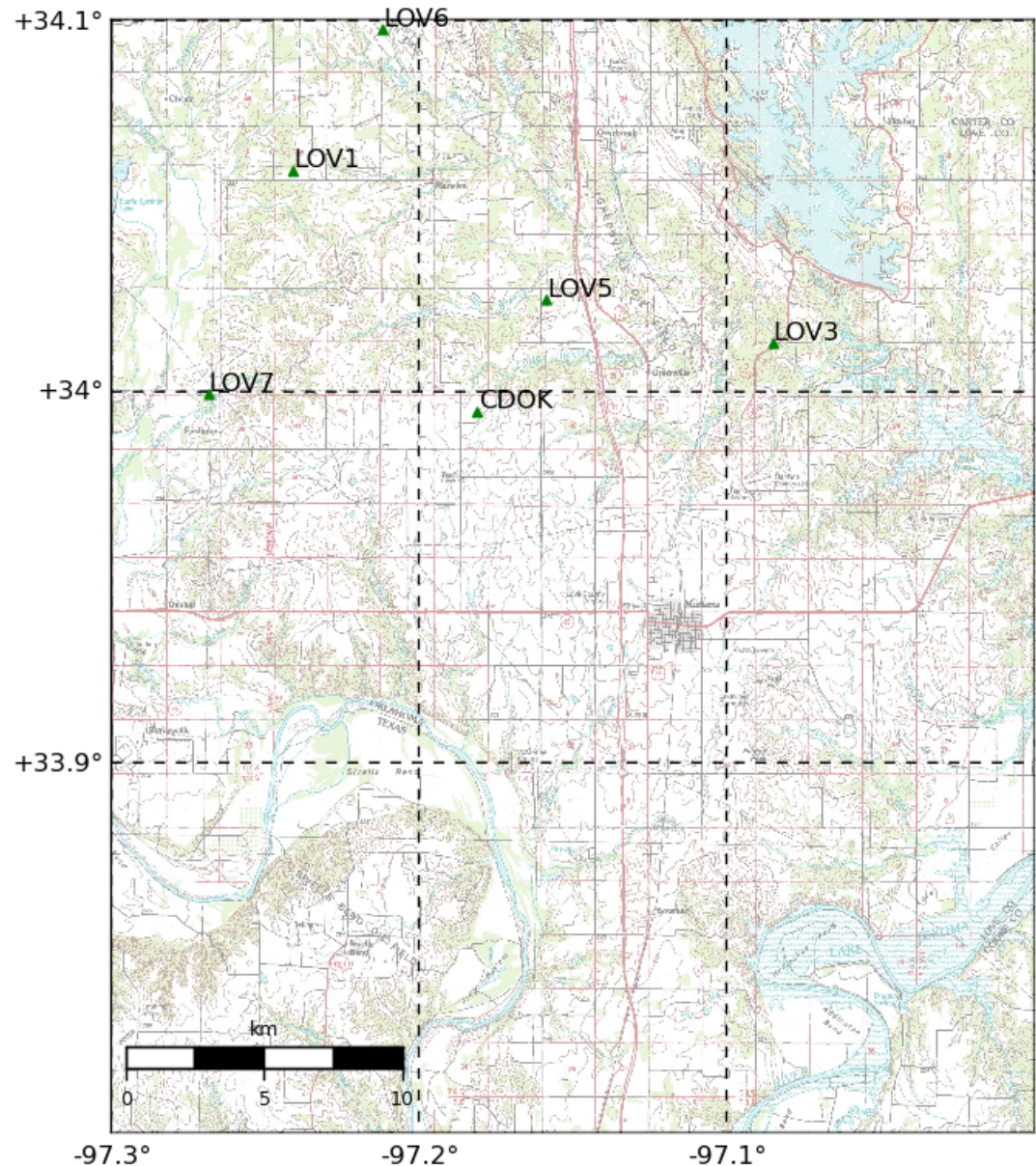


# Earthquakes 1882 - 08/29/2013



# Temporary Network

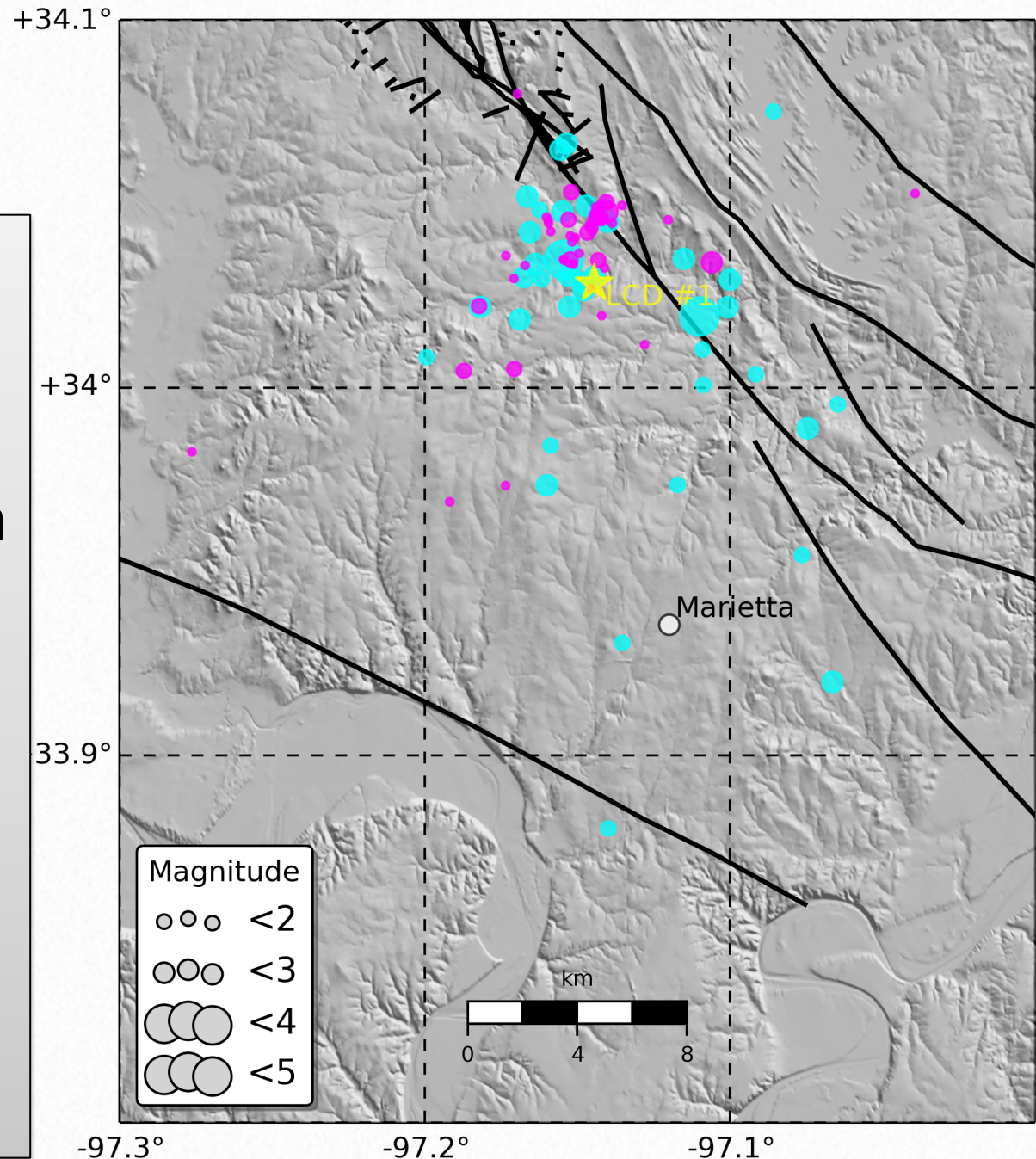
- First station installed 9/25
- Currently operating now 4 stations in the area
- One will be permanent
- 2 stations have been removed due to logistical reasons
- Detection threshold about M 0.5 within the area
- Status is continuously reported
  - <http://wichita.ogs.ou.edu/eq/love/stations/>





# Earthquake Locations

- prior to local network
- with local net
- Avg depth ~2 km
- Not enough events recorded with both networks to constrain relative locations





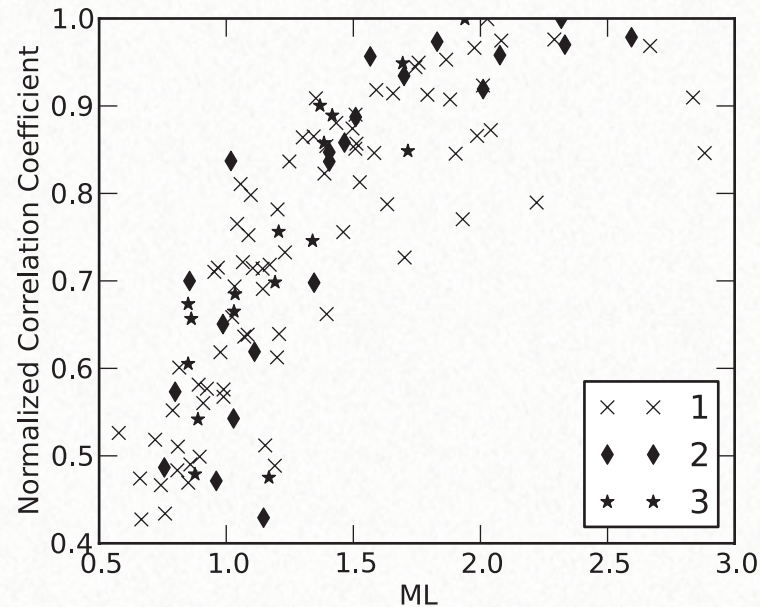
# Event identification using cross-correlation

## Template

2011-01-17T20:16:03.000000Z



xcor 0.999343, amp 410.348065

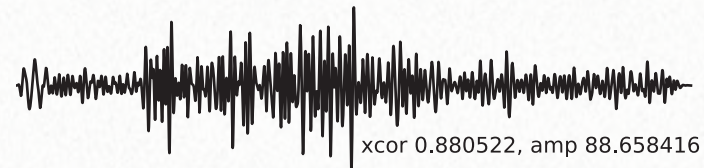


2011-01-17T19:35:33.950000Z



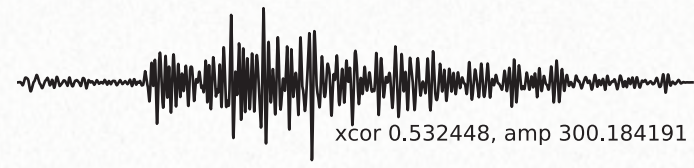
xcor 0.974703, amp 355.221352

2011-01-17T20:04:47.025000Z



xcor 0.880522, amp 88.658416

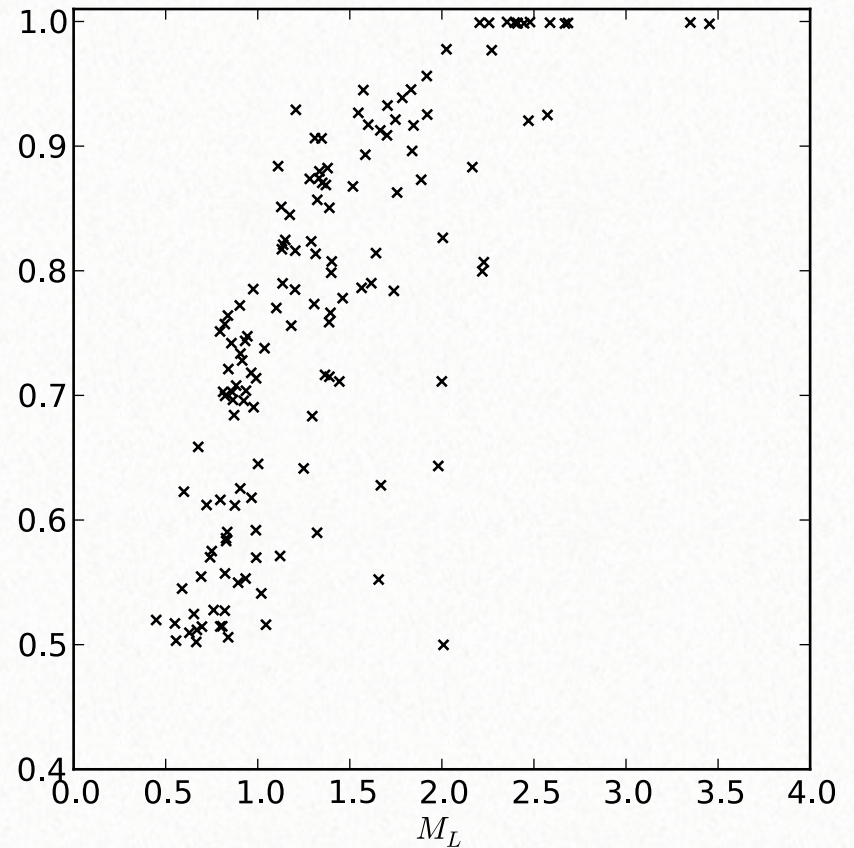
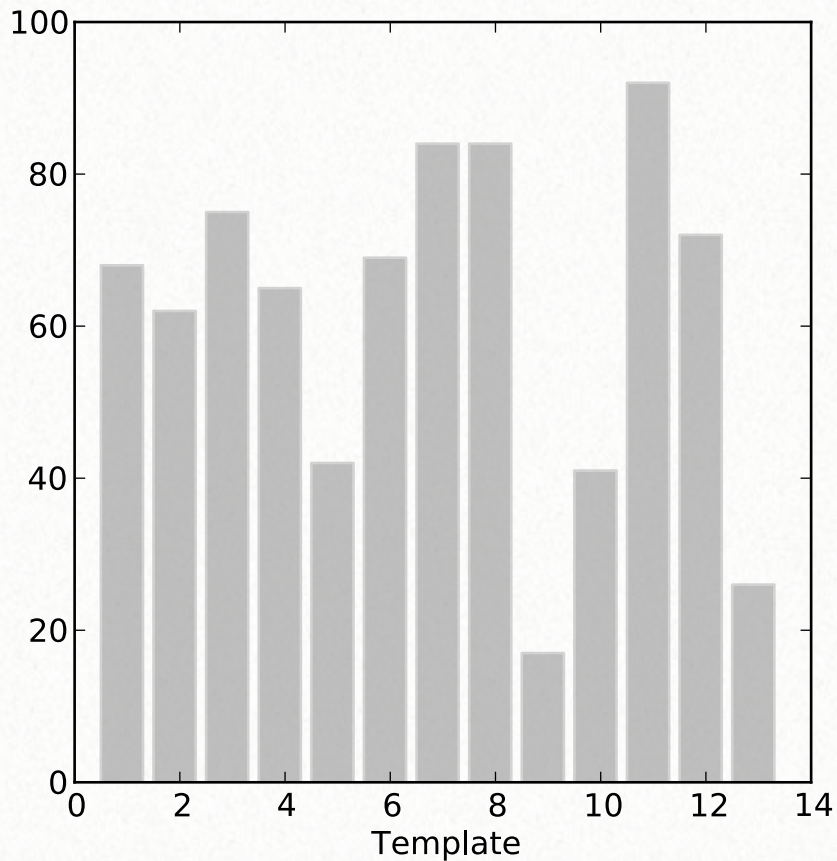
2011-01-17T21:46:32.700000Z



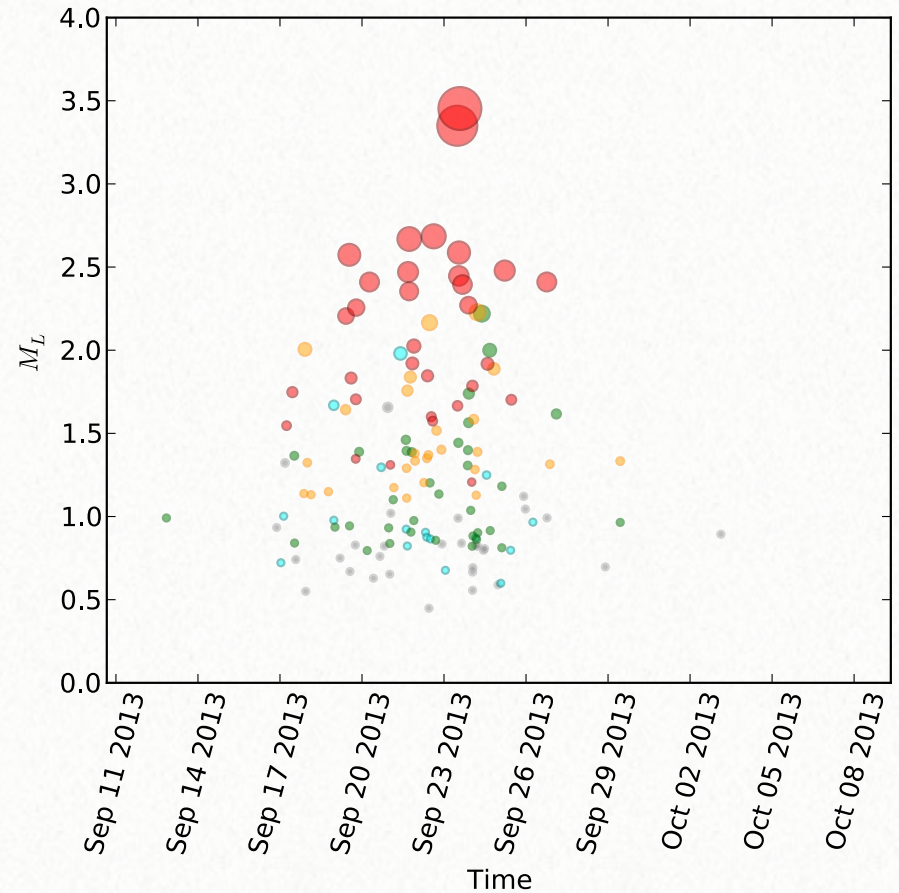
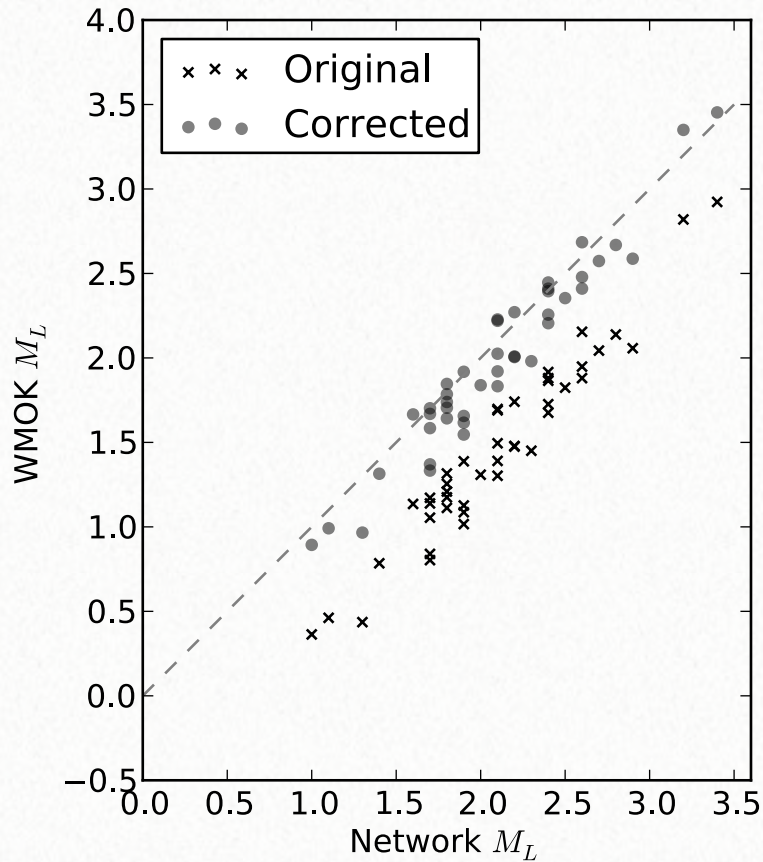
xcor 0.532448, amp 300.184191

# Cross-Correlations for Love County

142 Unique Events Identified through cross-correlation  
Using station WMOK

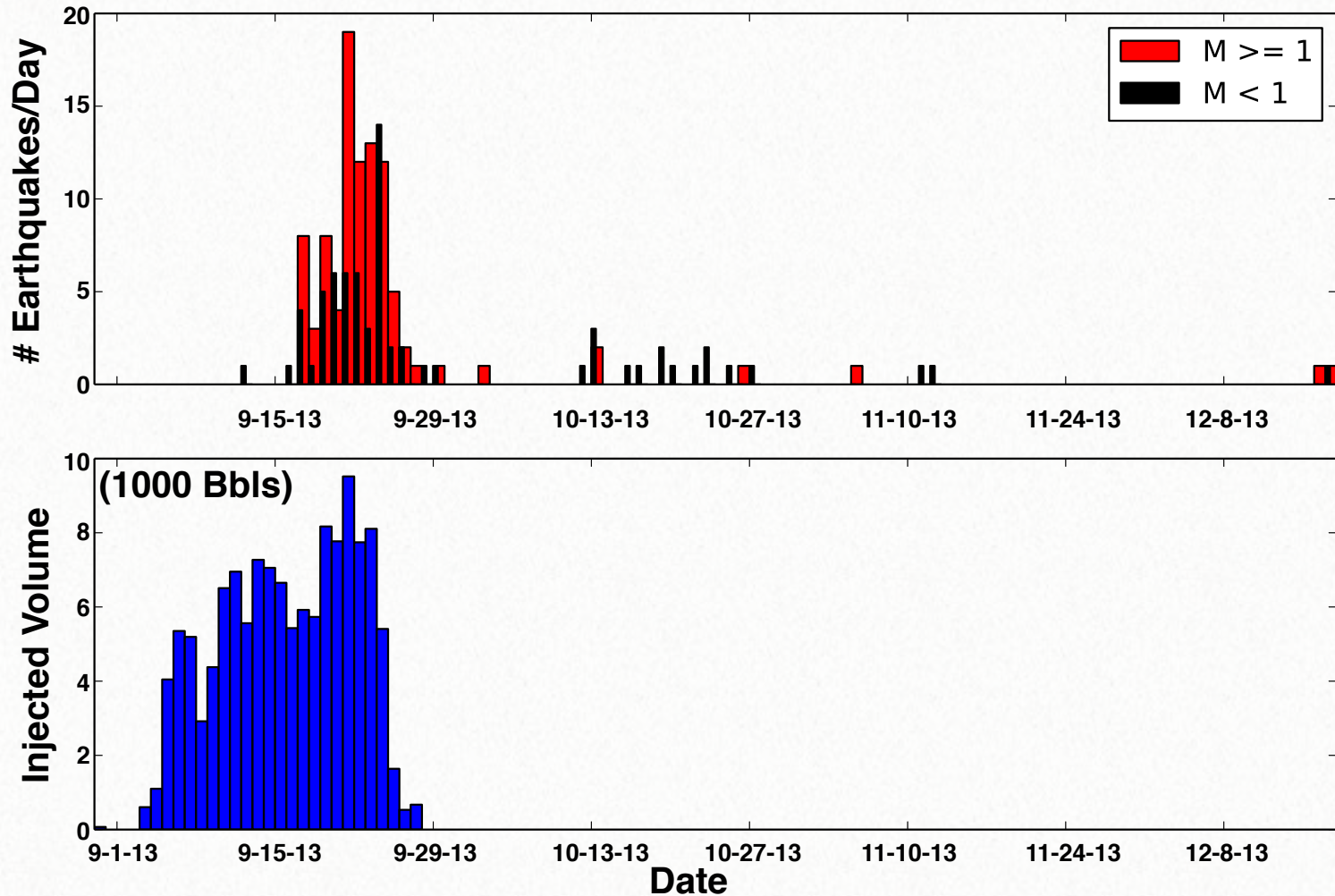


# Magnitude Calculations for Love County





# LCD #1 Injection and Earthquakes

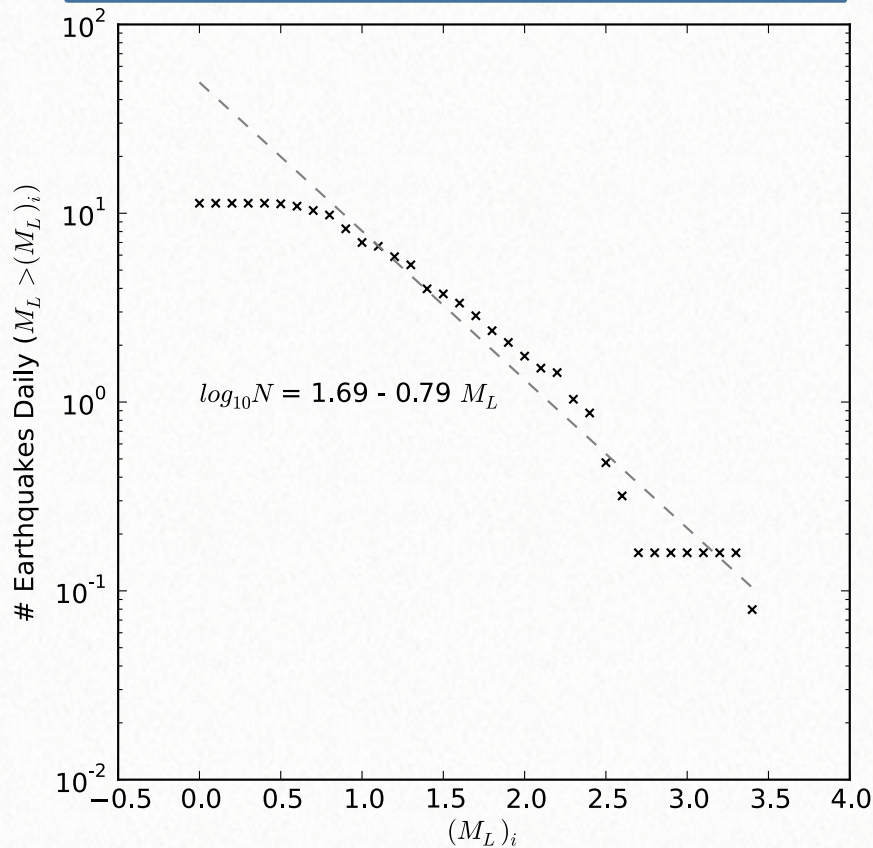


# Recurrence and b-values

## WMOK Cross Correlations

Events from: 9/16 - 9/29/13

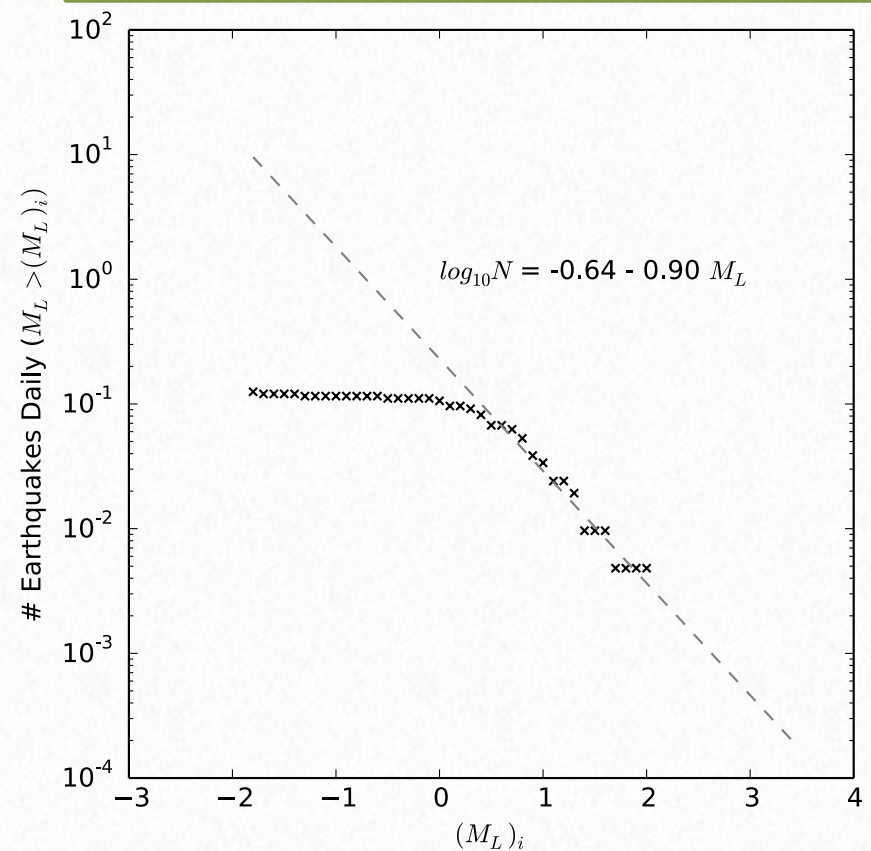
Magnitude of Completeness:  $M_c \sim 1.0$



## Earthquakes located using local network

Events from: 9/29 - 4/25/14

Magnitude of Completeness:  $M_c \sim 0.5$



Rate of earthquakes much greater during injection

# Why inject under a yellow light condition

- Cannot definitively state that the earthquakes were directly caused by injection at LCD #1
  - The earthquakes are similar in characteristic to past swarms in the area and could simply be an unlikely coincidence
- Developed traffic light criteria that would minimize risk should the operator to potentially continue operating
  - Cannot predict earthquakes and there is some risk in resuming injection
- There is still a financial incentive for the operator to attempt injection
  - Damage from the M3.4 is much less than the cost of a disposal well
  - Rate and pressure limits of yellow light are significant for operations
  - Operator may resume injection “soon”

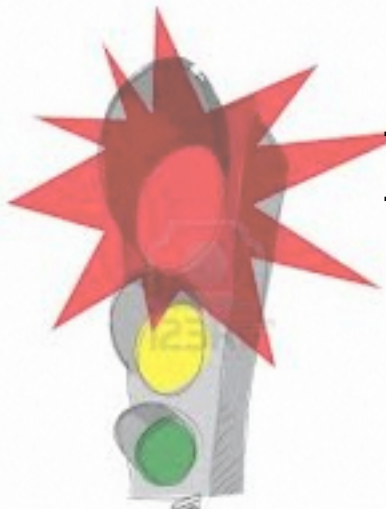




# Traffic Light Example

To resume at the yellow light with initial injection starting at the current rate (3,000 bbl/day) and pressure limit (375 psi)

- If all red light criteria are not met for ~21 days
- Injection could potentially increase to two pumps ~6,000 bbl/day and be held at this level for ~14 days
- If all is still fine injection, increase to full scale, but under the yellow light condition
  - Earthquake monitoring continues and a red light could occur if any of the earthquake conditions are met.



# Potential Red Light Criteria

If any one of these criteria is met a red light on injection is recommended

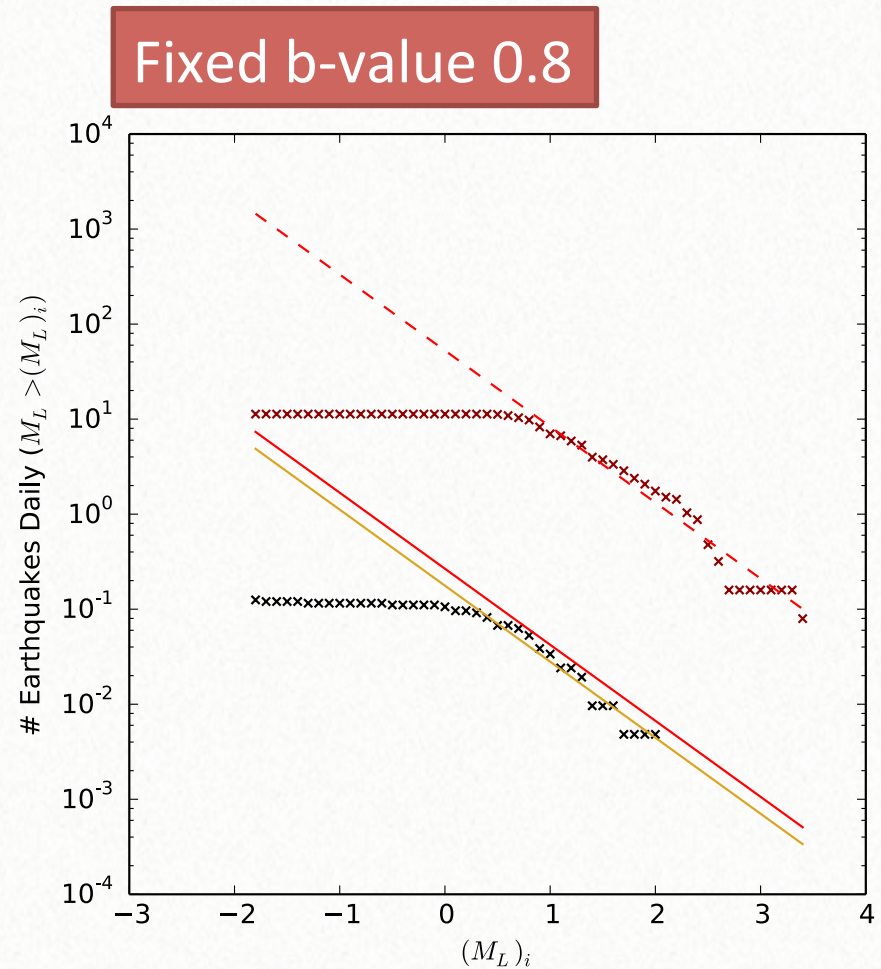
- M1.8 or verifiable felt earthquake
- If the rate of earthquakes increases after injection begins
  - such that at the 95% confidence interval that the rate of earthquakes is distinct from background
- If the probability based on the Gutenberg-Richter law is 95% for at least one M1.8 earthquake in the next 7 days

# Are single magnitude thresholds appropriate?

Probability of at least one M magnitude or greater in 60 days

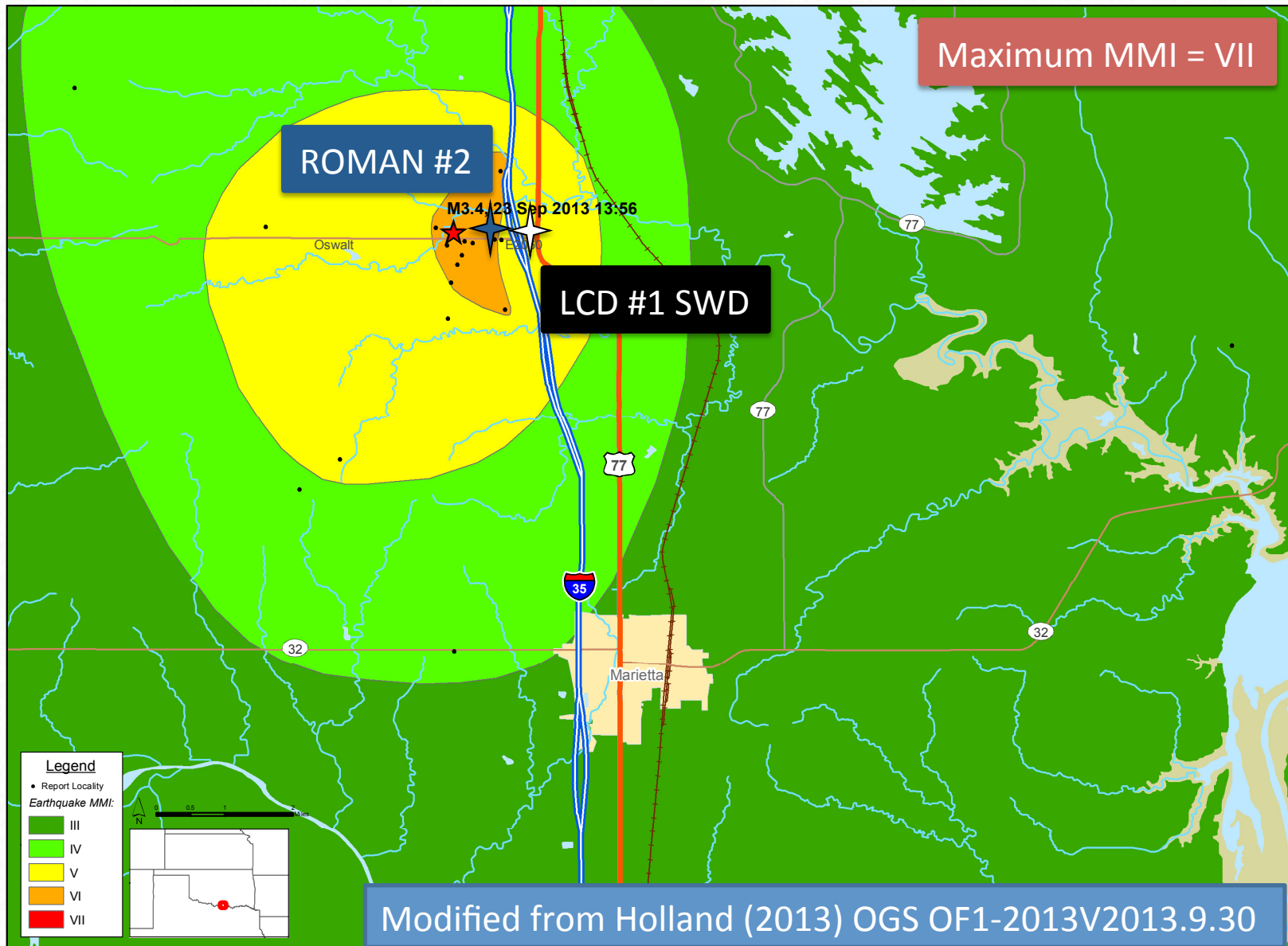
	a	% Prob M 1.8	% Prob M 2.5
Background	-0.7522	38.41	10.6
$2\sigma - 95\%$ CI	-0.5743	57.78	15.97
Injection	1.722	100	100

- Significant probability of a M 1.8 earthquake during yellow light condition.
- Is the magnitude threshold too conservative or not conservative enough?





# Felt Reports to Modified Mercalli Intensity



# Abstract

On September 17, 2013, a swarm of earthquakes began in Love County, Oklahoma, north of Marietta. These earthquakes began occurring about two weeks after injection began at a nearby disposal well. The largest earthquake was a magnitude 3.4, which did minor damage to structures in the epicentral area and had a maximum Modified Mercalli Intensity of VII. Local residents consistently feel magnitude 1.8 earthquakes. The earthquakes are occurring at shallow depths consistent with injection depths of the nearby disposal well. The sequence included 22 earthquakes of magnitude 2.0 or greater with more than 100 earthquakes identified during the period which injection occurred. Regional seismic stations provide poor coverage of the earthquakes, in part due to the shallow focal depths. A temporary network of six seismic stations was deployed in the area. This network greatly enhanced earthquake locations and dramatically improved the magnitude of completeness. Earthquakes continued after injection ceased but at a lower frequency and smaller magnitudes with only one felt earthquake. This area has seen similar shallow earthquake swarms in the past. It is important to address whether or not this swarm of earthquakes is caused by fluid injection at the nearby disposal or simply an unlikely coincidence. Techniques used to improve event identification and locations of the earthquakes are presented. A statistical method to quantitatively address seismicity changes is adopted and implemented in a monitoring system, in the event injection resumes in the disposal well or in a nearby well that was recently completed. The operator of the disposal well is currently restricted on injection rates and volumes and has ceased operations, if injection resumes the results of the statistical monitoring and traffic light system will be presented.