

## Induced Earthquakes in Central Arkansas

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Seismic hazard from induced earthquakes is minimized in Arkansas through:

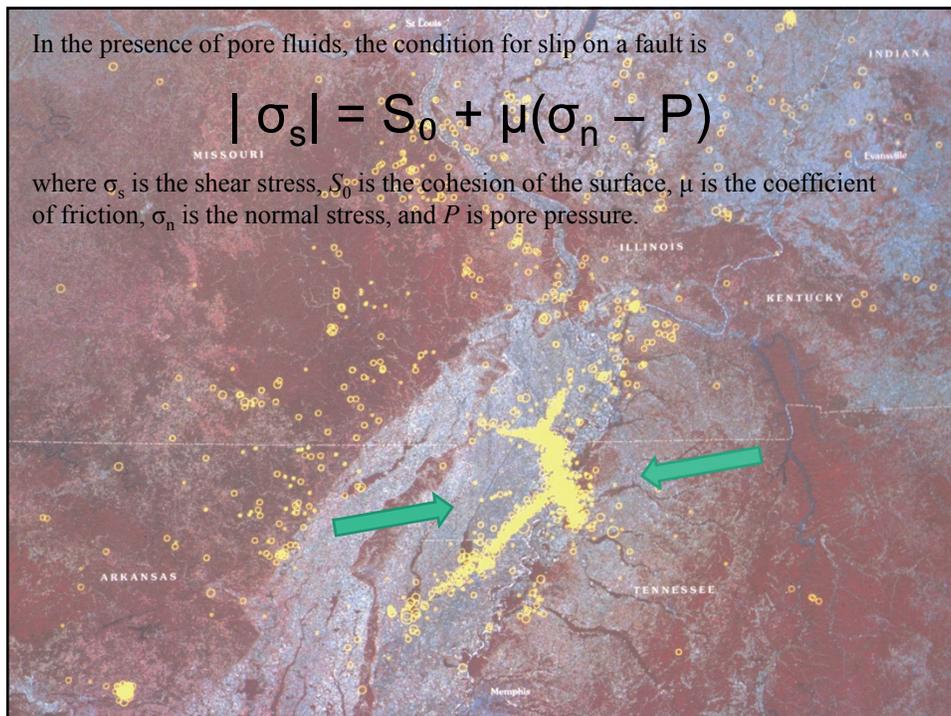
- Real-time Seismic Monitoring Targeting potential Induced Earthquakes starting 2009 (CERI, AGS)
- Shut in Disposal wells, Moratorium area, New Rules For Induced Seismicity starting 2011 (AOGC)
- Research on Induced Earthquakes starting 2009 (CERI, AGS)

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In the presence of pore fluids, the condition for slip on a fault is

$$|\sigma_s| = S_0 + \mu(\sigma_n - P)$$

where  $\sigma_s$  is the shear stress,  $S_0$  is the cohesion of the surface,  $\mu$  is the coefficient of friction,  $\sigma_n$  is the normal stress, and  $P$  is pore pressure.



Reservoir Pressure During Injection at Rocky Mountain Arsenal

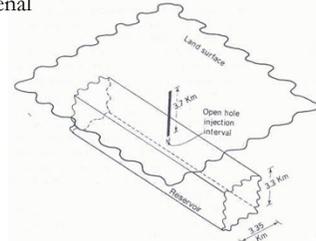
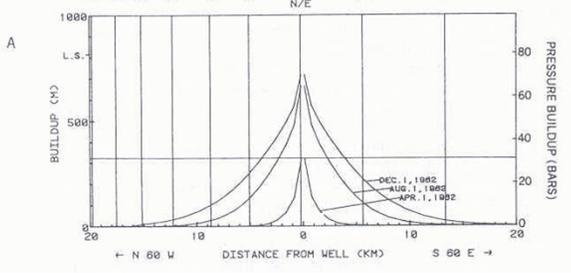
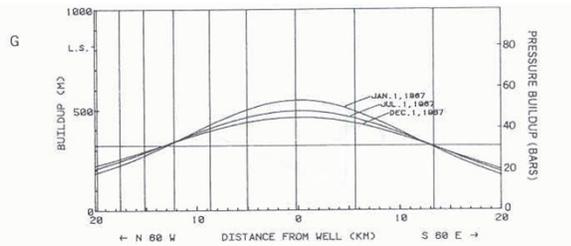


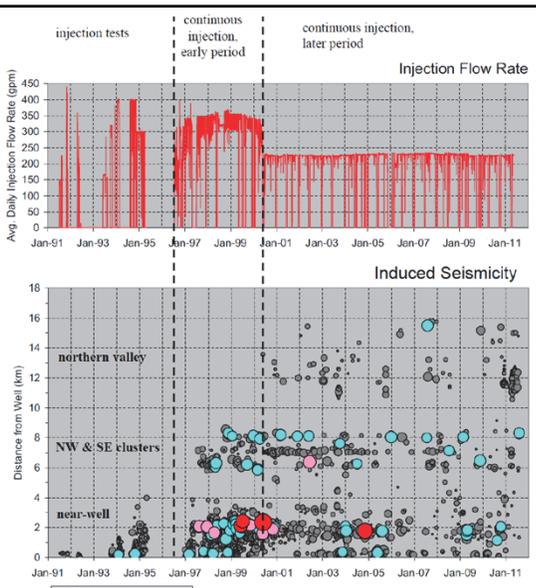
Fig. 4. Oblique view of the idealized reservoir modeled as a long, narrow prism of isotropic, porous medium.

Reservoir Pressure After Injection



From Hsieh and Bredehoeft, 1981

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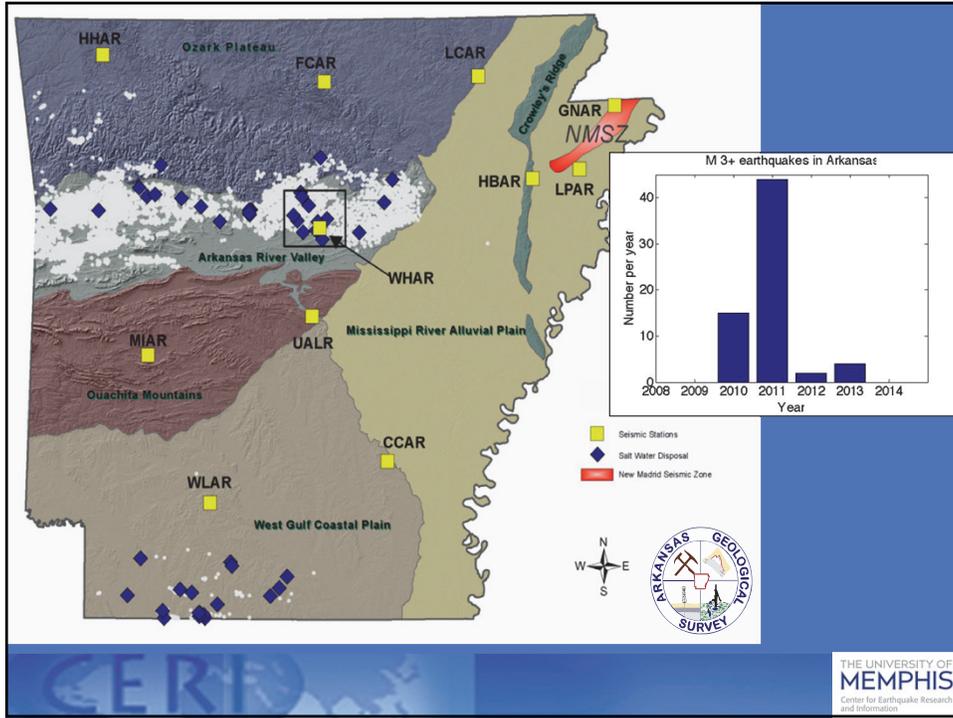


At Paradox Valley, CO, injection volume and pressure have been strategically adjusted to limit earthquake size and frequency over 20 years.

The well injects the brine into a limestone formation at a depth of approximately 14,100 feet to 15,750 feet. The project began in July 1996 with an initial injection rate of 345 gallons per minute at a pressure of 4,900 psi. Current injection rates are approximately 230 gallons per minutes at a pressure of 5,300 psi.

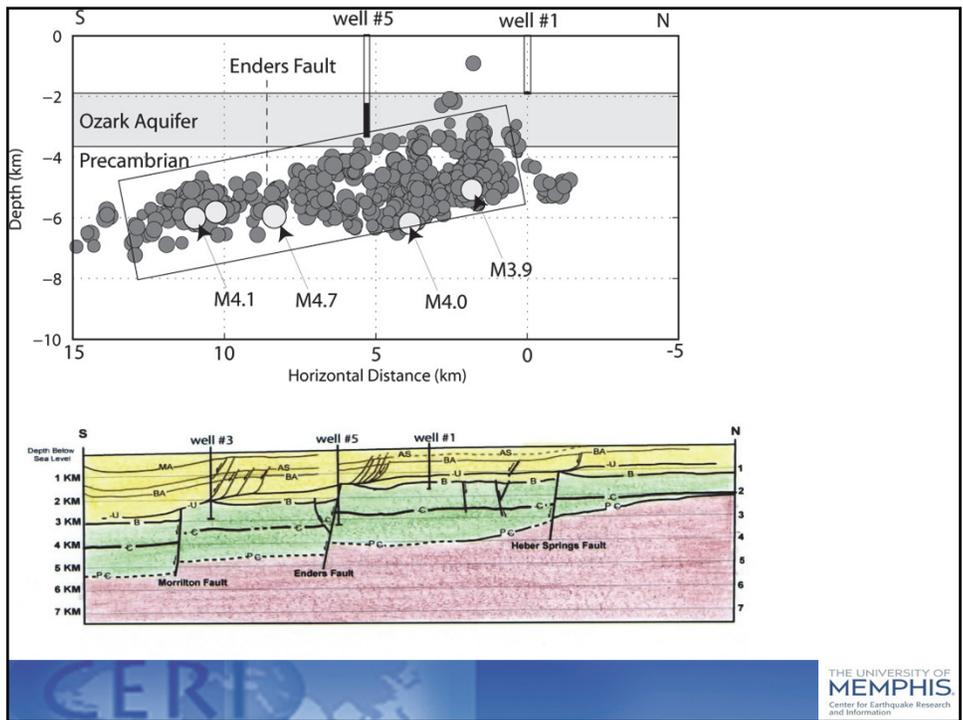
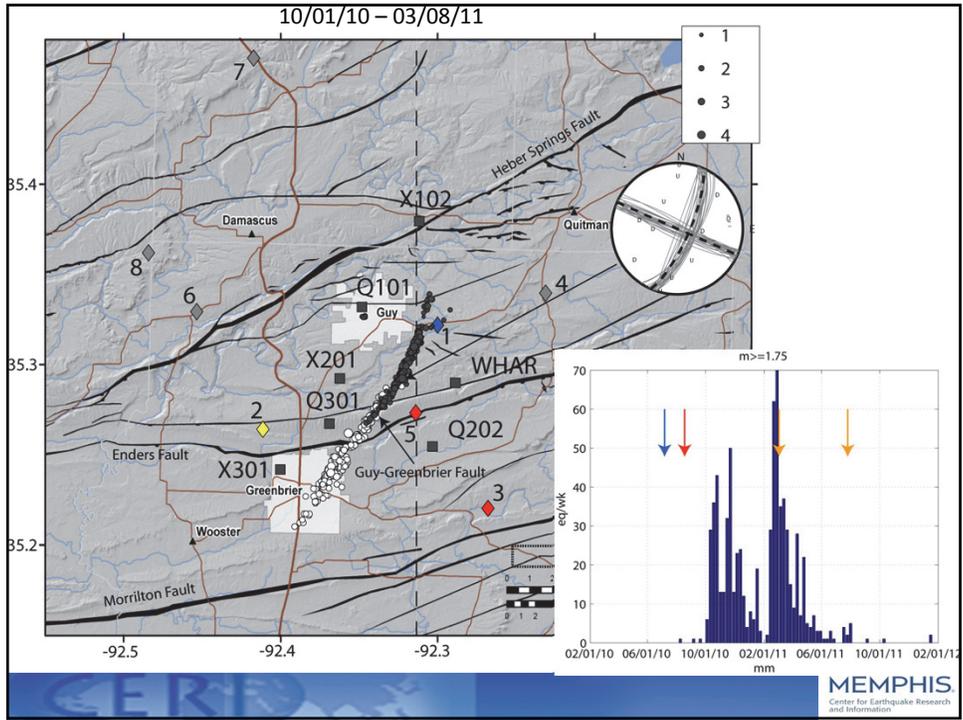
Earthquakes were recorded almost immediately after the beginning of injection in July 1996 with the first seismic event measured in November of 1996. Minor earthquakes continued through mid-1999 and two magnitude 3.5 events occurred in June and July of 1999. A magnitude 4.3 earthquake occurred in May 2000.

Twenty-year dataset collected by the Bureau of Reclamation for the Paradox Valley project. Upper figure shows the average daily injection flow rate in gallons per minute. Lower figure shows all induced events and their magnitudes over the same period with distance from the injection well. SOURCE: Block (2011).



## Portable, Real-Time, Broadband Seismic Acquisition System

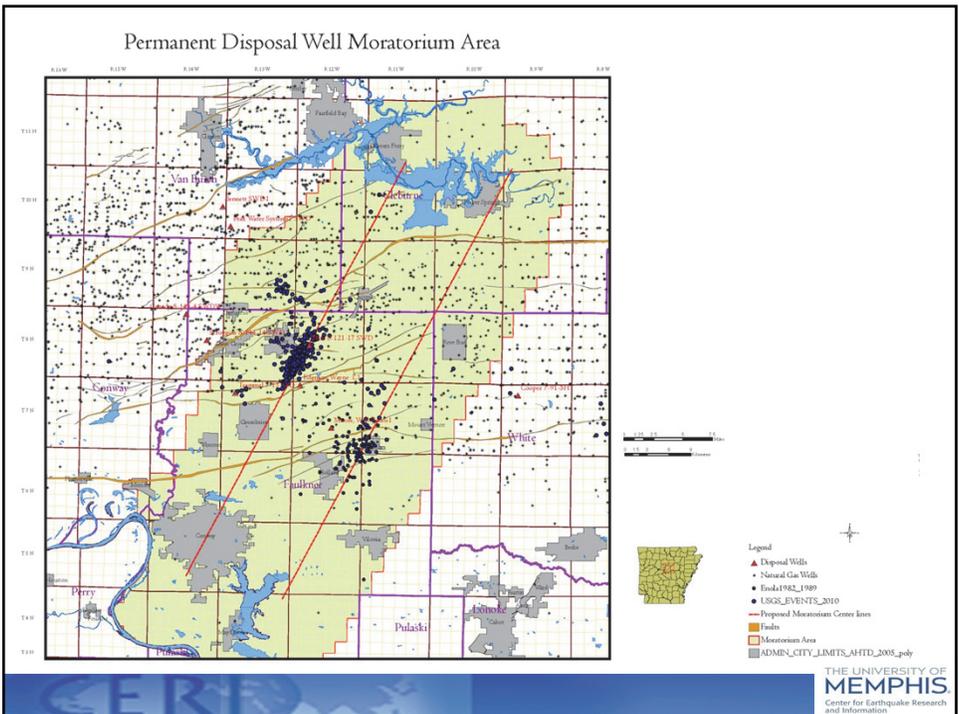
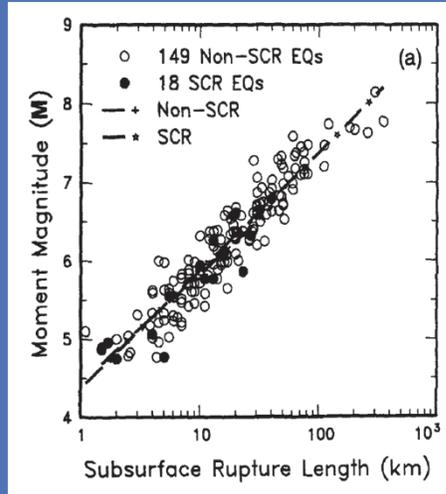
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Fault capable of M 5.6 – 6.0 earthquake if it ruptures as single event.

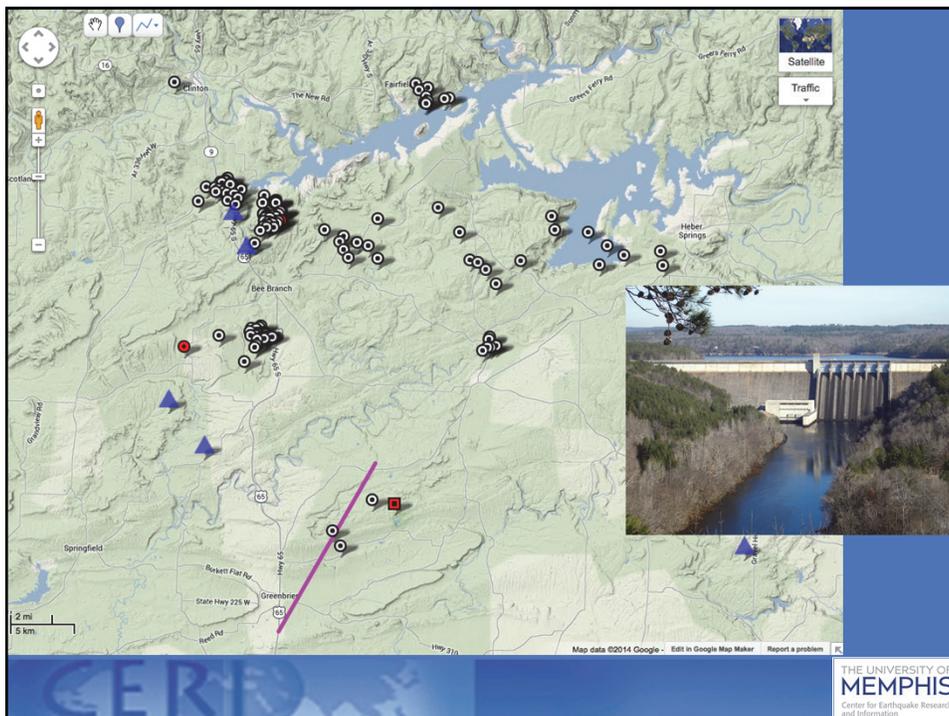
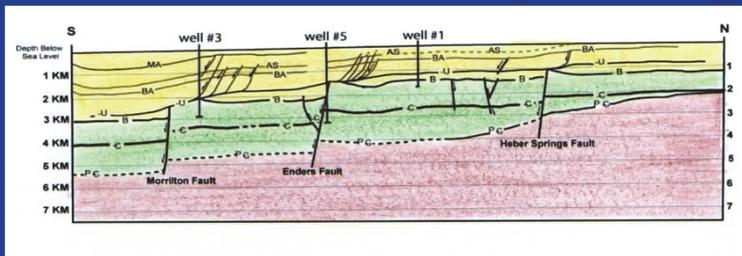
Wells and Coppersmith (1994)  
 $M = 3.98 + 1.02 \log(\text{area})$   
 $M(41) = 5.6$

$M = 4.33 + 1.49 \log(\text{RLD})$   
 $M(13) = 6.0$



## General Rule H-1 Disposal Well Permit Seismic Requirements Outside Moratorium Area in Fayetteville Shale Production Area

- Disposal wells not permitted within 1 mile of regional fault (defined) and within 5 miles of deep fault (defined).
- Disposal well spacing established based on stratigraphic depth of disposal zone (1/2 to 5 mile spacing).
- Information on faults required to be submitted with permit application. Director may request additional information if necessary.
- Permitted wells required to submit daily injection rate and pressure information.



## Summary

Fluid injection into the sub-surface can induce potentially damaging earthquakes

Seismic Hazard due to induced earthquakes can be minimized or eliminated.