

# Injection Induced Seismicity and Geothermal Energy: Lessons Learned from Past Injection Projects

Induced Seismicity in Energy Technologies  
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Testimony of Susan Petty, AltaRock Energy, Inc.

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# Injection Induced Seismicity Examples

- Rocky Mountain Arsenal - proof of theory
  - Hsieh and Bredehoeft (1981) *JGR*
- Paradox V. Brine Injection – large V, high P, continuous
  - Ake *et al.* (2005) *BSSA*
- Soultz – multiple EGS demos with varied results
  - Dorbath *et al.* (2009) *GJI*
- Basel – induced seismicity caused project shutdown
  - Häring *et al.* (2008) *Geothermics*
- Newberry – EGS demonstration planned for mid 2011

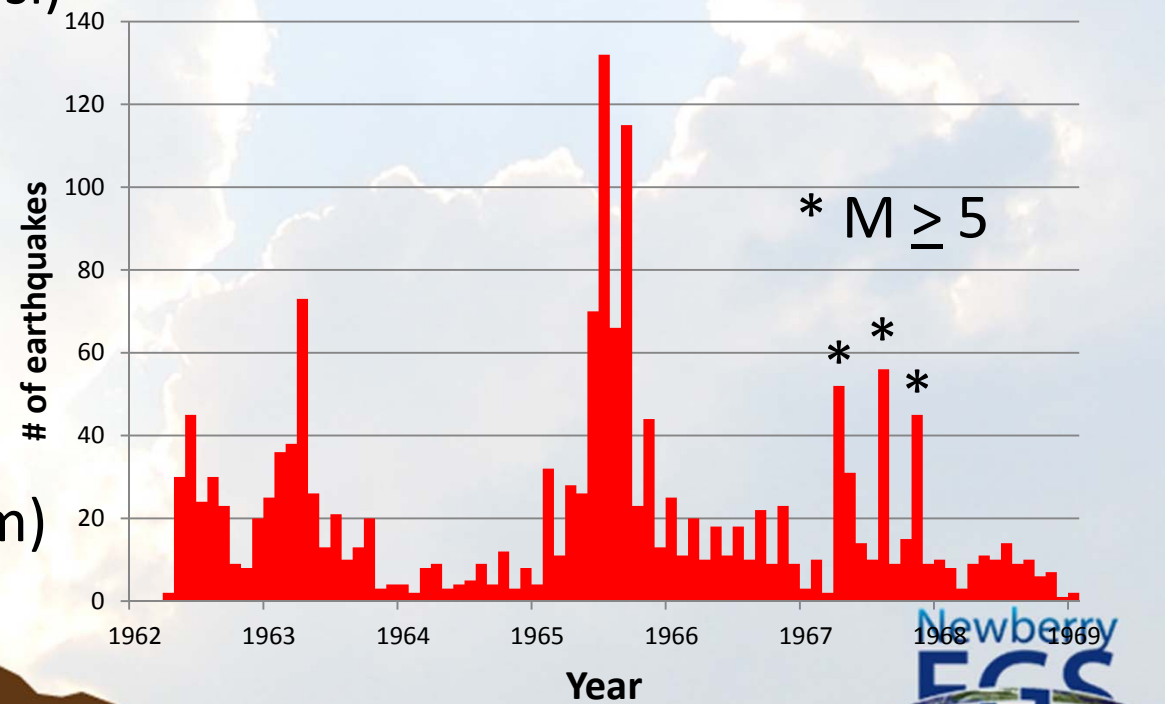
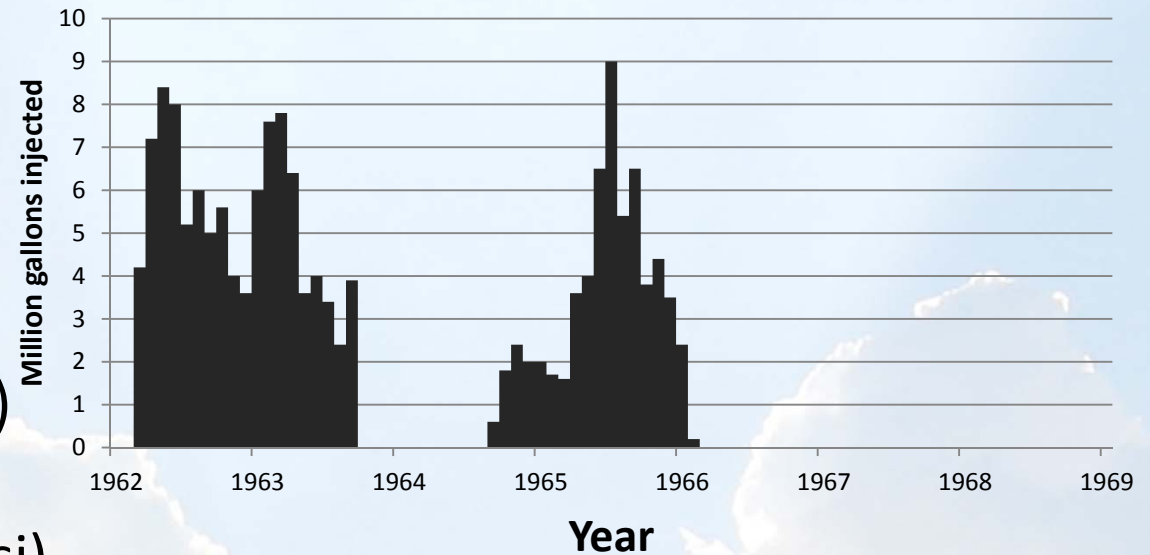
# Parameters affecting rate and size distribution IIS

- *In situ* stress and natural fluid pressure
- Frictional strength of faults and fractures
- Critical pressure to initiate *hydroshear*
- Tensile fracture pressures (minimum principle stress)
- G-R seismicity relation (b value)
- Characteristics of faults & fractures in the BH
- Well head pressure
- Injection rate, steps, and duration
- Total injected volume

# Rocky Mountain Arsenal

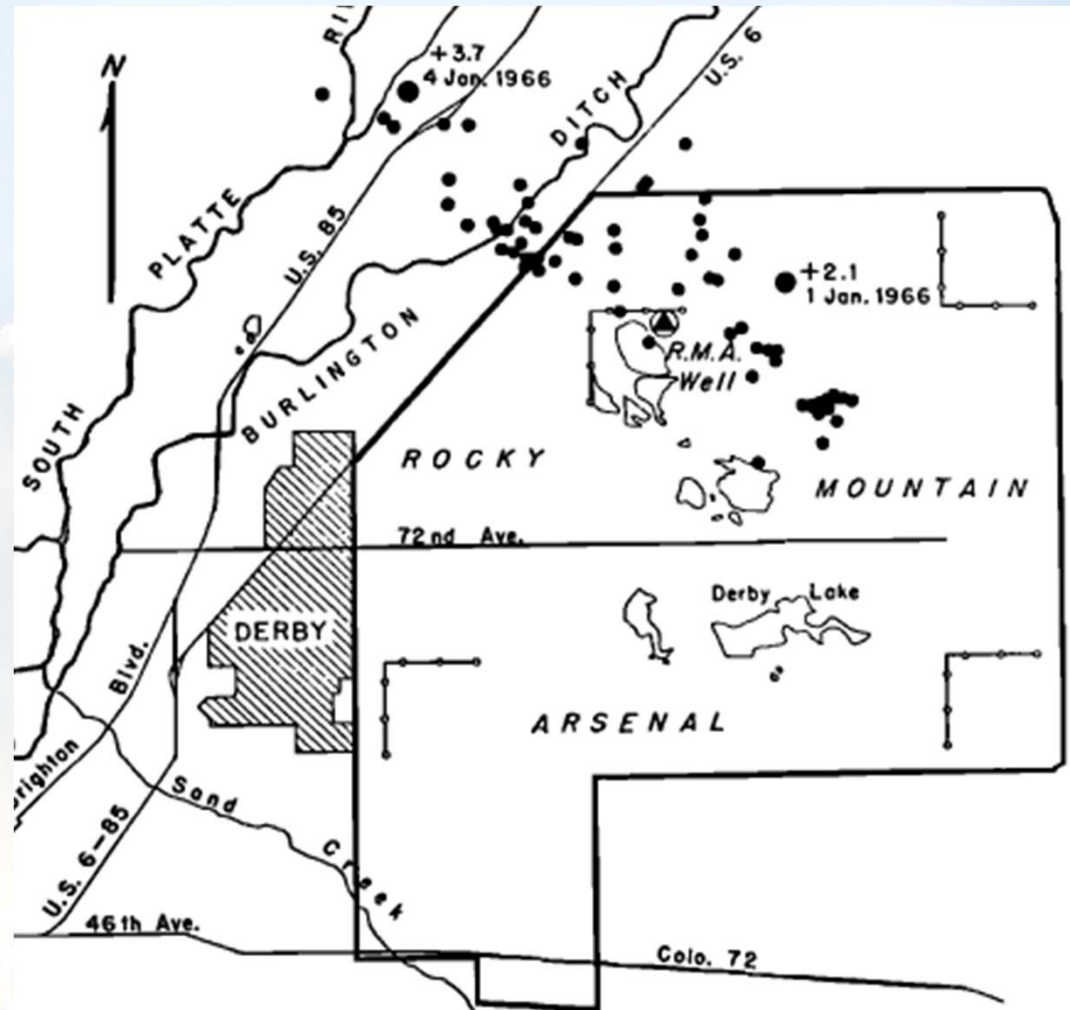
- Depth = 3.7 km (12000 ft)
- Fractured gneiss
- Max P = 7.2 MPa (1000 psi)
- Eventual gravity feed
- 4 years of injection

- Max R > 6.3 L/s (250 gpm)
- $M_{\max} = 5.3$



# Later Observations

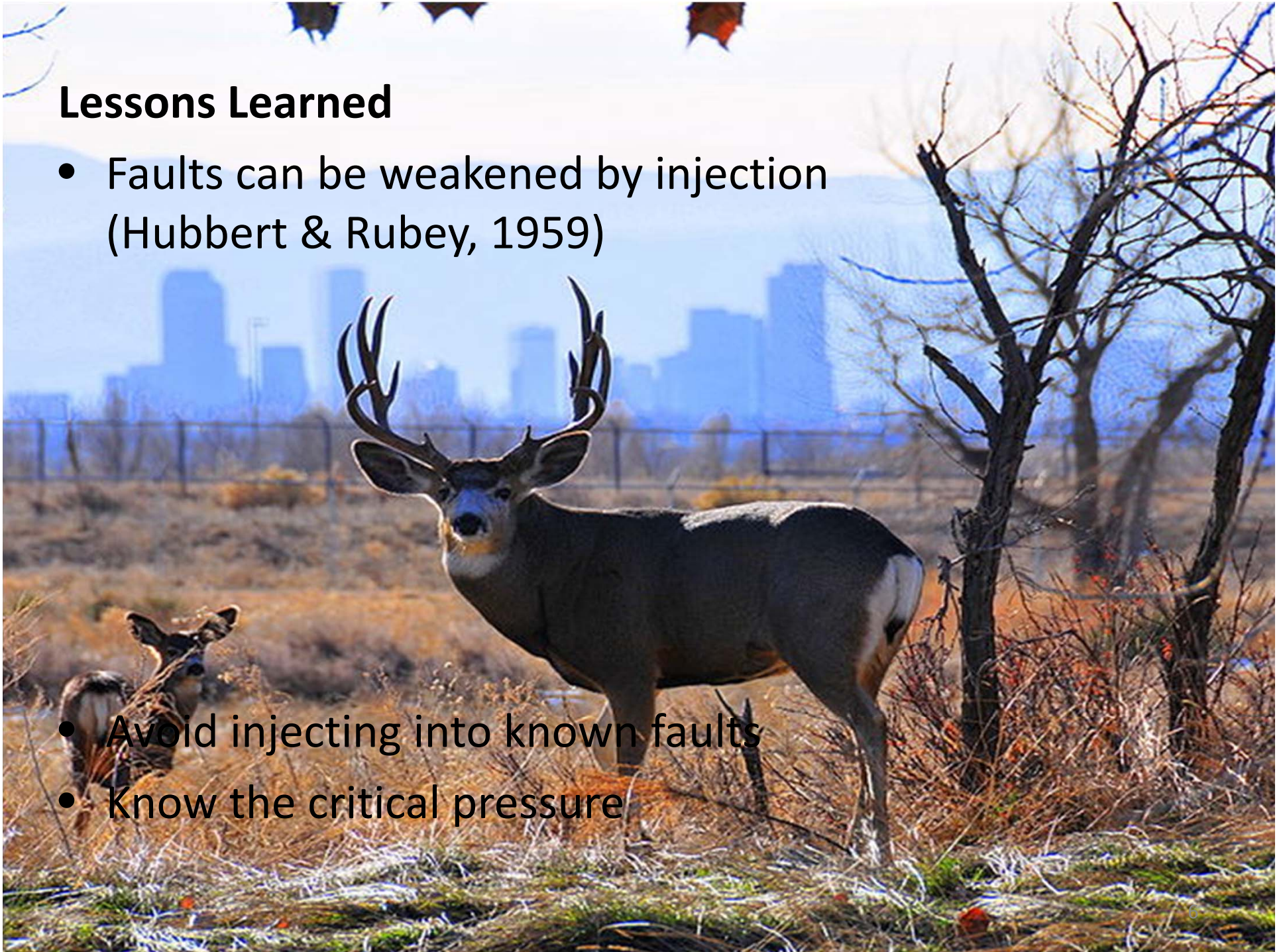
- Natural reservoir was under-pressured (925 m bgs)
- Seismicity didn't stop until WL dropped bgs
- $\Delta P_c = 3.2 \text{ MPa}$  ( $\Delta 325 \text{ m head}$ )
- 25 newspapers reported a similar earthquake in 1882



## Lessons Learned

- Faults can be weakened by injection (Hubbert & Rubey, 1959)

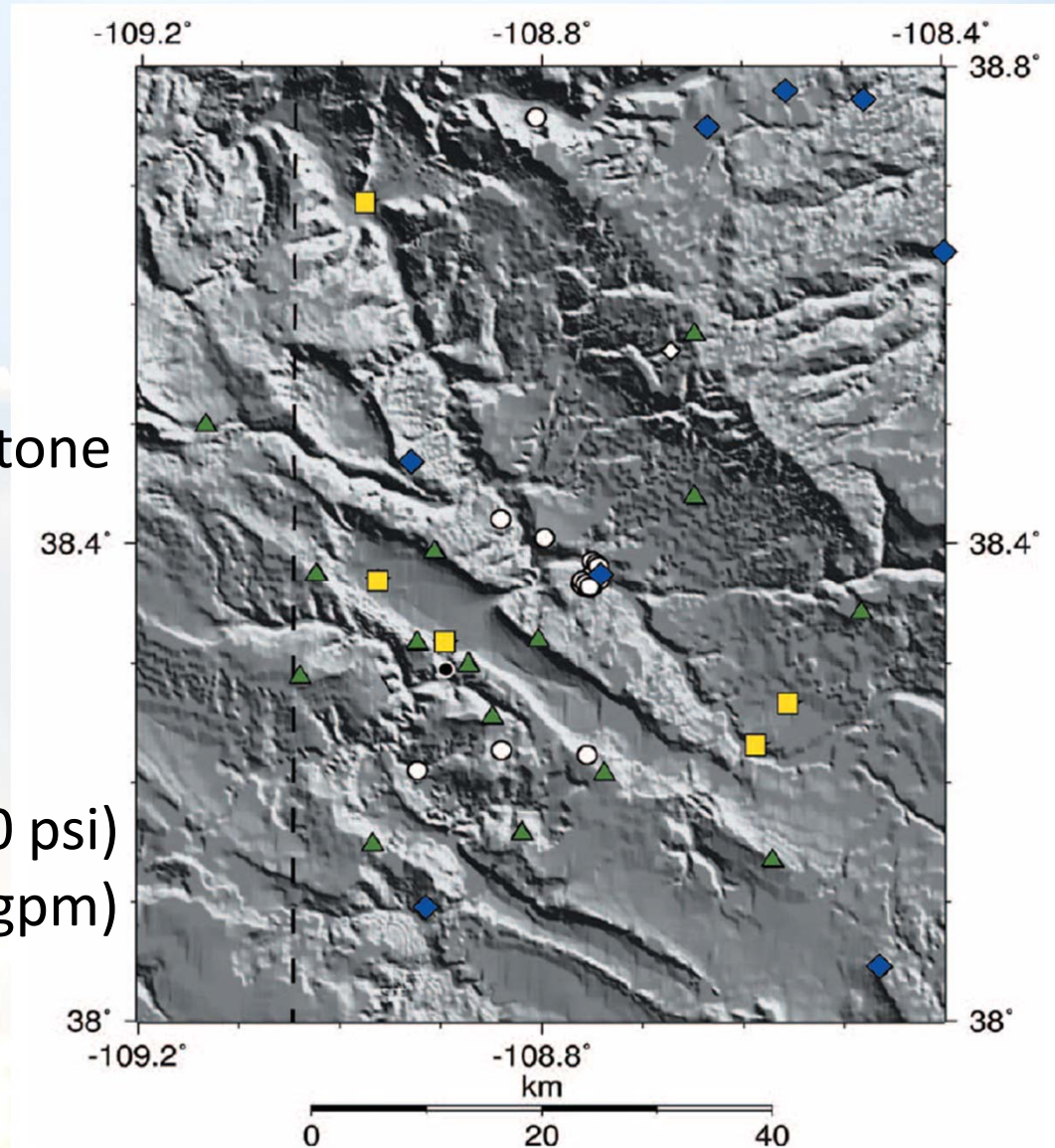
- Avoid injecting into known faults
- Know the critical pressure

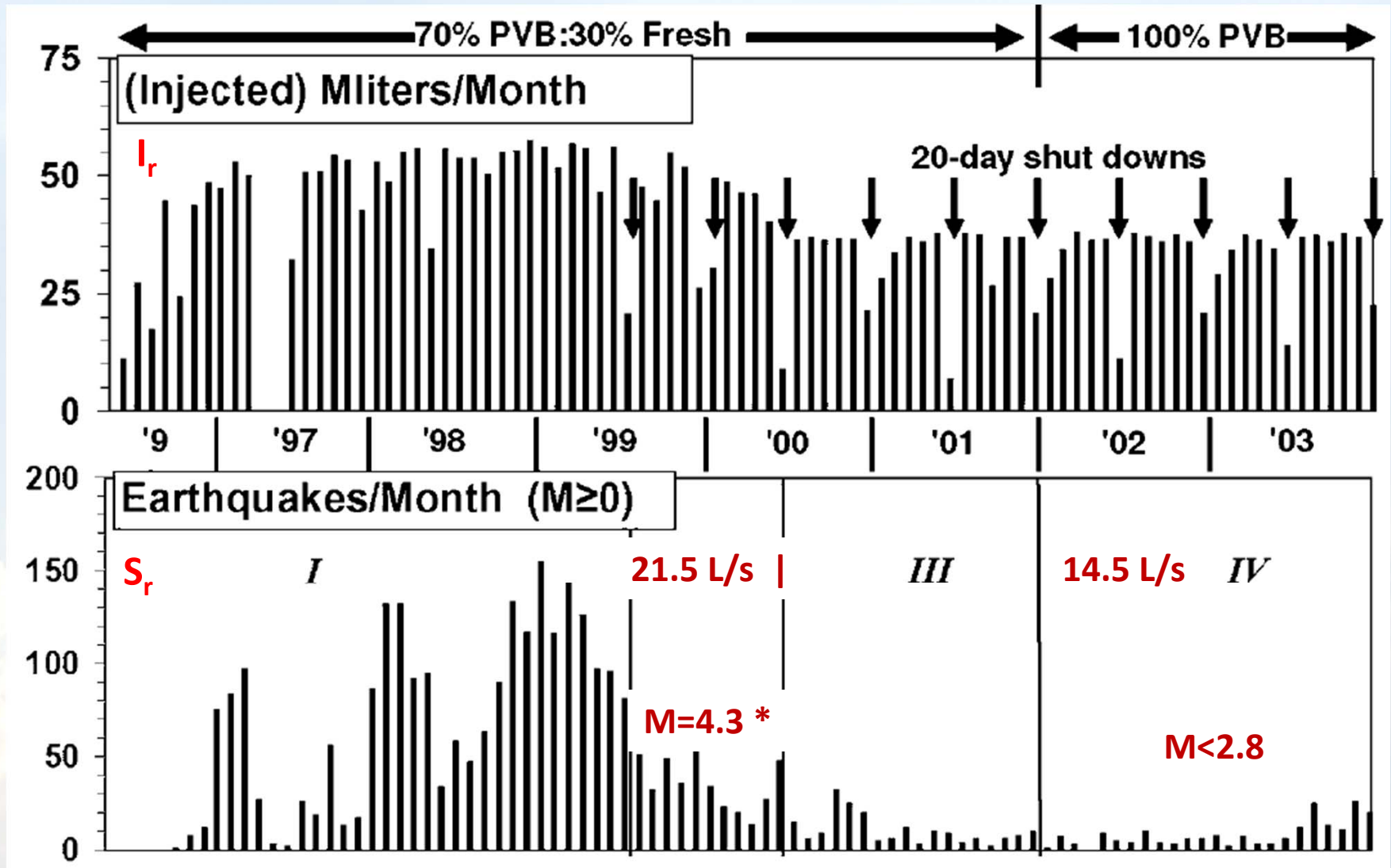


# Paradox Valley Brine Injection

- Depth = 4.5 km (14750')
- Fractured dolomitic limestone
- Continuous since 1996

- $\Delta P_c = 17$  MPa (2465 psi)
- Max  $P_{wh} = 34.2$  MPa (4960 psi)
- Max Rate = 21.5 L/s (340 gpm)





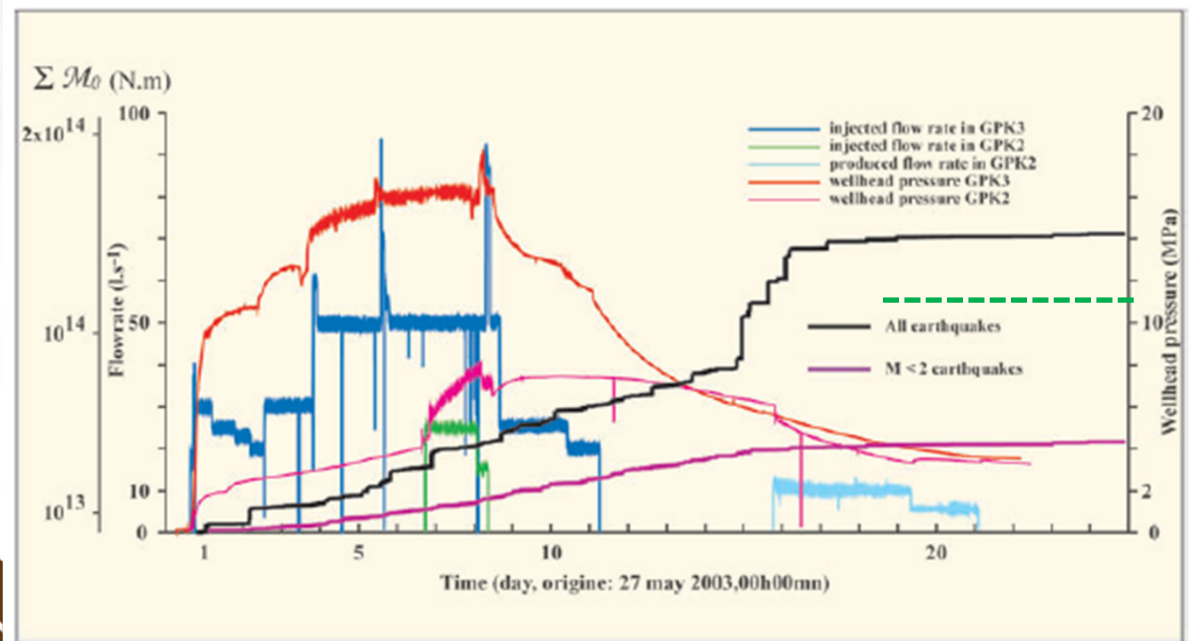
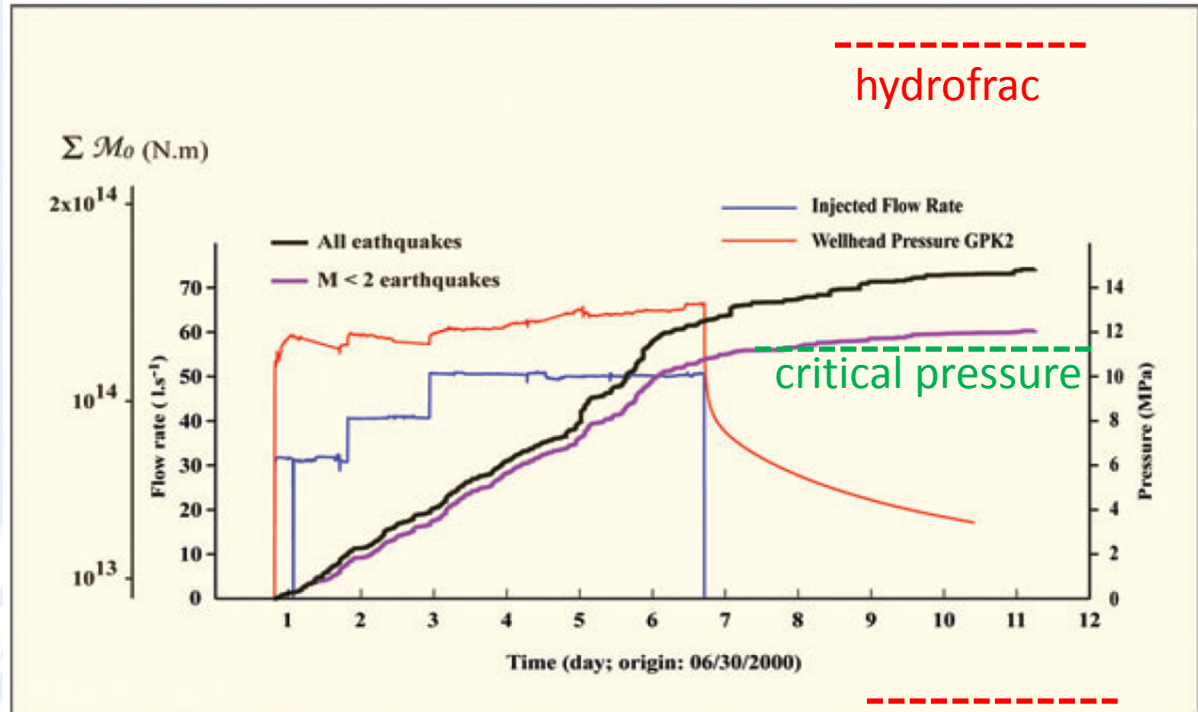
$S_r = 0.27 I_r - 3.1$

$R=96\%$  Newberry



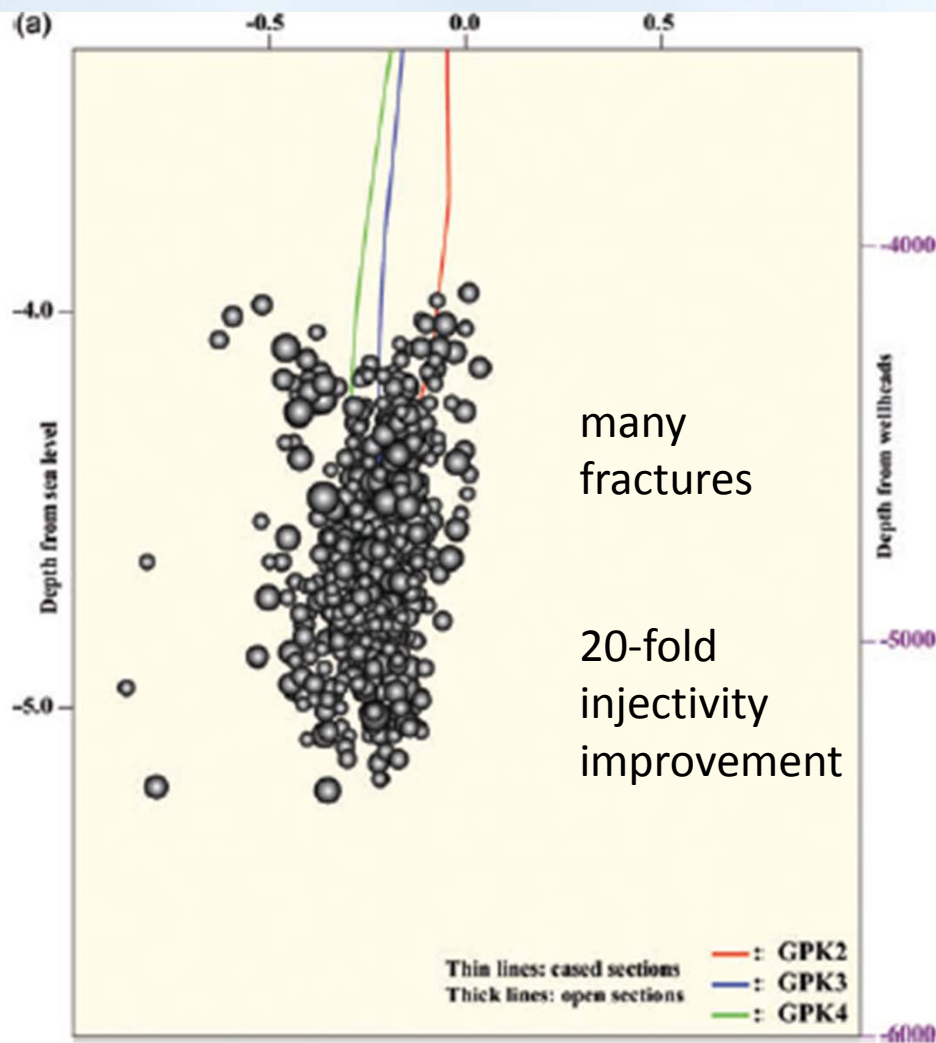
# Soultz

- 3 deep stimulations
- Depth = 5.0 km
- Granite
- $\Delta P_c \approx 12$  Mpa
- Max  $P_{wp} \approx 14-16$  MPa
- Max rate = 50 l/s
- 7-11 days of injection

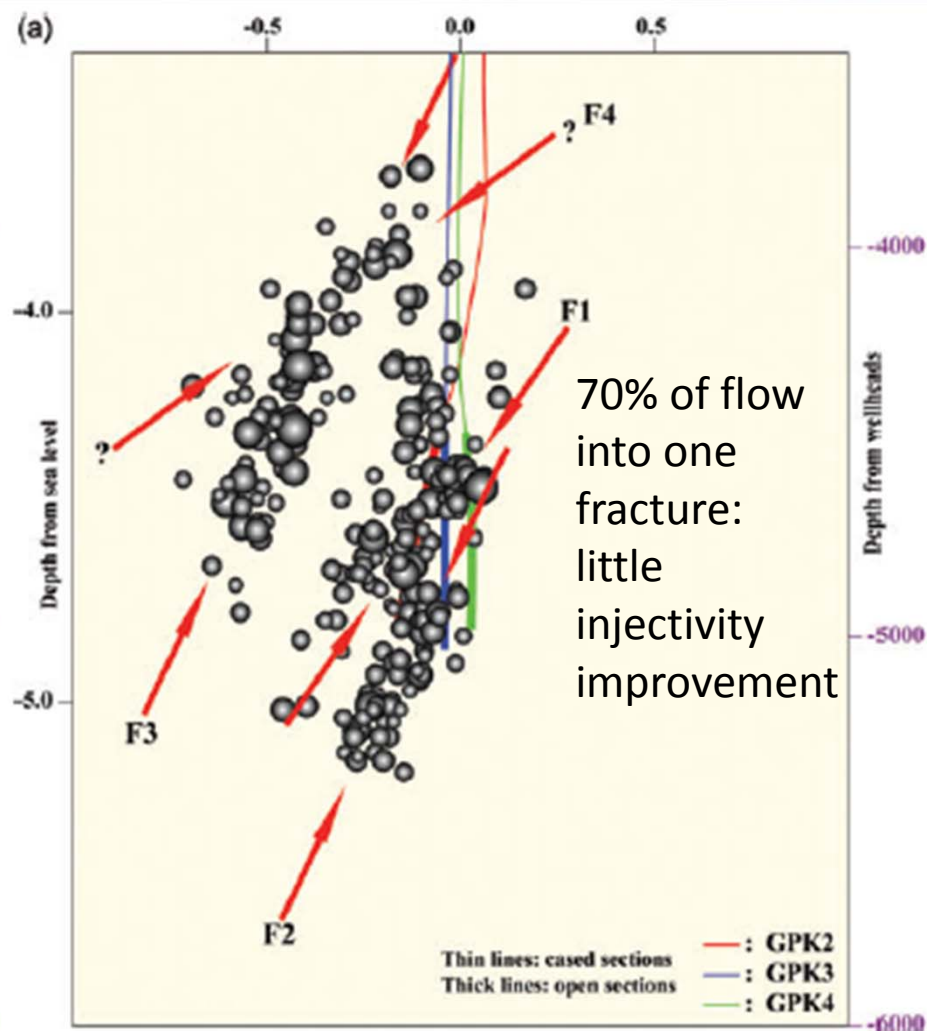


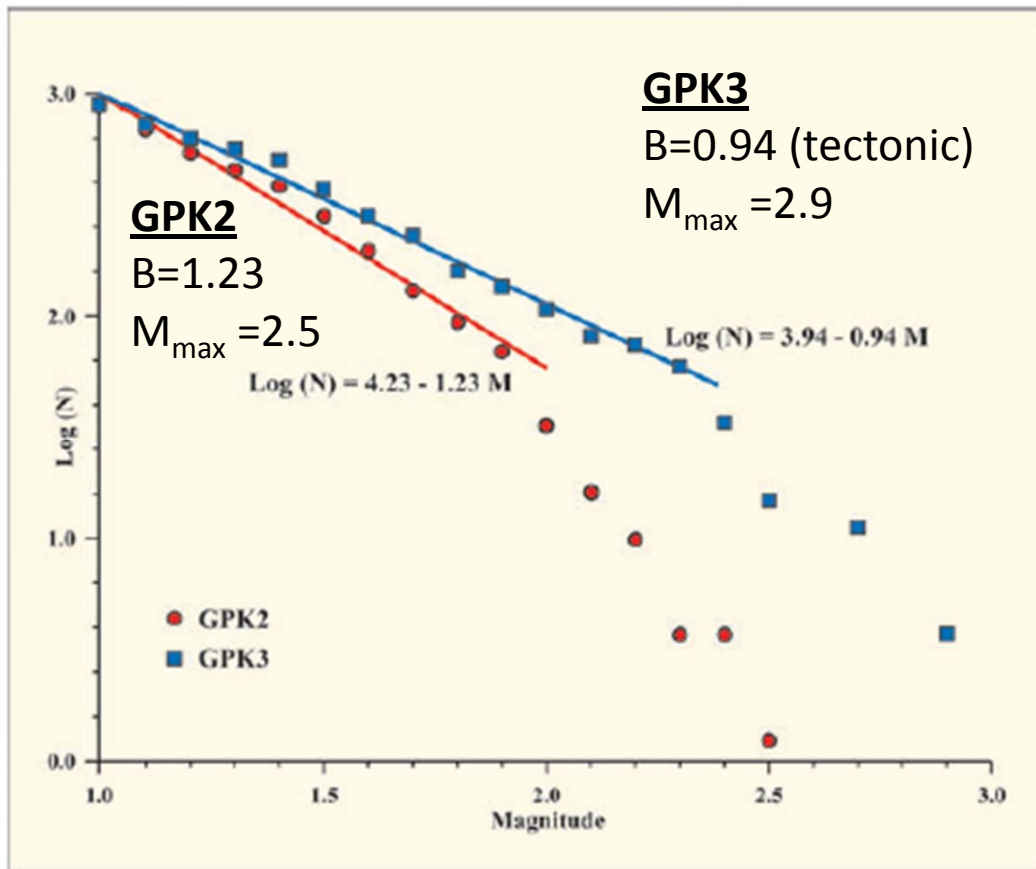
# Structure of GPK2 vs. GPK3

Side view of GPK2 stim



Side view of GPK3 stim



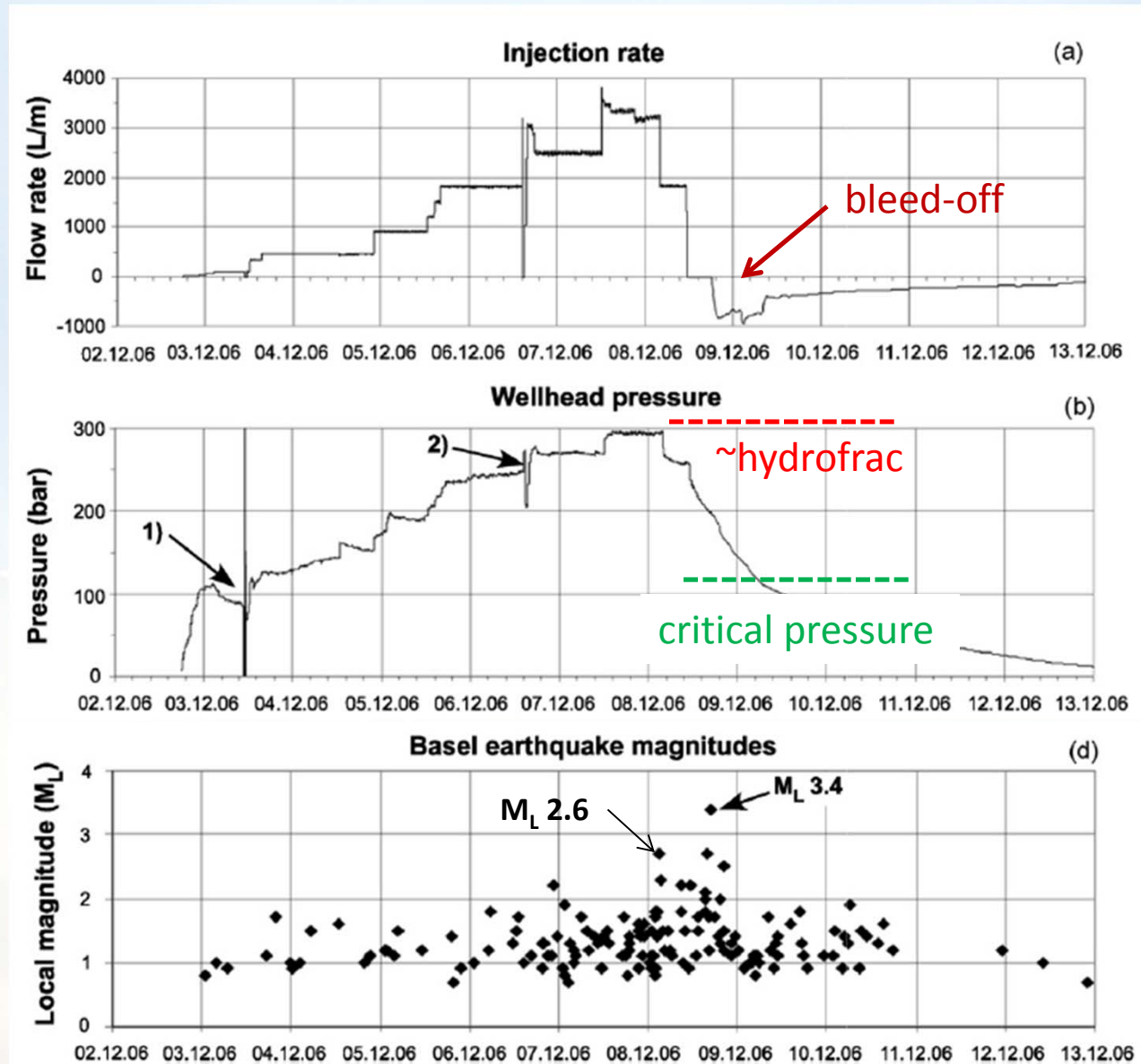


## Lessons Learned

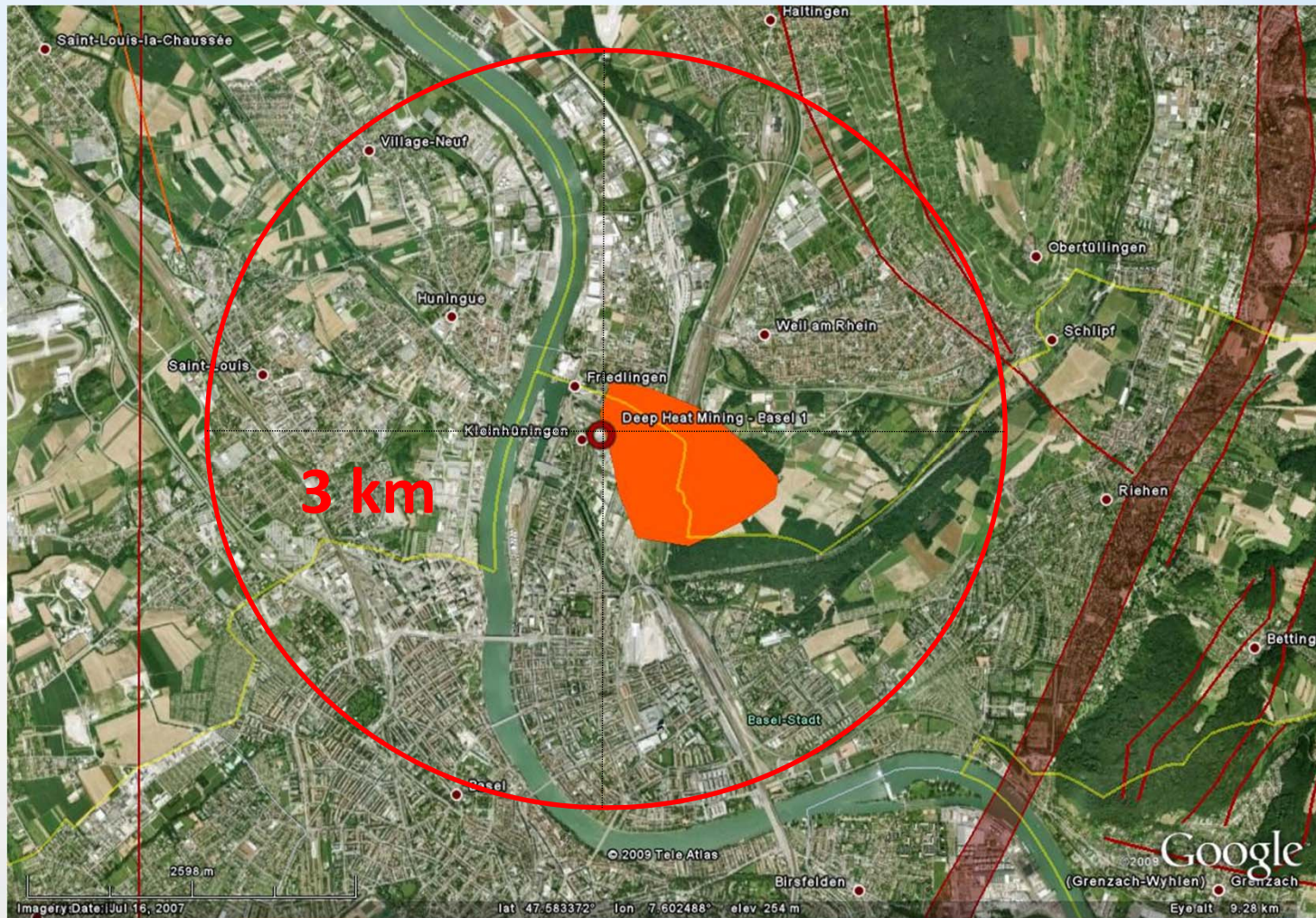
- Avoid injecting into fracture zones with already high transmissivity (GPK3)
- Higher b-value results in lower maximum event size and better fracture network for EGS

# Basel DHM

- Depth = 5 km
- Granite
- $\Delta P_c \approx 11$  Mpa
- Max  $P_{wh} = 29.6$
- Max Rate = 55 L/s
- $M_{max} = 3.4$



# Basel Deep Heat Mining Project

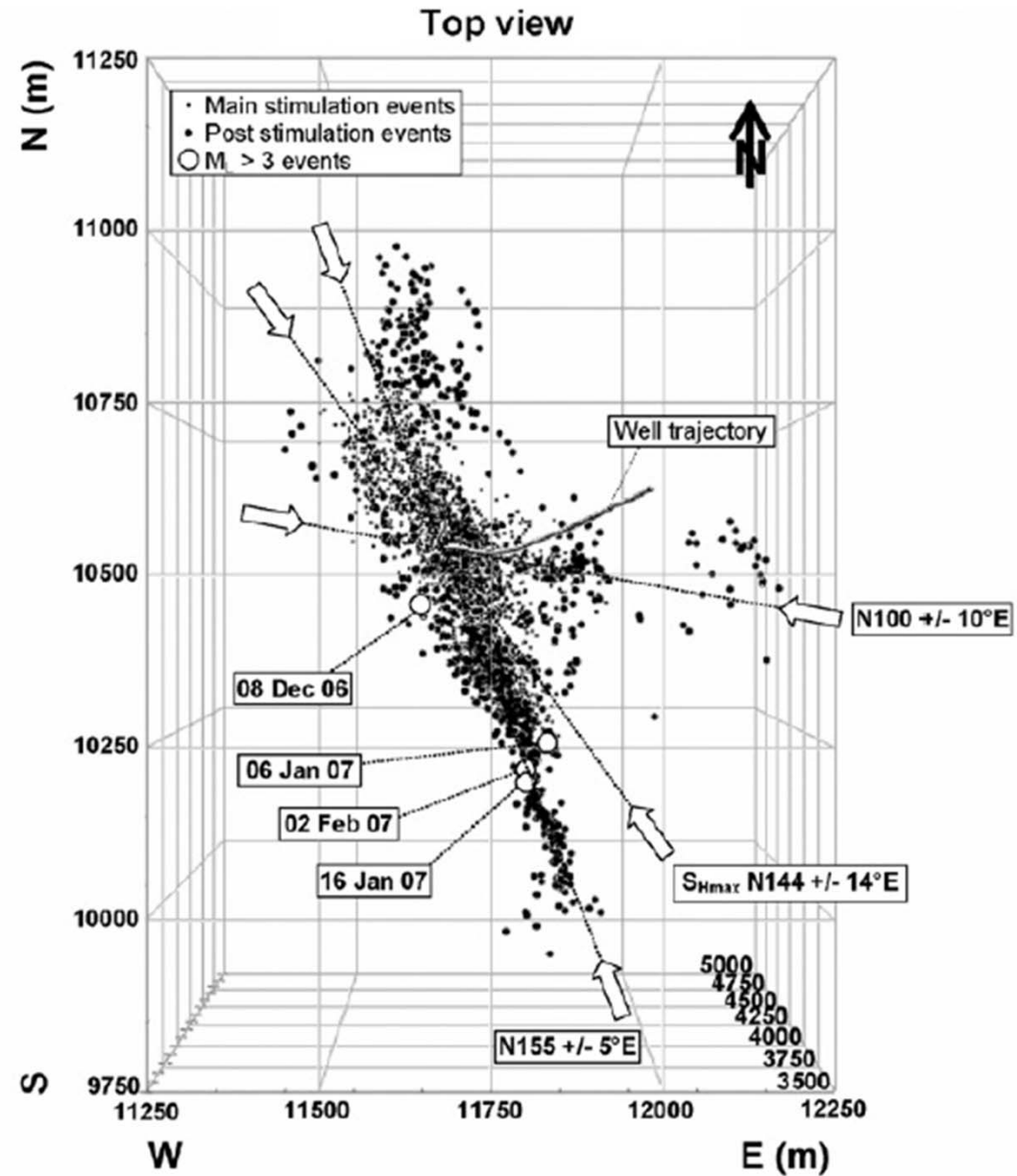


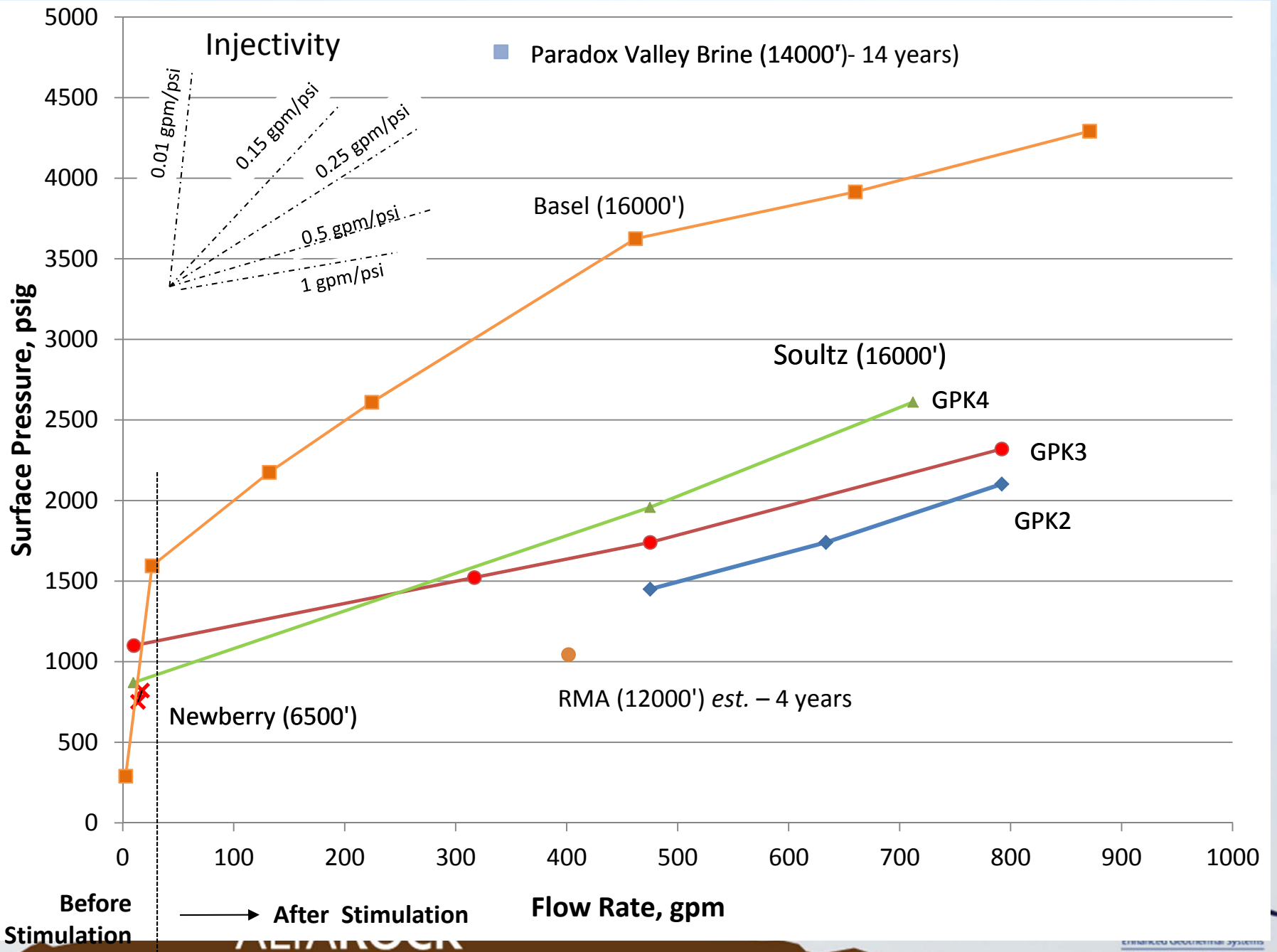
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## Lessons Learned

- Avoid injecting into faults
- If pressure builds, wait to increase rate
- Bleed off works to slow felt IIS





# Theoretical Model (Shapiro et al. 2010)

$$\log N_M(t) = \log Q_c(t) - bM + \{a - \log (CS/N)\}$$

where

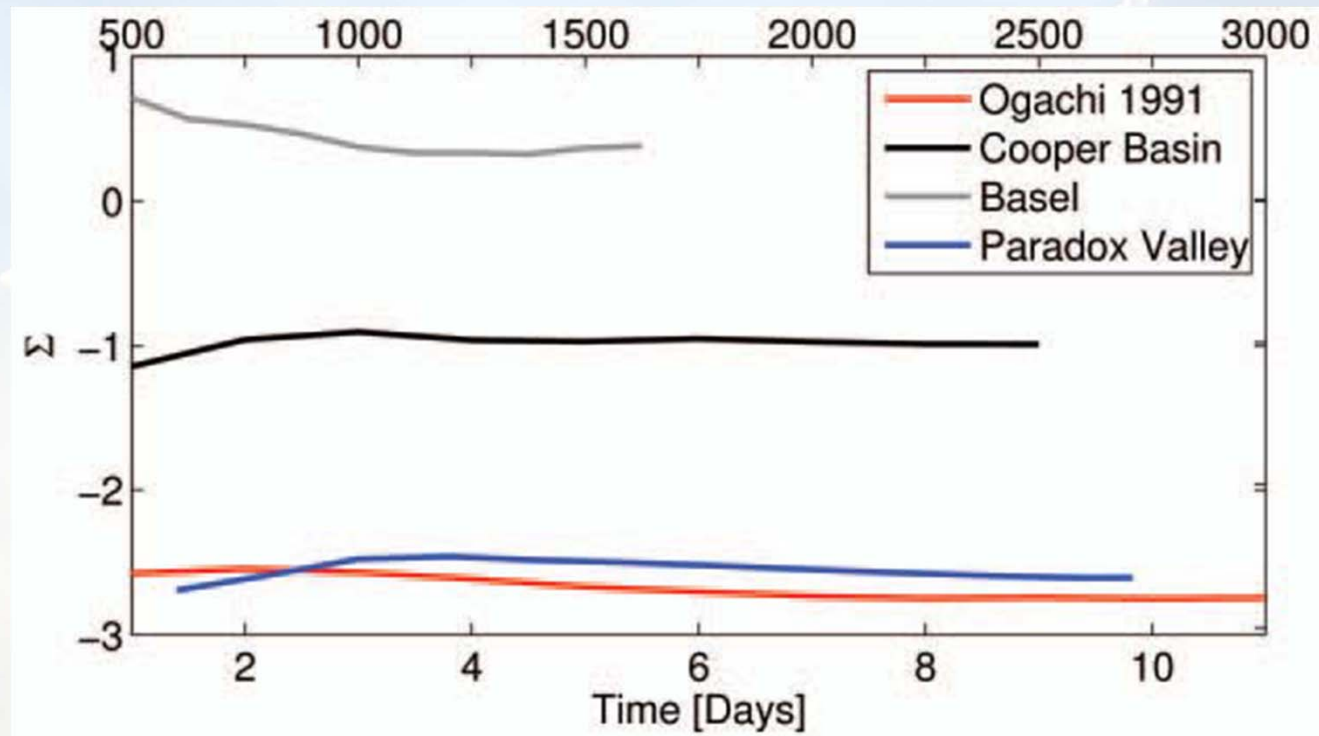
$\Sigma$

- $N_M(t)$  is number of events greater than  $M$
- $Q_c(t)$  is cumulative injected volume
- $b$  and  $a$  are constants in Gutenberg-Richter relation
- $\Sigma$ , the seismogenic index, is independent of the injection
- $\Sigma$  characterizes the rock mass (seismicity rate, critical pressure, fracture density, and poroelastic coefficient)
- $\Sigma$  can be determined from ongoing stimulation results



# Seismogenic Index for injection projects

the seismicity induced by the same quantity of injected volume will depend upon the inherited local geomechanical setting



# Newberry EGS Demonstration Project Experience: Strategy for Mitigation of Induced Seismicity

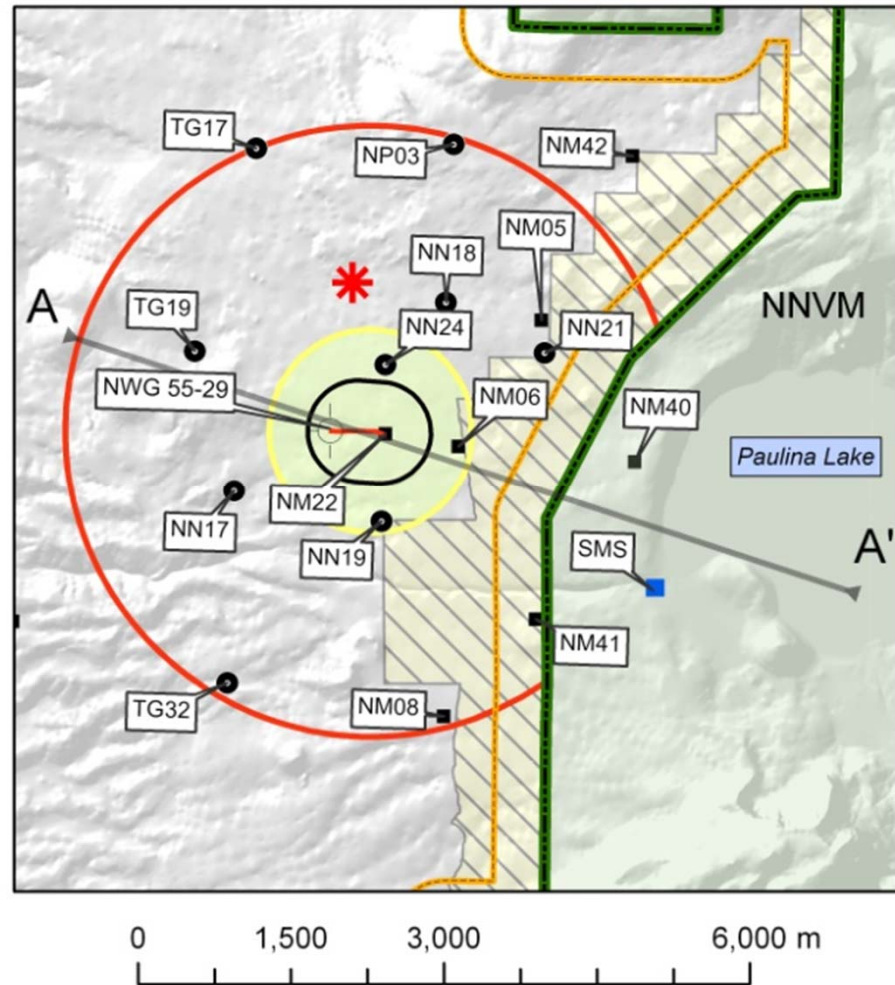
- EGS Demonstration Project with DOE 50% funding
- NEPA permitting process through BLM, Forest Service and DOE
- State and local permitting through BLM as lead agency
- Environmental Assessment includes Induced Seismicity Mitigation Plan

# Newberry EGS Demonstration – Pre-stimulation

- Baseline injection tests
- Surface shot calibration survey - USGS
- Monitor background seismicity
- LiDAR collection for neotectonic data
- Examine mud-logs & cuttings for evidence of faults
- Borehole televiewer survey
- Model expected seismicity with AltaStim
- Induced Seismicity Mitigation Plan
- Install permanent borehole MSA
- Monitor background data

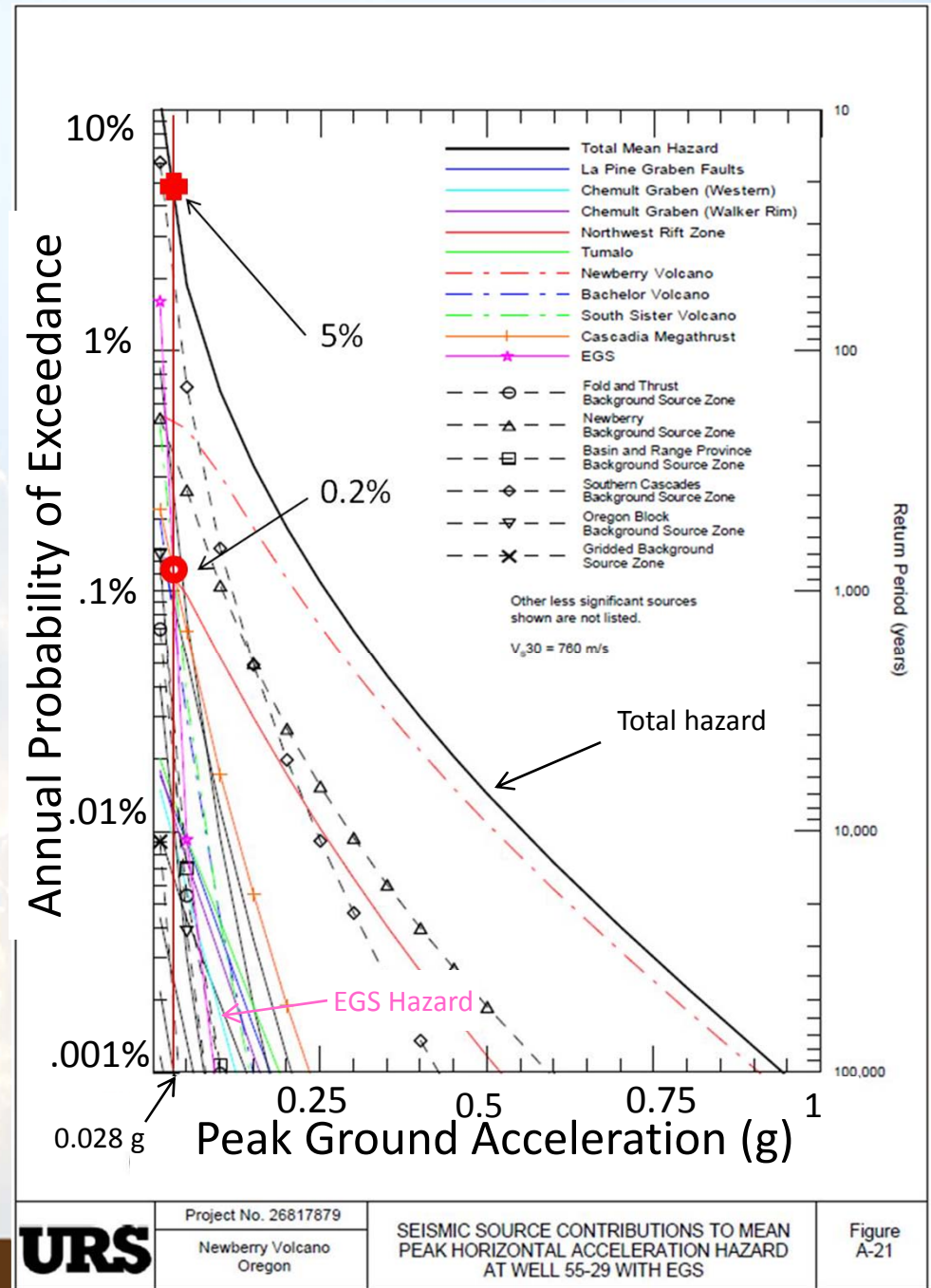
# Permanent Microseismic Array Design

- Phase II array – stimulation
  - 15-station array of borehole and surface sensors
  - Nine borehole sensors at 700-900 feet, with hole-lock
  - Six surface sensors
  - Real-time telemetry
- **Strong motion sensor (SMS) at Paulina Lake Visitor Center**
- **BH drilling and installation: March-June 2012**



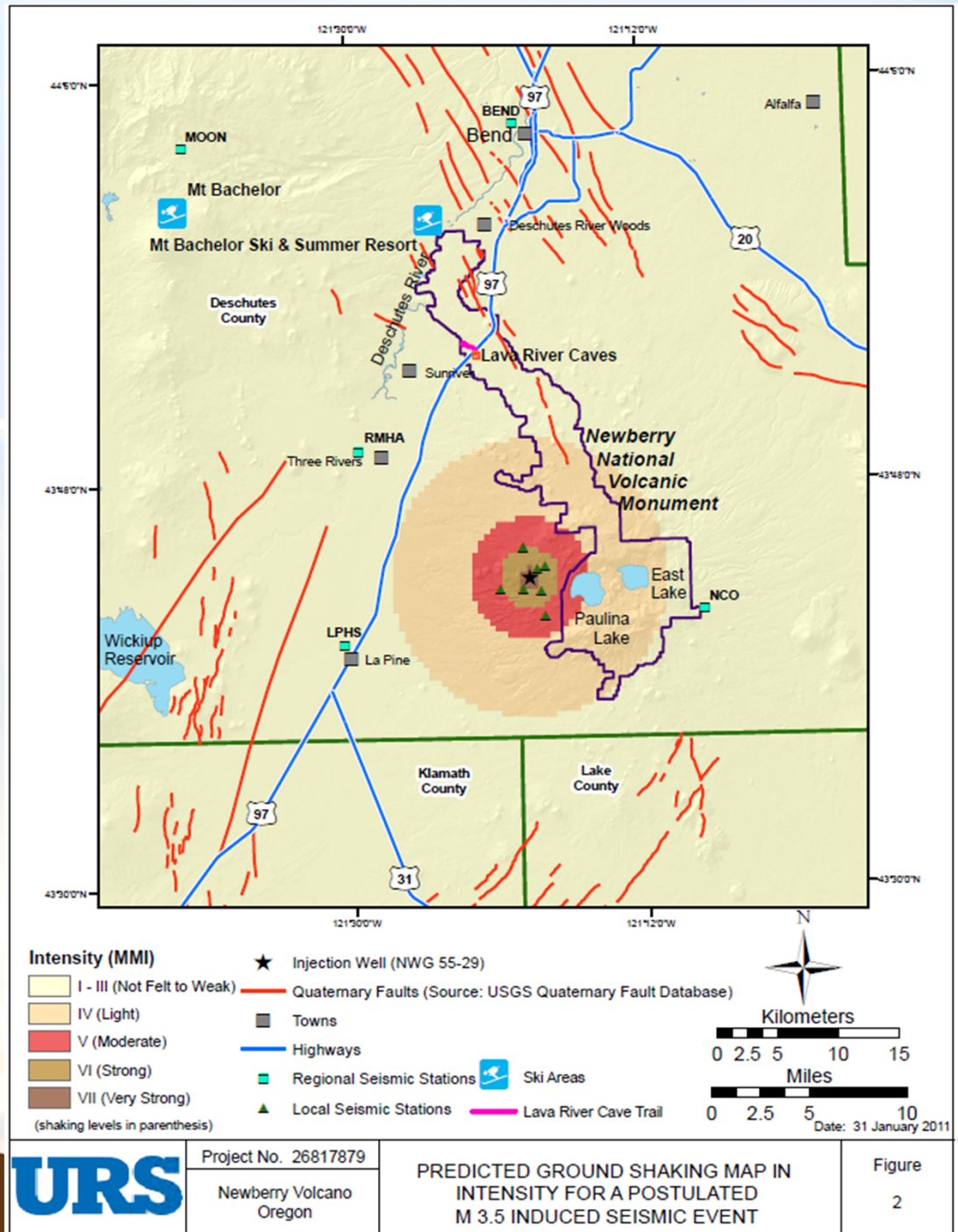
# Probabilistic Seismic Hazard Assessment

- Methodology: C.A. Cornell (1968)
- Software: HAZ38 (PG&E)
- Analysis: I. Wong, URS
- Seismic Sources
  - Natural and EGS
  - Source geometry
  - Earthquake recurrence
- $PGA > 0.028 \text{ g}$  has cosmetic damage potential, probability of exceeding threshold is
  - 5% per year for natural events
  - 0.2% per year for EGS events



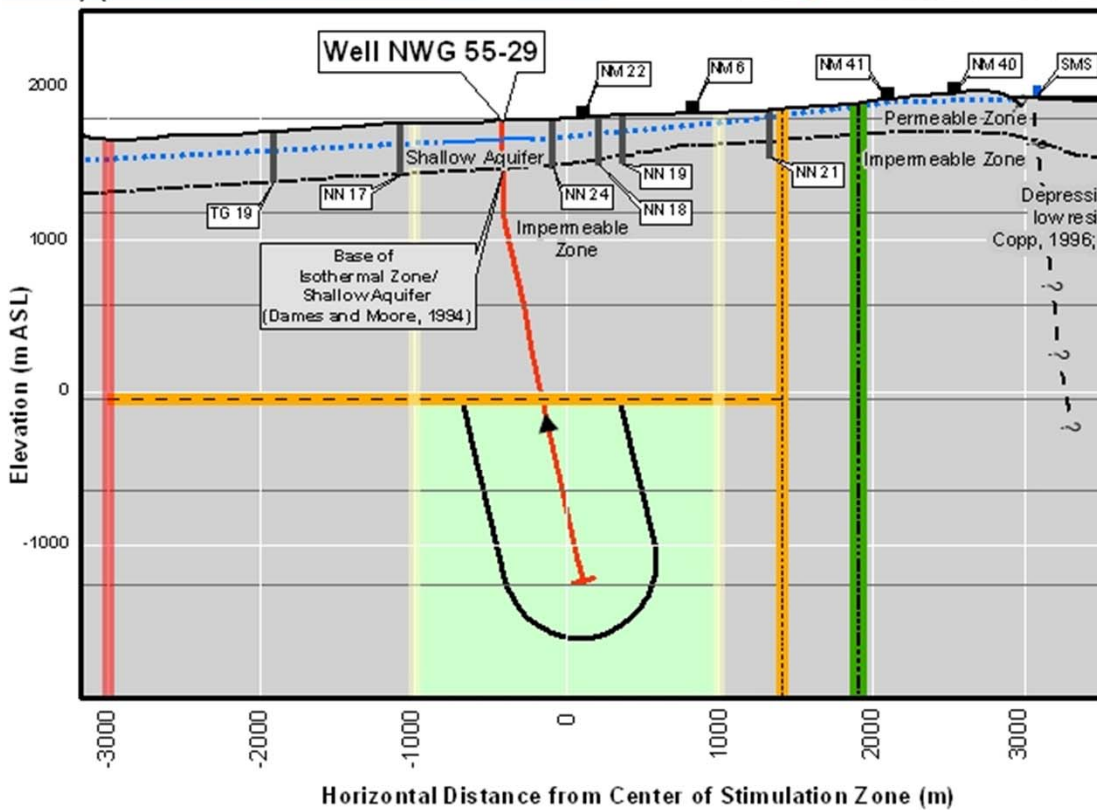
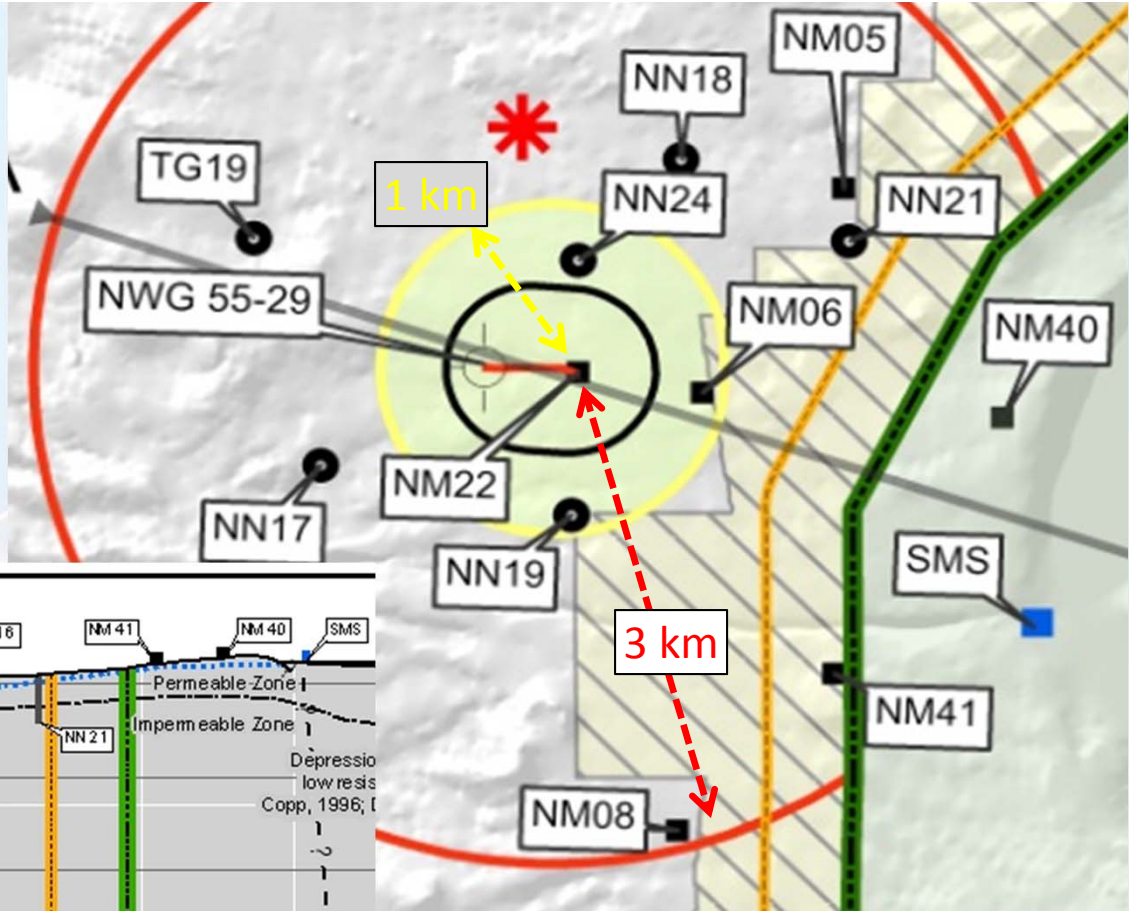
# Risk from induced event

- Historical / theoretical maximum magnitude = 3.5-4.0
- $M_w$  3.5 probability < 0.3% within 30 day stimulation period
- Shake Map shows predicted shaking from M 3.5 at well
- Nearest structures, cabins in NNVM: MMI V (felt, light damage potential)
- Nearest town MMI < III (barely felt, no damage potential)



# Seismic Triggers

- Outliers
  - horizontal
  - Vertical
  - NNVM



- Magnitude
- PGA on SMS

# Seismic Triggers and Mitigation Steps

## Event Characteristics

## Field Operation

- Regulator approval
- MSA/SMS active

Start

Initiate stimulation plan  
Conduct step-rate test

- Event >1 km from well
- Shallow (<6000 ft) event
- Within 500 m of NNVM

Outlier Alert

Confirm, then apply diverter  
No flow or pressure increase  
Assess result for 24 hours

- M 2.0 to 2.6 within 3 km

No Flow Increase

No flow or pressure increase

- M 2.7 to 3.4 within 3 km
- PLVC PGA: 0.014 to 0.028 g
- MMI: IV (Light, no damage)

Decrease Flow

Reduce flow to reduce P  
Wait 12 hours

- M  $\geq 3.5$  within 3 km
- PLVC PGA  $\geq 0.028$  g
- MMI: IV (Light, no damage)

Stop Injection –  
Flow Well

Stop injection  
Flow to surface (sump)

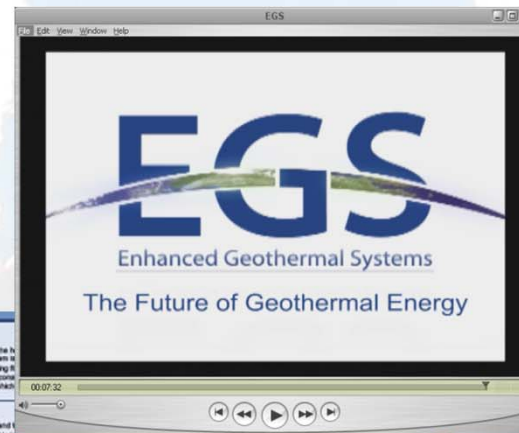


# Permitting and Review Process

- Induced Seismicity Mitigation Plan (DOE reviewed. Included in EA)
- Phase I Report and Phase II Plan (Submitted August 2012)
- Stage-Gate Review (DOE approved Nov. 2012)
- Environmental Assessment (BLM published December 22, 2011)
  - Public comment (completed January 25, 2012)
  - Decision record (*February, 2012*)
  - Phase IIa (MSA install and stimulation) may begin
- Phase IIb (production drilling) requires additional DOE stage gate review
- Construction and long-term operations will require more permitting (requires data collected during demonstration)

# Public Outreach

- Community meetings
- Print and radio interviews
- TV segments
  - Oregon Field Guide (Feb. 16)
  - Seattle news stations
- Documents posted online
- 855-USA4EGS
- Animated project video
- NNVM displays
- Facebook.com/NewberryEGS



**Geothermal Energy**

The Energy Beneath Our Feet

The word "geothermal" comes from the Greek words "geo" (earth) and "thermo" (heat). Geothermal energy is obtained from a natural heat that is stored deep within the surface of the Earth.

Heat from the earth can be used as an energy source in many ways. Both large and compact power plants can be used and relatively simple pumping systems. We can produce electricity as well as hot water and use it to heat buildings or generate electricity. Naturally occurring geothermal systems, or hydrothermal resources, are also found where heat and liquid materials (fluids) with water can be extracted of naturally shallow depths. But in the western U.S., and around the Ring of Fire, geothermal energy is a tremendous energy source, and environmentally friendly.

**History and Development**

In the 20th century, demand for electricity led to the construction of geothermal power as a generating source. The first geothermal power plant was built in 1904 in Larderville, Italy. It was built by the Edison Electric Power Company. Later, in 1911, the world's first commercial geothermal power plant was built there. Italy was the world's only industrial producer of geothermal electricity until 1995.

Electricity can be created from the heat pressure vessel, and the steam is exchanged, and the heated water is returned to the natural electric grid, and on to consumers after use at cooling, which

To harness geothermal energy and geothermal energy via the earth's energy are: 1) direct use, 2) geothermal heat pumps, and 3) generation of electricity.

**Where Geothermal is Found**

Large areas of naturally occurring hydrothermal (water or fluid) resources are called geothermal resources. Most geothermal resources are deep underground with no visible signs showing above ground. But geothermal energy sometimes finds its way to the surface in the form of a hot spring, geyser or fumarole (steam vent).

The most active geothermal resources are usually found along major plate boundaries where tectonic plates and volcanoes are concentrated. Most of the geothermal activity in the world occurs in an area called the Ring of Fire. This area encircles the Pacific Ocean.

**Geothermal Energy and the Environment**

The environmental impact of geothermal energy depends on how it is being used. Direct use and heating applications have almost no negative impact on the environment. Geothermal power plants do not burn fuel to generate electricity, so their emissions levels are very low. They release less than 1 percent of the carbon dioxide emissions of a fossil fuel plant. After the steam and water from a geothermal resource have been used, they are injected back into the earth. Some hot springs, geysers and fumaroles, such as those found in the Newberry National Volcanic Monument and Yellowstone National Park, are protected by law to prevent them from being disturbed.

**The Future of Geothermal Power**

Geothermal energy has the potential to play a significant role in securing the United States, and other regions of the world, toward a cleaner, more sustainable energy future. It is one of the few renewable energy technologies that can supply continuous, baseload power. Enhanced Geothermal Systems or EGS could allow us to reach this potential. A 2008 Massachusetts Institute of Technology report concluded that a modest \$40 billion investment over 15 years could produce 100 gigawatts of electricity by 2050 in the United States.

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