Environmental Anxiety Meets Geothermal Energy

Engineered Geothermal Systems and the Environment

The Energy Under Our Feet

Geothermal Energy

- The deeper you go the hotter it gets
- Some places get hotter faster than others
- Some places have natural fractures and faults that allow hot fluids to circulate near the surface – hydrothermal systems

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Using the Earth's Heat

Hydrothermal Sources

- Drill wells into fractured or porous rock
- Pump or self-flow water to surface
- Direct use of heat
  - Heating and cooling
  - Industrial processes – food drying, washing
  - Aquaculture
- Power Generation
  - Flashed Steam
  - Binary
  - Dry Steam

Combined heat and power at Chena Hot Springs, Alaska

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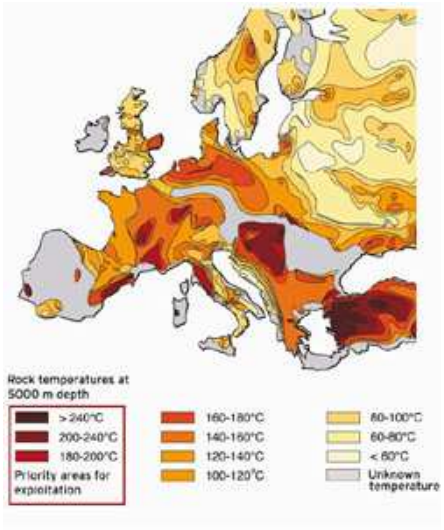
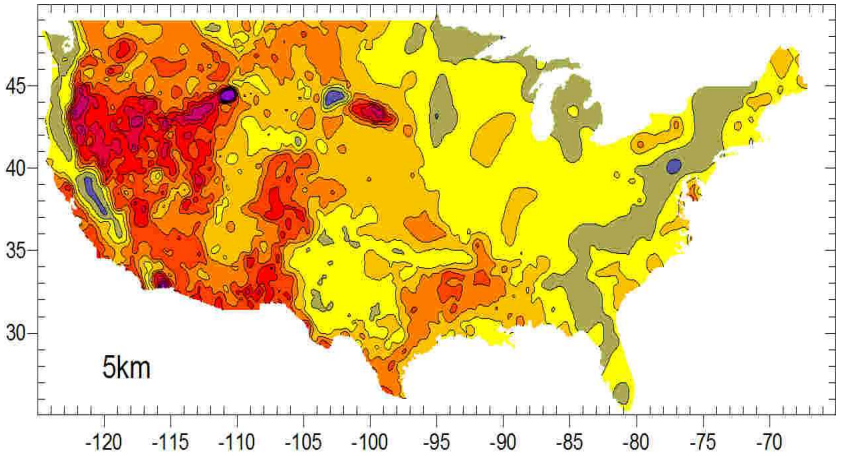
Expanding the Geothermal Resource
Enhanced Geothermal Systems

- Enormous resource stored as heat in rock
- Natural heat flow recharges stored heat
- Areas with high heat flow
  - Across the US
  - Around the world
- Development technically feasible today



Rock temperatures at 5 km depth



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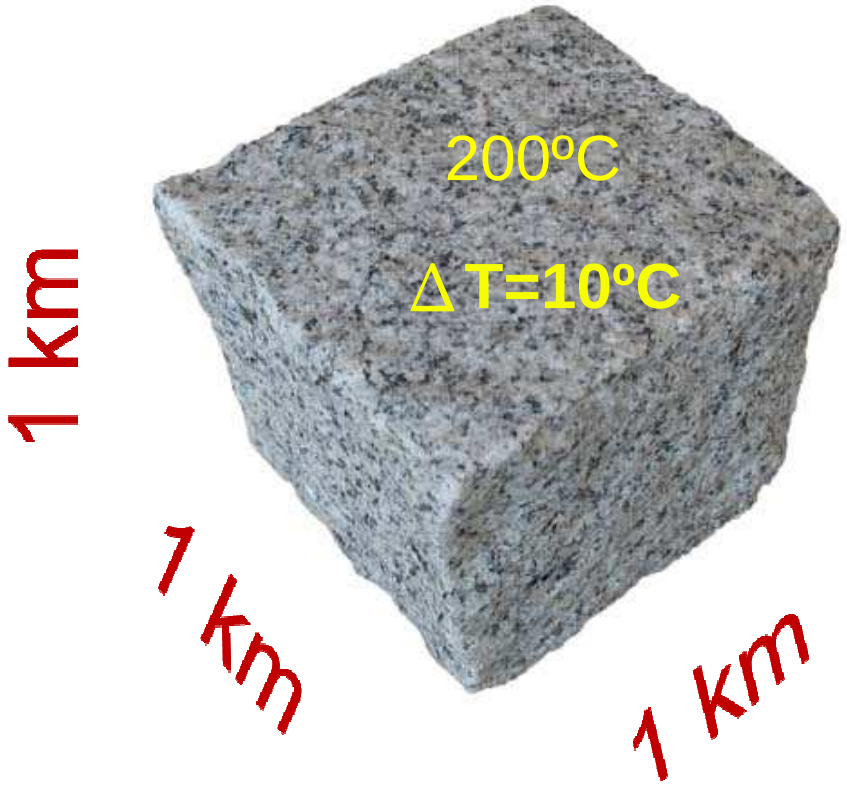
Heat Stored in Rock



1 km³ Granite

3,490,000 BBL of Oil Equivalent
or
1,360,000 MWh as electricity
(155 MWe)

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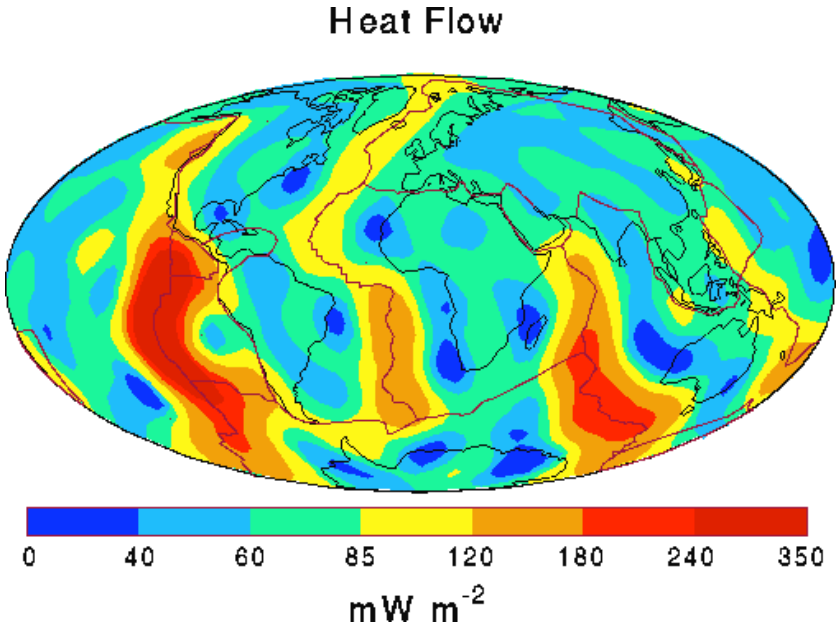
Where do we find it?

- Ring of fire – volcanic heat sources
- Thin crust – rifts and the Basin and Range
- Deep faulting
- Radiogenic granitic rocks



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Enhanced Geothermal Systems

What is EGS and how does it does it differ from conventional geothermal

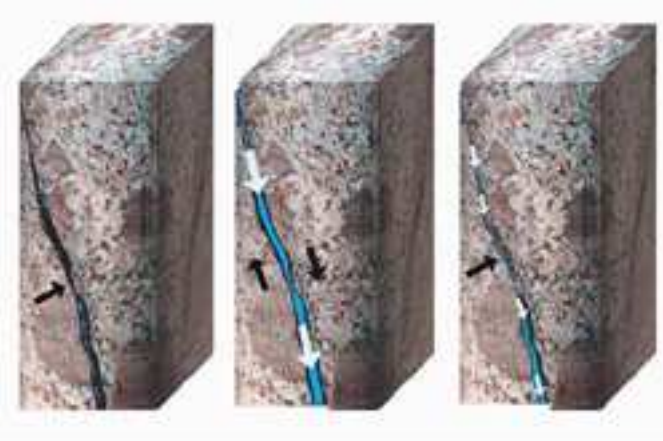
Hydrothermal Systems

- Natural permeability
- High flow rates
- Few big systems
- Located in Western US
- Exploration expensive
  - Must find temperature with permeability
  - Drilling is needed
  - Dry hole rate remains 80%
- Economic even for low temperatures
- >2800 MW on line
- ~98% average availability

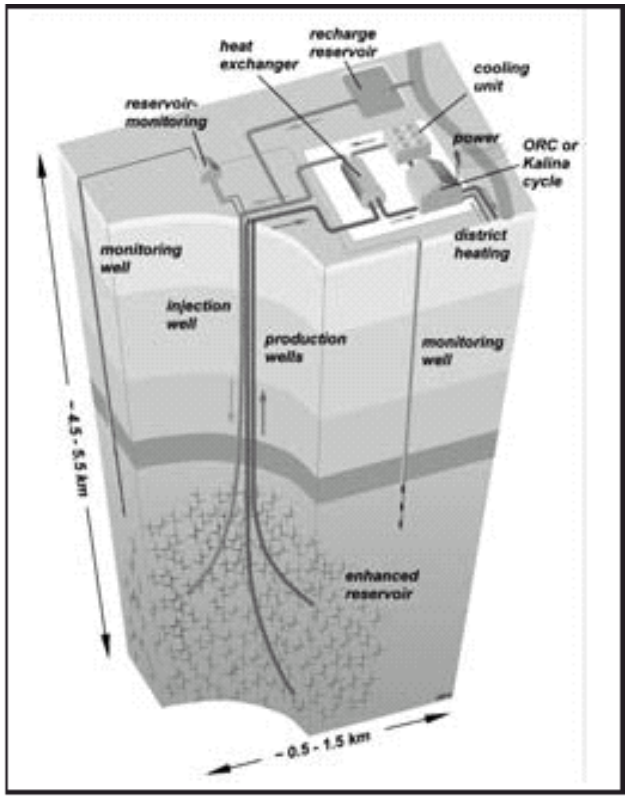
Enhanced Geothermal Systems (EGS)

- Low or no natural permeability
- Reservoir must be engineered to:
  - Obtain high flow rates
  - Develop good heat exchange area
- Exploration risk reduced
  - Temperature only needed
  - Drill deeper to get greater temperature
- Large systems can be developed
- Uses proven state of the art drilling technology
- Fracturing technology developing
- Potential for CO2 sequestration

Enhanced Geothermal Systems



Enhancing the rock's permeability. The subsurface at Soultz-sous-Forêts consists of granite containing natural fractures. These fractures have been partially sealed over thousands of years (1). To be able to use these rocks as a heat exchanger, these fractures have to opened up again. This is achieved by injecting water at high pressure. The water expands the fractures, allowing the rocks to move slightly along the fracture planes (2). When the pressure is released, the fractures no longer fit together perfectly, and there is enough space to allow the circulation of water (3). (Courtesy of EEIG "Heat Mining", European Hot Dry Rock Project)



Environmental Impact of Geothermal Energy

- Plant emissions – Air Quality
  - No plant emissions with binary plants
  - With flash plants, plant emissions extremely low, can be mitigated
  - Carryover from cooling towers can evaporate to small particles.
  - EGS unlikely to have H2S or other gases

- Drilling and site preparation
  - Relatively small land disturbance
  - Several wells drilled from one 100 ft x 300 ft pad
  - Plant is small, one story high
  - Rock cuttings and reservoir fluids benign with EGS resources

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Environmental Impact of Geothermal Energy

- Transmission line routing
  - Transmission lines for conventional geothermal projects may require long connection routing
  - EGS projects can be located near transmission lines
  - EGS projects can be located away from scenic areas
  - Sites will initially be in the west where large land areas are available, but transmission interconnection is limited

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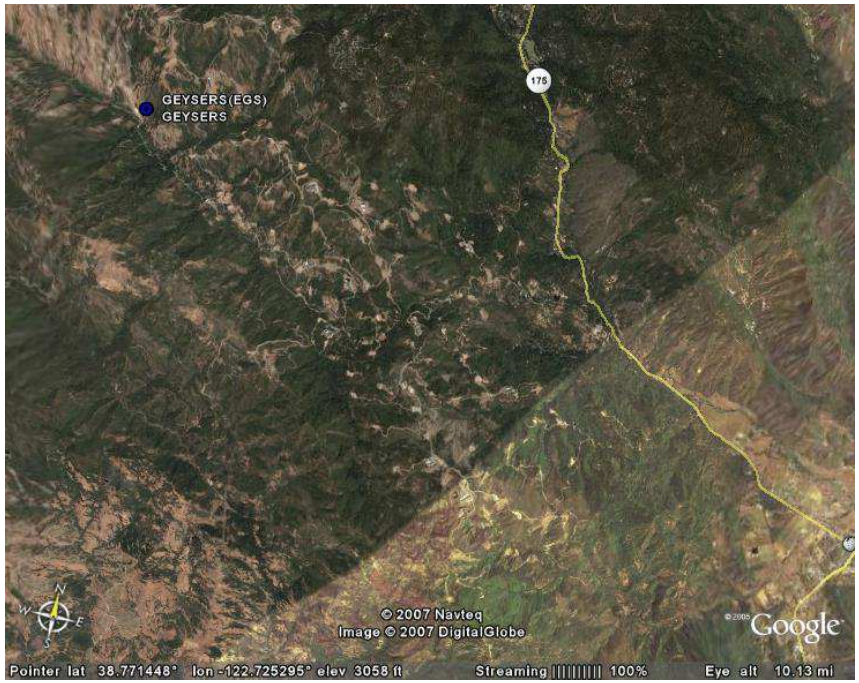
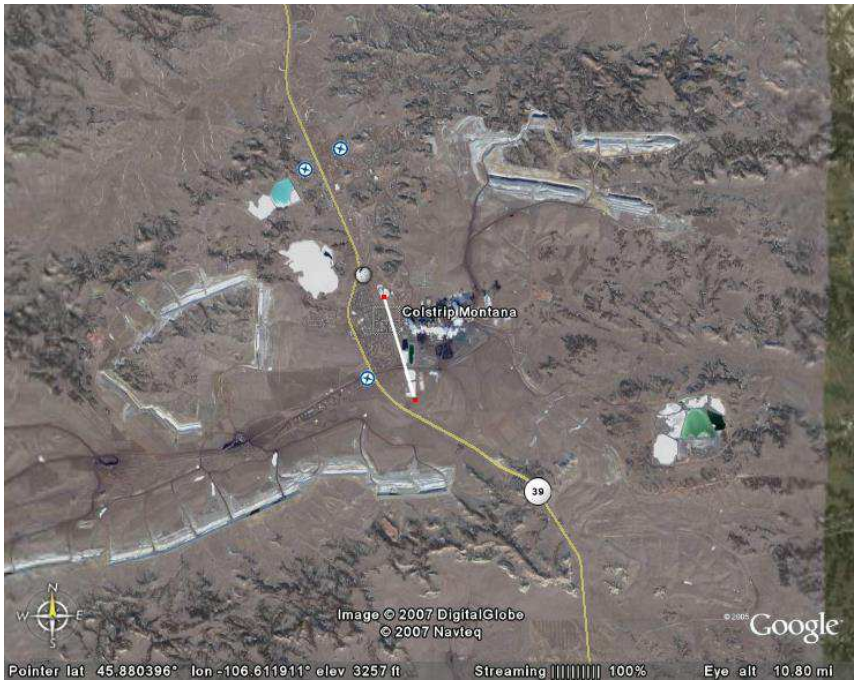
Small Footprint

1000 MW Geothermal facility from 10 miles up



1000 MW Mine mouth coal project from 10 miles up



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Water Quality

Dissolved Solids

- Geothermal in Rift Valleys and areas with evaporites can have high TDS
  - Salton Sea – Up to 275,000 ppm TDS
  - Djibouti – 200,000 ppm
- Mercury, arsenic and boron can be dissolved in hydrothermal fluids
- High dissolved NaCl in some high temperature systems
- Steam condensate may be acidic and damage casing connecting well to groundwater.
- Chemical additives to mitigate scale and corrosion generally not toxic
- Stimulation doesn't use additives. Clear water only.

Recovered Minerals

- Sulfur recovery from H2S abatement can be sold for fertilizer
- SiO2 can be recovered in a very pure form
- Lithium extraction may help reduce battery costs
- Metal extraction from high TDS brines can add economic value
  - Zinc
  - Copper
  - Nickel
  - Rare earths?

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EGS Stimulation doesn't use the additives that are of concern in O&G fracturing.

Water Use

Reservoir stimulation/make-up water

- Need about 38,000-95,000 cubic meters 10-25 Million gallons of water for initial stimulation per 1~0 MW
- Lose 1%-5% of water to rock in some systems, none in others
- With EGS can reduce potential impact on hot springs
- Can use waste water as long as no or very low particulates present
- Sources of waste water:
  - Treated sewage effluent
  - Produced water from oil and gas operations
  - Waste water from dewatering mines
  - Waste water from wet scrubbers at coal plants

Water Use is the Single Largest Issue for EGS Development

Cooling water make-up

- Need ~400 gpm circulating water per MW
- Lose ~10% to evaporation in evaporative cooling tower
- Binary plants can use dry cooling
- Hybrid systems possible
- Innovative cooling systems under development

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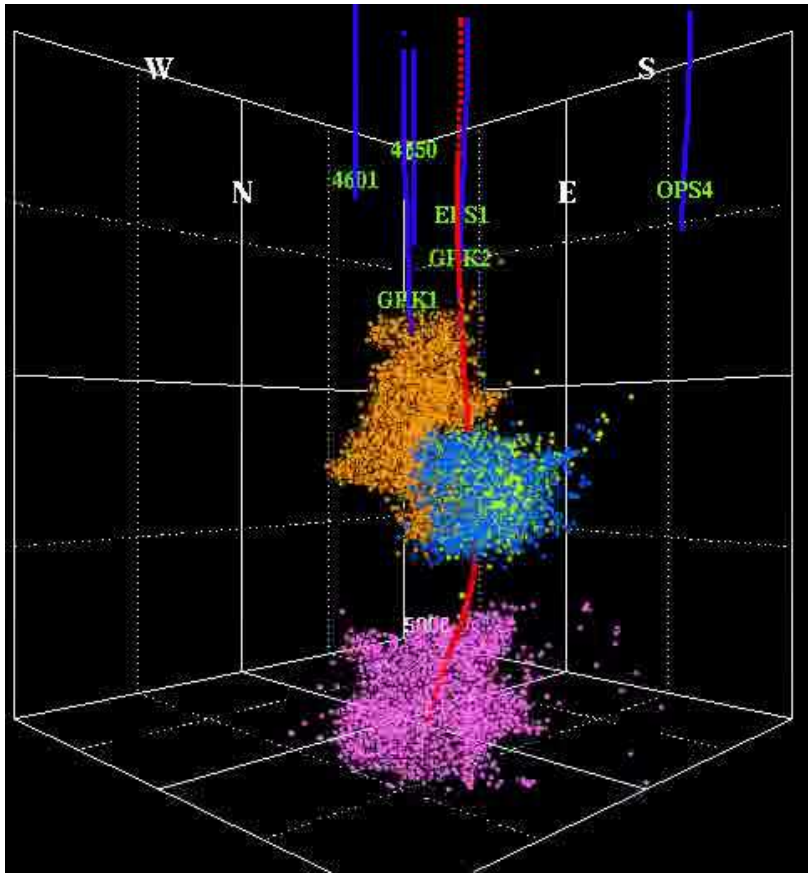
Induced Seismicity

- Inducing very small seismic events part of stimulation
- Seismicity is used to map the fractures to understand how they grow and where they go
- Can project size of maximum event through analysis if there is data
- Induced seismicity hazard assessment an established procedure for mining, reservoir full up and other projects
- Monitoring is constant during stimulation and operation
- Public awareness during technology development important to process



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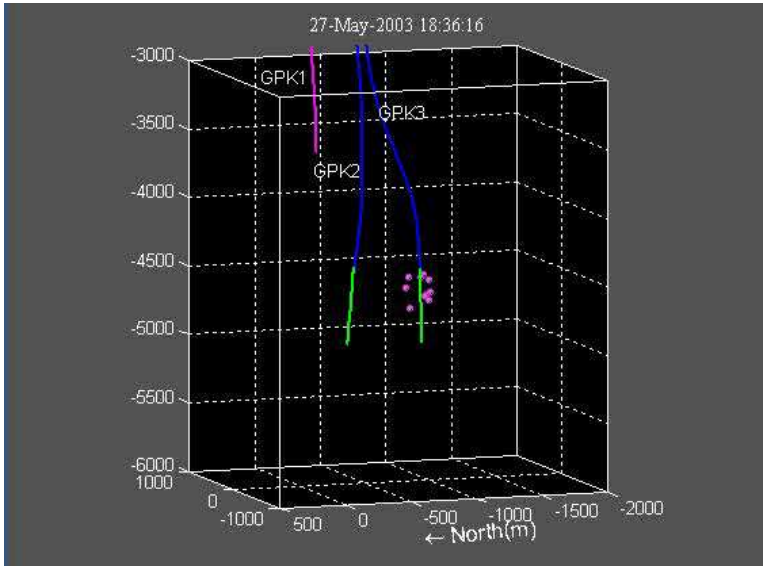
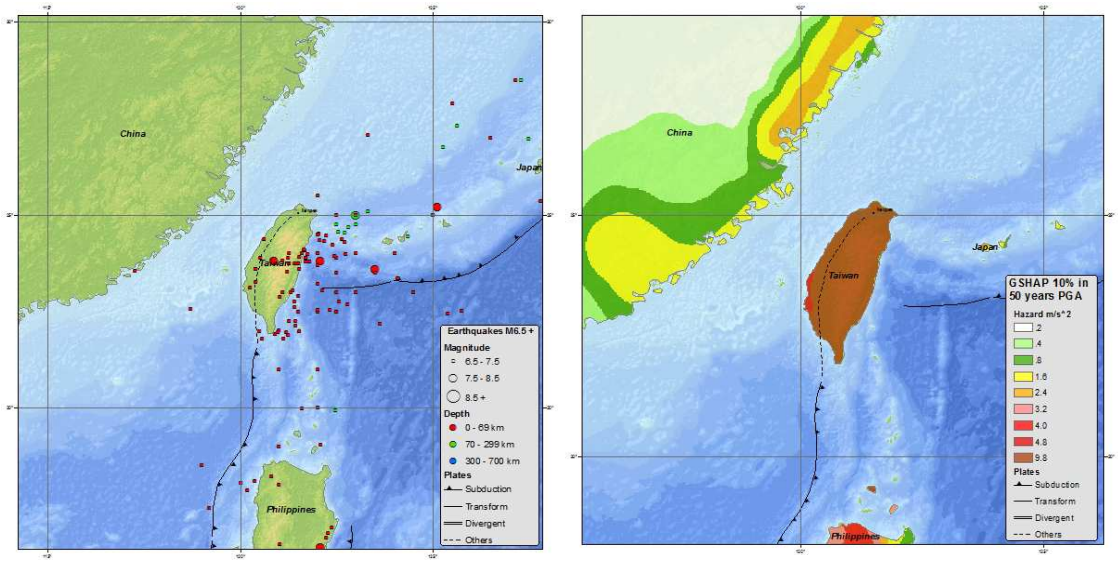
Earthquakes and Seismicity

- When a fault suddenly slips the energy release causes an earthquake
- The amount of energy released is related to the size of the slip surface
- Earthquake magnitude (M) is measured on a log scale; M=5 events cause ~10x the shaking on a seismometer as a M=4.
- You can't get big earthquakes without big faults
- Frequency of earthquakes is inversely related to M; since 2000 in Oregon there have been 19 events with M 4-5 and 320 events with M 3-4
- Subduction zone runs through Chinese Taipei so large events can occur.





Historic earthquake map and earthquake hazard map of Chinese Taipei showing subduction zone

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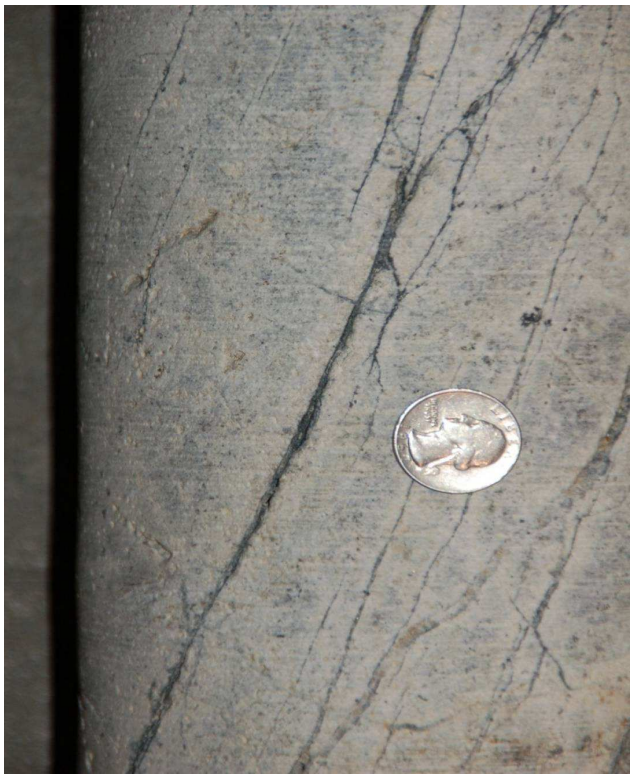
What is Induced Seismicity?

- Seismic events or earthquakes and microearthquakes (M<3) caused by human activity
- Due to increased fluid pressure and/or stress change in the earth's crust associated with
  - Oil and gas production and enhanced recovery
  - Geothermal production and fluid injection
  - Removal of materials during mining
  - Filling water-storage reservoirs
- Study of geologic faults is essential to quantify risk
  - Longer faults represent greater risk
  - Stored stress represents greater risk



Fractured Geysers felsite: Fluid pressure lubricates small fractures like these, creating tiny induced seismic events detectable only to precision instruments

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EGS and Induced Seismicity

- Conventional geothermal may tap existing faults.
- EGS sites selected to avoid known faults, maximize reservoir volume, and minimize induced seismicity.
- Tiny induced seismic events generate pathways for hot fluids
- Injection pressure controlled to favor small events, small fractures, and greater total surface area.
- Flow increase through pumping to reduce injection pressure
- During EGS operation, induced seismicity minimized to prevent reservoir growth and water loss
- Internationally accepted EGS protocols require monitoring stimulation closely to limit microseismic event size

EGS reservoir under Soultz, France imaged by locations of induced seismicity

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Newberry, Oregon, EGS Project

- Stimulated well 55-29 is on the west flank of Newberry Volcano
- Very little natural seismic activity was recorded at Newberry prior to the project.
- Active faults are not mapped within 5 miles of 55-29
- Likely heat source is shallow magma chamber.
- Thin crust contains only small faults and dampens seismic energy
- Induced seismicity is related to large injection volumes without withdrawal.
- As volume injected increases the risk bigger events increases.
- Largest magnitude event at Newberry predicted to be 3.5M.
- Largest measured event was 2.4M.

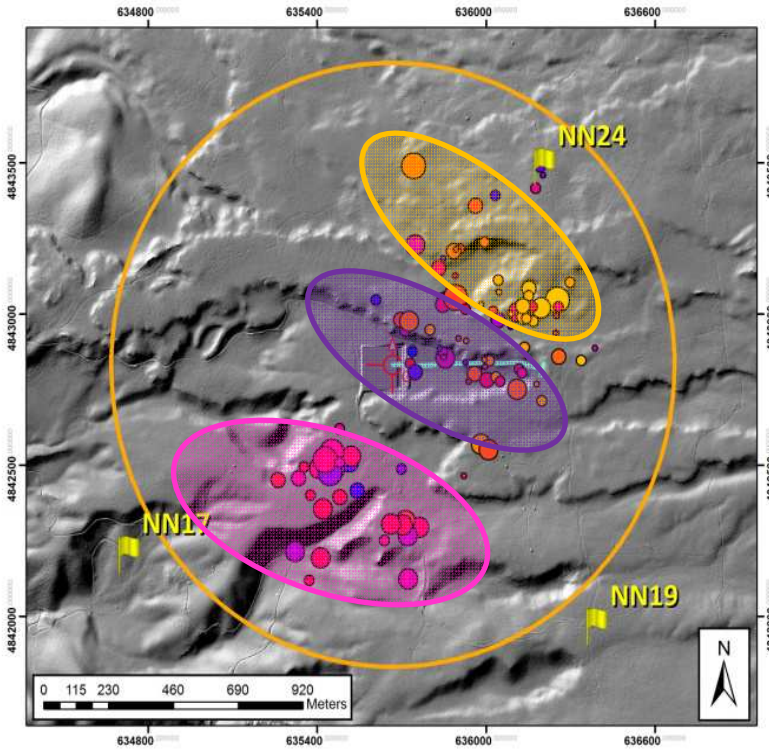

Image above shows 1 km radius around Newberry well 55-29 and seismicity from stimulation in fall 2012.

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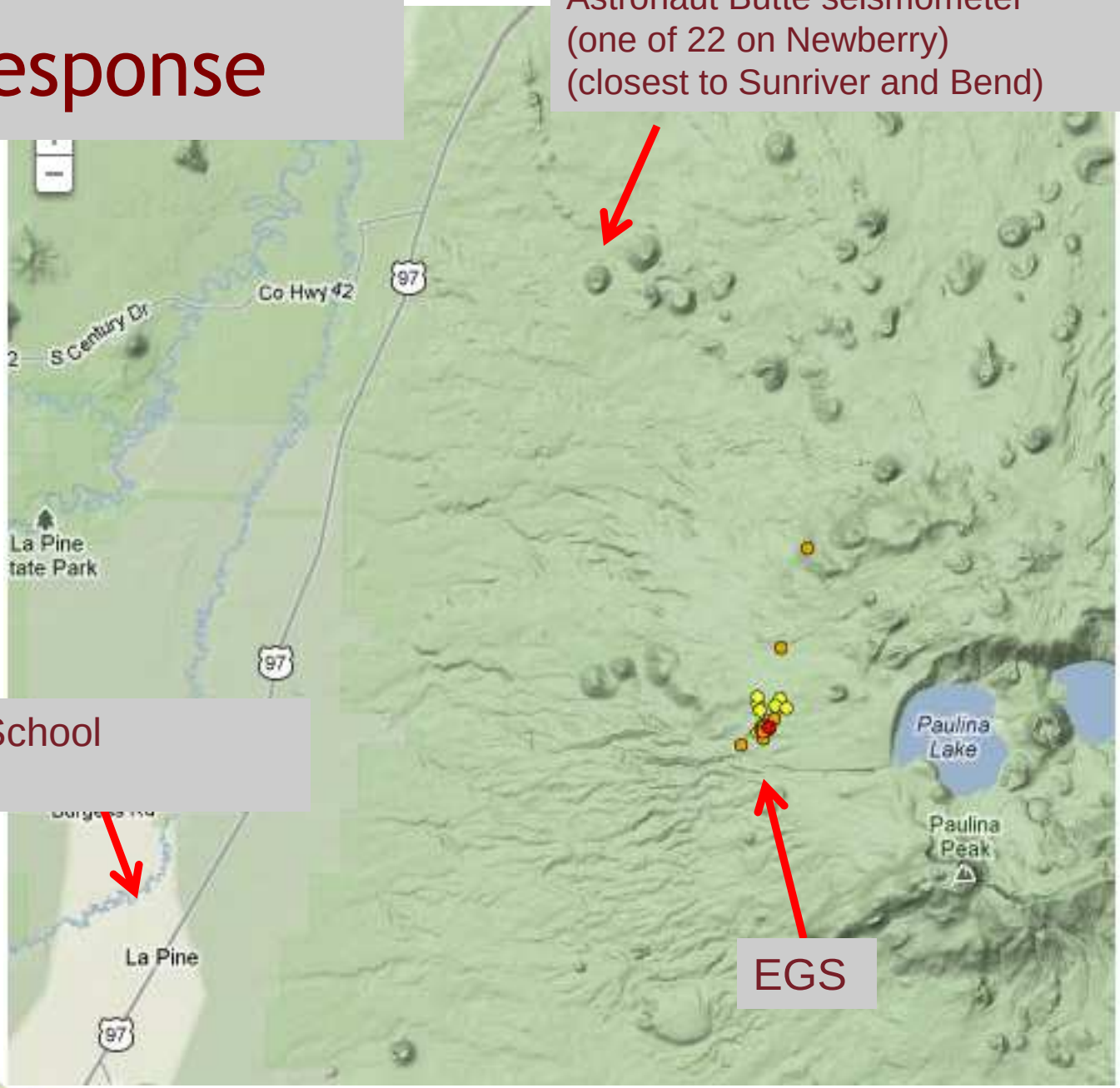
Seismic Response



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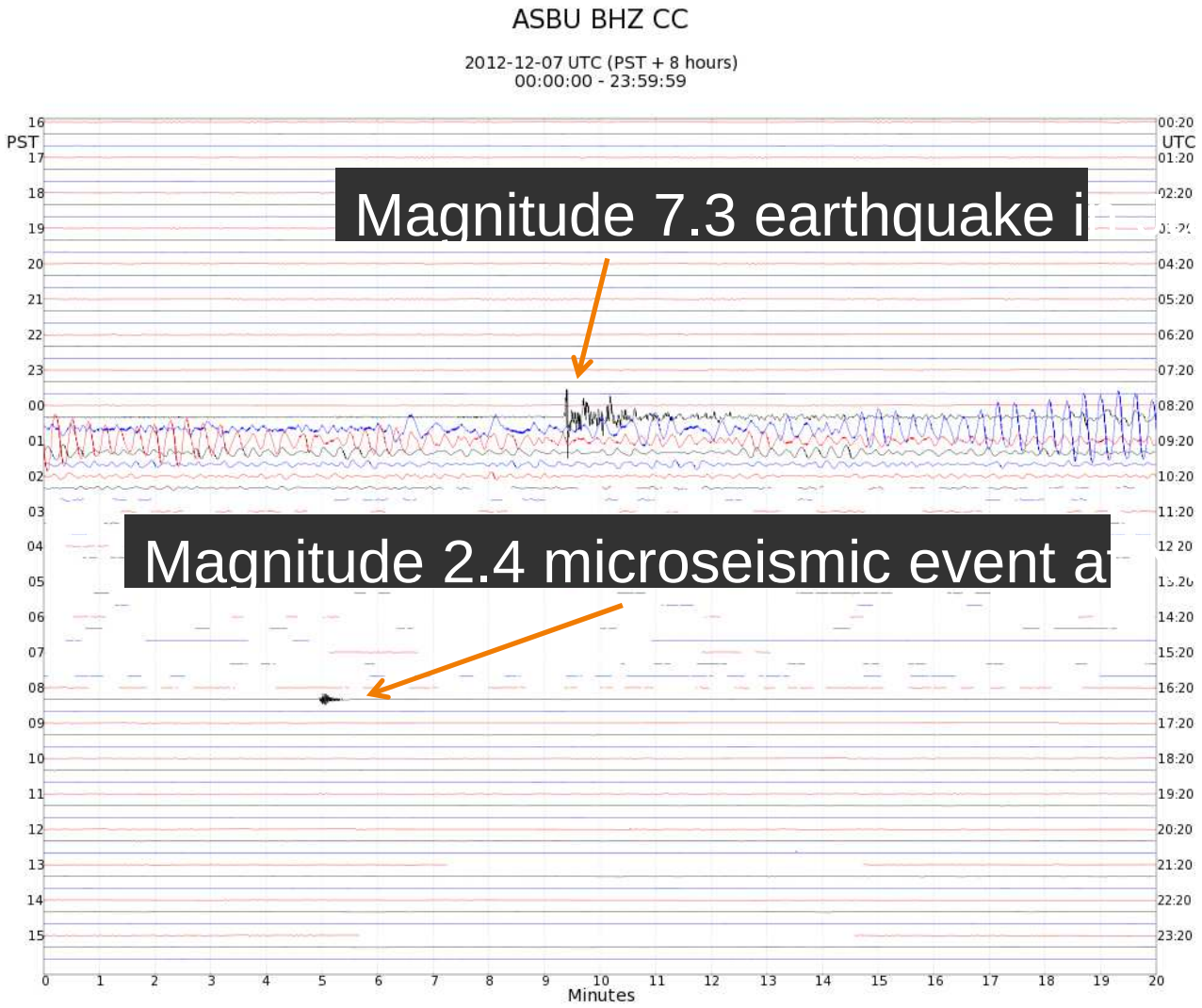
Seismogram of M_w 2.4 event on 12/07 08:25



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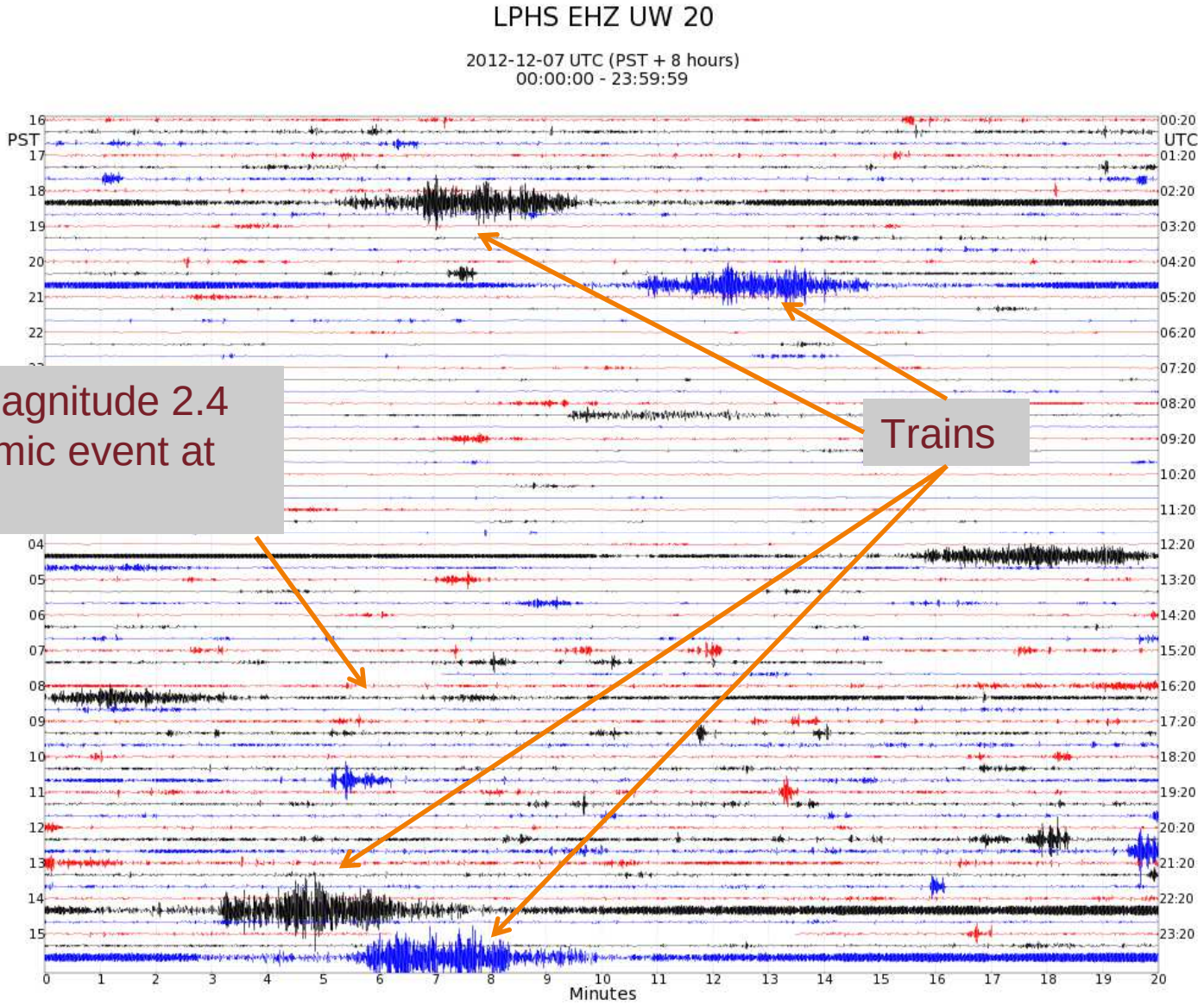
Seismogram of M_w 2.4 event on 12/07 08:25



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DOE Geothermal Process and Approach

- Draft LBNL internal whitepaper (2004)
- Three international workshops (2005-2006)
  - Form technical basis for understanding induced seismicity and a strategy for developing a protocol for designing “induced seismicity friendly” EGS projects
  - Gather international group of experts to identify critical issues (technical and non technical) associated with EGS induced seismicity
- Current products and activities
  - Peer reviewed white paper (IEA Report, Majer et al., 2007)
  - Protocol for the development of geothermal sites and a good practice guide (IEA Report). New protocol developed for DOE sponsored projects 2012.
  - Establish Website for community and scientific collaboration
  - Instrument all DOE EGS projects for monitoring induced seismicity
  - Require all DOE EGS projects to follow protocol
  - Establish international collaborations (Iceland, Australia, GEISER)

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A Basis for a Protocol

- ***Technical***
  - Identify and understand factors controlling microseismicity
  - Effect of microseismicity on man made structures
- ***Legal - Community interaction***
  - Propose guidelines for a geothermal developer to deal with the issue of induced seismicity.
  - Inform and interact with the community to understand their concerns and partner with them to achieve a win-win situation

Both are linked and overlapping

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Status of EGS Induced Seismicity

- Technical basis for understanding and controlling EGS induced seismicity has been established.
  - White paper and protocol finished and adopted by IEA
- Issues are similar to other induced seismicity cases which have been successfully addressed
- Issues are both technical and non-technical
  - Must pay attention to both
  - Seismicity can be a benefit in understanding the resource
  - Technical issues remain on fully utilizing seismicity as a reservoir management tool
- Induced seismicity is not (or need be) an impediment to EGS development

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Policy Needs

- Require EGS operators and others injecting large volumes of fluids into the subsurface to follow protocol
  - Update as EGS technology progresses
  - Follow technical and community/regulator interaction
- Adapt risk based procedure for estimating potential mitigation requirements for geothermal areas
  - Probabilistic
  - Physics based
- Community outreach
  - Develop materials and education programs
  - Help the public understand geothermal energy, EGS and induced seismicity

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