#### Geothermal in the Oilfield: Using Hot Produced Water for Power Generation

#### Tom Anderson<sup>1</sup>

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#### **Abstract**

At the Rocky Mountain Oilfield Testing Center (RMOTC) near Casper Wyoming, a demonstration project has been completed using what was a common waste product from oil production - large volumes of "hot" water - to generate electricity. The Teapot Dome oilfield produces 40,000 barrels of water per day at near 200°F from the Tensleep oil reservoir, about 5500 ft below the surface. This water is relatively fresh (<2400 TDS), and is discharged into Little Teapot Creek after three cooling ponds. Working with ORMAT Nevada Inc., RMOTC installed into this flowstream a binary "Organic Rankine Cycle" geothermal power generation unit, which uses iso-pentane as a closed system working fluid (boiling point of 85°F). The unit has been operational since September 2008. It averages 180 KW output, which helps to offset the power requirements of the oil field, saving substantial operating costs for electricity to power the pumps. This is the first application of geothermal power generation in an oilfield in the U.S.

The Teapot Dome region has an anomalously high heat flow - the gradient is about twice the average for the region. Published geothermal-assessment maps indicate east-central Wyoming not to be a promising area for geothermal energy. However, there is something unusual about the geohydrologic system in the area that heats the groundwater to this degree, and investigations are underway to identify the causes.

There are many other locations in the U.S. where conditions are favorable to apply this technology. RMOTC produces the water from relatively shallow depths, but many other "stripper" oilfields that produce water along with the oil from deeper depths and are currently re-injecting the water, may be candidates as well. The binary system allows lower temperature fluids to (indirectly) run the turbine. Often the economic limiting factor for ongoing oil production is the cost of electricity. Geothermal has the potential to extend

the economic life of the oil field, as well as increase the oil reserves and ultimate recovery. Also, oil fields by nature have existing infrastructure in the form of wells, flowlines, and gathering systems, reducing the up-front cost of geothermal installations.

Other innovations being tested at RMOTC include the improvement of drilling technology to reduce costs for drilling geothermal wells. In addition, advanced geophysical methods are being investigated to identify and characterize geothermal potential not only in the oil reservoirs, but also in the granite basement rocks at depth, for future EGS development.

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#### Website

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USGS National Seismic Hazard Maps: Web accessed June 29, 2010 <a href="http://www.usgs.gov/hazards/earthquakes/">http://www.usgs.gov/hazards/earthquakes/</a>

# Geothermal in the Oilfield: Using Hot Produced Water for Power Generation







Tom Anderson, Chief Scientist, Rocky Mountain Oilfield Testing Center (RMOTC), Casper, Wyoming

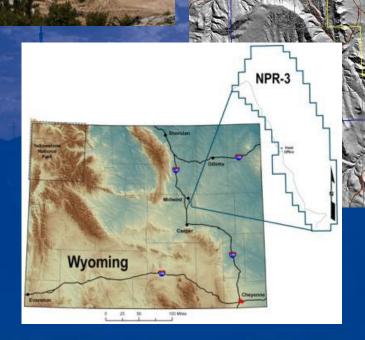


## **Outline**

- What is RMOTC
  - Testing center
  - Natural geological laboratory
- Geology
  - Heat flow
  - Gradients
  - Structure
  - Groundwater
- Oil & water production
- Geo-power project
- EGS potential
- Induced seismicity?

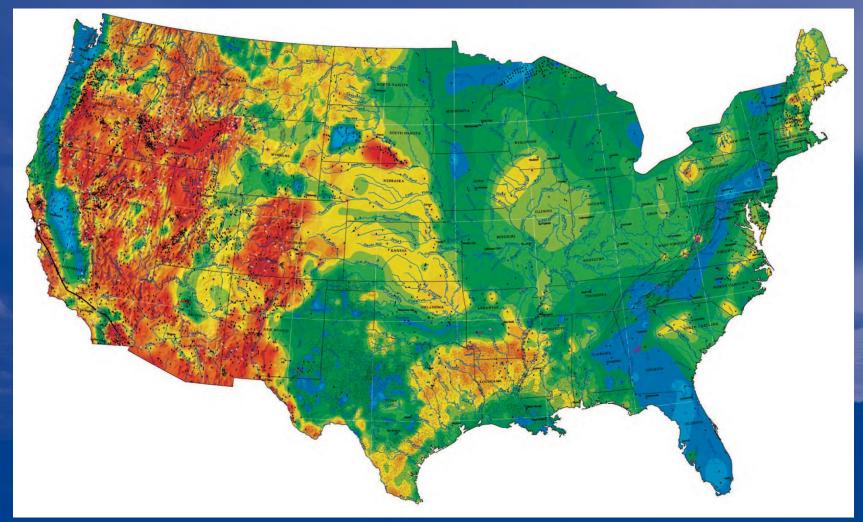


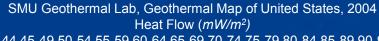






## Heat-flow map of the conterminous United States





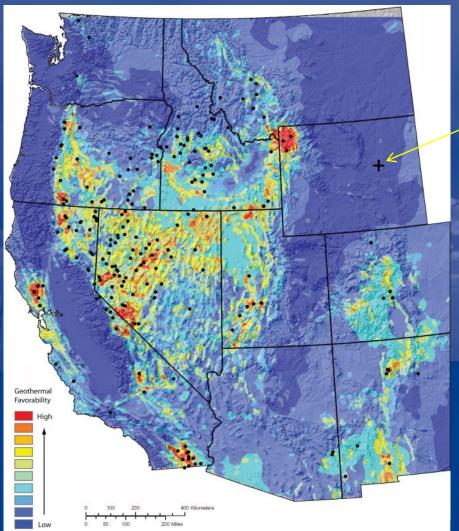
25-29 30-34 35-39 40-44 45-49 50-54 55-59 60-64 65-69 70-74 75-79 80-84 85-89 90-94 95-99 100-149 150+







# Moderate and High Temperature Geothermal Resources, Western U.S.

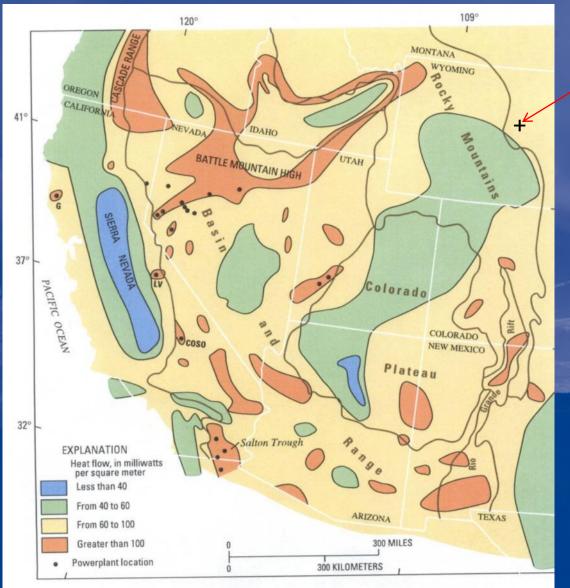


NPR-3 (Teapot Dome)

Example map showing the relative favorability of occurrence for geothermal resources in the western contiguous United States. Warmer colors equate with higher favorability. Identified geothermal systems are represented by black dots. (USGS Fact Sheet, 2008-3082)



## Heat Flow in the Western U.S.



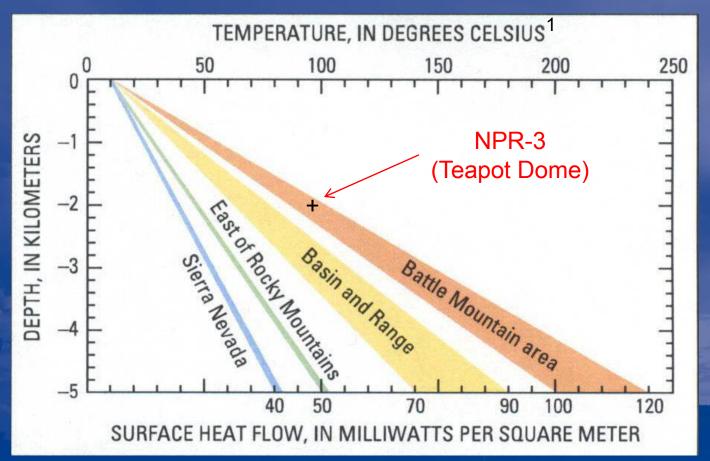
NPR-3 (Teapot Dome)

Source: W. Duffield & J. Sass, 2003, Geothermal Energy—Clean Power From the Earth's Heat: USGS Circular 1249





# Geothermal gradients



—fre average heat flow for the southern Powder River Basin…is 52 mW/m<sup>2</sup>"

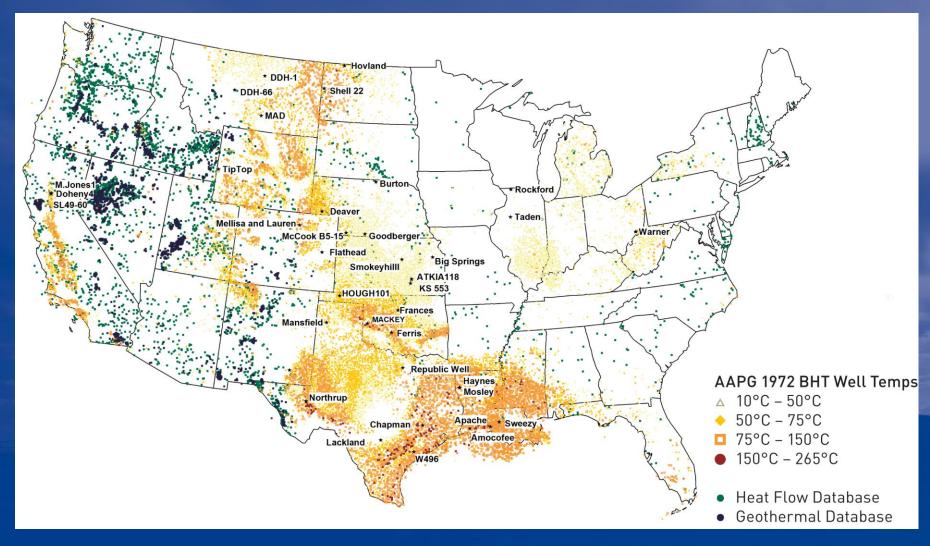
<sup>1</sup>Source: W. Duffield & J. Sass, 2003, Geothermal Energy—Clean Power From the Earth's Heat: USGS Circular 1249

<sup>2</sup>Source: B. McPherson & D. Chapman, 1996, Thermal Analysis of the southern Powder River Basin, Wyoming: Geophysics, vol. 61, no. 6, p. 1689-1701





### From Oilfield to —Enegy Field" with Geothermal



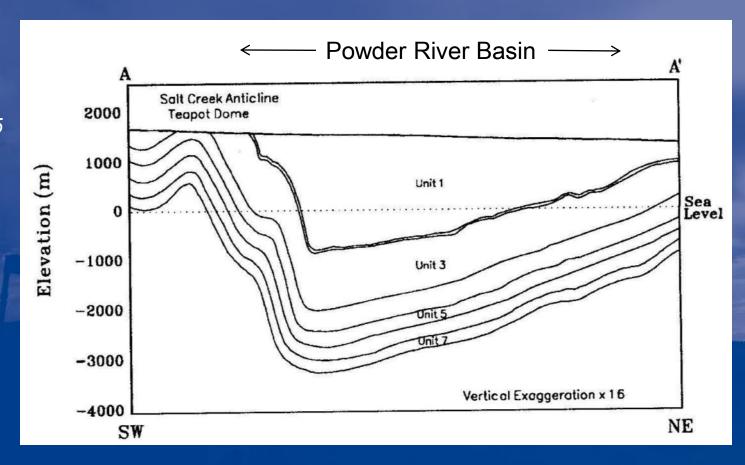


- Relatively low temperature produced water (≈ 200° F) can be used to generate electricity.
- About 20 billion barrels per year of water are produced from almost 1 million wells in 33 states.
  - Reservoir depletion over time generally increases the volume of water that is co-produced with the oil and gas increasing both the cost for disposal and the potential for generation.



# **Anomaly at Teapot Dome**

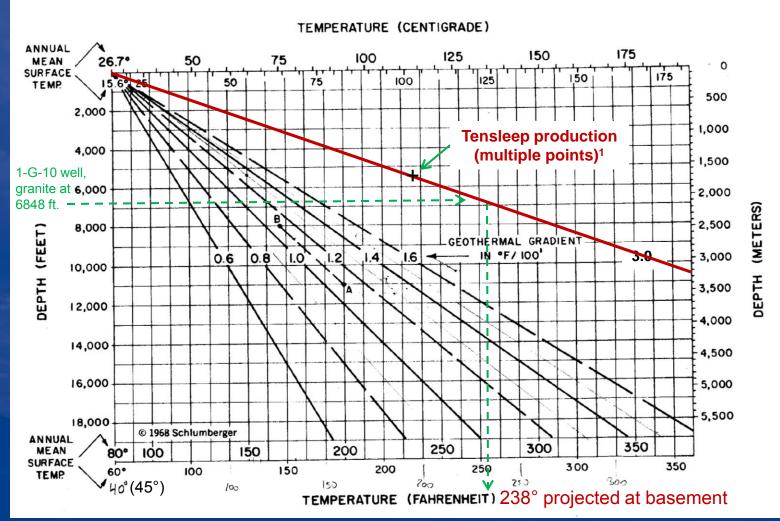
"Extremely high heat flow in the region occurs in two areas. Values up to 225 mW/m<sup>2</sup> are observed at Teapot Dome, and up to 150 mW/m<sup>2</sup> are observed at the Salt Creek anticline ... these anomalies are likely caused by groundwater movement."1





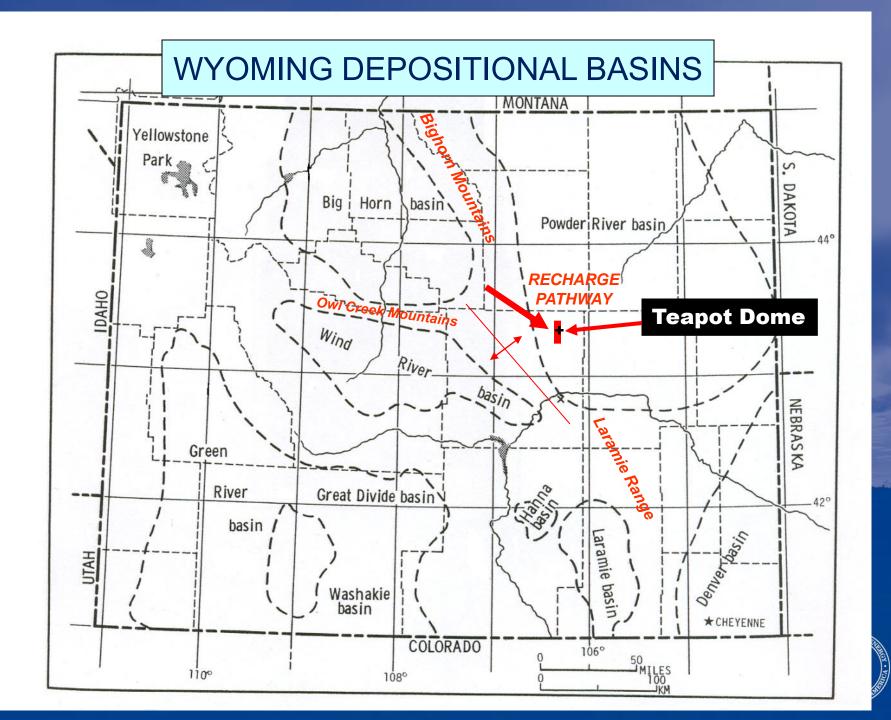


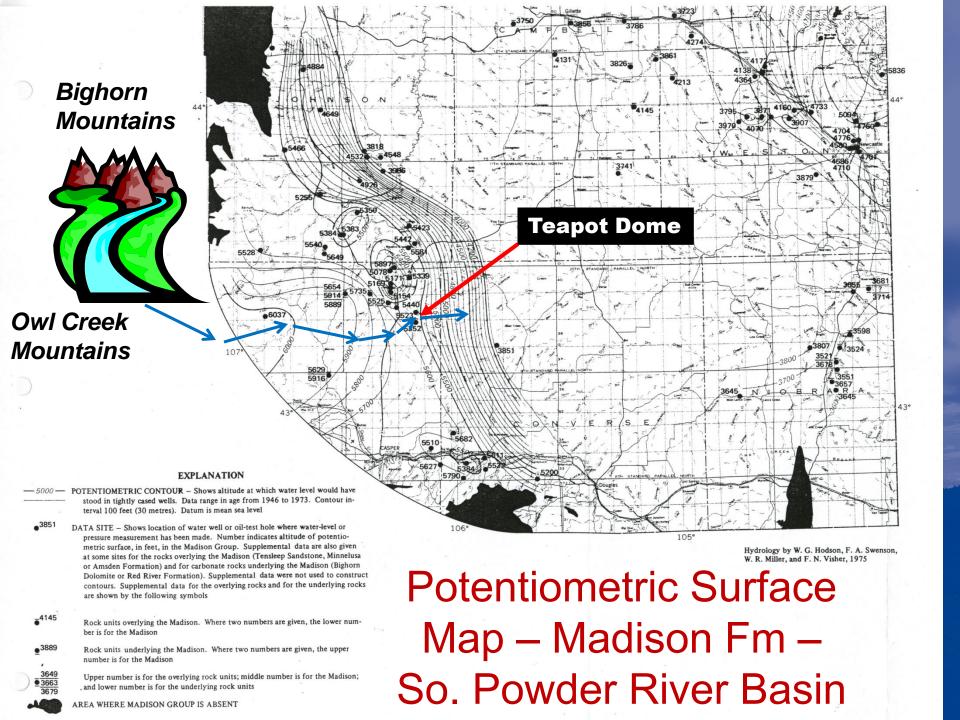
## Geothermal Gradient at Teapot Dome



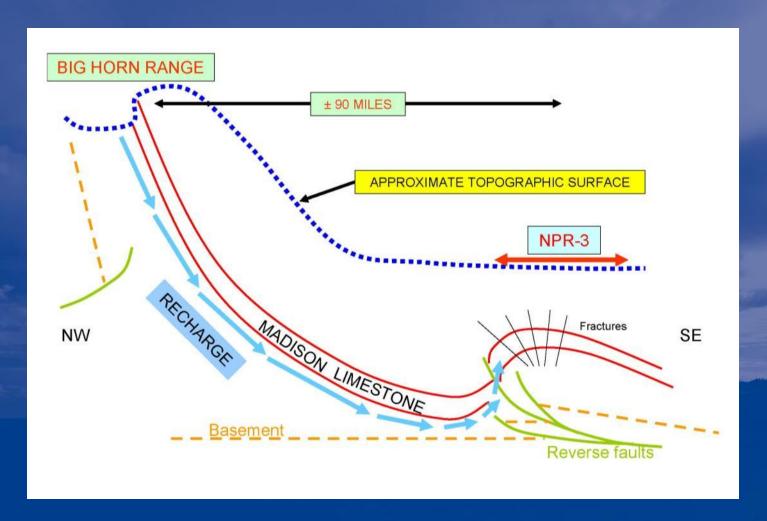






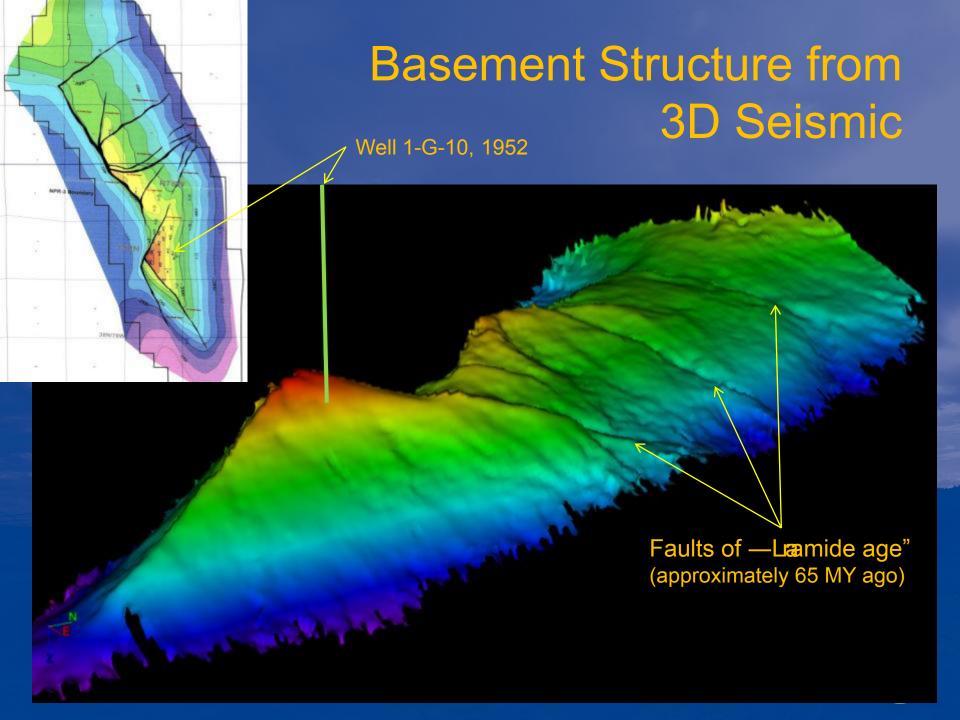


# Teapot Dome Recharge System









DEPTH

1000

2000

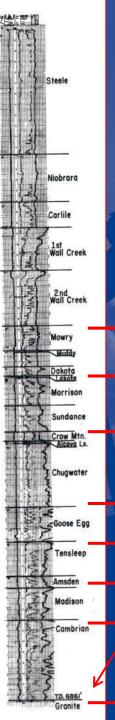
3000

4000

5000

6000





# Teapot Dome Stratigraphy

#### **UPPER CRETACEOUS**

Well 1-G-10, 1952

"Granite, dark red-brown, large feldspar crystals in quartz matrix, some hornblende crystals, highly fractured and brecciated with matrix of green gouge"

LOWER CRETACEOUS

**JURASSIC** 

TRIASSIC CHUGWATER

PERMIAN GOOSE EGG

**PENNSYLVANIAN** 

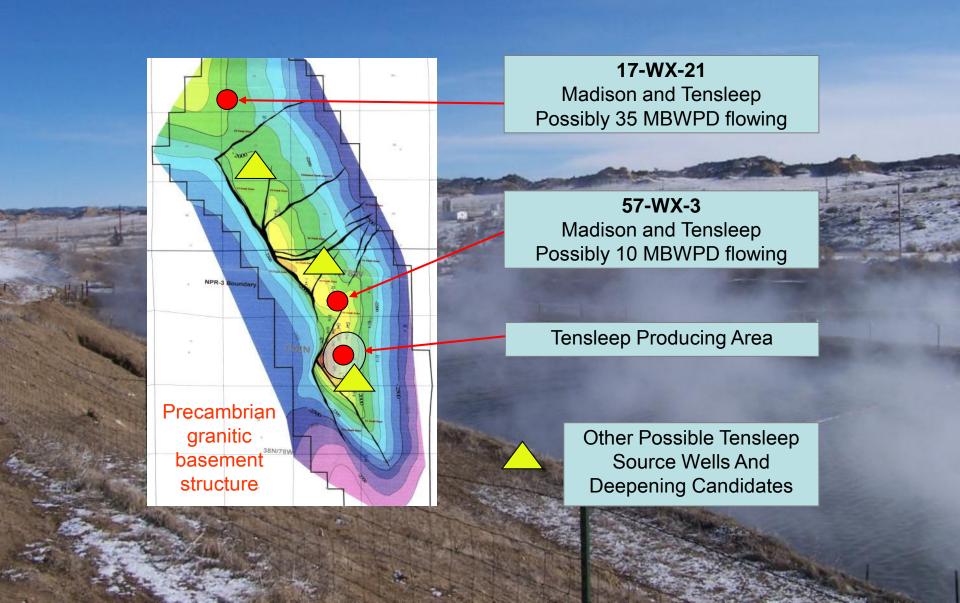
MISSISSIPPIAN MADISON LS

**CAMBRIAN SS** 

PRECAMBRIAN BASEMENT

7000

# Geothermal Potential at Teapot Dome



# Co-Production Geothermal Potential

Well	Zone	Rate, MI	BWPD	Comments
		Low	High	
17-WX-21	Madison	20	25	Flowing
17-WX-21	Tensleep	4	10	Needs perforating
41-2-X-3	Tensleep	1	3	Flowing
41-2-X-3	Madison	6	12	Needs deepening
48-X-28	Tensleep	2	6	Capable of flowing
61-2-X-15	Tensleep	2	6	Flowing
61-2-X-15	Madison	6	12	Needs deepening
57-WX-3	Madison	2	6	Flowing
Total New Flowing Production		43	80	Projected
Total New Pumping & Production		86	160	Projected
Total present Tensleep Production		40	60	Pumping (ESP)
All Potential Production		126	210	If all on pump



# Teapot Dome Geothermal Heat Potential

#### **Assumptions**

- 1. 130,000 BWPD (126,000 to 210,000 range on last slide)
- 2. 210 F surface temperature of water (measured)
- 3. 45 F Mean ambient temperature (WY Geological Survey)
- 4. 350 BTU per F per BWPD

#### **Heat content**

Total heat content =  $(350)(210 - 45) \times 130,000$ =  $7 \times 10^9$  BTUs per day

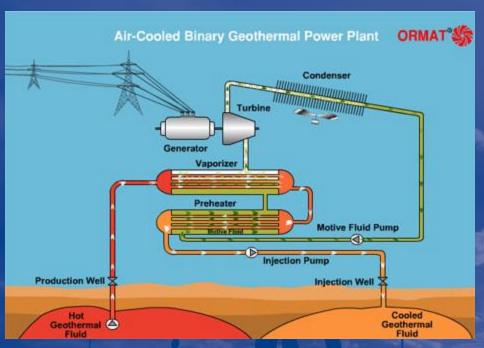
#### **Power potential**

1 MW can be generated from 170,000 BWPD at 200 F (SMU) For 130 MBWPD, power = 130/1.7 = 760 KW





# Low-T Demonstration Project Goals



Testing partner: ORMAT Nevada, Inc.

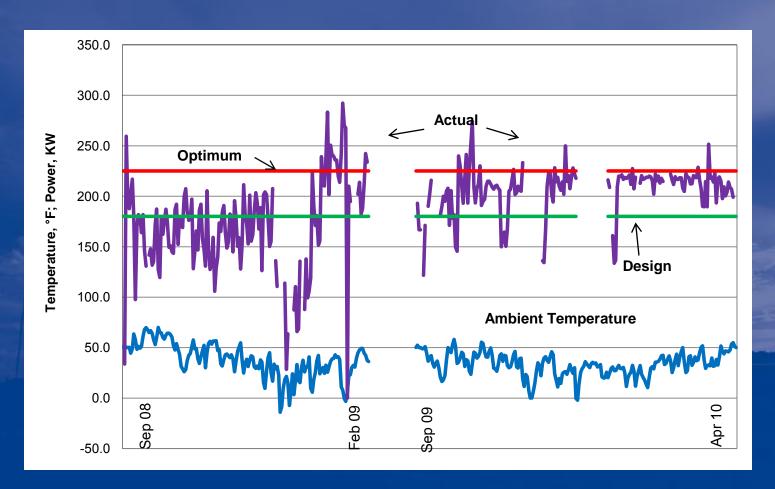
Completed unit installed at RMOTC, summer 2008

- Validate the use of a binary geothermal power generation system that uses produced oilfield hot water to generate electricity
- Test the system for one year
- Provide a technical and economic analysis of the process





# Phase 1 and 2 Operational Trends







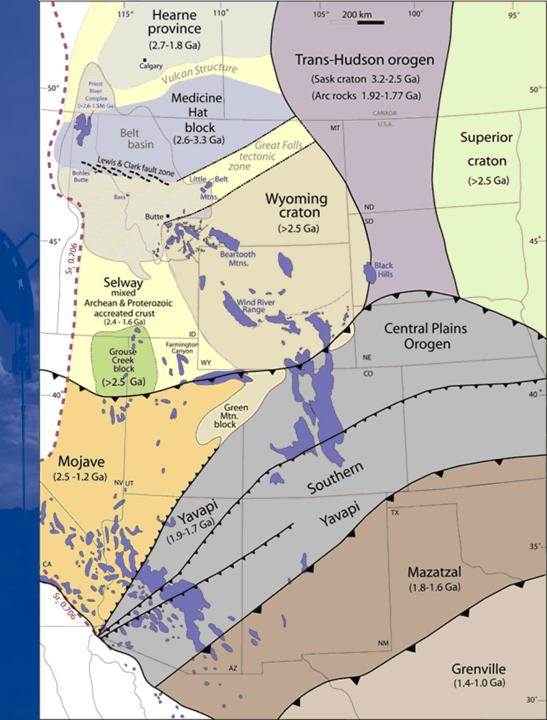
# **Operational Summary**

	Phase 1	Phase 2	
On Line Days, Total (Actual)	161 (151)	214 (124)	
Inlet Brine Temp, °F	195-198	196-198	
°C	90-92	91-92	
Brine Volume, bbls	3,047,370	3,462,394	
$m^3$	484,493	550,520	
Net Power Produced, kWhr	586,574	732,970	
Overall			
On line percentage	91	70	
Avg net power, kW	159	143	
Overall w/o Field Downtime			
On line percentage	97	97	
Avg net power, kW	171	198	
Avg Net Power last 30 days,kW	/ 207	212	



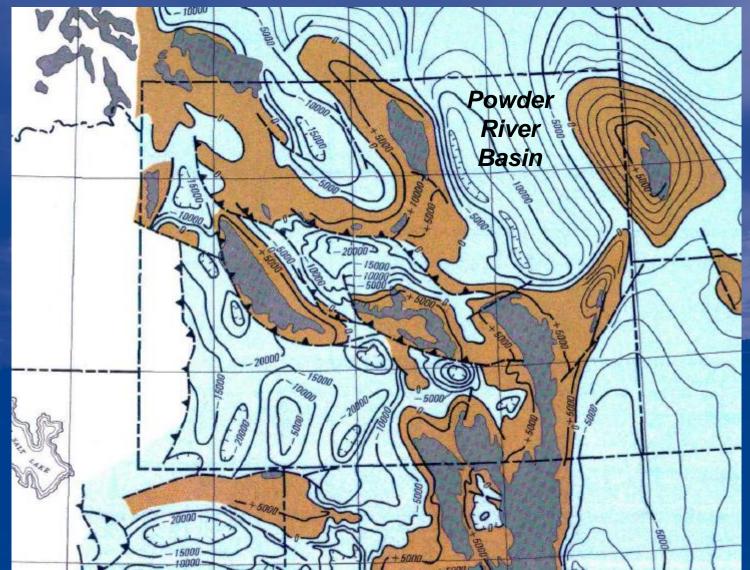


# PreCambrian Basement Terranes





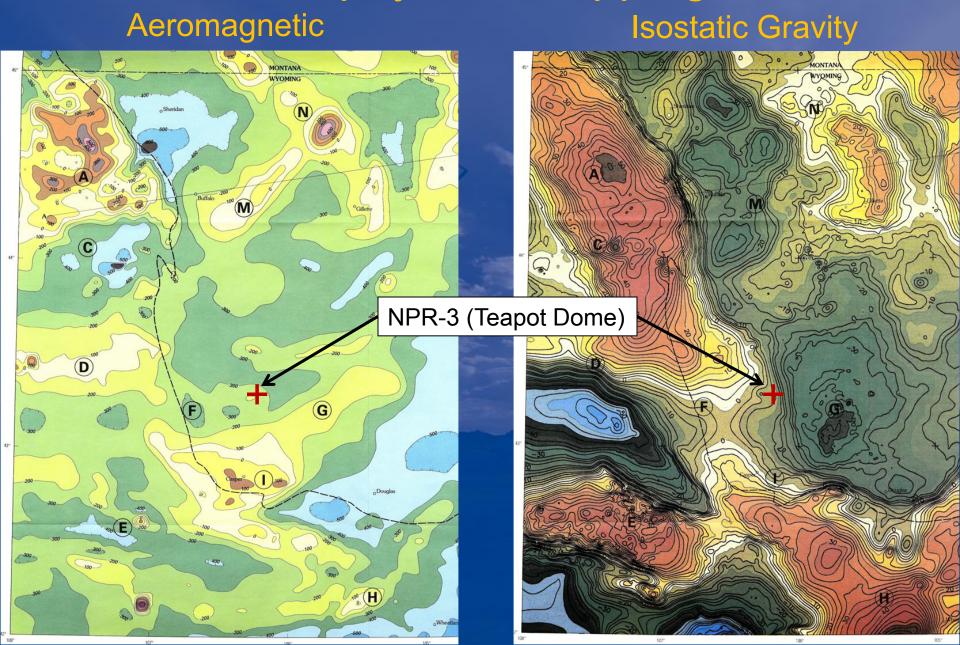
# Configuration of the PreCambrian Basement Rock Surface in Wyoming

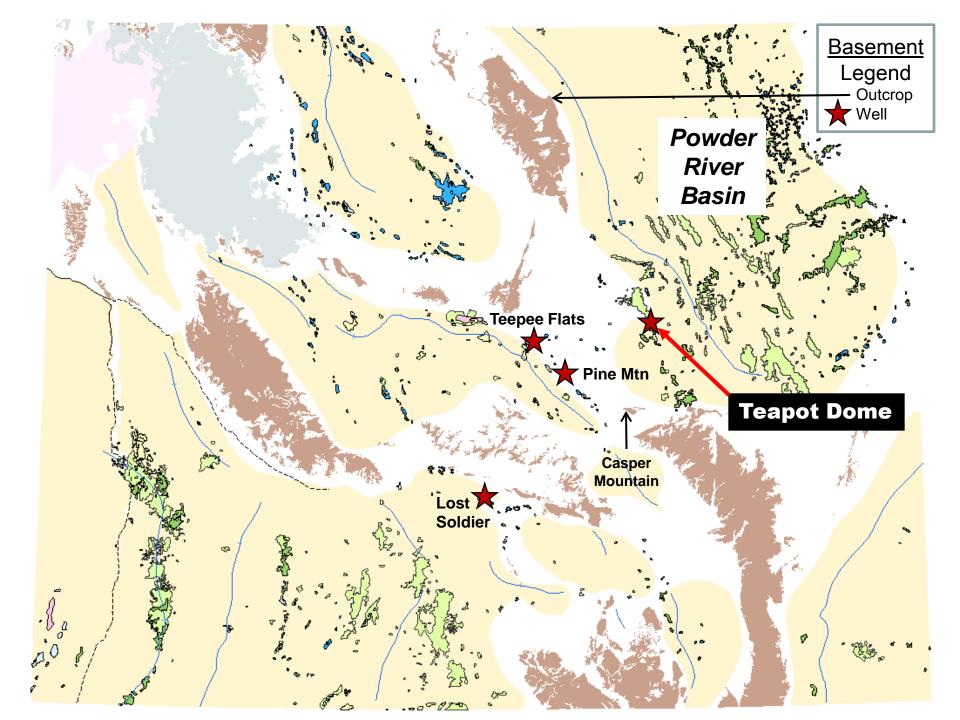






# PRB Geophysical Mapping Data





# **Basement Crystalline Rocks**

#### Lost Soldier well:

Granite wash Diabase dike

Granite

Gneiss, amphibolite Diabase dike

Gneiss, amphibolite

Pegmatite dike Gneiss, amphibolite

Granite

Gneiss, amphibolite

Granite

Diabase dike

#### Casper Mountain outcrop:

Pegmatite dike Gneiss, amphibolite, granodiorite

Granite

Diabase dike

Gneiss, amphibolite

Diabase dike

Granite

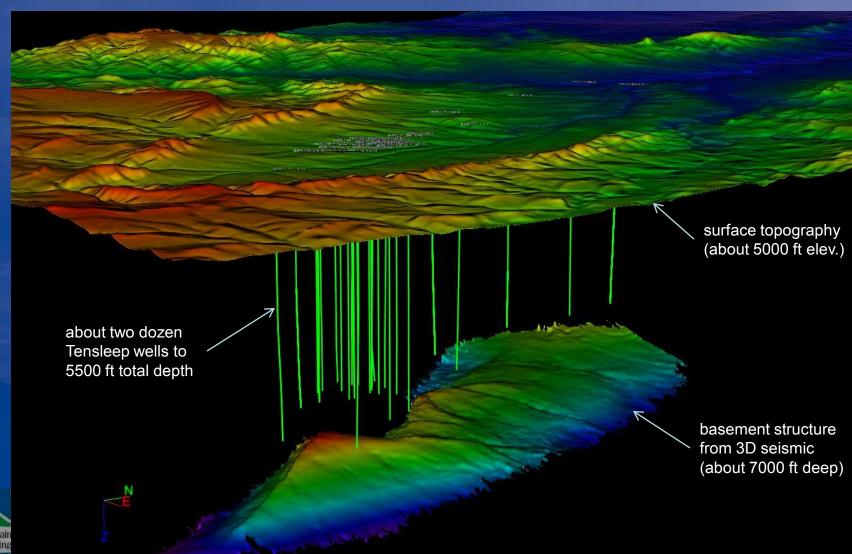
Teapot Dome 1-G-10 well:
"Granite, dark red-brown, large
feldspar crystals in quartz matrix,
some hornblende crystals, highly
fractured and brecciated with
matrix of green gouge"

Granite





# Existing — Deper Wells that Could Be Deepened to the Granite Basement





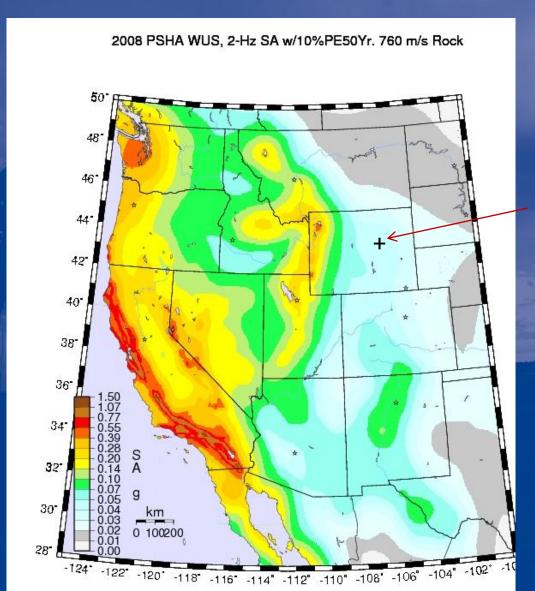
# Probability of Ground Motion – Seismic Hazard Risk Assessment

Is there any risk of induced seismicity at a RMOTC EGS test facility?

This map represents that there is only a 10% probability of exceeding these ground accelerations in g's (contours) within 50 years at 2 Hz

NPR-3 = 0.04 g

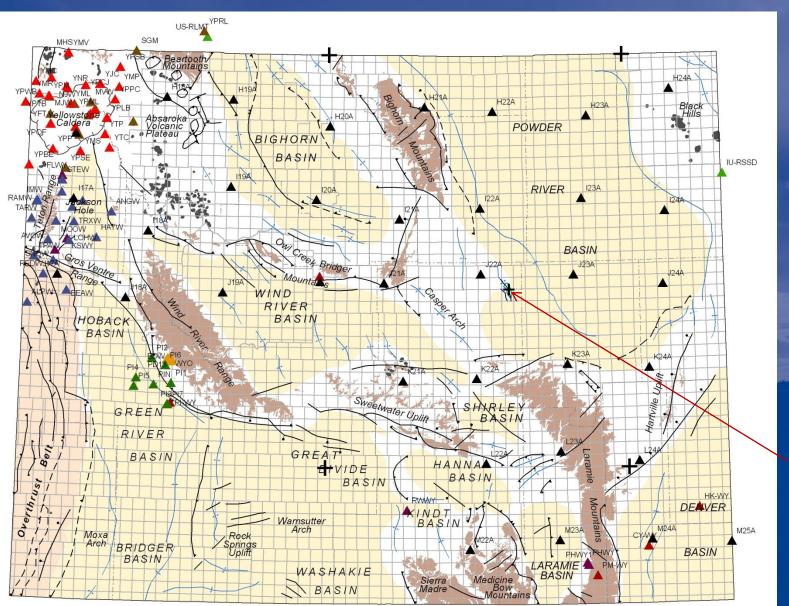




NPR-3 (Teapot Dome)



# Wyoming Seismograph Stations



Network of seismograph stations for real-time earthquake reporting

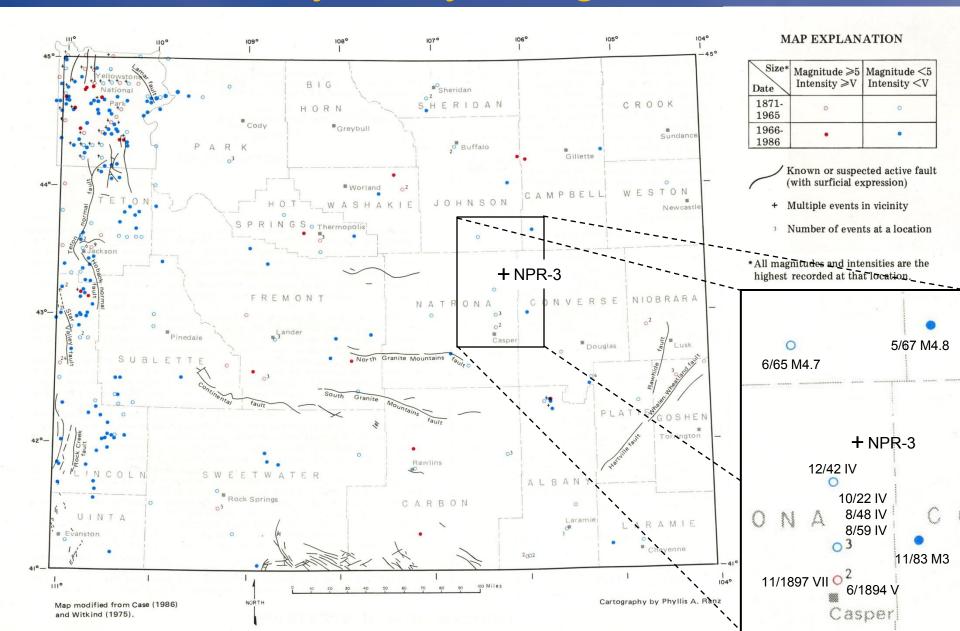
Seismograph stations
Network

ANSS
LRSM
MINLO
NEIC
REX
SLCY
USAF
USBR
USGS
USTA

NPR-3 (Teapot Dome)



# Seismicity in Wyoming 1871-1986



# Current Program and Future Plans

Through a collaborative program with the U.S. DOE's Geothermal Technologies Program, RMOTC's infrastructure is being expanded to permit:

- Installation of a 250kW water-cooled unit (UTC) with associated air cooling tower; operate for three years to evaluate long-term operability
- Continued operation of the existing 250kW unit (Ormat) for 3 years to look at long-term operability
- Development of a testing facility for smaller scale prototype power production systems requiring either air or water cooling

Also analyzing infrastructure needs to provide an EGS testing facility.

 Drill a new well or deepen an existing well into the granite to obtain scientific information

