The Geologic and Hydrologic Setting of NPR-3 (Teapot Dome) Wyoming and its EGS Geothermal Potential

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Keywords

EGS, co-production, Wyoming, Teapot Dome, granite, oilfield, DOE, heat flow

ABSTRACT

Teapot Dome, Wyoming, has anomalously high heat flow as seen in produced water in association with oil production from relatively shallow depths between 5000 and 6000 feet. Water temperatures of approximately 200 °F and volumes of 45,000 barrels per day provide an oilfield setting that supports a 250 kW hybrid geothermal power unit in a demonstration project. The known geothermal gradient of 3.0°F per 100 feet of depth suggests a deep source of heat that may be a good setting for EGS development. Existing datasets including 2D and 3D seismic, hundreds of wellbores with wire-line logs, aeromagnetic surveys, and regional gravity mapping are being interpreted and integrated to better characterize the deep EGS potential. A future science well into the granite basement is being planned to augment the current interpretation.

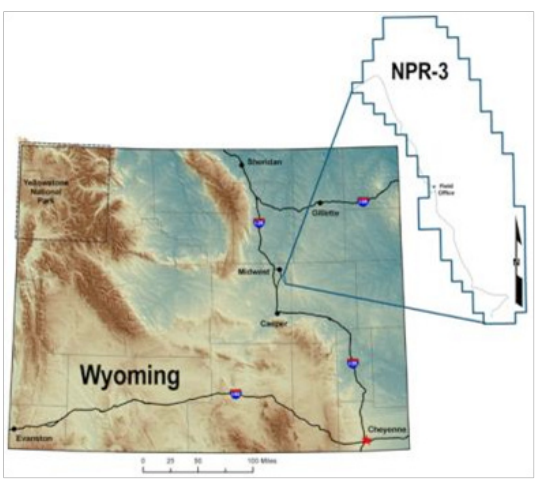

Figure 1. Location map.

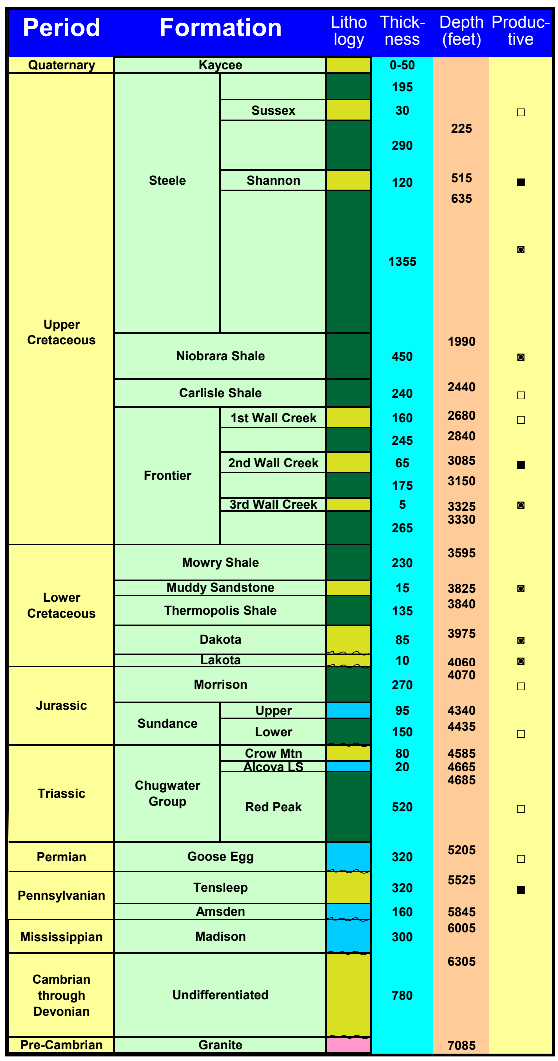

Figure 2. Teapot Dome Geologic Column.

RMOTC is located at the Teapot Dome oil field, also known as the Naval Petroleum Reserve No. 3 (NPR-3). The field is thirty-five (35) miles north of Casper, Wyoming (Figure 1). NPR-3 is operated by the U.S. Department of Energy as a test site for new and developing oil and gas and renewable energy related technologies, and as a producing oil field.

The field is a 9,481-acre operating mature oil field offering a full complement of associated facilities, production, and drilling equipment onsite. There have been 1,319 wells drilled in the field with 589 of them plugged and abandoned. Of the 730 remaining wellbores, 300 are producing wells in nine producing reservoirs ranging in depth from 250 to 5,500 feet. The remaining wellbores are temporarily shut-in or are used for testing.

As a technology testing center, RMOTC offers the following:

- The only government-operated oil field in the U.S.

Figure 3. Produced water cooling ponds.

- Testing and demonstration of new technologies in a real-world environment with partners from government, academia, and industry
- Offering drilling rigs, experienced managers, field staff and complete oil field infrastructure to the oil industry for 15 years
- A 10,000 acre site with both surface and mineral estates under government control
- A location at the center of a regional O&G supply hub
- Potential for cost-sharing and risk-sharing with the government
- Hundreds of existing wells and extensive geologic and hydrologic site characterization
- Most National Environmental Policy Act (NEPA) work completed
- Relatively shallow access to crystalline basement rock having much higher temperatures and heat flows than are typical of the region.

Two formations at NPR-3, the Pennsylvanian Tensleep and Mississippian Madison formations, produce sufficient hot water for the generation of low-temperature geothermal energy (Figure 2). The current flowing water resource from these formations is 45,000 barrels of water per day (BWPD) (Figure 3). It is projected that with some work on existing wells (Figures 4 & 5), the rate for the combined Tensleep and Madison produced water would be between 126,000 and 210,000 BWPD, and this rate could be expanded further by drilling additional wells or possibly re-entering older abandoned wells. The average production temperature for the Tensleep Formation is 195°-200°F and for the Madison is 200°-210°F.

In September 2008 an air-cooled, factory-integrated, skid-mounted standard design 250 kW Organic Rankine Cycle (ORC)

Well	Zone	Rate, MBWPD		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

Figure 5. Co-Production Geothermal Potential (M = 1000's).

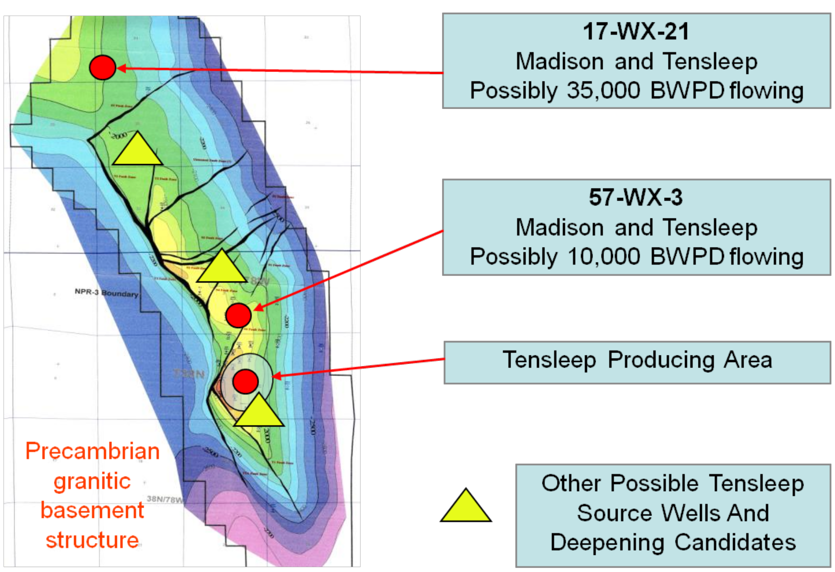

Figure 4. Geothermal potential at Teapot Dome.

Figure 6. Demonstration project ORC power plant at RMOTC.

Table 1. ORC power plant at Teapot Dome Oilfield operational summary.

	Phase 1	Phase 2
On Line Days, Total (Actual)	161 (151)	214 (124)
Inlet Brine Temp, °F	195-198	196-198
Inlet Brine Temp, °C	90-92	91-92
Brine Volume, bbls	3,047,370	3,462,394
Brine Volume, m^3	484,493	550,520
Net Power Produced, kW-hr	586,574	732,970
Overall		
On line percentage	91	70
Average net power, kW	159	143
Overall without field downtime		
On line percentage	97	97
Average net power, kW	171	198
Average Net Power last 30 days, kW	207	212

power plant was installed to demonstrate (for the first time) small-scale power generation in an oil field (Figure 6). The goals of the demonstration project were to 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, and provide a technical and economic analysis of the process. Results are shown in Figures 7 and Table 1. This unit continues operations today and additional binary power system installations are planned including installation of a 250kW water-cooled unit with associated air cooling tower at the 17-WX-21 Madison well in the north (Figure 4).

NPR-3 is not located in an area of known high regional surface heat flow (Figure 8), so the produced water temperatures seen from the relatively moderate depths of 5,500 feet are anomalous for the area. Based on the temperatures observed from Tensleep and Madison production, the local geothermal gradient is 3.0°F per 100 feet of depth (55°C per km). This is significantly greater than the average thermal gradient for the southern Powder River Basin of 2.2°F per 100 feet. The heat flow at Teapot Dome is more similar to the "Battle Mountain High" of northern Nevada with values up to 225 mW/m^2 (McPherson, 1996) as compared to the southern Powder River Basin with an average of 52 mW/m^2 (Figure 9).

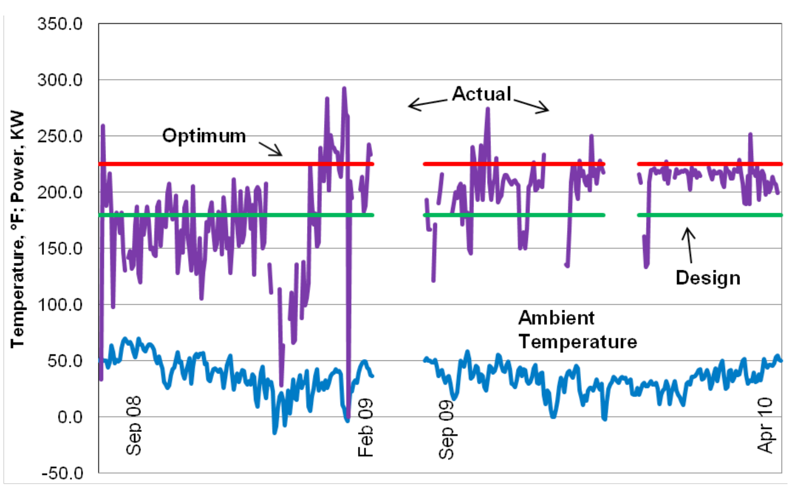

Figure 7. Operational results of low-T binary demonstration power unit using oilfield produced water.

The groundwater resource in both the Tensleep and Madison formations is continuously recharged from mountains to the west (Figure 10), and the Tensleep oil reservoir has a strong water drive, resulting in no loss of reservoir pressure (2350 PSI) over 30 years of production. The hydrologic system in the area apparently has the groundwater heated by proximity to deep basement rocks prior to entering into the Teapot Dome anticline. And yet, analysis of aeromagnetic and gravity data (Figure 11) and 2D and 3D seismic surveys (Figure 13) over the site indicate there is not a significantly deeper top of basement surface along the groundwater migration pathway. The seismic shows vertical displacement of the fault at the basement level is about 800 feet. So either there is a zone of much higher heat flux in the area near the sedimentary-crystalline basement interface, or there may be deep fractures into the basement allowing groundwater flow down into the granite prior to entry into the Teapot Dome structure.

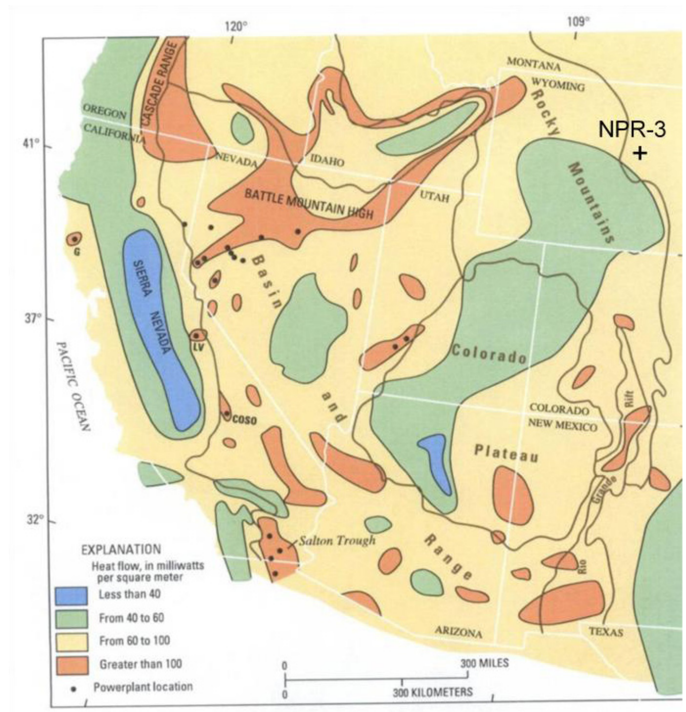

Figure 8. Heat Flow in the Western U.S. (Duffield 2003).

There is one deep well at NPR-3 drilled just into the granite in 1952 (Figure 12, center) providing depth control and limited temperature information. The wire-line log bottom-hole temperature (6864 feet depth) was 188°F, but it is unknown how much time had elapsed since circulation ceased, so this temperature can't be relied upon as indicative of static formation temperature at the top of the granite. There was no temperature profile, but the well tested water from the Tensleep (5465 feet depth) at 200°F. No modern logs are available at this location. Rock samples confirm the crystalline basement at this spot is truly a granitic lithology.

There is some limited deep drilling in the region, outside of the NPR-3 boundaries, and outcrops of Pre-Cambrian basement rock occur in the vicinity in Laramide uplifts. Two relatively recent (1980's) deep wells do have an extensive

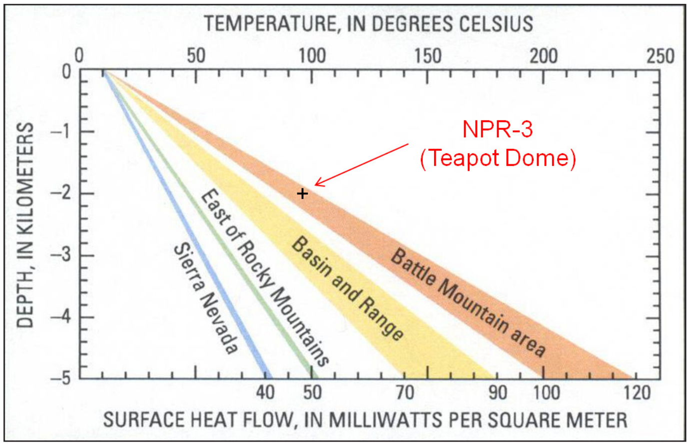

Figure 9. Geothermal gradients (Duffield 2003).

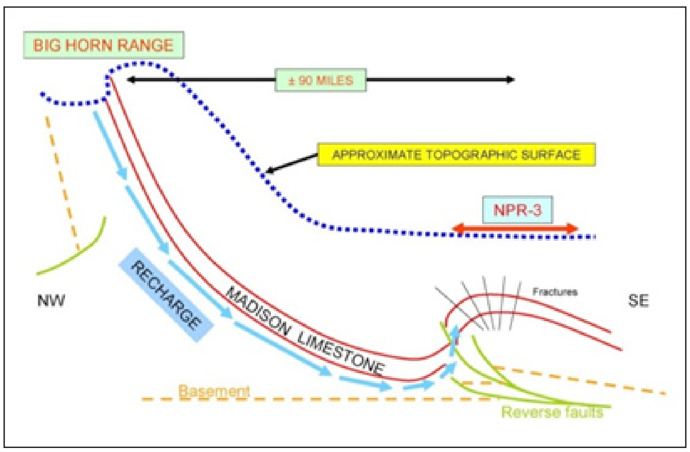

Figure 10. Groundwater recharge system.

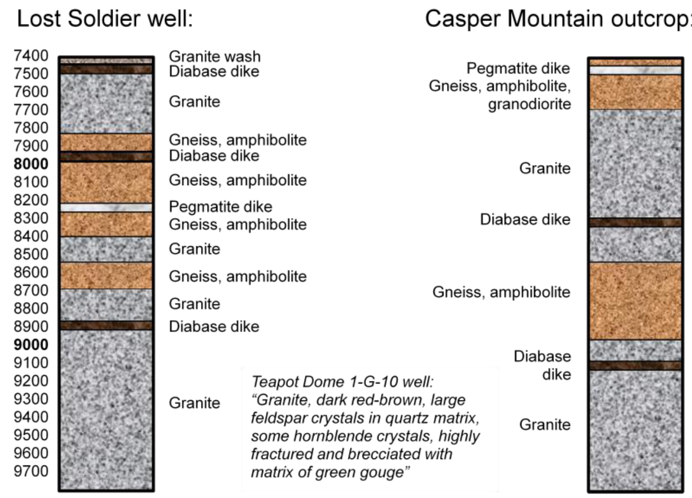

Figure 12. Basement lithology in a nearby deep well and outcrop.

modern logging suite to help characterize the crystalline rocks. One of these, located in the Lost Soldier Field (100 miles southwest of NPR-3), is summarized in Figure 12, left. The maximum bottom-hole temperature reached with wire-line logging tools in this well was 206°F at 9700 feet depth. Interpretation of aeromagnetic mapping (Figure 11) over Teapot Dome and the southern Powder River Basin in general indicates highly variable lithologies in the basement, but it appears that any additional drilling at NPR-3 would be totally within a basement block bounded by ancient faults or sutures probably consisting mostly of the same granite found at the one deep well.

RMOTC plans to either drill a new well or deepen an existing well down to and into the granite 1,000 – 2000 feet, as a "science well" to find out additional information on the setting (Figure 13). By linear extrapolation of the known gradient from 5500 feet down (the only reasonable assumption that can be made without additional information), we expect an anticipated temperature of 300 °F at 9000 feet depth. This well program will include temperature profiling, a modern logging suite (including a spectral gamma-ray and imaging tools), and coring to obtain samples of the basement that can be further evaluated for geomechanical properties, fracturing, and determination if the granite is radiogenic. This information should enable us to better understand the thermal gradient within the crystalline basement rock, presence of natural

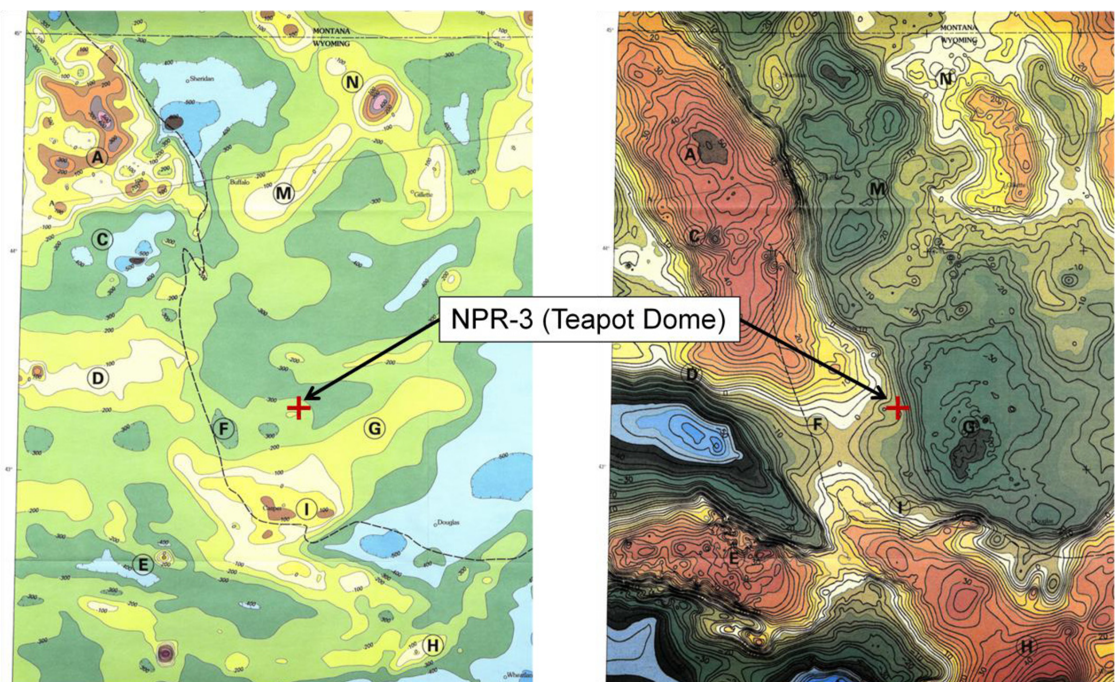

Figure 11. Aeromagnetic (left) and isostatic gravity (right) maps of the Powder River Basin area showing the Teapot Dome location on the edge of a platform on the southwestern flank of the basin (Robbins, 1994).

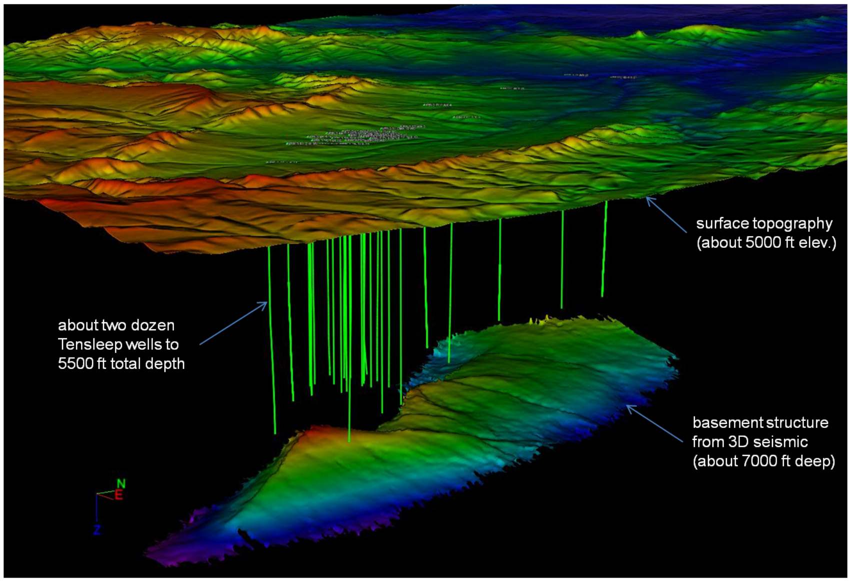

Figure 13. Existing "Deep" Wells that Could Be Deepened to the Granite Basement.

fractures, rubble zones, or "granite wash", and the potential for induced fracturing methods for an Enhanced Geothermal System (EGS) reservoir.

The RMOTC site at Teapot Dome provides an ideal location to test and evaluate emerging EGS technologies in an area of known higher heat flow. Existing oilfield infrastructure and characterization of the site should reduce many of the risks and some of the costs of EGS drilling and facilitate a test-bed for improving the state of the technology.

Acknowledgements

Lyle Johnson, PE, DOE, RMOTC
Everett Walker, Navarro Research & Engineering, RMOTC
Dan Schochet, (formerly) Ormat Nevada, Inc.

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[1] Rocky Mountain Oilfield Testing Center