Structural Analysis of a Hot Dry Rock Geothermal Energy System

The Scenario:

Energy prices are rising rapidly, and utility companies are beginning to seek alternatives to fossil fuels electrical generation. One promising technology is a type of geothermal energy referred to as “Hot dry rock”. Hot dry rock was heavily researched during the 1980’s by the Department of Energy, but then abandoned when energy prices dropped in the early 1990’s.

Conventional geothermal energy is generated by drilling into groundwater deposits that have been superheated by shallow magma chambers. Thus, it is only economically viable in locations of active volcanism with rapid groundwater recharge (like Yellowstone, Iceland or Hawaii). Hot dry rock, by comparison, could be used in any area with a relatively high geothermal gradient (such as most of the Southwestern U.S.). One possible method is to drill three boreholes (one injection hole and two extraction holes) to a depth of several kilometers, where the ambient rock temperature is high enough to superheat water. (temperatures of 150-250°C will do the job). The boreholes are then hydrofractured to create a system of open fractures between them. Cool water is pumped down the injection hole and is superheated while flowing through the fractures to the production holes. The superheated water then spins a steam turbine to generate electricity (Figure 1).

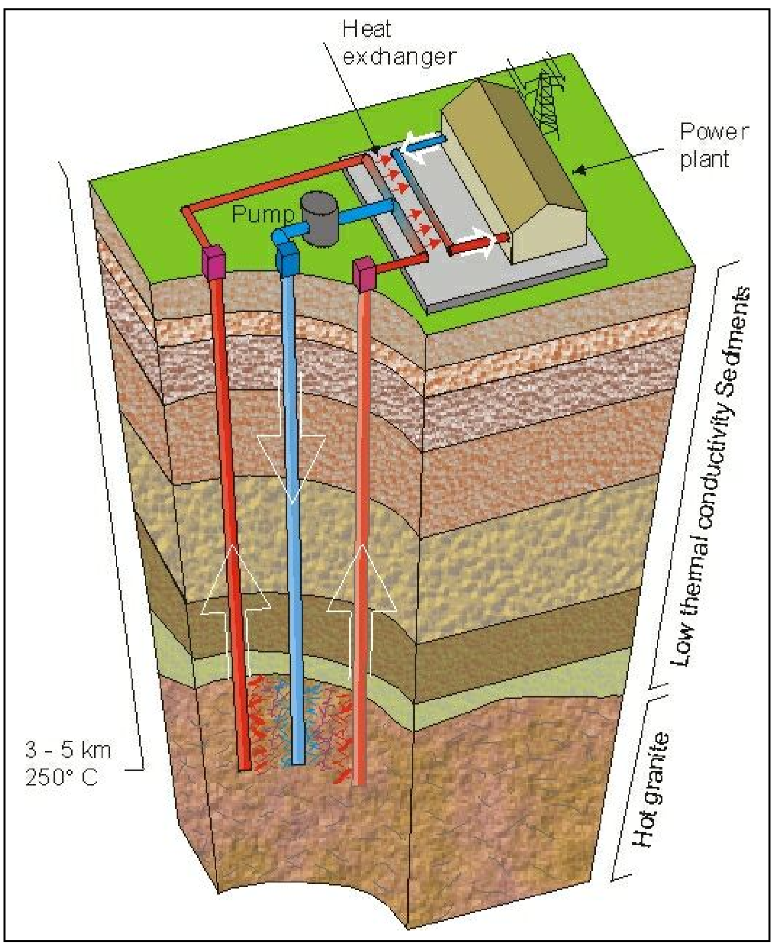

Figure 1. Conceptual model of a hot dry rock geothermal power plant; **Image from the Hot Rock Energy Program at Australian National University**

You work for a consulting firm that has just been contracted by Ms. Ima Bigwig of Fatwallet Energy to construct such a hot-dry rock system in Golden, Colorado. Follow the tasks listed below to design your system.

The system will consist of one injection well and two production (extraction) wells that will spin a 3 Megawatt steam turbine and harvest excess thermal energy to heat surrounding buildings. The geology of the Golden site comprises east-dipping Mesozoic and Permian sedimentary rocks over an east dipping non-conformity (Figure 2), beneath which lies the Precambrian Idaho Springs Formation (metamorphosed granite). Assume that the sedimentary rocks and the unconformity have a constant attitude across this area of 348, 42 NE. The specifications call for the extraction well to be drilled a depth such that it penetrates 1000 meters into the Idaho Springs Formation.

Show all of your work: Full credit will not be awarded to assignments with hard to follow calculations.

Task 1: Determine depth to drill the injection well (10 pts). The design specifies that this well must penetrate at least 1000 meters into the Idaho Springs Formation to insure that all water circulation occurs within the crystalline bedrock (and that none is lost into overlying sediments). See the geologic map of Golden (Figure 2) to help you with this step. Assume that the sedimentary rocks and the unconformity have a constant attitude across this area of **348, 42 NE**, and that the ground surface is horizontal. The distance from the unconformity to the injection well is 4.5 km in the direction **078**. You will need to draw a cross section to help you. **How deep should this well be drilled?**

Task 2: Determine the ambient temperature of the bedrock at this depth (5 pts). The average geothermal gradient in this area has been measured in other wells to be 41°C per kilometer depth. **How hot is the rock at the base depth of the injection well?**

Task 3: Determine the strength characteristics (Coulomb Coefficient (friction angle) and Cohesion) of the Idaho Springs Formation metagranite (15 pts). You sampled the Idaho Springs Formation where it is exposed on the surface and ran a series of four triaxial compression tests (Results listed below). Determine the coulomb coefficient (or friction angle) and cohesion of this rock.

	Confining Pressure	**Axial Load at Failure**
Test 1:	4.5 MPa	35.5 MPa
Test 2:	9 MPa	50 MPa
Test 3:	17 MPa	73 MPa
Test 4:	26 MPa	104 MPa

Task 4: Determine the fluid pressure that must be applied to the base of the production well to initiate a system of shear fractures (15 pts). Use your rock strength characteristics determined in Task 3 to construct a Mohr envelope and plot a Mohr's circle to determine fluid pressure to fracture rock.

Required Information:

- Assume that σ_1 is vertical
- The Mesozoic and Permian sedimentary rocks have an average density of 2100 kg/m3
- The Idaho Springs Formation has an average density of 2800 kg/m3
- σ_3 is horizontal is known to be 54 MPa oriented in the direction 096.

Task 5: Determine how deep each of the production wells must be drilled to intercept the fractures formed in Task 4 (15 pts). To complete this task, you need to determine the strike and dip of fractures formed during hydrofracturing. Assume that fractures form parallel to σ_2. You can determine the θ angle from your Mohr Envelope. It is likely that two sets of conjugate fractures would form on either side of the σ_3 direction, one east dipping and one west dipping. Assume that the dominant set formed in this case is **East Dipping**.

Hints: 1) Determine the strike and dip of fractures; 2) Draw a cross section of the geology through the production well to visualize the situation; 3) To complete this, you will need to either determine apparent dips of the fractures, or perform a three point problem backwards.

Required Information:

- Production well #1 is located 500 m from the injection well in the direction **295**
- Production well #8 is located 400 m from the injection well in the direction **140**
- Assume a horizontal ground surface

Task 6: Write a letter to your client reporting your results (20 pts). Your letter should succinctly summarize the methods you used and the results of your calculations, as well as any recommendations for the final design of the system. It must be typed and include a name of your company (make one up).

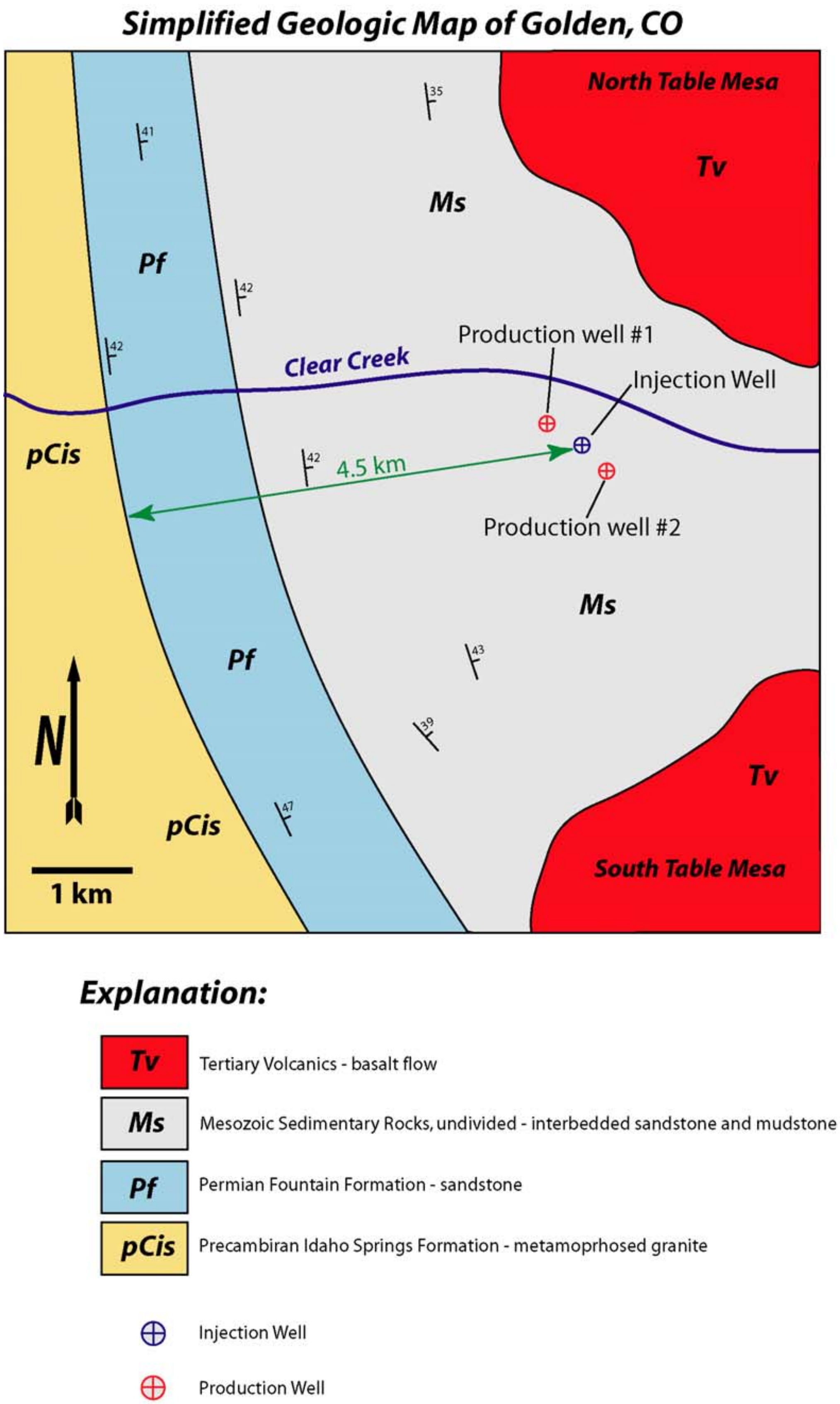

Figure 2. Simplified geologic map of Golden, CO showing locations of wells for the hot dry rock geothermal energy system