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Thermal modeling of the Mountain Home Geothermal Area

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ABSTRACT

The Mountain Home area is characterized by high heat flow and temperature gradient. Temperature data are available from 18 boreholes with depths equal to or greater than 200 m. Although there are large variations, the average temperature gradient exceeds 80°C/km. This paper presents a preliminary 3-D numerical model of the natural-state (i.e. pre-production state) of the Mountain Home geothermal area. The model volume is 34,320 cubic kilometers (110 km in the east-west direction, 80 km in the north-south direction, and 3.9 km in the vertical direction). Available temperature profiles from the five deep wells with depths ranging from ~1340 m to ~3390 m (MH-1, MH-2, Bostic1, Lawrence D No.1, and Anschutz No. 1) are used to constrain the 3-D numerical model.

1. INTRODUCTION

Under a co-operative agreement with the U.S. Department of Energy (DOE), Utah State University is carrying out a research program to identify promising geothermal prospects in the Snake River Plain (SRP) volcanic province (Shervais et al., 2016). The goals of this Phase 1 study are to: (1) adapt the methodology of *Play Fairway Analysis* to geothermal exploration, creating a formal basis for its application to geothermal systems, (2) assemble relevant data for the Snake River Plain volcanic province from publicly available and private sources, and (3) build a geothermal play fairway model for the Snake River Plain that will allow the delineation of the most promising plays. The model will serve to integrate the diverse data sets and serve as a point of departure for future exploration efforts in the region. A promising play type is associated with the SRP basaltic sill-complexes characterized by fault-controlled permeability, volcanic sill heat source, and lake sediment seal. The area around Mountain Home Air Force base in western Snake River Plain (Figure 1) hosts a geothermal system of this type.

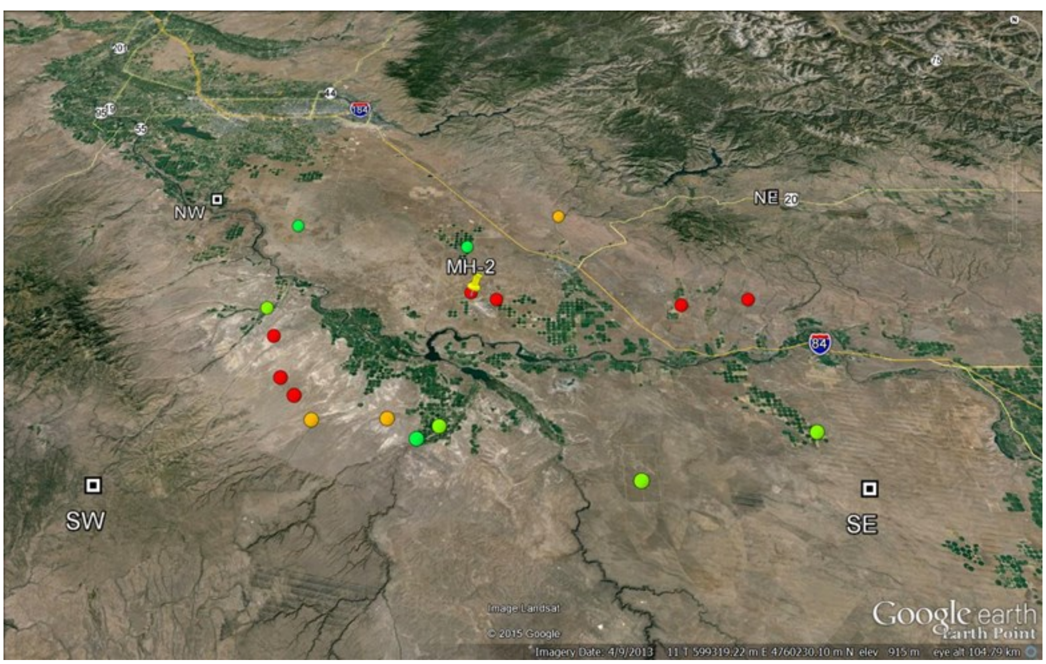

Figure 1: Mountain Home area showing the locations of boreholes greater than 200 meters in depth. The NW (Lat: 43.31, Long: -116.51), NE (43.31, -115.19), SW (42.71, -116.50), and SE (42.71, -115.20) denote the four corners of the area of interest.

The Mountain Home area is characterized by high heat flow and temperature gradient. Temperature data are available from 18 boreholes (Figure 1) with depths equal to or greater than 200 m; although there are large variations, the average temperature gradient exceeds 80°C/km. This paper presents a preliminary 3-D numerical model of the natural-state (i.e. pre-production state) of the Mountain

Home geothermal area conditioned using the available temperature profiles from the five deep wells with depths ranging from ~1340 m to ~3390 m (MH-1, MH-2, Bostic1, Lawrence D No.1, and Anschutz No. 1); the preliminary natural state model will be further developed during Phase 2 as additional geological, geophysical, and well data become available.

2. COMPUTATIONAL VOLUME, MODEL GRID, FORMATION PROPERTIES, AND BOUNDARY CONDITIONS

The ground surface elevation in the Mountain Home area varies from about 690 mASL (meters above sea-level) to over 2200 mASL. The bottom of the deepest well drilled so far Anschutz 1 is at about -2555 mASL. We therefore decided to place the bottom of the model grid at 3000 m below sea-level; thus the model grid extends about 450 m below the deepest well. The top of the model grid is placed at the assumed water level (1 bar surface).

At present, no pressure transient data are available from any of the wells in the Mountain Home area. The vertical permeability values were determined during the development of the numerical model in order to match the measured well temperatures. The horizontal permeability values in the model are largely unconstrained. In the future, permeability values used in the model will be modified as additional geological, geophysical, and well test data become available.

The model volume is divided in to a 22x16x18 grid in the x- and y- and z-directions (east, north, and vertically upwards) respectively. In the z-direction (k=1, …, 18), the grid blocks are either 100 m or 250 m. In the x- and y-directions (i=1, …, 22; j=1, …, 16), a uniform grid spacing of 5 km was employed. The total number of the grid blocks is 6,336, and the model volume is 34,320 cubic kilometers (110 km in the east-west direction, 80 km in the north-south direction, and 3.9 km in the vertical direction). An overlay of the horizontal grid over the Mountain Home area is shown in Figure 2. The vertical grid is displayed in Figure 3.

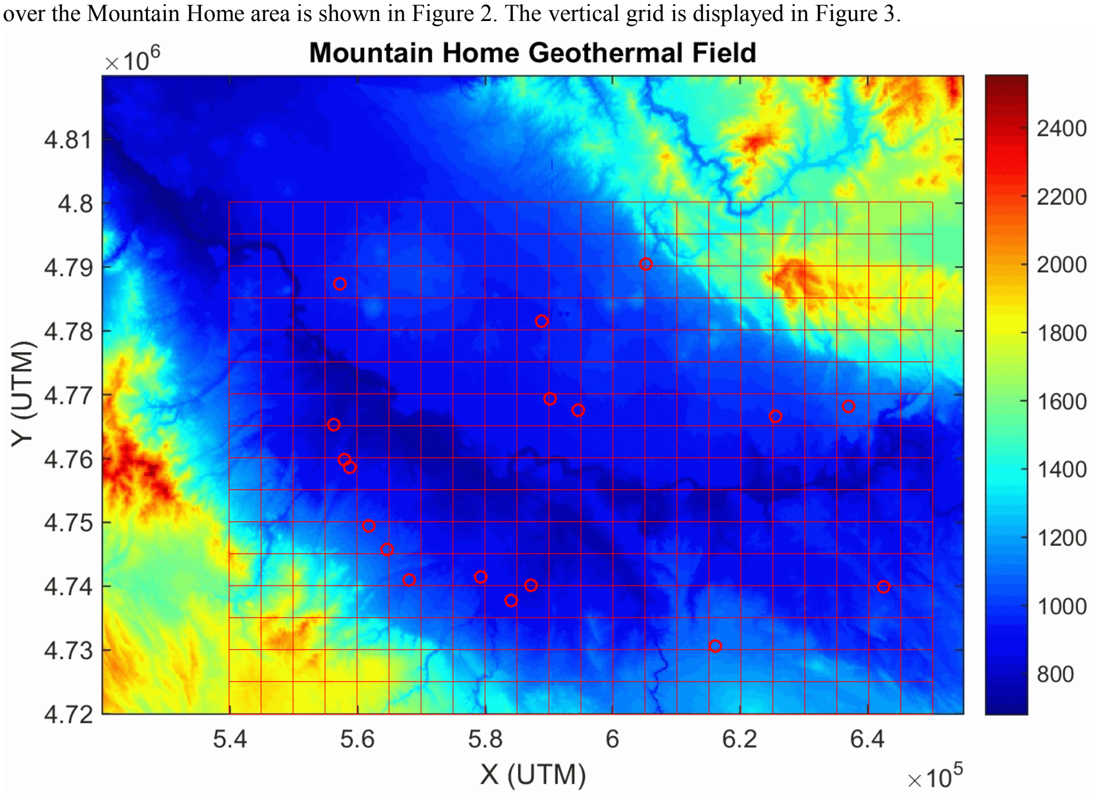

Figure 2: Horizontal grid (x-y grid) superposed on a topographic map of the Mountain Home geothermal prospect; warm colors denote higher elevations. Well-heads (red circles) are also shown. The origin of the model grid is at 540,000 mE and 4,720,000 mN (UTM).

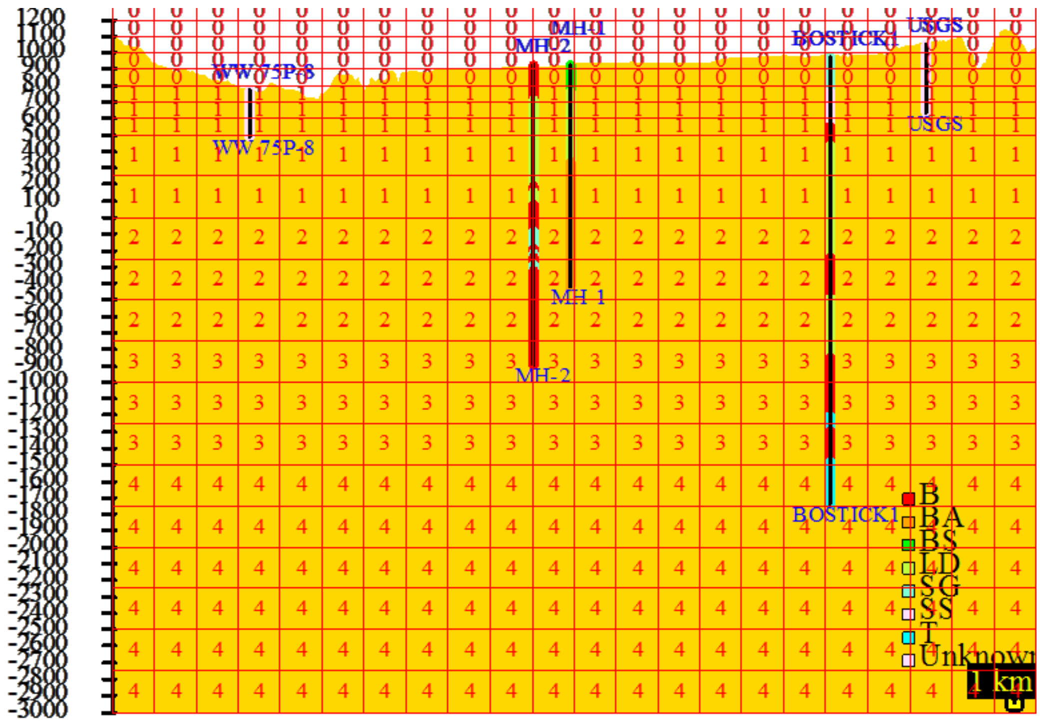

Figure 3: Vertical (x-z) model grid at y= 47.5 km (j=10). The bottom of the grid is at -3000 mASL. The bottom 14 grid blocks (k=1 to 14) are of uniform thickness (250 m each); a smaller thickness (100 m) is used for blocks k=15 and higher in order to more closely represent the water level surface. Numbers in grid-blocks (1, 2, 3, and 4) denote the formation type (see below). The void blocks are tagged with 0. Also shown is the lithology from the deep wells (MH-1, MH-2, and Bostic1) passing through j=10.

The 3-D numerical model was constructed using Leidos's STAR geothermal reservoir simulator (Pritchett, 2011). In order to carry out model computations with STAR (or for that matter any other reservoir simulator), it is essential to prescribe distribution of thermo-hydraulic properties (*e.g.,* permeability, porosity, thermal conductivity, specific heat, etc.) for the entire grid-volume, and boundary conditions along the faces of the model grid. During the development of the natural-state model for the Mountain Home geothermal prospect presented below, the boundary conditions (*i.e.,* heat flux along the bottom boundary, pressure specification along the top boundary) and the formation permeabilities were freely varied in order to match the observed temperature profiles in wells. Several such calculations were carried out; in the following, we will only describe the final case.

Formation properties utilized for the Mountain Home natural-state model are given in Table 1. Rock types assigned to individual grid blocks are based on lithologic logs from wells MH-1, MH-2, and Bostic1. Intrinsic rock density, rock grain specific heat, global thermal conductivity, and porosity values in Table 1 are based on published data (see e.g., Hyndman and Drury, 1977; Eppelbaum et al., 2014; Blackwell, 2013). The average vertical permeability at Mountain Home appears to be rather low. More specifically, a low vertical permeability is required for matching the mostly conductive temperature profiles recorded in the area wells. As mentioned previously, the assumed horizontal permeabilities are essentially arbitrary, and are unconstrained at the present time. In addition to formation properties given in Table 1, it is necessary to specify capillary pressure and relative permeabilities. The capillary pressure is assumed to be negligible. Straight-line relative permeability curves with a liquid (gas) residual saturation of 0.2 (0.0) are used. Since two-phase flow is unlikely in the "natural state" at Mountain Home, the capillary pressure and relative permeability have no effect on the computed natural-state.

Along the top boundary, the water table (i.e. 1 bar surface) is assumed to be at an elevation given by:

$$z_w = 0.10(z - 750) + 750 = 0.10z + 675 \qquad (1)$$

where z_w denotes the water table elevation (mASL) and z is the local ground surface elevation. The ground surface temperature and shallow subsurface temperature gradient are assumed to be 10 °C and 85 °C/km, respectively. If the water table given by Eq. (1) falls below the mid-point of a grid block, the grid block is flagged as void. Use of Eq. (1) renders many grid blocks in layers k=17 and k=18 void. Sources and sinks are imposed in all the top-most grid blocks in each vertical column (i, j; i=1,…, 22, and j=1, …, 16) to maintain the pressures and temperatures consistent with Eq. (1), and the assumed surface temperature and shallow subsurface temperature gradient. Along the bottom boundary, a non-uniform conductive heat flux is imposed along the entire surface (see Figure 4). All the vertical faces of the grid are assumed to be impermeable and insulated. The reservoir fluid is treated as pure water.

Table 1: Formation properties.

Formation Name	Intrinsic rock density (kg/m^3)	Rock grain specific heat (J/kg-°C)	Global Thermal Conductivity (W/m-°C)	Porosity	Permeability in x-direction (mdarcy)*	Permeability in y-direction (mdarcy)*	Permeability in z-direction (mdarcy)*
1.Sediments/basalt	2800	1000	1.5	0.100	5	5	0.1
2.Basalt upper	2800	1000	1.5	0.025	5	5	1
3.Basalt Lower	2800	1000	1.5	0.025	5	5	1
4.Rhyolite/basalt	2800	1000	1.5	0.025	1	1	0.1

*It is assumed here that 1 millidarcy is exactly equal to 10^{-15} m^2

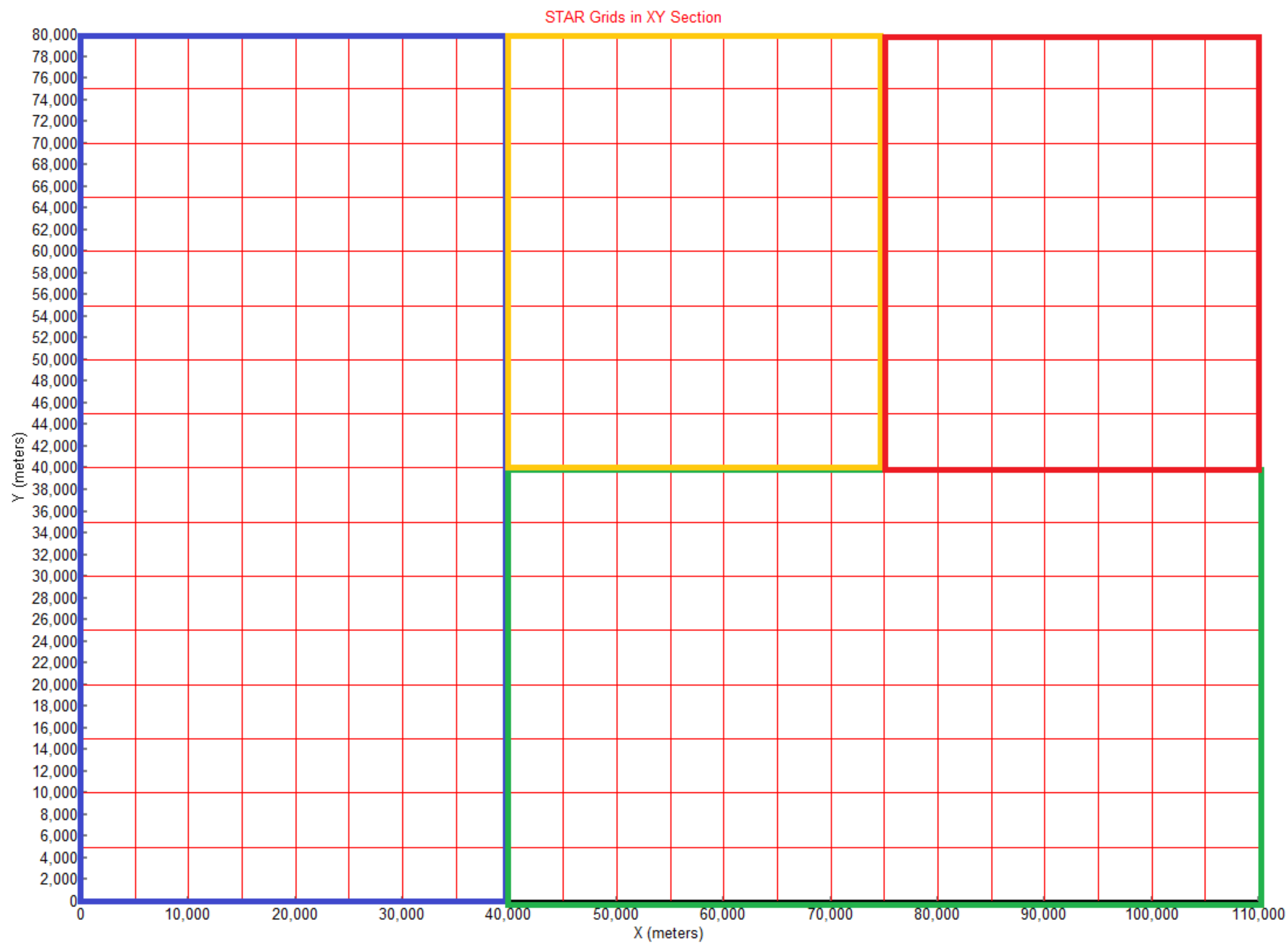

Figure 4: Heat flux distribution along the bottom boundary. Area enclosed by 1. blue outline, heat flux = 60 mW/m^2, 2. green outline, heat flux = 75 mW/m^2, 3. yellow outline, heat flux = 100 mW/m^2, and 4. Red outline, heat flux = 110 mW/m^2.

3.COMPUTATION OF QUASI-STEADY NATURAL STATE

Starting from an essentially arbitrary cold state, the computation was marched forward in time for about 625,000 years. The maximum time step used was 25 years. The change in total thermal energy in the computational grid is displayed in Figures 5. At very early times (<50,000 years), the thermal energy declines and the fluid mass increases. After this early transient period, the thermal energy increases and the fluid mass declines. The changes in thermal energy and fluid mass moderate over time. After about 500,000, the change is quite small over a time scale of 50 to 100 years. The computed temperature values at cycle 15,000 (about 625,000 years) were compared with the available data.

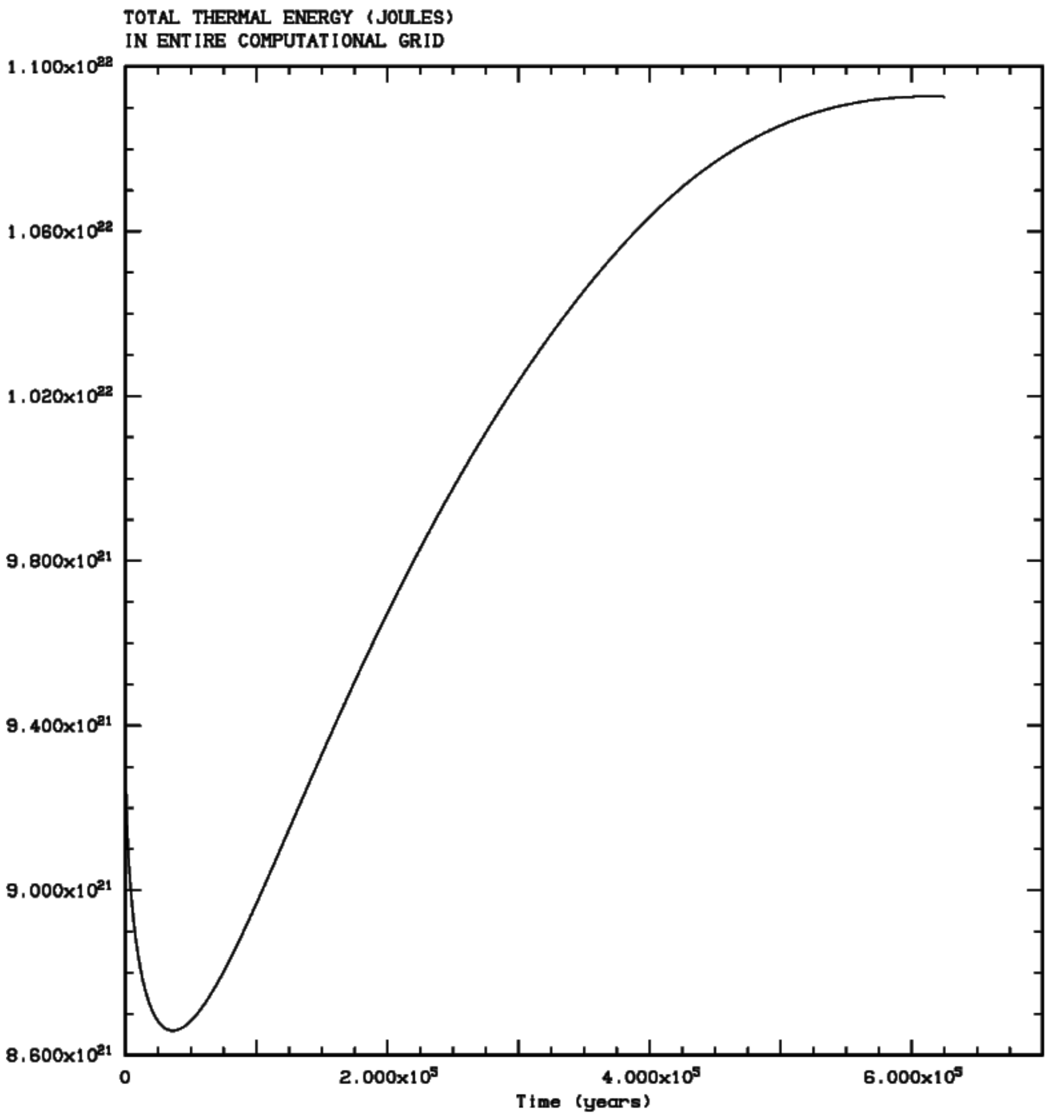

Figure 5: Computed total thermal energy in the computational grid

The measured temperatures in the deep Mountain Home wells are compared with calculated results from the model in Figures 6-10. For almost all of these wells, it is not known if the available temperature data represent stable formation temperatures. The only available temperature survey for well Lawrence D No.1 was obtained after a shut-in time of 8 hours, and the measured temperatures are in all likelihood much lower than the undisturbed formation temperatures. Well Anschutz No. 1 is quite close to well Lawrence D No. 1; measured temperatures (shut-in time ~ 66 hours) in the Anschutz well are considerably higher than those recorded in the Lawrence well. No information on shut-in time is available regarding the temperature surveys in other wells. Given the current data limitations, the agreement between the measured and computed temperature values is considered satisfactory.

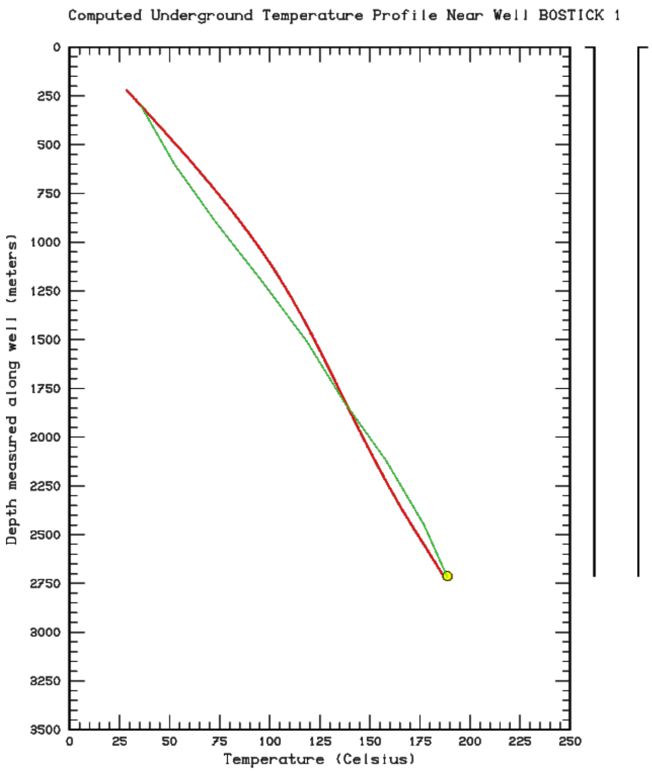

Figure 6: Comparison between computed (solid red line) and measured temperature profiles (solid green line and yellow circle) for well Bostic1. No information is available concerning the shut-in time at which the temperature survey was taken.

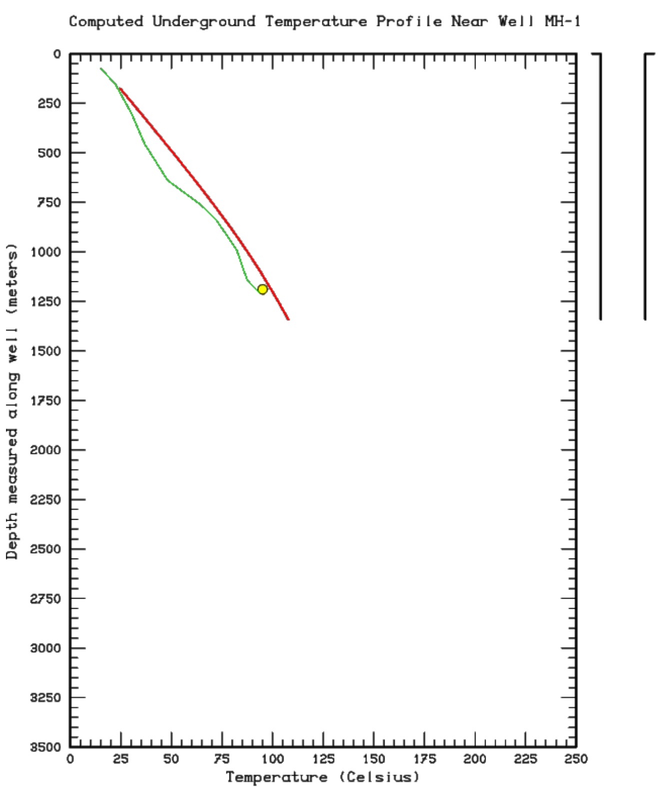

Figure 7: Comparison between computed (solid red line) and measured temperature profiles (solid green line and yellow circle) for well MH-1. No information is available concerning the shut-in time at which the temperature survey was taken.

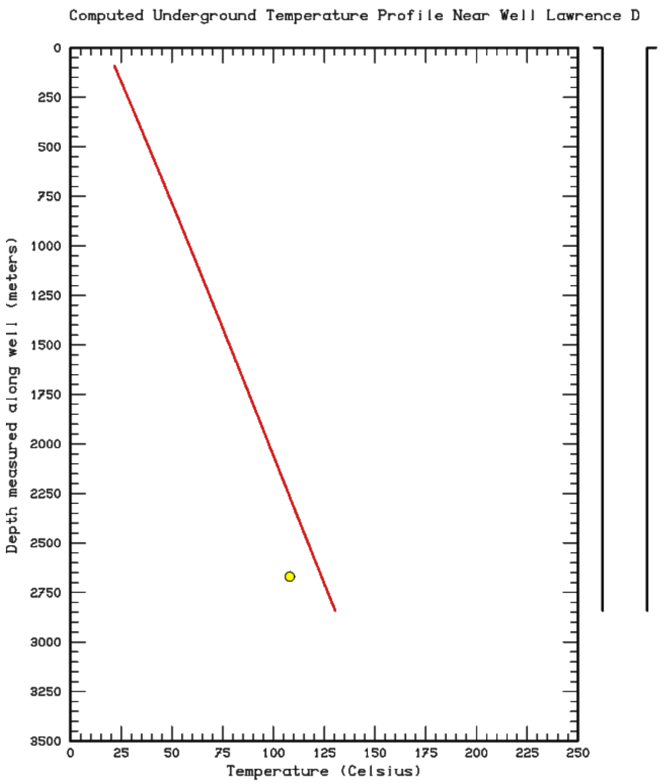

Figure 8: Comparison between computed (solid red line) and measured temperature profiles (yellow circle) for well Lawrence D No. 1. The measured temperature was recorded after the well had been shut-in for only about 8 hours.

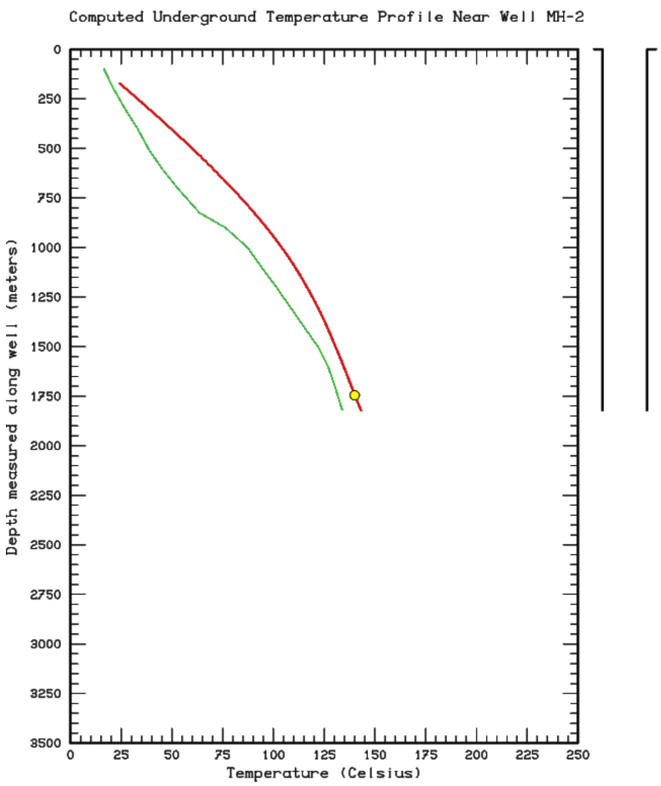

Figure 9: Comparison between computed (solid red line) and measured temperature profiles (solid green line) for well MH-2. Survey was run 76 days following completion of drilling. The yellow circle is the measured flowing temperature at this depth. Since the measured flowing temperature is higher than the recorded shut-in temperature (solid green line), it is almost certain that the shut-in survey does not represent the stable formation temperatures.

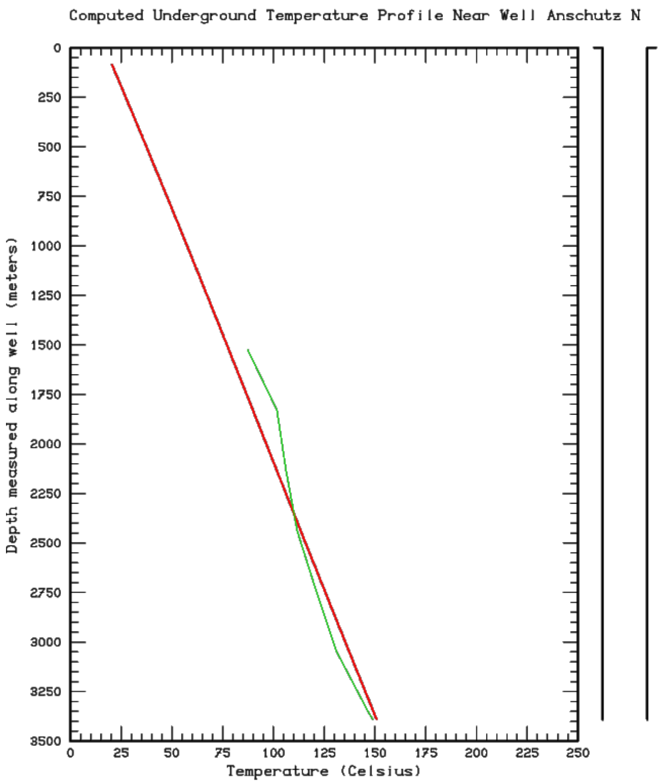

Figure 10: Comparison between computed (solid red line) and measured temperature profiles (solid green line) for well Anschutz No. 1. The temperature survey was taken after the well had been shut-in for about 66 hours.

4.COMPUTED TEMPERATURE DISTRIBUTION AND FLUID FLOW

Computed temperatures and fluid flux vectors in two horizontal x-y planes are exhibited in Figures 11 and 12. The highest ground at Mountain Home (see Figure 2) is to the northeast and southwest; these areas are the recharge areas (see Figure 12; layer k=15); the flow is generally to the northeast from southwest and southwest from northeast. The latter flow pattern, especially from that from southwest to northeast, persists at depth (Figure 11). Fluid flow pattern and temperature isotherms are rather complicated in the northeast part of the computational grid.

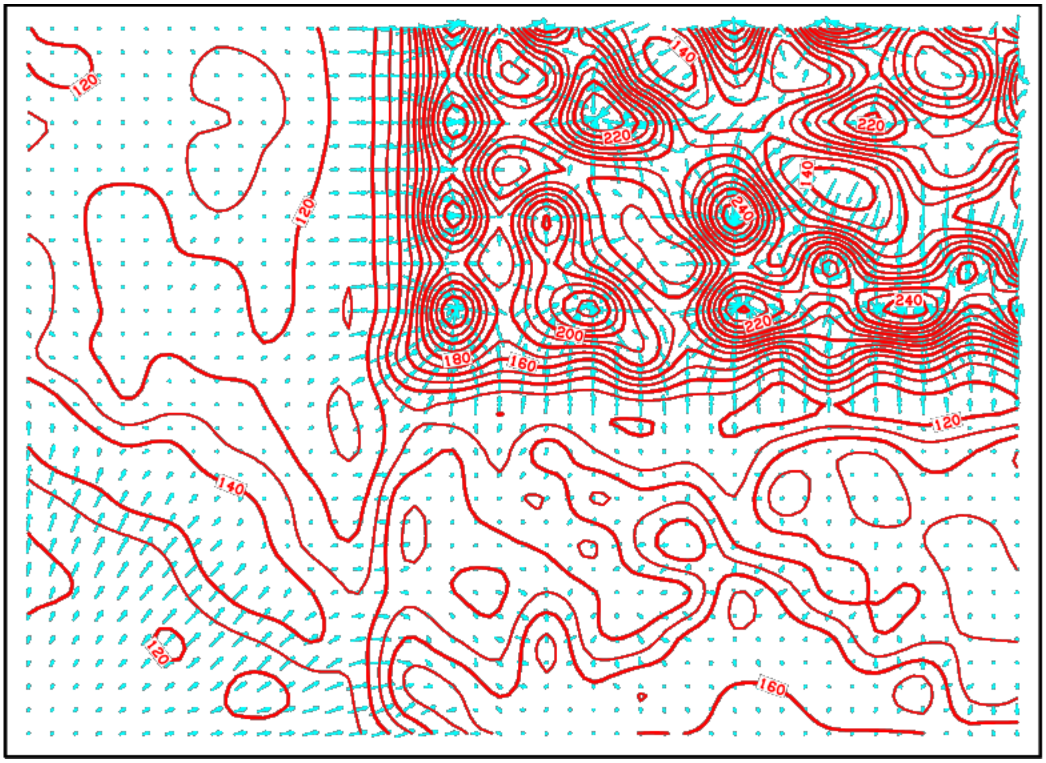

Figure 11: Isotherms (red lines) and flow vectors (blue) in the vertical x-y plane k=5.

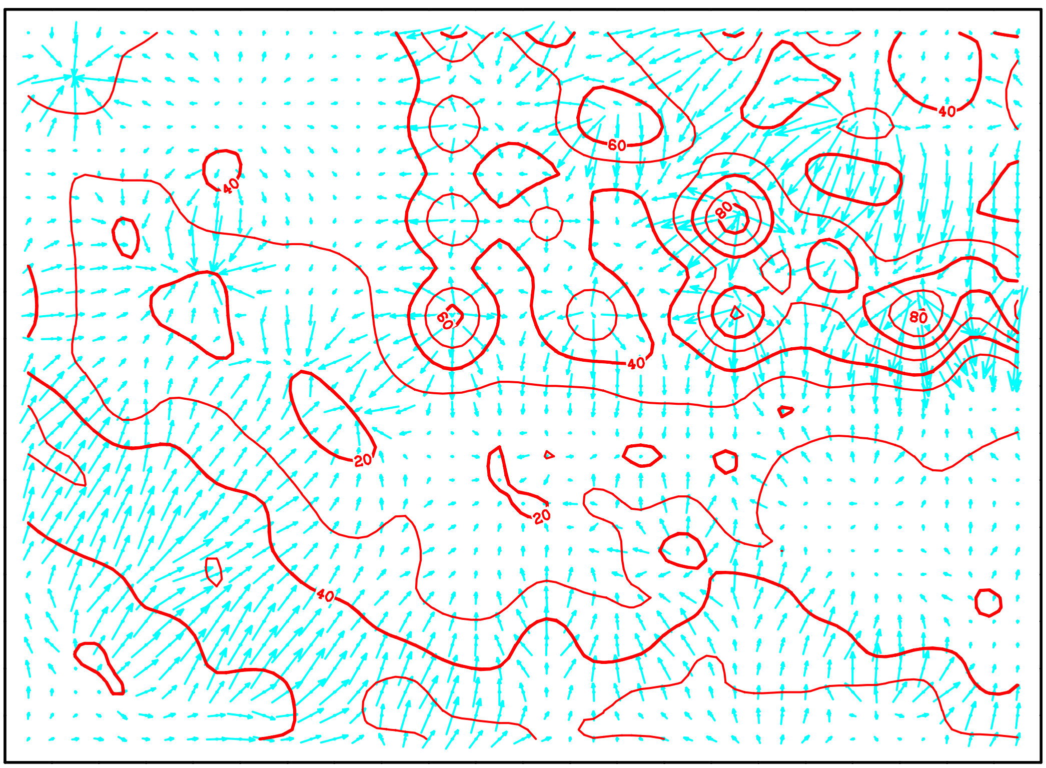

Figure 12: Isotherms (red lines) and flow vectors (blue) in the vertical x-y plane k=15.

5.FUTURE WORK

The preceding sections present a preliminary 3-D natural state model for the Mountain Home geothermal prospect. The model was conditioned using the available temperature data from five (5) deep wells in the area. In Phase 2 (Shervais et al., 2016) and subsequent years, the model will be improved in several ways. A particularly simple representation of lithology was used in the preliminary model, and horizontal permeability distribution is poorly constrained. Results from ongoing analyses of faults and lithology will be helpful in improving these aspects of the preliminary model. An MT survey is planned for Phase 2; results from this survey are expected to provide additional information on permeability distribution in the area. Presently available data are insufficient for defining the pressure distribution in the reservoir, and it is not known if the computed pressures correspond to reality.

In order to carry out definitive reservoir assessment, it is essential to acquire data such as (1) formation lithology, (2) pressure, temperature, and fluid composition, (3) subsurface permeability distribution, and (4) discharge and injection characteristics of wells. Acquisition of these data will require access to deep large-diameter wells or slim holes. Nielson and Garg (2016) discuss the use of slim holes for generating the required reservoir data. It is likely that one or more slim holes will be drilled in the area during Phase 3. The model will no doubt evolve as additional data become available.

Acknowledgment

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References

Blackwell, D. (2013), SMU Geothermal Laboratory heat flow database, Available through National Geothermal Data System.

Eppelbaum, L., Kutasov, I., Pilchin, A. (2014), Applied Geothermics, Springer, pp. 99-149.

Hyndman, R.D., Drury, M.J. (1977), Physical properties of basalts, gabbros and ultramafic rocks from DSDP Leg 37, Initial Reports DSDP, 395-401.

Nielson, D.L., Garg, S.K., Slim hole reservoir characterization for risk reduction, to be presented at the 40th Stanford Geothermal Reservoir Engineering Workshop.

Pritchett, J.W. (2011), STAR User's Manual Version 11.0, Leidos Inc., San Diego, California, U.S.A.

Shervais, J.W., Glen, J.M., Nielson, D., Garg, S., Dobson, P., Gasperikova, E., Sonnenthal, E., Visser, C., Liberty, J.M., Deangelo, J., Siler, D., and Evans, J.P. (2016), Play Fairway Analysis of the Snake River Pain: Phase 1, to be presented at the 40th Stanford Geothermal Reservoir Engineering Workshop.