Finding the Hot Stuff in Oregon

The Geothermal Discovery Well Drilled by Davenport Resources on the Flank of Newberry Volcano

by Al Waibel, Columbia Geoscience and GRC Annual Meeting Technical Program Chairman

A pre-Annual Meeting GRC Fieldtrip will visit Cascade Volcanoes including Newberry Crater departing at 8:30 am on Friday September 26. The two-day trip, led by Trenton Cladouhous, Senior Vice President of Research and Development at AltaRock Energy and David Blackwell, Hamilton Professor of Geothermal Studies at Southern Methodist University, will visit the Newberry EGS Demonstration site including the well described in this article. More information, including registration can be found on the GRC Website at: www.geothermal.org/Annual_Meeting/fieldtrips.html

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Newberry Volcano has been the focus for geothermal exploration for more than thirty-five years. The main attraction for geothermal explorers has been the size of the volcano, the long history of volcanic eruptions on the volcano, and the silicic character of the Holocene lavas. Perceived conflicting cultural use of the volcano by various interests was resolved in 1990 with the passage of the Newberry National Volcanic Monument legislation, which set aside the central part of the volcano, including the caldera and related young volcanic vent areas to the north, as a national monument, to be administered by the U.S. Forest Service. The legislation specifically designated the area outside the monument as open for timber harvest and for geothermal exploration.

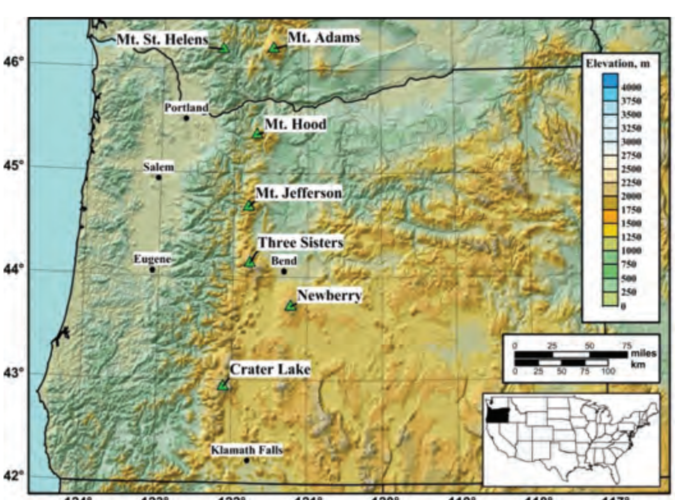

Figure 1. Location of Newberry Crater and other volcanic features in Oregon.

Davenport Resources began exploration for geothermal resources on the volcano in 2002. In 2008 they drilled two deep exploration wells. One well, NWG 46-16, intersected an active geothermal system. The second well encountered high temperatures with no fractures capable of flowing geothermal fluid. Well NWG 46-16 was opened in September of 2012 to bleed off wellhead pressure. The initial flow through a 4-inch bleed line was non-condensable gases, transitioning to liquid phase. This was the first geothermal discovery well drilled on geothermal leases on Newberry Volcano.

A total of four deep exploration test wells have been completed on the upper northwestern flank of Newberry Volcano, two drilled by Davenport (2008) and two drilled by California Energy Company (1994-95) (Figure 2). All four wells exhibited high bottom-hole temperatures, ranging from 550 to 625°F.

Well NWG 55-29 was drilled to a measured depth of 10,060 ft. High temperature, brittle greenschist facies thermally-metamorphosed rock
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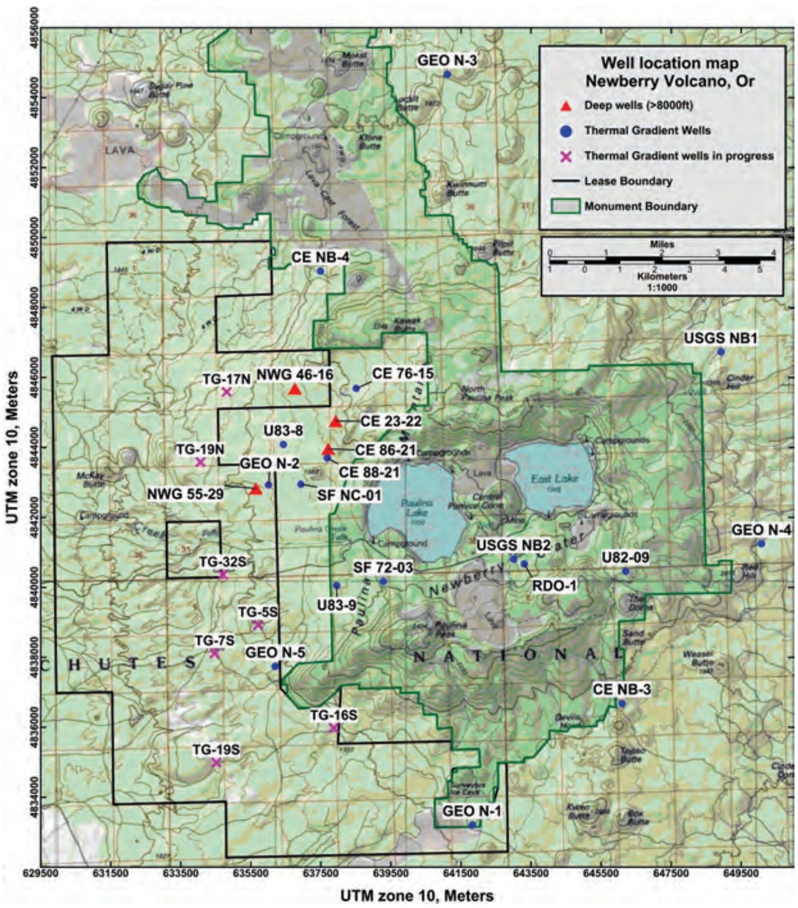

Figure 2. Well location map: Red triangles are deep exploration test wells; Davenport wells NWG 46-16 and NWG 55-29, California Energy wells CE 23-22 and CE 88-21. Blue dots are temperature gradient and shallow test wells. Red x are incomplete Davenport temperature gradient wells.

was intersected at a depth of 6,400 feet. Below 7,500 feet both silicic and basaltic subvolcanic dikes were encountered. The well has a measured bottom-hole temperature of more than 316°C (600°F). Small pulses of non-condensable gas (predominantly CO2) were observed intermittently during drilling, and were more common below 9,200 ft. Drilling perturbations associated with the gas pulses were observed by the driller. These data are interpreted to indicate fracture intersects. No evidence of hydrothermal fluid, fossil or current, were observed in the drill cuttings, and flow testing of the well eventually depleted fluid in the well. This indicates that open fractures were encountered in these wells, though they were isolated with no extended connectivity with larger fracture systems.

Well NWG 46-16, the geothermal discovery well, is the only deep exploration well to have intersected hydrothermal fractures. It was drilled approximately 2 km WNW of well 23-22, encountered epidote facies thermally-metamorphosed volcanic rock at a depth of 7,200 ft. The well was drilled to a measured depth of 11,600 ft., and had an estimated bottom-hole temperature in excess of 316°C (600°F). This well is located within two miles of the caldera boundary. This is the only deep exploration well to have encountered significant evidence of a hydrothermal system. Druze epidote and epidote-quartz crystal clusters were observed in the cuttings at 7,330 ft, 7,360-70 ft, 9,280 ft, 9,350 ft, and 9,400 ft. Significant increases in gasses were observed in these zones, particularly pronounced in the 9,000-9,500 ft range. Non-thermally degradable lost circulation material (LCM) was intermittently added to the drilling fluid below a 120 bbl mud loss between 8,100-8,200 ft. The purpose of the LCM was to try to protect any smaller fractures during drilling, and testing them later after the hole reached Total Depth (TD) and had been logged.

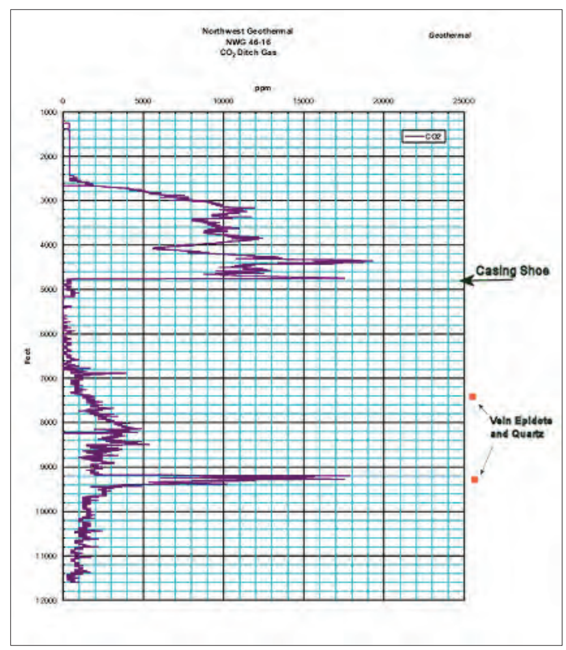

Figure 3. A graph showing CO2 values measured by Epoch Mudlogging during drilling of well NWG 46-16. To the right are noted the depth of the casing shoe and the location of hydrothermally precipitated druse quartz and epidote observed in the drill cuttings. The shallow CO2 shows are attributed to biogenic gas from organic matter within clastic layers.

Well stability problems were encountered in the well when flow testing was attempted. Light gray to gray-green cemented crystal tuff encountered near 5,000 ft. began to fail and come into the hole when well bore fluid was markedly decreased while unloading of the hole for a rig flow test. The tuff had been lithified from compaction. With a formation temperature of about 150°C (300°F), re-crystallization is limited predominantly to phyllosilicates. Evidence of plastic shearing in the tuff was found in recovered rock fragments from the bridge, though no evidence of shear-related permeability is indicated. This cemented tuff does appear to have micro-porosity, with extremely limited permeability. This section of the hole showed good stability during drilling, with high bore-hole fluid pressure. Problems occurred when the hole was unloaded in order to investigate potential geothermal productivity from fractures encountered near and below 9,000 ft. The most likely cause of formation failure/hole instability appears to be from pore-fluid pressure exceeding the formation strength when the fluid pressure in the well bore was reduced.

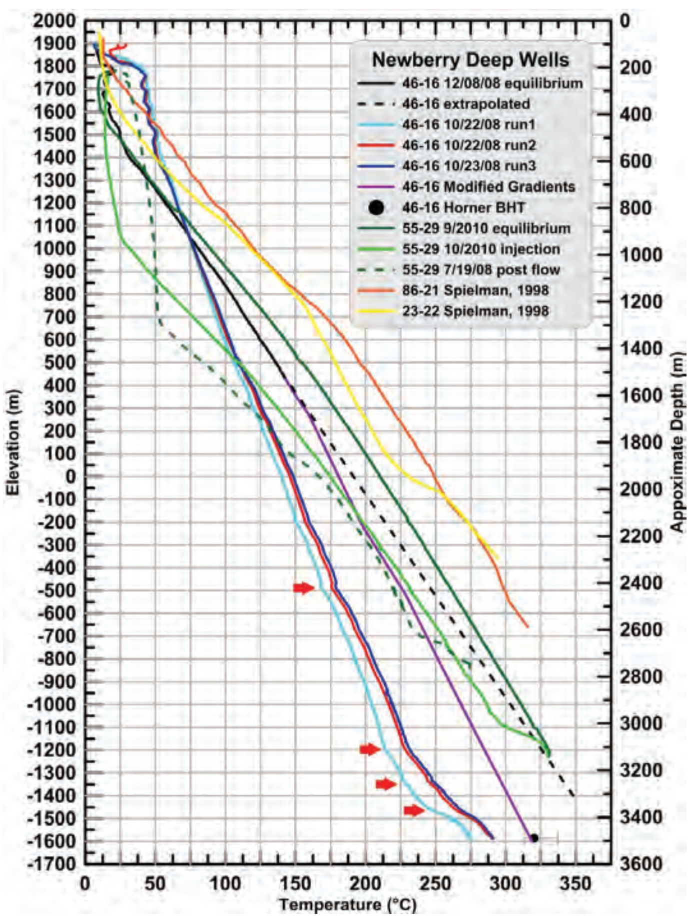

Figure 4 shows the temperature gradient profiles of three of the deep exploration wells, 46-16, 55-29, 23-22 and 86-21. The equilibrium temperature profile for well 55-29 (green) shows a good straight conductive gradient without formation fluid flow. This matches well-site data observed while the hole was being drilled. The profiles for well 46-16 (red and blue lines) show significant perturbations indicative of formation fluid flow affecting the temperature profile of the well. The red arrows are locations where Dr. David Blackwell observed evidence in the temperature profiles of formation fluid flow.

Formation fluid flow from hydrothermal fractures intersected by well 46-16 has shown remarkable resilience in spite of well condition problems. Currently there are four mechanical conditions in the well that have the potential to restrict hydrothermal fluid flow. The bridge in well 46-16 creates a major constriction in the well bore. The bentonite component of the drilling mud entering formation fractures would be irreversibly thermally-metamorphosed to illite, a non-swelling phyllosilicate. This transition is an effective method for constricting fracture permeability. LCM was added to the drilling fluid during drilling. There is no way of reliably estimating where the LCM is and how it may affect fracture permeability in the well at this time. Another unknown is the amount of debris that has accumulated in the lower portion of the well, possibly restricting or blocking flow from any fractures in the bottom 1,000 ft. of the well.

Approximately one year after the well was shut in, it was discovered that the well was producing a steady flow of non-condensable gasses, and that the water level in the well had dropped to approximately 2,070 ft below surface level with a well-head pressure of about 500 psi, measured while logging the well in 2009. Wellhead pressure would build back up to near 600 psi in 3 to 4 hours subsequent to bleeding off the pressure through a 2-inch bleed line. Shut-in wellhead pressure in well 55-29 was also measured at near 600 psi prior to EGS injection tests. Well 55-29 was shut in during May of 2013. As of the second week in August of 2013 the well-head pressure had built back up to 12 psi.

Well 46-16 was opened again on the 8th, 9th and 10th of September, 2013, as part of the Sigma micro-seismic monitoring program. The program called for the well to be opened to bleed off the pressure for about four hours, then shut in to re-build well-head pressure. The goal of this exercise was to stimulate fluid flow within the hydrothermal fractures. The flow line was a four inch pipe with a 90 degree elbow at the end to direct the flow upward (Figures 5 & 6). The well-head valve was opened and a strong flow of gas, reflective of the 600 psi, began. Gas flowed for almost 2 hours, at

Figure 5. Initial gas flow from well NWG 46-16 through a 4-inch bleed line (8 September 2013).

which time the pressure guage showed a reading of 300 psi. After almost two hours the flow changed abruptly from gas to a light brown water, drilling fluid that had been left in the hole. The temperature of the liquid started out as slightly warm, increasing over time to quite warm, though not really hot. The flow of drilling mud lasted for about one and a quarter hours, then changing to gas with short bursts of very thick drilling mud. Variations on this pattern occurred in each of the three flowing cycles.

A few deductions can be made from the well-flowing episodes. Non-condensable gas accumulating within the well bore reached a pressure of 600 psi because it was acting as a piston within the confines of the casing, pushing the liquid level downward within the well, pushing water back into formation fractures. A well-head pressure of 600 psi would indicate a depression of the water column of well over 1,000 ft. The very aggressive gas discharge through the 4-inch flow line is effected by the formation water pressure acting as the piston, pushing the gas out of the well. This action requires liquid flow upward through the bridge, which in turn would require water flow from the formation fractures into the well bore. The flow rate was too low through the bridge and four-inch flow line, and the upper well bore too cool, for steam "flashing" within the well bore to have contributed to the discharge. However, degassing of CO_2 within the liquid ascending within the well likely occurred. The combination of liquid flow from the formation into the well bore and exsolution of CO_2 within the water column appears to have been enough for the well to flow on each of the three days the well was unloaded in September of 2013.

The discovery of a high-temperature geothermal resource by Davenport Resources on Newberry Volcano validates the long-held hypothesis of viable geothermal resources associated with Pleistocene and Holocene volcanism along the Cascade Range of Oregon. Newberry Volcano in particular is now a proven valuable geothermal exploration target.

Figure 6. Author Al Weibel stands next to drilling fluid flowing through a 4-inch bleed line, approximately 45 minutes after the liquid flow commenced (8 September 2013). ■