Overview of the Deep Geothermal Production at the Peppermill Resort

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ABSTRACT

In 2009, Peppermill Resort Casino expanded its use of geothermal waters by drilling at depth into the Moana geothermal resource. The geothermal resource is of meteoric origin and is assumed to be heated by an intrusive body at depth. Past production of fluids from the resource was limited to shallow, Neogene clastic sediments. The first well drilled into the deeper Kat Peak formation was completed in 1988 and was completed as an injection well. In 2007, with the beginning of a large expansion to the facility, it was decided to make geothermal an integral part of the development plan. Two new deep wells were drilled in 2009 and 2010 to provide additional production and injection capacity. These wells demonstrated a significant improvement in temperature and flow over the earlier shallow wells. The use of acoustic and microresistivity logs, combined with other wireline logs and cuttings analysis, helped to develop a more detailed view of the resource. An intensely fractured zone occurs in the highly permeable andesite from approximately 2,500 ft to 3,400 ft. The majority of fractures in the Kate Peak trend northerly with a dip to the west. This data, with existing structural data, allows hypotheses regarding underlying controls of the Moana geothermal resource, as well as a foundation for further economic evaluation for commercial use.

KEYWORDS: Moana KGRA, Truckee Meadows Basin, direct use, Peppermill geothermal, Kate Peak fm

Introduction

The Peppermill Resort Casino in Reno, Nevada, is expanding its use of low-temperature waters from the Moana geothermal resource to achieve its goal of making geothermal waters the primary heat source for its entire facilities. The Peppermill's initial development of geothermal energy began in the early 1980s with production from two shallow wells. Subsequently, a deep well was completed to reinject spent waters. Use of geothermal waters to heat new exterior pools, spas, and domestic hot water for the newly constructed hotel tower in 2008 demonstrated the potential for significant energy savings. In 2009 the Peppermill elected to expand the capacity of its geothermal heating system, resulting in the drilling of two deep wells on its property since August 2009.

This paper will review the history of geothermal development at the Peppermill, discuss our understanding of the Moana geothermal system in light of the recent drilling, and describe changes to the physical plant that will enable the Peppermill to meet virtually 100% of its heating requirements from geothermal energy.

Geothermal Setting – Moana Geothermal Resource

One of the earliest documented uses of the thermal waters of the Moana geothermal resource occurred at the Moana Springs resort, located about ½ mile (0.8 km) south of the present-day Peppermill. The resort opened in 1905. Its amenities included a large bath house with a heated pool fed by thermal waters from the Moana geothermal resource (Nevada Historical Marker 234). Marked expansion of the resource for direct-use heating began in the 1970s, with more than 250 wells and a large-scale district space-heating system providing heat for homes, domestic hot water, swimming pools, hot tubs, at least one driveway de-icing system, and various commercial establishments by 2001 (Flynn, 2001).

Thermal waters in the Moana geothermal resource are meteoric in origin (Bateman and Scheibach, 1975), entering the hydrologic system in the Carson Range just 2 miles (3.2 km) SW of the Peppermill. These waters are presumed to be heated indirectly by an intrusive body at depth, with no contribution of waters of magmatic origin (figure 1). Trexler (2008) reported dilute geothermal fluids produced by the Nevada Geothermal Utility Company of only 900 to 1,300 parts per million (ppm) total dissolved solids from the company's two producing wells. Non-thermal waters in the greater Reno area contain even lower total dissolved solids that average only about 480 ppm, with concentrations of fluoride and arsenic within national drinking standards as opposed to concentrations exceeding these standards for thermal waters (Bateman and Scheibach, 1975).

Moana Geothermal Anomaly, Reno, Nevada

Contour map showing temperature in degrees Fahrenheit at approximately 400 feet below ground level from selected wells displaying bottom hole temperature and calculated temperature at 400 feet below ground level or measured temperature at 400 feet below ground level.

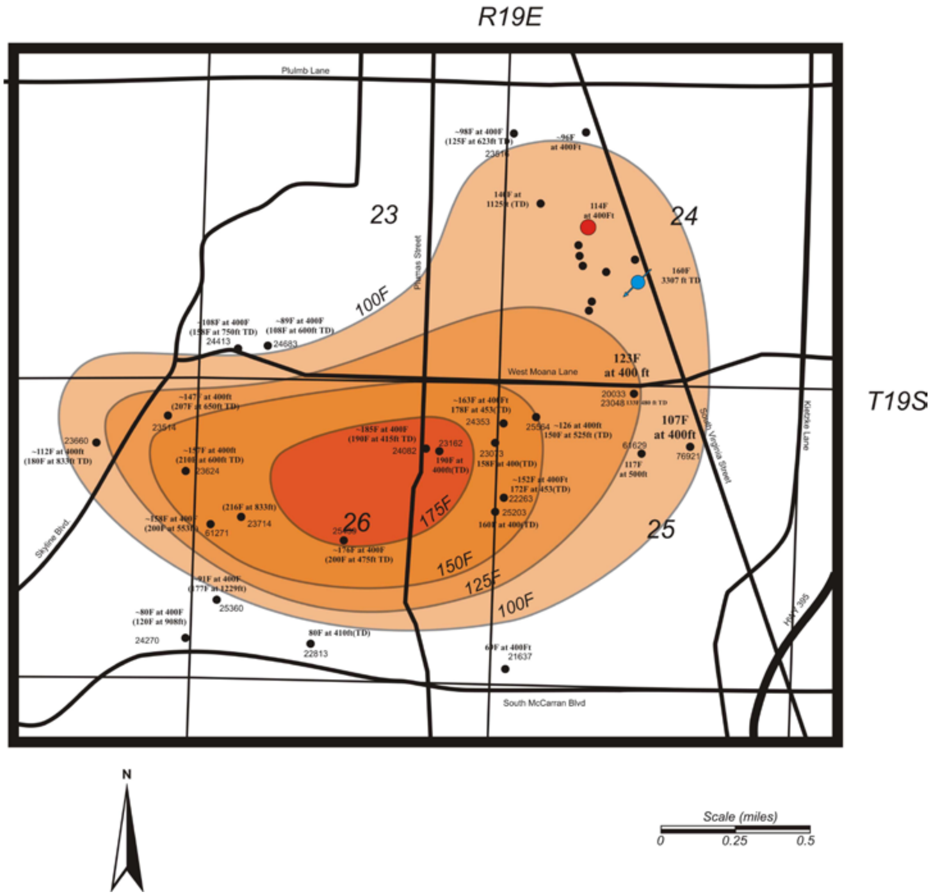


figure 1

Movement of thermal groundwater from the recharge area in the Carson Range to the Moana geothermal resource is thought to be controlled by a series of north-trending faults (Flynn and Ghusn, 1983). Thermal waters convectively rise to near-surface reservoirs along these faults (Flynn, 2001) and migrate laterally into permeable sediments and rock units. The thermal waters cool during this lateral outflow. Prior to the drilling of the two deep Peppermill wells in 2009 and 2010, production of thermal waters in the Moana resource area were from depths ranging from 10 ft (3 m) to 1,000 ft (305 m). Temperatures of usable thermal well water generally ranged from 100°F to 215°F (38°C to 102°C) (Flynn, 2001). The maximum reported temperature is 234°F (112°C) (Trexler, 2008). Although most wells are not capable of artesian flow, a northerly alignment of wells capable of artesian flow suggests the presence of a fault that controls the outflow of thermal waters from its deep source (Bateman and Scheibach, 1975).

Calculations using silica (chalcedony) geothermometry methodology indicate an estimated resource temperature of about 258°F (126°C), which is in close agreement with the estimated temperature of 260°F (127°C) from the alkali geothermometer. We assume that the system is in equilibrium with chalcedony based on geologic descriptions of drill cuttings. A temperature of 210°F (99°C) has been reported in wells located approximately a half mile (0.8 km) SW of the Peppermill which supports the interpretation that the production at the Peppermill is an outflow plume sourced by a deeper 260°F (127°C) system.

Geologic Setting – Truckee Meadows Basin

Reno is located in the Truckee Meadows basin. It is bounded on the west by the Carson Range, which is composed of metasedimentary and metavolcanic rocks, granodiorite, Tertiary volcanics of the Kate Peak Fm., and Quaternary-Tertiary basaltic andesites and basalts. The Virginia and Pah Rah ranges form the eastern boundary of the basin. They consist principally of Tertiary Alta and Kate Peak volcanics, and Quaternary-Tertiary basaltic andesites and basalts. Steamboat Hills, consisting of metasedimentary rocks, granodiorite, Tertiary volcanics of the Kate Peak Fm., and Quaternary-Tertiary basaltic andesites, basalts and hydrothermal sinter, define the Truckee Meadows' southern limits, while Peavine Peak's metavolcanic, granitic and volcanic rocks bound its NW edge.

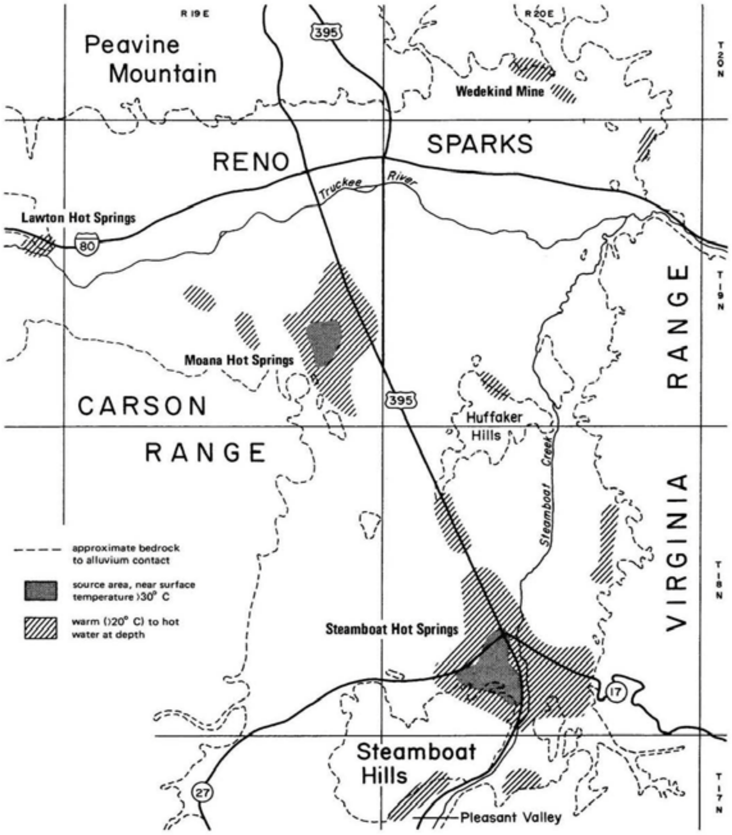
The Truckee Meadows basin is located at the confluence of the Sierra Nevada uplift and Basin-and-Range transition zone. In addition, the Carson domain of the Walker Lane, characterized by NE-trending left-lateral strike-slip faults, abuts the NE edge of the Truckee Meadows (Trexler and Cashman, 2007). The interplay of east-west extension and overall dextral deformation of the Walker Lane may have important implications for understanding the geologic controls on the Moana geothermal resource.

Abbott and Louie (2000), using new and existing gravity data, determined that the elongated Truckee Meadows basin consists of western and eastern sub-basins. Both sub-basins are elongated in a N-NE direction. However, the eastern sub-basin is more markedly oriented. The authors calculated a depth of almost 3,300 ft (1,000 m) to bedrock in the deeper western depression, whereas the eastern sub-basin contains only an estimated 2,000 ft (610 m) of valley-fill sediments and volcanics. As Miocene-Pliocene valley-fill outcrops along the western edge of the western sub-basin indicate recent

Quaternary uplift, subsidence and filling of this sub-basin likely took place entirely during the Neogene.

The Moana geothermal resource is located on the N-NE trending structural saddle between the two sub-basins (figure 2). The Peppermill site lies on the saddle, adjacent to the transition zone from the saddle to the E-SE edge of the western sub-basin.

Structural deformation in the Truckee Meadows began in the middle to late Tertiary (Bonham, 1969), and has continued to the present, as demonstrated by the Mogul earthquake swarm of 2008 that occurred along NW-trending right-lateral strike-slip faults. Young faults are also found at the NW end of the Moana geothermal resource, as presently defined. These N-NE trending normal faults at Virginia Lake juxtapose Quaternary alluvium against Pleistocene glacial outwash deposits.



Map showing areas of known thermal groundwater occurrence in the Truckee Meadows, Washoe County (modified from Bateman and Scheibach, 1975).

figure 2

History of Geothermal Development at the Peppermill Resort Casino

The Peppermill is located on the Moana geothermal resource. Since the early 1980s, the Peppermill has used the resource's low-temperature thermal waters as the primary heat source for the Montego Bay Wing and an exterior pool. Initially, two shallow wells – the

Peppermill #1 and #2 – produced about 127°F (53°C) water from Neogene epiclastic sediments of the informally named, lithologically heterogeneous Sandstone of Hunter Creek at the total rate of approximately 100 gallons per minute (gpm) (6.3 liters per second) from depths between 328 ft (100 m) to 934 ft (285 m). Injection of the spent geothermal fluids into the producing formation was not required by the regulatory agency, allowing the surface disposal of the geothermal waters. However, the Nevada Department of Environmental Protection terminated the Peppermill's permit for surface disposal in 1988, which necessitated the drilling of an injection well. The Peppermill #4 well was drilled from December 1988 to July 1989 to a total depth of 3,307 ft (1,008 m) in andesites of the Tertiary Kate Peak Fm. Sixteen inch (40.6 cm) surface casing was set and cemented at 220 ft (67 m), 10¾ inch (27.3 cm) intermediate casing set and cemented at 1,220 ft (372 m), and 7 inch (17.8 cm) liner hung from 1,220 ft (372 m) to 3,307 ft (1,008 m) with perforations from 2,600 ft (792 m) to total depth. It was flow tested using air-lift from approximately 180 ft (55 m). Results indicated the well was capable of producing 160°F (71°C) water at the rate of 170 gpm (10.7 liters per second) under artesian conditions. It was completed as the disposal well, with the injection of the spent geothermal fluids into permeable volcanic andesites below 2,620 ft (799 m).

In 2007, the Peppermill began construction on a large expansion of their facility, adding over 500,000 square feet (46,452 square meters) of finished space and a new centralized power plant that would become an integral component of the geothermal master plan. As part of this expansion, the Peppermill furthered the use of the existing shallow wells by adding a heat exchanger and heating the new exterior pools, spas, and domestic hot water for the new Tuscan Tower. In 2009, as a result of significant energy savings from the limited geothermal development, the Peppermill elected to expand the capacity of its geothermal heating system, making it the primary heat source for the entire campus.

The Peppermill #8 well was drilled in August-September 2009, reaching total depth of 4,421 ft (1,348 m) in andesites of the Kate Peak Fm. It was completed as a production well with 13⅜ inch (34.0 cm) surface casing set and cemented at 1,509 ft (460 m) and a 9⅝ inch (24.5 cm) perforated liner hung from 1,415 ft (432 m) to 4,421 ft (1,348 m). The well was tested flowing 1,185 gpm (74.8 liters per second) of 175°F (79°C) water from highly fractured altered andesite, exceeding the required fluid temperature and flow rate. This volume of new production, however, required drilling an additional well to supplement the Peppermill's injection capacity. Because the second well was designed as an injection well it had to meet more stringent design criteria. The Peppermill #9 was drilled in December 2009 to January 2010 to total depth of 3,900 ft (1,189 m) in the Kate Peak andesites. Twenty inch (50.8 cm) surface casing was set and cemented at 483 ft (147 m), 13⅜ inch (34.0 cm) intermediate casing set and cemented at 2,202 ft (671 m), and 9⅝ inch (24.5 cm) perforated liner hung from 2,091 ft (637 m) to 3,896 ft (1,188 m). The liner was perforated between 2,361 ft (720 m) and 3,859 ft (1,176 m). The well was tested flowing 345 gpm (21.8 liters per second) of 153°F (67°C) water from highly fractured altered andesite. An injection rate of 708 gpm (44.7 liters per second) at 246 pounds per square inch (psi) (1.69 MPa) was achieved during injection testing. Both vertical wells were extensively logged, including image logs acquired in the Peppermill #8.

The primary challenge encountered during the drilling process was from sloughing clayey formations in highly altered zones. Simple gel-based mud was used in order to avoid contamination of the aquifer; no stabilization additives were added to the drilling fluids. It was occasionally necessary to “wait-out” the running formation and allow it to reach an angle of repose before drilling ahead. The surface and intermediate drilling presented few problems.

Impact of Recent Drilling on Understanding of the Moana Geothermal Resource

Wellsite lithologic logs and a robust suite of open-hole wireline logs, including acoustic and microresistivity imaging logs in the Peppermill #8 well, have provided a window into the subsurface. Uniting the new deep-well data with reflection seismic lines recently acquired by the United States Geologic Survey (Frary, 2009) and Abbott and Louie's (2000) gravity modeling will greatly improve the current understanding of the geology of the Truckee Meadows basin.

The stratigraphic section penetrated by the Peppermill #8 and #9 wells is laterally consistent overall. However, lithologic heterogeneities and structural complexities challenge correlation of units between these two wells located only a quarter mile (0.4 km) apart.

A 185 ft (56 m) thick interval of Quaternary pebble-cobble gravel was penetrated from surface. This gravel is mapped as the Pleistocene Donner Lake Outwash by Bonham and Rogers (1983). The gravel was clay-free, containing predominantly volcanic and common granodiorite rounded clasts. Sand grains consisted almost entirely of dark gray volcanic clasts.

A thick interval of undifferentiated Neogene sediments was cut below the pebble-boulder gravel. In the #9 well, it is likely that the initial 190 ft (60 m) of drilling cut gravel, sand, and clay of Bonham and Roger's (1983) Pleistocene Alluvial fan deposits of Peavine Mountain before penetrating sediments of the Miocene-Pliocene Sandstone of Hunter Creek. However, the Alluvial fan deposits of Peavine Mountain unit is apparently missing in the #8 well, as it cut into the Sandstone of Hunter Creek immediately below the Pleistocene gravels.

The Sandstone of Hunter Creek is a heterogeneous unit, consisting of clay, diatomaceous mudstone, sand, and gravel. Sand is the dominant lithology, composed principally of volcanic clasts. Gravels consist of both rounded and well rounded andesitic and granitic clasts. Clays range in hues from medium to dark gray, brownish gray, and pale brown. Diatomaceous mudstone was only present in an 85 ft (26 m) interval, interbedded with brownish gray clay, in the #8 well. Fractures and striations characterized the diatomaceous mudstones.

The top of the Miocene Kate Peak Fm. in the Peppermill wells was identified by a reverse drilling break, a noticeable increase in drilling-mud temperature, and first appearance of andesite cuttings. The andesite in the #9 well possessed a brownish gray matrix mottled by dark yellowish brown and light gray to white irregular patches. Its texture was sugary. Phenocrysts consisted of milky white to clear feldspar and black hornblende crystals. Rare fractures were filled by calcite and chloritic clay.

Approximately 1,010 ft (308 m) in the #8 well and 1,840 ft (561 m) in the #9 well of heterogeneous lithologies, consisting of andesite, clayey andesites, and clay, were cut in the upper section of the Kate Peak volcanics before a lower section dominated by andesite with only rare clay was penetrated. The principal geothermal reservoir rock is found in this lower unit. It consisted of medium to medium dark gray, dark greenish gray, and medium gray-green andesite mottled by light gray patches. Greenish cast is suggestive of slight propylitic alteration. Common milky white feldspar and rare hornblende phenocrysts up to 1 mm in length, rare disseminated euhedral pyrite crystals, and occasional calcite and chloritic fracture-fill are present.

Differentiation of the upper Kate Peak interval from the lower volcanics, and the permeable reservoir from the tight non-reservoir volcanics is readily made using open-hole wireline logs. The upper Kate Peak is characterized by long intervals with low deep-resistivity values of less than 5 ohm-meters interspersed with occasional indurated andesites with deep resistivity values between 10 and 40 ohm-meters. Deep-resistivity values in the lower Kate Peak are predominantly greater than 1,000 ohm-meters. The high permeability geothermal reservoirs in the lower Kate Peak are characterized by an invasion profile exhibiting abnormally large separation of shallow-reading versus deep-reading resistivity curves, slower acoustic velocities, and washouts that identify highly fractured and/or faulted intervals.

The borehole acoustic (STAR) and microresistivity (CBIL) imaging logs recorded by Baker Atlas in the #8 well clearly display the intense fracturing developed in the highly permeable andesite zone from approximately 2,500 ft (762 m) to 3,400 ft (1,036 m). These images confirm the interpretation that the well developed invasion profile seen on the Baker Atlas resistivity (HDIL) log is the result of highly fractured rock. This separation of the resistivity curves is a result of the deep-reading resistivity device being less influenced by fracturing than a shallow-reading device. A temperature profile run in the #8 after three months of shut-in provides the final confirmation that this zone produces the geothermal waters.

An east-west structural cross-section through the Peppermill #8 and #9 wells and the Salem Plaza Condominium Association Inj.-1 well demonstrates the faulted, segmented nature of the east-dipping sediments and volcanics in this portion of the Truckee Meadows basin. Furthermore, interpretation of the two east-west reflection seismic profiles acquired by the U.S.G.S. in 2009 (Frary and others, 2009) – one line 2 miles (3.2 km) north of the Peppermill along the Truckee River from Keystone Ave. to Rock Blvd., the second line 0.9 mile (1.4 km) south of the Peppermill on Mazanita Dr. from just east of S. McCarran Blvd. to just west of S. Virginia St. – corroborates the interpreted structure based solely on well data.

These data can be used to hypothesize about the underlying controls on the Moana geothermal resource, as well as the geologic history of the Truckee Meadows basin. Questions to be addressed include the following. 1) What is the source of the heat for the geothermal waters of the Moana resource? 2) What are the migration pathways for these heated waters from the heat source to the geothermal reservoirs? 3) What factors control the location of the hottest waters as well as the highest flow rates? 4) What is the areal extent for economical development of the Moana resource?

Speculation on the heat source for the Moana resource can be made by analogy to the geothermal resource at Steamboat Springs. Silberman and others (1979, p. D1) state, "The source of energy for the thermal convection system is probably a large rhyolitic magma chamber that supplied the pumice and from which the rhyolite domes were emplaced." The domes to which Silberman and others (1979) referred are aligned N50°E along a 6¾ mile (11 km) trend, from the SW edge of the Steamboat Hills to the western boundary of the Truckee Meadows with the Virginia Range. Farther north, the Huffaker Hills volcanic outcrop trends N25°E, as does a subpopulation of faults in the Carson Range two miles (3.2 km) SW of the Peppermill and two young faults ¾ mile (1.2 km) SE of the Peppermill. The Moana geothermal resource extends off a NE-plunging nose of the Carson Range. And, the general direction of ground-water movement from the Carson Range into the Truckee Meadows basin is to the NE (Bateman and Scheibach, 1975). All these observations support the conclusion of NW-directed extension along NE-striking fault zones in the Truckee Meadows basin.

There is a second subpopulation of faults in the Truckee Meadows that trend northerly, the most prominent example being the Virginia Lake faults a half mile (0.8 km) west of the Peppermill. The image log in the Peppermill #8 well clearly shows the majority of the fractures in the lower Kate Peak volcanics trend northerly with west dip. However, there is a small number of fractures which trend N35°E with dips to both the NW and SE. The question to examine is two-fold. 1) Which set of fractures is more permeable (i.e., open)? 2) What is the relationship, if any, among the numerous structural trends found in the Truckee Meadows?

It is important to recognize that the Truckee Meadows is an area where diverse deformational trends meet: the extension of the Basin-and-Range and Sierra Nevada block, the right-lateral strike-slip shear in the Pyramid Lake domain of the Walker Lane NW of the Truckee Meadows, as well as the left-lateral strike-slip deformation of the Carson domain as exemplified by the Olinghouse fault immediately NE of the Truckee Meadows (Trexler and Cashman, 2007).

Faulds and others (2003) addressed the question concerning geologic controls on the location of the Desert Peak and Brady geothermal fields in the Hot Spring Mountains, located about 50 miles (80 km) NE of Reno. They speculate that the regional W-NW extension of the Basin-and-Range may be accentuated by the left-lateral shear of the Humboldt structural zone. They state (Faulds and others, 2003, p. 36 and 37), "A small component of sinistral shear, combined with both regional west-northwest-directed extension and greater fault and fracture density associated with the transfer of strain between the many en echelon overlapping normal faults, may promote the deep circulation of fluids along north-northeast-striking fault zones within the Hot Spring Mountains and other parts of the Humboldt structural zone." A similar explanation may apply to the geologic controls on the location of the Moana geothermal resource in the Truckee Meadows basin.

An alternate hypothesis suggests a deep NE-trending master fault zone with principally oblique dip-slip and a component of left-lateral shear controls the heat source of the thermal waters, which is overlain by a system of north-trending faults and fractures. The deep master fault system may die out upward, with shallow deformation controlled by Reidel shearing associated with the deep left-lateral shearing. Thus, the NE-trending faults would control movement of thermal waters from the heat source, and the north-trending fractures and faults, in combination with brittle andesitic lithologies, would control the distribution of permeable, high productivity reservoirs (figure 3).

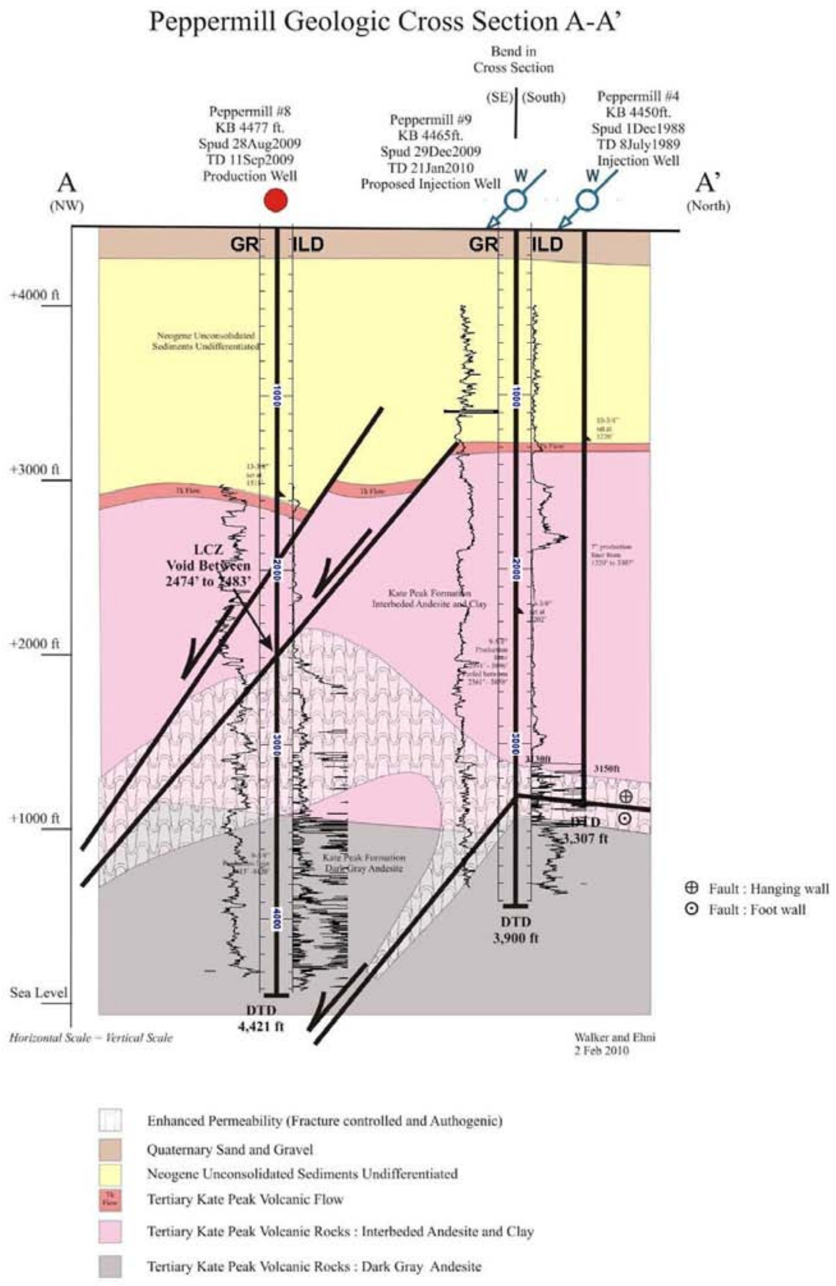


figure 3

Peppermill's Current Geothermal Operations

The Peppermill's new production and injection system is anticipated to be online by early summer of 2010. The new system utilizes well #8 as the sole production well, and discontinues geothermal water production from the shallow wells #1 and #2. A sophisticated submersible pump, capable of a flow rate of 1,400 gpm (88.3 liters per second) and controlled by a variable frequency drive, is placed at depth of 400 ft (122 m) and pumps the 170°F (77°C) water to a heat exchanger in the New Central Plant. After the heat exchanger in the New Central Plant extracts the heat, the 130°F (54°C) water is pumped over to the existing Tuscan Tower heat exchanger. From the Tuscan Tower, the water is pumped to a 400 horsepower horizontal injection pump. This pump is a capable of producing a 400 psi (2.76 MPa) head on the discharge side of the pump. This horizontal pump sends the 110°F (43°C) water into both disposal (injection) wells #4 and #9. This new system is estimated to reduce the Peppermill's natural gas consumption by 85%. Given the size of the campus this reduction in natural gas consumption equates to considerable savings making this a very sound investment. In addition to the direct cost savings of the geothermal system, the Peppermill has also positively benefited from the green energy using it in their marketing efforts. At this time, no future drilling is planned on the Peppermill property. However, the Peppermill does own adjacent land and buildings, and the use of geothermal heating for these buildings is a consideration. On a larger scale, the clear demonstration of the availability of large volumes of moderate temperature fluids in the Kate Peak Fm. holds promise of an even greater application of direct-use geothermal in the Moana geothermal resource.

The success of the deep drilling program at the Peppermill Resort has spurred a good deal of interest in developing the moderate temperature resource of the Moana geothermal resource (figure 4). The area is well-developed, and the expansion of district heating as well as larger commercial applications such as the Peppermill's could much benefit from additional deep-resource exploration. There has been some discussion of low enthalpy, utility-grade development as well, but further evaluation is needed to determine if this resource has that potential.

figure 4

References

Abbott, R.E., and J.N Louie, 2000, Depth to bedrock using gravimetry in the Reno and Carson City, Nevada, basins: *article available on web at* http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.40.8745&rep=rep1&type=pdf

Bateman, R. L., and R. B. Scheibach, 1975, Evaluation of geothermal activity in the Truckee Meadows, Washoe County, Nevada: Nevada Bureau Mines and Geology Report 25, 38 p.

Bonham, H.F., 1969, Geology and mineral deposits of Washoe and Storey counties, Nevada: Nevada Bureau of Mines and Geology Bulletin 70.

Bonham, H.F., Jr., and E.C. Bingler, 1973, Geologic map, Reno Folio: Nevada Bureau of Mines and Geology Environmental Series, Reno Area.

Bonham, H.F., Jr. and D.K. Rogers, 1983, Mt. Rose NE quadrangle geologic map: Nevada Bureau of Mines and Geology Map 4Bg.

Faulds, J.E., L.J. Garside, and G.L. Oppliger, 2003, Stratigraphic and structural framework of the northern Hot Springs Mountains, Desert Peak and Brady geothermal fields, northwestern Nevada: *in* S. Foster, ed., Oil, gas, and geothermal occurrences in northwestern Nevada: Nevada Petroleum Society 2003 field trip guidebook, pp. 31-38.

Flynn, T., 2001, Moana geothermal area, Reno, Nevada – 2001 update: Geo-Heat Center Quarterly Bulletin, v. 22 no. 3, p. 1-7.

Flynn, T., and G. Ghusn, Jr., 1983, Geologic and hydrologic research on the Moana geothermal system, Washoe County, Nevada: US DOE Session 15, Geothermal Research in Nevada.

Frary, R., W. J. Stephenson, J. N. Louie, J. K. Odum, J. Z. Maharrey, M. Messmer, I. Tomlinson, E. F. Littlefield, A. Hughes, S. Jha, K. Kohls, M. S. Dhar, S. Konkol, A. Wakwak, P. H. Cashman, J.H. Trexler, R. Kent, and C. Hoffpauir, 2009, Preliminary analysis of high-resolution seismic imaging profiles acquired through Reno, Nevada, for earthquake hazard assessment: presented at 2009 American Geophysical Union Fall Meeting, Dec. 14; abstract in Eos Trans. AGU, 90(52), Fall Meet. Suppl., Abstract NS13A-1135.

Nevada Historical Marker 234: *article available on web at* http://nevadaculture.org/shpo/index.php?option=com_content&task=view&id=381&Itemid=9

Silberman, M.L., D.E. White, T.E.C. Keith, and R.D. Dockter, 1979, Duration of hydrothermal activity at Steamboat Springs, Nevada, from ages of spatially associated volcanic rocks: U.S.G.S. Professional Paper 458-D.

Trexler, D.T, 2008, Nevada Geothermal Utility Company: Nevada's largest privately owned geothermal space heating district: Geo-Heat Center Bulletin vol. 28, no. 4, Oregon Institute of Technology, January 2008, pp.13-18.

Trexler, J. T., and P.H. and Cashman, 2007, Neogene basins of northwestern Nevada: *in* S.H. Limerick, ed., Geology, geothermal resources and petroleum exploration of Neogene basins in the Reno, Nevada area: Nevada Petroleum Society 2007 field trip guidebook, pp.29-49.