Deep Blue No.1—A Slimhole Geothermal Discovery at Blue Mountain, Humboldt County, Nevada

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Keywords

Geothermal, drilling, temperature and pressure surveys, basin and range, gold mineralization, hot springs, hydrothermal alteration, maximum registering thermometers, core tube data logger, gradient, well stimulation, flow testing, slimhole, Nevada

ABSTRACT

The purpose of this paper is to provide a summary of the geology, drilling operations, and down-hole measurements obtained during the drilling of Deep Blue No.1. This well was sited on the basis of proximity to numerous gold exploration holes that indicated thermal water, high temperature gradients recorded in the 12 shallow gradient holes, and low resistivity values associated with certain interpreted major faults. The well was targeted to intersect fracture zones associated with the West and Central Faults, two prominent west-dipping normal faults identified on the western flank of Blue Mountain, within the main thermal anomaly. The maximum temperature recorded in the well was 292.5°F (144.7°C) at a depth of 2114.6ft (644.5m).

Introduction

Noramex Corp., a Nevada company, owns a 100% interest in geothermal leases at the Blue Mountain Geothermal Area in Humboldt County, Nevada. Noramex is a wholly owned subsidiary of Nevada Geothermal Power Inc.

The Blue Mountain prospect comprises 12 sections of geothermal leases, located 20 miles (32km) west of the town of Winnemucca, Humboldt County, Nevada (Figure 1, Location Map). The prospect is centered at 118° 08' W. Lat. and 41° 00'N. Long, at the base of Blue Mountain, located at the southern end of the NNE-SSW trending Desert Valley. The project site is 15 miles (24km) over relatively flat, undeveloped lands to the Rose Creek Substation, on a 120kV transmission line owned by Sierra Pacific Power Company. The Blue Mountain geothermal leases are ideally situated for electric power development, with no obvious environmental, cultural, social, or logistical impediments to drilling operations or future geothermal steam field and power plant development.

In the fall of 2000, Noramex was awarded a cost share program under the US Department of Energy's "Geothermal Resource Exploration and Definition Program". Phase I of the program was an evaluation report on the geothermal potential of the Blue Mountain area prepared for DOE (Fairbank, 2000). Phase II provided for drilling the first intermediate depth (nominal 2296ft/700m) test hole, designated Deep Blue No.1 (DB1), at Blue Mountain. The well was drilled from April 27 to June 12, 2002.

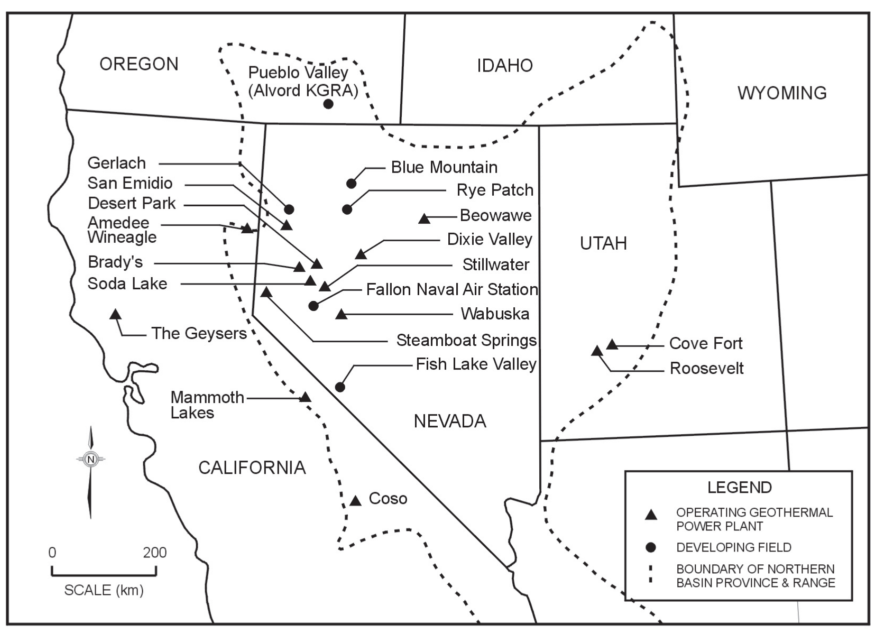

Figure 1. Location Map.

Hot water was originally 'discovered' at Blue Mountain during drilling for precious metals. Approximately $2,000,000 was expended on precious metals exploration, including detailed geologic mapping, geochemical sampling, aeromagnetic, ground magnetic, IP-resistivity, gravity, and seismic surveys, and over 25,000ft (7,600m) of drilling in seventy-seven drill holes, all less than 500ft (150m) deep. Hot water up to 190°F (87°C) was encountered in many mineral exploration holes drilled and artesian flows of 20 – 30 gpm (1.3 – 1.9 L/sec) at an average temperature of 175°F (80°C) were recorded in six holes (Fairbank et al, 1999).

From 1996 to 1999 an initial geothermal evaluation was completed including geological, self potential (SP), resistivity surveys and temperature gradient measurements in twelve holes to depths ranging from 164ft to 705ft (50m to 215m), with assistance from the Energy & Geoscience Institute (EGI), Utah (Ross et al 1999). The work defined a two square mile thermal zone open in all directions. Well DB1 confirmed minimum temperatures of approximately 300°F (150°C) for the inferred geothermal resource at Blue Mountain.

Geology

The Blue Mountain project area is located in the Basin and Range geomorphic province of northern Nevada, characterized by high terrestrial heat flow related to crustal extension and thinning resulting in tertiary, quaternary and recent lateral and normal (block and/or detachment) faulting. The Blue Mountain geothermal prospect lies in a complex structural setting, at the intersection of range front fault systems that trend northeast and northwest, and a third set of faults that trend north-south (Figure 3).

Siliclastic metasedimentary rocks of the Triassic Grass Valley and Raspberry Formations underlie the Blue Mountain area. The Grass Valley Formation, exposed on the west slope of Blue Mountain, consists of gray to black, thin bedded, non-calcareous, carbonaceous platy argillite and intercalated, thin to thick, mature sandstone beds. Younger Raspberry Formation gray to gray-green, laminated, silty, and locally sandy phyllitic mudstone forms a low bench at the base of Blue Mountain. White, unmineralized quartz veins crosscut both units and are products of greenschist facies metamorphism along with chlorite and muscovite. The contact between the Grass Valley and overlying Raspberry Formation dips shallowly to the west.

Diabase dikes intrude the sedimentary rocks along steeply dipping north-trending structures and form a major dyke swarm on the west flank of Blue Mountain. Variably altered, light gray quartz-feldspar porphyry dikes were intersected in many of the mineral exploration drill holes. Alunite from a felsic dike outcrop yielded a K-Ar date of 3.9 Ma (Garside et al, 1993). Alunite is associated with the gold-mineralizing event at Blue Mountain and the age-date probably represents a minimum age of geothermal activity associated with paleo-hot spring gold mineralization.

Stratified lacustrine deposits, younger pediment gravel and sand mask bedrock geology in the broad valley west of the known gold and geothermal zone at the foot of Blue Mountain.

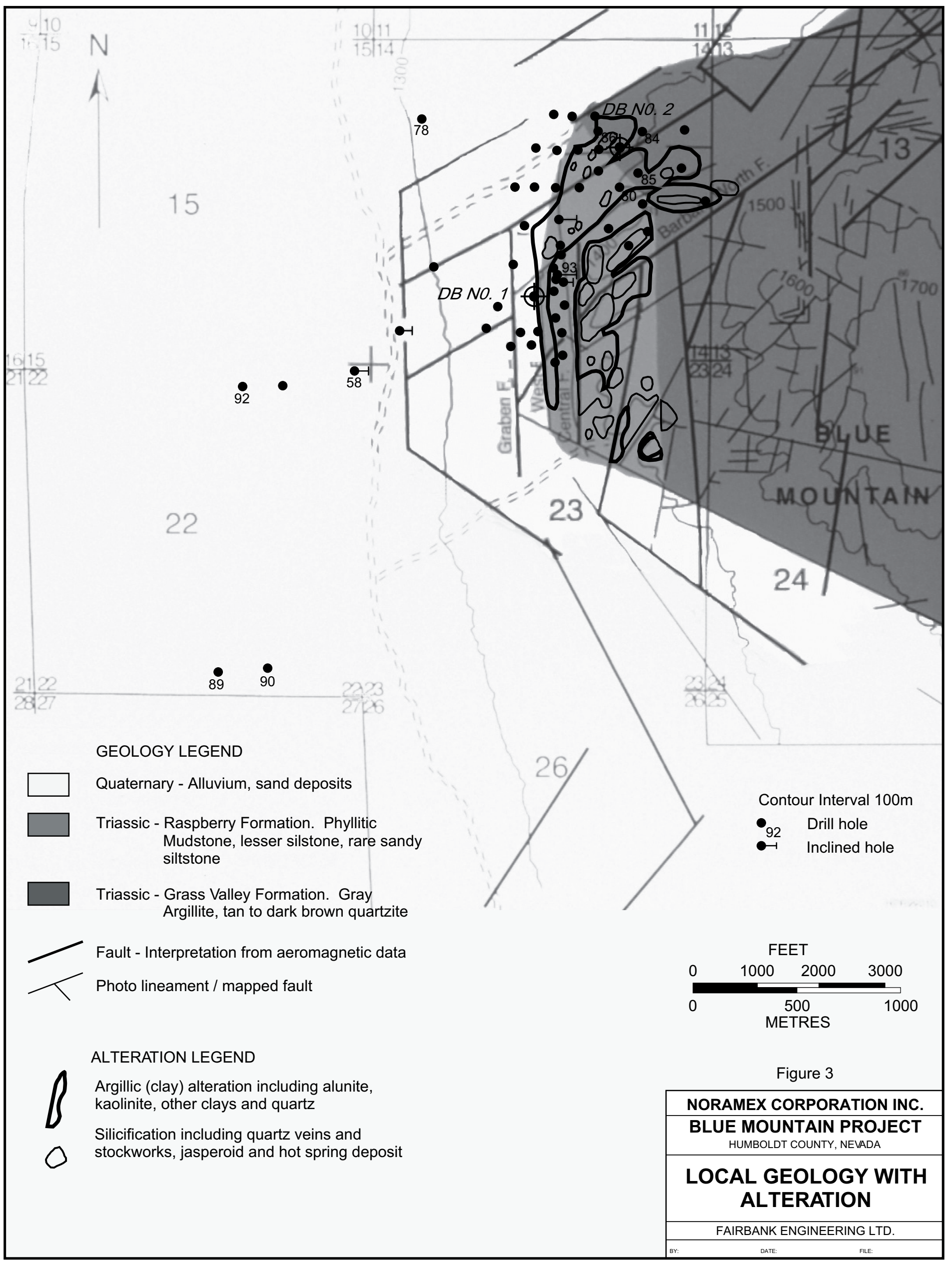

Figure 3. Local Geology with Alteration.

Three sets of normal faults at Blue Mountain are important controls of geothermal fluid movement. Northwest (305° azimuth) and northeast (055°) trending high-angle normal faults of Tertiary to Recent age, formed in response to widespread crustal extension. North-striking, west-dipping normal faults offset gold mineralization and have produced prominent scarps along the base of the range (Sadlier-Brown, 2001).

Alteration is extensive throughout the prospect area and is most intense along or at the intersections of faults and fault zones. Alteration includes quartz veins and stockworks, intense silicification, chalcedonic and opaline silica hot spring deposits, moderate to advanced argillic alteration, alunite and quartz-alunite replacement and veining, and pervasive hematite formation, especially in the silica-altered rocks.

Recent work by Sandra Wyld (2002) indicates that presently accepted stratigraphic and structural models for the Blue Mountain area require a review. A fieldwork study by Fairbank Engineering Ltd. to revise the geology of the project area is in progress.

Drilling

DB1 was drilled by Dynatec Drilling Inc., using a truck-mounted UDR 1500 drilling rig with a hydraulic top drive, equipped for both conventional rotary drilling and wire line continuous coring diamond drilling operations.

The well was spudded April 27, 2002 with continuous drilling operations, in two 12 hour shifts. The hole was drilled with water-based bentonite and polymer mud. The well was completed to a total depth of 2205 ft (672.1m) using conventional rotary drilling to 367ft (111.9m) and continuous coring from 367ft to 2205ft bottom. Severe lost circulation problems were encountered in the upper section of the hole which caused considerable difficulty with the drilling and cementing operations for the 7" and 4 ½" cased intervals of the well. A combination string of blank and slotted NQ liner (2.75" OD) was set into the hole to a depth of 2165ft (659.9m) (Figure 2). Total drilling time for the well was 43 days (spud to TD), and 47 days from spud to rig release on June 12, 2002.

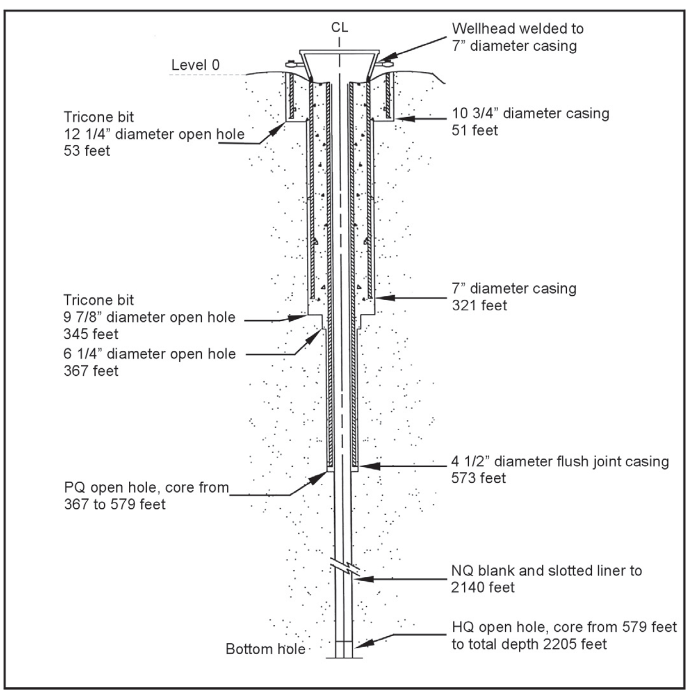

Figure 2. Schematic of completed well ~ DEEP BLUE No. 1.

DB1 core encountered variably fractured and veined, fine-grained metasedimentary rocks of the Raspberry and Grass Valley Formations and two types of intrusive rocks: fine-grained, strongly altered and mineralized felsic dikes, and generally less altered, fine to medium grained felsic to intermediate dikes (Figure 4, overleaf).

Pale gray mudstone of the Raspberry Formation grades downward to gray-black argillite and mudstone of the Grass Valley Formation at a depth of about 200ft (61m). The contact between the two formations has been interpreted as a thrust fault that may have been a major focus for gold mineralization (Percival, 1993).

Silicified rocks are prominent below approximately 130ft (40m), with pyrite becoming increasingly abundant from 180 to 230ft (55 to 70m). Strongly altered, veined, and mineralized felsic dikes may be genetically related to the gold mineralization in the area. There is no clear indication of the main gold zone in DB1 because of the proximity of the well to the West Fault.

In addition to widespread open fractures, the intensity of quartz veining observed in many intervals of core indicates a high degree of fracturing and fluid flow. Silica-bearing fluids, almost certainly hotter than 392°F (200°C), moved through fractures and deposited chalcedonic to coarsely crystalline quartz. The extent of deposition was such that many heavily veined to quartz-flooded intervals are now sealed.

Hydrothermal alteration adjacent to fractures and veins is variable in intensity, and is absent in many instances. An interval of soft, pale gray sandstone at 725 to 737ft (221 to 225m) is veined and argillically altered, forms the hanging wall of a fault zone exhibited by extremely broken argillite and clay-rich fault gouge from 737 to 789ft (225 to 240.5m). Pervasive silicification is the most widespread form of alteration in argillite and mudstone.

Drusy and vuggy veins or open fractures and cavities are present throughout most units intersected in the well. Permeability has not been quantified, but has been estimated as 'moderate' to 'high' in many intervals with open fractures 1 to 10 mm wide.

Temperature Measurements While Drilling

Bottom hole temperature (BHT) data were collected during the drilling of DB1 using maximum registering thermometers (MRT), and a core tube thermistor data logger tool provided by the Sandia National Laboratories (US Department of Energy) without significant interruption or disruption to the on-going drilling operations. Sandia National Laboratories core tube data logger thermistor tool had an upper temperature limit of 212°F (100°C) so it was used only in the uppermost section of the well. Although the BHT measurements are not equilibrated, the BHT profile provides a good indication of in-situ temperature conditions.

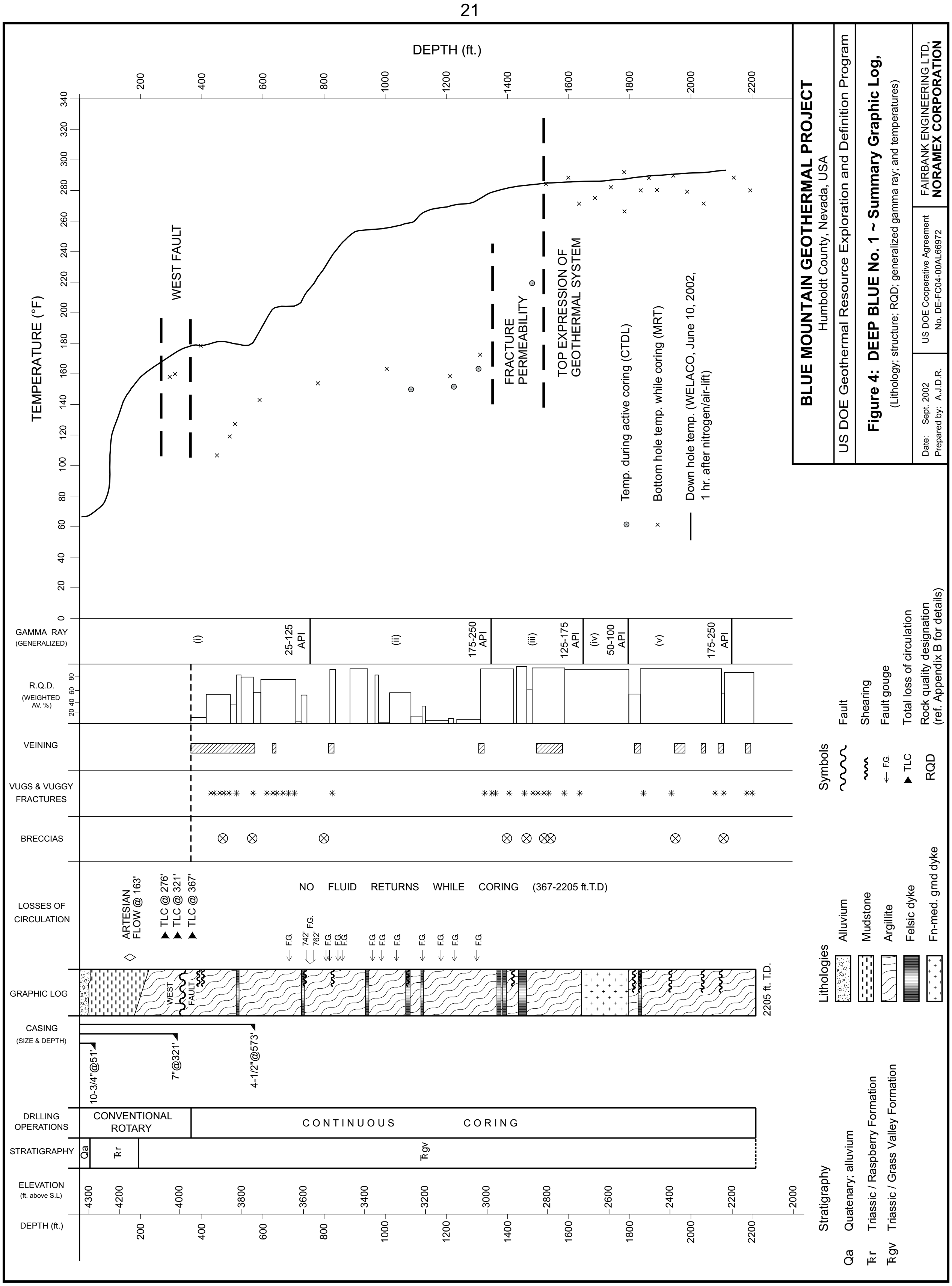

Figure 4. DEEP BLUE No. 1—Summary Graphic Log.

Partially equilibrated temperatures of 158°F (70°C) at 295ft (90m) and 178°F (81°C) at 394ft (120m) indicate hot water at shallow depths in the West Fault (Figure 3). MRT and data logger temperatures recorded during coring between 449 and 1309ft (137 to 399m) gave non-equilibrated temperature readings of 106°F to 174°F (41° to 79°C) in relatively impermeable rocks. Below 1339ft (408m), substantial fracture permeability was encountered and unequilibrated BHT's increased steeply to 271°F (133°C) at 1545ft (471m). From 1545ft (471m) to the eventual bottom of the hole, BHT measurements stayed within a narrow range between 271° to 291°F (133° to 144°C) in moderately veined, generally less permeable rock.

Well Logging after Completion

A suite of down-hole temperature, pressure and gamma ray logs was run by Welaco Well Analysis Corporation, of Bakersfield, California, twenty-six hours after the well was shut in. A second suite of temperature, pressure and gamma ray logs was run the following day, after a well discharge attempt using nitrogen stimulation. The maximum depth reached with the Welaco logging tools was 2115ft (644.7m). The maximum temperature recorded was 292.5°F (144.7°C), at a depth of 2,114.6ft (644.5m).

The temperature log shows temperatures increasing rapidly to approximately 177°F (81°C) at about 427ft (130m). The interval from about 377 to 590ft (115 to 180m) is essentially isothermal, at a temperature of 176°F (80°C). This interval corresponds to the section of hole below the 7" casing shoe, to the shoe of the 4 ½" casing at 573ft (174.7m), through the West Fault. There may be some down-flow of hot water originating from the West Fault, behind the 4 ½" casing over this interval of the hole.

Post drilling temperatures increase sharply below the 4 ½" casing to 248°F (120°C) at a depth of about 900ft (274m). The temperature continues to rise steadily with increasing depth to about 286°F (141°C) at 1650ft (502.9m). This section of the hole between 574 ft and 1650ft (175m and 503m) has heated up relative to the BHT profile measured while drilling. Hot water appears to be convecting up the hole from greater depths and/or thermal water may be entering the hole from the permeable formation interval below 1339ft (408m). Below 1650 ft (503m) temperatures increase marginally to a maximum recorded temperature of 292.5°F (144.7°C) at a depth of 2114.6ft (644.5m), the maximum depth reached with the Welaco logging tools (Figure 4).

There was also significant heating in the upper section of the hole in the cased section above the 7" casing shoe (321ft/97.8m), where a temperature increase of 12°C is observed at a depth of about 164ft (50m), the depth of the artesian flow intersected in the well.

The pressure logs, taken 26 hours after the well had been shut in, record a hydrostatic gradient, with the fluid level in the well indicated at a depth of about 95ft (29.0m); this is higher than the water level recorded in the well during drilling, 164 to 180ft (50 to 55m).

Well Stimulation

After the well was completed an attempt was made to discharge the well to obtain samples of the well fluid. A 6" horizontal discharge line fitted with a 6" gate valve (geothermal trim), upstream and downstream pressure gauges, temperature probe, 2 x 1" sampling ports, and a 6" James tube was connected to the flow 'T' of the rotating head.

Nitrogen was used to pressure up the well through an NQ liner which was slotted below a depth of 885ft (270m) in order to depress the water level in the well. Well pressure could not be maintained because of leaks in the rotating head and the gate valve in the horizontal discharge line. Nitrogen injection did airlift the fluid in the well (wellhead pressure of 250 to 260 psi) and induced a flow of hot, dirty water, at zero wellhead pressure, and a flow-line temperature of 150°F (66°C). A sample of the discharge fluid was obtained. The well ceased to flow once the available nitrogen had been injected. Further air lift tests are planned using a suitably designed well head and compressor.

Summary

Drilling took longer than scheduled due to severe losses of circulation in the shallow subsurface causing considerable disruptions with the drilling and difficulty with cementing the 7" and 4 ½" casing. An artesian flow of hot water was encountered at 163ft (49.7m) but efforts to obtain an uncontaminated sample of the water were frustrated by unstable hole conditions.

In contrast, the 3.782" HQ interval of the well, continuously cored from 579 to 2205ftTD (176.5 to 672.1m), was trouble-free and completed as scheduled. The core provides the first detailed geologic (lithology; hydrothermal alteration; fracturing) and temperature information relating to the Blue Mountain geothermal resource at depth.

Acknowledgements

Noramex Corp. wishes to acknowledge the high level of commitment and support provided by the US DOE staff, Albuquerque Operations Office, throughout the drilling of Deep Blue No.1. The financial commitment of the DOE through the difficult early stages of the well was instrumental in ensuring a successful first deep geothermal test hole at the Blue Mountain geothermal area.

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