GEOLOGIC AND HYDROLOGIC RESEARCH ON THE MOANA GEOTHERMAL SYSTEM WASHOE COUNTY, NEVADA

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ABSTRACT

The Moana geothermal area is the largest single low- to moderate-temperature geothermal resource in the State of Nevada presently employed for direct-use applications. Approximately 150 individual wells, representing a total estimated investment of $5 to $7 million, are presently used to provide heat and hot water to more than 130 private residences, several churches and two large motels. Although most of the wells are constructed to meet the heating needs of individual homes, a large-scale district space heating system, designed to supply heat to 60 houses from a single well, is now being developed. Usable temperatures range from 50° to 99°C (120° to 210°F); well depths range from 60 to 400 m (100 to 1300 ft.). The number of new wells coming on-line in Moana is two to three per month. Development of the resource has been largely unregulated and questions dealing with reported reservoir temperature and water level declines, loss of artesian flow, and fluid disposal have recently surfaced.

In October, 1982, a geologic and hydrologic research program began that was designed to provide detailed geothermal reservoir data to present or prospective developers. The program combines geophysical, geochemical, and geological surveys of the Moana resource area with a drilling program for 5 monitor/observation wells. Data from this program are supplied directly to developers as well as state and local government agencies to provide for prudent resource development. This paper summarizes the program elements and describes the present status.

INTRODUCTION

Bateman and Scheibach (1975) reported a total of "35 geothermal heating systems in use throughout the Truckee Meadows." Ghusn (in Trexler and others, 1982) listed nearly 120 individual wells in the Moana area alone (fig. 1). Today there are approximately 150 individual geothermal wells and that number is increasing by 2 to 3 wells per month.

The Moana area is the largest single geothermal reservoir in the State of Nevada that supports direct heat applications. An estimated $3 to $5 million has already been invested in residential heating systems. An additional $2 to $3 million in commercial money brings the estimated total investment to $5 to $7 million. Present development includes additional new individual wells and at least one proposed district space heating system.

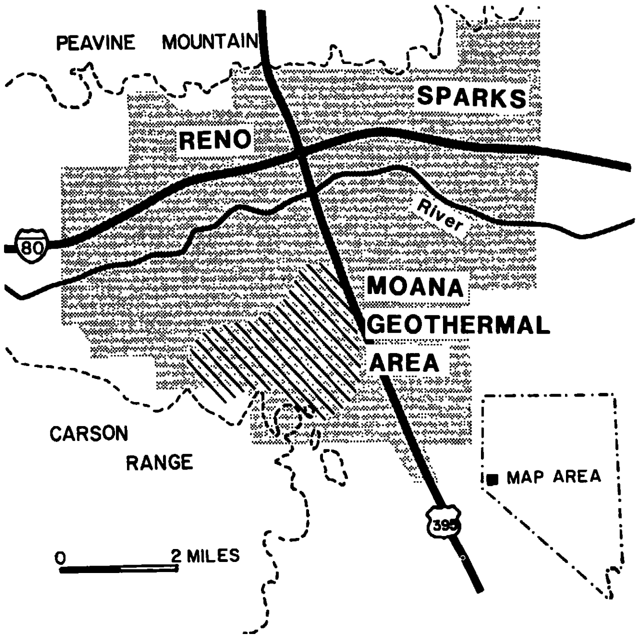

Figure 1: Location map of the Moana geothermal area.

Development of the reservoir has been largely unmanaged and unregulated. Moana is the site of Moana Hot Springs which reportedly ceased to flow 20 to 25 years ago. More recently, an artesian thermal well that discharged 5-7 GPM also ceased to flow. In addition, Ghusn (in Trexler and others, 1982) has shown that reservoir contamination can occur in poorly completed wells. Additional problems include premature deterioration of copper heat exchangers or steel casing or both as a result of anode-cathode reactions. Disposal of fluids from geothermal wells is another problem that has been largely ignored.

This paper describes work in progress on a research program that focuses on the geologic and hydrologic aspects of the Moana reservoir. Much of the data is derived from previous studies (Bateman and Scheibach, 1975; Ghusn, in Trexler and others, 1982; Carlson, 1982). This information is supplemented by geologic reconnaissance of the suspected reservoir rocks that outcrop to the north and west of Moana. A gravity survey that extended from Moana to Steamboat (10 miles to the south) was completed to possibly identify structures in the volcanic basement (north-trending normal faults) which are believed to provide the hot water to the shallow reservoir. Samples of thermal and nonthermal fluids were collected and analyzed for major, minor and trace elements, stable isotopes of hydrogen and oxygen (including tritium), and carbon-14. Many of the developers have cooperated by providing drill chip samples from the many wells that are presently under construction. These data, coupled with temperature-depth profiles derived from the same wells have been used to identify the reservoir rock.

The final phase of the program consists of long term observations and measurements in strategically placed monitor wells. These wells were drilled to a total depth of 400 feet (one was drilled to 800 feet) and cased with 2½ inch diameter steel pipe. In addition to the lithologic information derived from each hole, the water levels and temperatures will be monitored for 6 to 12 months prior to, during, and after the heating season.

GEOLOGY

The Moana area is located along the western edge of the Truckee Meadows. It is a structural basin bounded on the east by the Virginia Range and on the west by the Carson Range, a spur of the Sierra Nevada. Late Tertiary and Quaternary faulting offsets Tertiary volcanics and volcaniclastic sediments and Quaternary alluvium and outwash. Late Quaternary alluvium and glacial outwash cover many Quaternary and Tertiary structures (Bingler, 1975; Mizell, 1975).

The lithologic units found within the Moana area include alluvial deposits of the Truckee Meadows, glacial outwash from Quaternary glacial periods, Tertiary lacustrine and fluvial sediments, and Tertiary volcaniclastic and volcanic units (Bingler, 1975). Driller's logs provide some subsurface lithologic information, but the quality of these data are generally poor and inconsistent.

The oldest formations in the Moana area are Tertiary volcanic and volcaniclastic rocks. These are generally andesitic flows, agglomerates and breccias with interbedded tuffs, and lacustrine and diatomaceous sediments. These units are all considered to be part of the Kate Peak Formation (Bingler, 1975; Cohen and Loeltz, 1964; Thompson and White, 1964).

Unconformably overlying the Kate Peak Formation are Tertiary lacustrine and fluvial sediments. Thompson and White (1964) assigned these units to the Truckee Formation, first described by King (1878). These units consist of fine-grained lacustrine sand and silt deposits with intercalated gravels, volcaniclastics, diatomaceous siltstone, and diatomite. Estimates of the thickness of the Truckee Formation range from 2100 feet (Anderson, 1908) to greater than 3000 feet (Cohen and Loeltz, 1964).

Bingler (1975) identified those units associated with the Truckee Formation in the Truckee Meadows as the Sandstone of Hunter Creek. Lithologic descriptions of this formation include some clastic fluvial and volcaniclastic members previously associated with the Kate Peak Formation. Estimates of thickness of the Sandstone of Hunter Creek range from 3000 to 4000 feet. The lowest member consists of a sequence of fining-upwards coarse gravels and clastic sediments. Overlying this member is a thick (1000 to 3000 feet) section of diatomite, diatomaceous siltstone and sandstone. In outcrops west of Moana, these diatomaceous units are white to medium gray in color. The uppermost units are coarse to fine sands and silts interbedded with diatomaceous sediments.

The Tertiary units all dip to the east forming a homoclinal structure from the Carson Range into the Truckee Meadows. Anderson (1908) identified the Carson Range as a broad anticline and Truckee Meadows as a broad syncline.

The Sandstone of Hunter Creek is overlain by outwash gravels from Quaternary glacial runoff as well as alluvial fan and pediment units from the surrounding ranges. Bingler (1975) describes these units in detail in his study on Quaternary geology of the Truckee Meadows.

Pre-Holocene faulting resulted in a series of horsts and grabens in the Moana area and the western Truckee Meadows. These faults juxtapose late Quaternary and Tertiary units in several areas. Younger faulting offsets both Quaternary and Tertiary units. The Holocene alluvial units obscure many of the faults in the Moana area, but they are known to exist by the stratigraphic variations and offsets seen in well logs of the area.

Of special interest in the Moana area is the geologic relationship between the Sandstone of Hunter Creek and the Kate Peak Formation. The Kate Peak has been mapped as the formation underlying the Hunter Creek, and evidence of this relationship is clearly seen in the hills west of Moana. The Kate Peak andesite recovered from wells drilled in Moana consists of either fine-grained devitrified rhyolite/rhyodacite or highly altered "blue clay." Both the altered and unaltered Kate Peak constitute the reservoir rock for thermal fluids. The overlying units consist of Quaternary alluvial fan deposits of pebbles, brown clay, sand, and silt, and the diatomaceous siltstone member of the Sandstone of Hunter Creek.

GRAVITY SURVEY

This survey was used to delineate the basement structure from Steamboat north through Moana. Three hundred and fifteen stations were occupied, including 85 stations for which elevations were already known and 230 stations whose elevations were obtained by surveying. Gravity measurements were obtained with a LaCoste-Romberg Gravimeter.

Reduction of these data included calculation of the simple Bouguer anomaly according to the 1939 International Gravity Formula and terrain corrections calculated by Hammer (1939) for selected points and applied to all points. From the resulting complete Bouguer gravity values, an evenly spaced grid of values was interpolated by computer application of Laplacian cubic splining (fig. 2). The surface here is inverted; a gravity high appears as a depression.

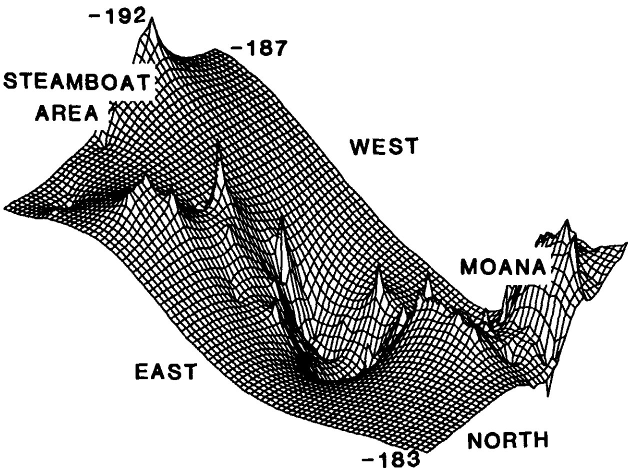

Figure 2: Three-dimensional complete Bouguer Gravity Anomaly Grid from Steamboat Hot Springs to the Moana geothermal area.

Figure 2 shows a gravity high through the center of the Moana area. The gravity low (raised in the diagram) corresponds to the low density diatomite of the Sandstone of Hunter Creek. There is some indication that the northeast-trending structure in Moana corresponds to fault trends mapped in the area. This trend may also represent the contact between the Kate Peak andesite and the less dense sedimentary rocks. The large gravity high (depression) in the center of the diagram corresponds to outcrops of the Kate Peak andesite. Fault scarps here are difficult to identify because offset along the faults is small.

THERMAL FLUIDS GEOCHEMISTRY

The Moana geothermal fluids are sodium-sulfate type waters that show little or no absolute correlation with the sodium-chloride type water from Steamboat Hot Springs. Although relative percentages of cations are identical for fluids from Moana and Steamboat (fig. 3), the absolute concentrations of cations and anions are different by a factor of at least two. The thermal fluids from Moana are chemically similar to other low- to moderate-temperature geothermal fluids that are widespread throughout western Nevada.

Variations in the composition of Moana thermal fluids are directly related to the degree of mixing

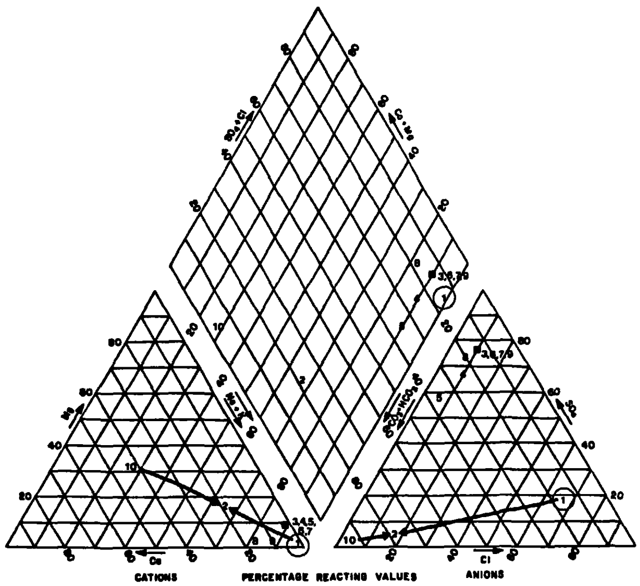

Figure 3: Chemical characteristics of thermal and non-thermal fluids from Steamboat area (1, 2) and Moana (3-10).

of thermal and non-thermal fluids. These variations are also observed in the gradual decrease in temperature from west to east across Moana. In general, along a west to east traverse, bicarbonate and magnesium increase and boron, silica, sulfate, and calcium decrease. Mixing of thermal and non-thermal fluids can also be seen in the Steamboat area (fig. 3). Zolezzi Springs (#2, 34°C) fluid composition appears to be the result of mixing Steamboat fluids (#1, 96°C) with the surface waters from Thomas Creek (#10, 10°C).

Major chemical analyses are supplemented by analyses of tritium and carbon-14. The carbon-14 isotopic age of Steamboat fluids is in excess of 25 Ka. The carbon-14 isotopic age of Moana fluids ranges from 1 Ka to 32 Ka. These are uncorrected values, but the older fluids are high-temperature (>85°C) and are closely associated with mapped faults in the west-central part of the reservoir. These faults are believed to be the ultimate source of hot water in Moana. Tritium is virtually absent in the high-temperature waters in Moana (and Steamboat), but increases in tritium are observed in the cooler waters in the eastern part of Moana.

LITHOLOGIC AND TEMPERATURE-DEPTH MEASUREMENTS

Drill chips are collected regularly from well drillers and developers throughout Moana. In addition, temperature-depth profiles of geothermal wells are completed soon after drilling, but prior to hardware installation. Figure 4 is a typical lithologic log for the central portion of Moana. The accompanying temperature-depth profile shows that the highest temperatures are achieved and maintained in the dacite-rhyolite (Kate Peak an-

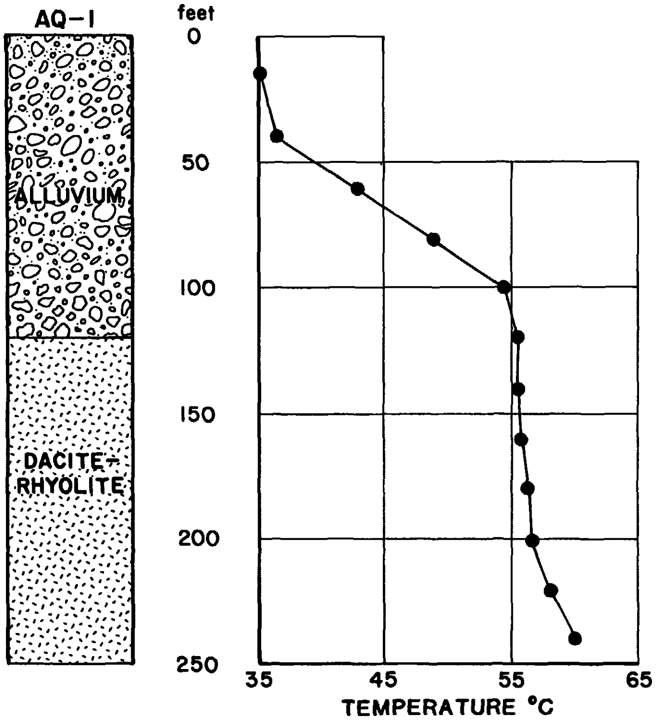

Figure 4: Lithologic log. and temperature-depth profile of geothermal well in center of Moana.

desite). To the west and north, the Kate Peak andesite is overlain by a thick section of diatomaceous siltstone (the middle member of the Sandstone of Hunter Creek), and wells in this area must be drilled to depths of 800 to 1300 ft. to reach high-temperature fluids.

Surface exposures of the Kate Peak andesite crop out south and west of the Moana geothermal area, and consist of perlitic (devitrified volcanic glass) rhyolite-dacite. In the subsurface, the Kate Peak andesite is a hydrothermally altered product of the surface rocks, and often has the appearance of a sandy "blue clay." X-ray diffraction patterns of this clay show that it is composed almost entirely of smectite and no other clay minerals (Dave Bish, LANL, personal communication). In addition, minor amounts of quartz, cristobalite, alkali feldspar, calcite and gypsum were also detected in the clay. Smectites are often formed by hydrothermal alteration of volcanic glass. Whole rock chemical analyses of the "blue clay" reveal anomalous concentrations of arsenic, antimony, thallium, gold and silver. These elements probably represent hydrothermal alteration of the volcanic glass in the Kate Peak andesite by mineralizing fluids.

Although water temperatures within the "blue clay" are high (80 to 95°C), aquifer transmissivity is very low. Many geothermal wells are completed with draw-off pumps that remove cooled fluids from the well bore. The pumped fluids are then replaced by hotter formation fluids. These spent fluids are traditionally disposed of in nearby irrigation ditches and storm sewers.

OBSERVATION/MONITOR WELLS

In order to accurately determine the effects of thermal fluid withdrawal during the heating season (October through March), five observation/monitor wells were drilled in strategic locations throughout the Moana geothermal area (fig. 5). Four wells (1, 2, 3, 4) were drilled to a total depth of 400 feet. The remaining well (5) was drilled to a depth of 800 feet. All five wells were cased with 2½ inch diameter steel pipe to total depth. The bottom 20 feet of the casing has torch-cut perforations and is gravel-packed. The top 50 feet of the wells have cement sanitary seals. The remaining annulus interval is backfilled with drill cuttings.

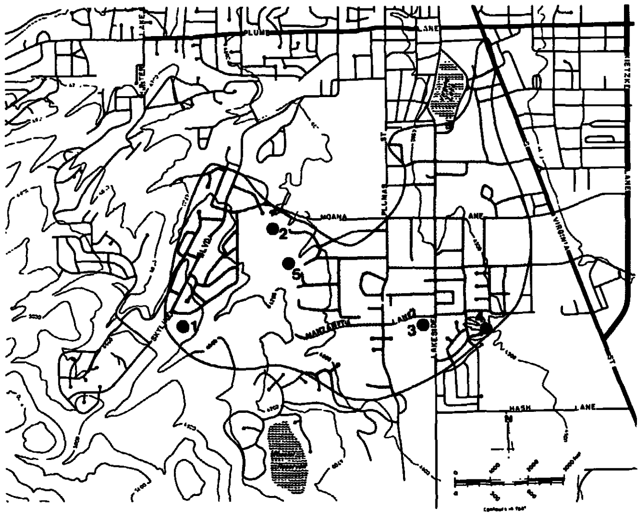

Figure 5: Location map of Moana area and observation/monitor wells.

The lithologic units penetrated by these five holes illustrate the complexities of the Moana geothermal reservoir. All five wells encountered hot water; bottom hole temperatures range from 35°C (well #2) to an estimated 85°C (well #5).

In wells 1 and 2, only two lithologic units were encountered, alluvium underlain by diatomaceous siltstone (middle member of the Sandstone of Hunter Creek). In wells 3 and 4, the alluvium was underlain by hydrothermally altered Kate Peak andesite; no diatomite was encountered. Hole 5 was started in alluvium, penetrated the Sandstone of Hunter Creek (including a previously unknown organic-rich unit near the base) and was completed in the altered andesite.

Monitoring techniques for these wells include measurements of static water level and temperature-depth profiles. Measurements are performed prior to the heating season to determine natural fluctuations that result from barometric changes.

PRESENT DEVELOPMENT

Geothermal well drilling and completion for individual residences is proceeding throughout Moana at a rate of 2 to 3 new wells per month. Carlson (1982) described a geothermal space heating system that is designed to deliver hot water to a space heating district consisting of as many as 60 homes. Several new churches and businesses have developed plans for space heating. One existing motel that already uses geothermal waters for heating has expanded and will develop another geothermal well to supply additional heat to the new structure.

Corrosion of metal parts in heat exchangers occurs sporatically throughout Moana. Most newly completed wells now use fiberglass tubing as a heat exchanger instead of copper or steel. Although the thermal conductivity of fiberglass is much less than copper or steel, it is an excellent insulator; the water is less likely to cool from the well bore to the house. In addition, the fiberglass carries a 50 year guarantee.

Disposal of fluids from geothermal wells remains a problem in Moana. State regulators urge developers to reinject spent fluids into the aquifer from which they are produced. The cost of a reinjection well is prohibitive for small-scale developers; large-scale developers must incorporate a reinjection system.

CONCLUSIONS

Reports of overdevelopment and reservoir depletion of the Moana geothermal area are presently being evaluated with a combination of geologic, geophysical, and geochemical surveys coupled with down-hole measurements in observation wells. Geologic surveys reveal that a complex sequence of Tertiary sedimentary rocks and hydrothermally altered andesite constitutes the reservoir rock. Spatial variations in subsurface temperatures are related to the distribution of hydrothermally altered Kate Peak andesite. A gravity survey completed in this area appears to have delineated the easternmost boundary of the less dense sedimentary rocks. Geochemical analyses of Moana thermal fluids suggest little or no correlation with nearby Steamboat Hot Springs. Slight variations in fluid composition from west to east correlate with decreasing temperatures. Radiocarbon and tritium analyses suggest that the Moana thermal fluids originate from a series of north-trending faults in the west-central part of the reservoir. These fluids then spread out laterally to the east, north, and south. A series of observation wells will be monitored prior to, during, and after the heating season to determine the extent of reservoir depletion as a result of fluid withdrawal by the 150 geothermal wells in the Moana area. Recommendations for prudent resource development are being formulated and supplied to government agencies and prospective users.

Work performed under US Dept. of Energy Contract No. AC03-82-RA50075.

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ACKNOWLEDGMENTS

The authors would like to thank Bob Loux of the Nevada Department of Energy and the U.S. Dept. of Energy, San Francisco Operations Office for supporting this research. Many thanks to the residents and well drillers in Moana. The hard working professionals and staff at the Division of Earth Sciences, including Dennis Trexler, Elaine Bell, Susan Parkhurst, and Cam Covington, helped with preparation of the manuscript. Steven Weiss wrote the computer program that generated the 3-D grid.