

GEO THERMAL EXPLORATION

ACTIVITIES AT THE

STEAMBOAT SPRINGS KGRA

Steamboat, Nevada

Prepared for
SB GEO, Inc.

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Geothermal Exploration in the Steamboat Springs KGRA

1.0) Steamboat Springs KGRA Geothermal Overview

The Steamboat Springs Known Geothermal Resource Area (SBS KGRA) is located in the South Truckee Meadows area approximately 9 miles south of Reno, Nevada (see Figure 1). The geothermal system consists of a high temperature area (Steamboat Hills) with measured downhole temperatures $>400^{\circ}\text{F}$ and a moderate temperature geothermal area with reservoir temperatures between 285°F to 360°F (Steamboat Springs). The Steamboat Springs resource region is located directly northeast of the Steamboat Hills area. The Steamboat Springs and Steamboat Hills resource areas share a common heat source; however, the producing geothermal geologic horizons differ.

Several low temperature (80°F to 250°F) geothermal areas have been identified in the South Truckee Meadows area. These low temperature geothermal systems are formed from mixing of geothermal and groundwater fluids. The distribution, in terms of subsurface depth and areal location, of these low temperature areas is not well defined.

Currently, approximately 43 MWnet of electrical power is being generated through three-power plant operations in the SBS KGRA. These operations include the: SB 1/1A 7 MW air-cooled binary power plant (US Energy Systems-1986), the Yankee-Caithness Joint Venture (YCJV-1990) 12 MW water-cooled single-flash steam plant, and the 24 MW air-cooled binary power plant (Far West Capital-1992). The geothermal power plant locations are shown in Figure 2.

Geothermal exploration and development in the SBS KGRA for balneological uses began in the early 1920's. Geothermal exploration by the USGS, for scientific studies of mineral systems, began in the late 1940's and continued through the 1960's. Geothermal exploration for commercial power generation uses began in the late 1950's

by Nevada Thermal Power (a subsidiary of Magma Power). Geothermal exploration is currently underway in the area to determine additional geothermal resource availability.

Additional geothermal resource drilling investigation is needed to define the full production potential of the SBS KGRA system. SB Geo is currently in the process of extending its geothermal resource base with the drilling of a slim hole on the southern portion of its Meyberg properties.

2.0) Geothermal Resources Development in the South Truckee Meadows

Felix Monet reportedly "discovered" Steamboat Springs in 1860 (Garside and Shilling, 1979). This "discovery" transpired during the same period that mineral operations development of the Comstock Lode in the Virginia Range (1859) and the Union mine (1860), located in the Galena Mining District on the southeast flank of Steamboat Hills, were begun (Bonham, 1969). The geothermal hot springs at Steamboat were so-named, reportedly, because of the noise created by steam and water escaping from springs and fissures in the area. The United States Geological Survey (USGS) classified the Steamboat Springs geothermal area as a Known Geothermal Resource Area in the early 1970's.

Numerous geothermal and mineral exploration wells have been drilled in the Steamboat Springs KGRA area since the discovery of Steamboat Springs. The locations of selected exploration wells, drilled for commercial geothermal investigations, are shown in Figure 3.

These exploration wells have led to the development of two geothermal production areas in the Steamboat Springs KGRA. These production areas are operated by two separate entities (see Figure 2 for power plant locations):

- a) Steamboat Springs Geothermal Region- SB Geo, Inc (SBG) operates the Steamboat - Springs power plant operations area. SBG operations utilize binary power plant technologies to generate electrical power from thermal fluids at average temperatures of $\square 325^{\circ}\text{F}$. The SBG power plant operations consist of two independently owned

plants. The SB 1/1A power plants have a nominal rating of 7.1 MWnet. The SB 2/3 power plants have a nominal rating of 24 MWnet. In the SBG operations area, a total of twelve production wells and five injection wells are used for electrical power generation activities. Power plant operations began in 1986 for SB 1/1A and in 1992 for the SB 2/3 operations.

- b) Steamboat Hills Geothermal Region- Caithness Power, Inc. (CPI) operates the Steamboat Hills power plant generation facilities. The CPI power plant utilizes single-flash steam power plant technology to generate a nominal 12 MWnet of electrical power. Average produced geothermal fluid temperatures are reportedly 425°F (Goranson and others, 1990). Three production wells and one injection well are used in power generation operations. Power plant operations began in 1990.

In addition to wells drilled specifically for commercial geothermal exploration and geothermal production operations, homeowners and private and quasi-municipal water companies have drilled numerous groundwater wells in the South Truckee Meadows. Several wells have been drilled for mineral exploration. Many of the wells drilled for groundwater uses and mineral exploration have encountered geothermal and mixed groundwater-geothermal fluids at depths.

2.1) Geothermal Drilling Exploration in the Steamboat Springs KGRA

Early commercial uses of geothermal fluids at Steamboat Springs were for bathing, spa and heating operations. Thermal fluids flowing from the Steamboat Springs Upper and Lower Terrace area were connected to use areas with surface piping. In the early 1920's, several production wells were drilled on the Low Terrace hot spring area (see Figure 2) to supply fluids, in a more dependable manner, to the Steamboat Resort. Production wells were also drilled on the Main Terrace spring area to supply thermal fluids to the Reno Resort swimming pool and Mt. Rose Resort. One well drilled in the 1940's, the West Reno well, was used for pool uses at the Reno Resort until 1965. Additional wells were drilled between 1930 to 1980 at the Steamboat Spa (Steamboat Resort, Lower Terrace area). Several of these wells are still in use at the Steamboat Spa.

The USGS conducted a research program between 1945 to 1952 in the Steamboat Springs area to investigate the fundamental hydrothermal mechanisms related to ore-bearing (epithermal) deposition. The Steamboat Springs area was viewed as an area where natural hydrothermal ore-forming processes were occurring that could not be duplicated in the laboratory. These USGS investigations culminated in a series of four professional papers covering the research activities (White, et al 1964 -1968). Numerous published and proprietary reports have been produced based on the USGS research and other commercial and private groundwater and geothermal development activities in the South Truckee Meadows/SBS KGRA areas.

The USGS exploration program included the drilling of eight small-diameter exploratory wells, GS-1 through GS-8, in the Steamboat Springs area between 1950 and 1951. These small-diameter exploratory wells (well locations not shown) were diamond drilled core holes and varied in depths between 130 feet to 686 feet. Fourteen shallow auger holes (hole locations not shown), Auger 1 through 9, 10a and 10b, Auger 11, 12 and 13, were also drilled with depths ranging between 2 feet to 18 feet. Data from these wells and several other wells in the Steamboat Springs and South Truckee Meadows area drilled by private entities were evaluated and documented in the USGS reports. The available data include temperature versus depth, thermal fluid level as a function of time, fluid geochemistry and subsurface geological data. Seventy-four hot springs were located in the Steamboat Springs and South Truckee Meadows areas. Data relating to spring fluid level, thermal fluid discharge and fluid geochemistry as a function of time were obtained and documented.

In the mid-1950's a privately owned company, Nevada Thermal Power (a subsidiary of Magma Power Company), began the drilling of several large diameter production-size exploration wells. A total of six large diameter wells, NTP-1 through NTP-6, were drilled in the Steamboat Springs area between 1954 and 1962 (see Figure 3 for well locations). Well depths ranged between 716 feet to 1,830 feet. These holes were drilled as exploratory production wells, employing large diameter casings. Several of the wells were flow tested during and subsequent to the drilling activities. The available data

include temperature versus depth, thermal fluid levels and fluid geochemistry. The geothermal wellbores reportedly scaled with calcite during discharge testing and discharge periods were, therefore, limited. No data are available on the testing activities.

Gulf Mineral Resources Company and Phillips Petroleum Company separately began geothermal exploration activities in the Steamboat Hills and South Truckee Meadows areas in the late 1970's. These two companies entered into a joint exploratory and operations agreement (as Phillips-Gulf) in 1980. The initial exploration program included the drilling of twenty-five shallow thermal gradient holes, SB-1 through SB-25 (see Figure 3 for well locations). These small diameter holes were drilled in 1976 to depths ranging between 170 feet to 300 feet. Temperature versus depth and subsurface geologic data were obtained for these wells.

Phillips-Gulf jointly drilled fourteen deep small-diameter stratigraphic test holes, ST-1 through ST-14, in the Steamboat Hills and South Truckee Meadows areas between 1977 and 1981. These wells were drilled to depths ranging between 844 feet to 1,990 feet. These stratigraphic test well locations are shown in Figure 3. Static temperature versus depth and subsurface geologic data were obtained from these test holes.

Two large diameter exploration wells (well locations are shown in Figure 3) were drilled in the Steamboat Hills area by Phillips-Gulf. The first well, SBP-1, was drilled in 1979 to a depth of 3,050 feet. This well was discharge tested and termed a commercial geothermal production well. Maximum downhole temperature was reported at 440°F. A second large diameter well, COXI-1, was drilled in 1980 to a depth 3,471 feet. The well was not judged to be a commercial production well at the time of completion (currently this well is used as an injection well by YCJV). Maximum downhole temperature was reported as 350°F. Data available from these wells include static temperature versus depth, fluid geochemistry and subsurface geologic data. Some flow test data were obtained for well SBP-1.

Hunt Oil Company drilled several thermal gradient wells in the 1980's. These wells were drilled in the southeast portion of the South Truckee Meadows area. There are no data available for these wells.

Geothermal Development Associates (GDA) drilled three small diameter exploration holes, OW-1 through OW-3, in the Steamboat Springs Upper Terrace area in 1985 (well locations shown in Figure 3). These wells ranged in depths between 570 feet to 966 feet. Static temperatures versus depth data are available. The wells were drilled under loss of circulation conditions and subsurface geologic data are limited.

Far West Capital, Inc. (FWC) drilled one production-size geothermal exploration well, Hot Air #4 (HA#4), in the Steamboat Springs Upper Terrace area in 1990 (see figure 3 for well location). This well was drilled to a depth of 729 feet. The well was discharge tested after drilling and completed as a commercial geothermal production well. Daily drilling operations, static temperature versus depth and subsurface geologic data (above 525 feet) are available. Fluid geochemistry data were also obtained for this well. No geologic samples were obtained below 525 feet due to loss of circulation drilling conditions.

FWC drilled three small diameter core holes, TH-1, TH-2 and TH-3, in 1991 near the Main and Upper Terrace areas of Steamboat Springs (well locations are shown in Figure 3). These slimholes ranged in depths between 861 feet to 910 feet. The slim-holes were injection tested after completion to determine reservoir characteristics. The available data include daily drilling operations, static temperature and pressure versus depth, pressure and temperature versus depth during injection and pressure fall-off data. Subsurface geologic data include cores.

These TH series slimholes were subsequently discharge tested in 1992. Discharge rate versus time, fluid geochemistry, flowing pressure, temperature and spinner (PTS) survey data and downhole pressure build-up data were obtained.

In 1993, SB Geo (operations entity for Far West Capital) drilled a deep exploratory slim-hole (GTH 87-29) to a depth of 4,000 feet in the Upper Terrace area of Steamboat Springs. The well location is shown in Figure 3. This slimhole was drilled in conjunction with the US Department of Energy and Sandia National Laboratory. The slimhole was drilled to investigate the effectiveness of using inexpensive small-diameter wells to delineate and measure the productive capacities of geothermal systems. The available data include; daily drilling records, static temperature and pressure surveys, flowing temperature, pressure and spinner surveys, downhole pressure build-up and fall-off data, discharge rate versus time and geothermal fluid and non-condensable gas data. In addition, subsurface geologic data are summarized and cores are available.

SBG drilled an exploratory slim hole, MTH 21-33, in 1994 (see Figure 3 for the well location). This slimhole was drilled to a depth of 710 feet near the northeastern edge of Steamboat Hills. Daily drilling records and static pressure and temperature versus depth data are available. Subsurface geologic data include cores.

3.0) Geothermal Power Plant Operations at the Steamboat Springs KGRA

Power plant operations in the Steamboat Springs KGRA began in 1986. Total fluid production rate (year 2000) from the Steamboat Springs KGRA is \square 26,200 gpm (\square 12,000,000 pph). The total amount of fluid produced, since power plant operations began in 1986, is \square 110 billion gallons (525 billion pounds). Total electrical (nominal) power output is \square 43 MWnet.

Three geothermal power plants are operating within the USGS defined Steamboat Springs KGRA. Figure 4 shows the location of the power plants and associated production and injection wells. Two of the power plants, SB 1/1A and SB 2/3, are operated by SB Geo, Inc (SBG). and are located on private property in the Steamboat Springs area. SBG wells supply thermal fluids to their respective power plants using downhole shaft-driven pumps. These power plants use binary technology to convert thermal heat from produced geothermal fluids to electrical power. Air-cooled condensers are used in the binary-fluid cooling process.

A third power plant, operated by Caithness Power, Inc. (CPI), is located in the Steamboat Hills area. This plant operates on a combination of federal US Bureau of Land Management (BLM-subsurface rights) and US Department of Agriculture (Forest Service-surface rights) lands and private properties. CPI wells are produced to the power plant by free-flowing methods, i.e., by density driven conditions developed within the wellbore under discharging conditions. A single-flash steam power plant converts thermal heat of the steam separated from the produced fluids to generate electrical power. The power plant uses a standard wet-cooling (cooling tower) process in power generation operations.

4.0) Regional Geologic Description of the South Truckee Meadows

Thompson and White (1965) have best described the regional geology of the Steamboat Springs KGRA and the South Truckee Meadows areas (detailed geologic map not shown in this report). The major features of the region are the result of the Sierra Nevada Batholith and Basin and Range block faulting. Voluminous Tertiary volcanism (Kate Peak and Alta formations) covered most of the Truckee Meadows at one time. The volcanics were deposited from numerous vents. The Cenozoic uplift of Cretaceous granodiorite is the result of high-angle, normal faulting thought to be caused by major tectonic extensional forces. As a result, structural basins have been formed between the Carson and Virginia Ranges. Alluvial fans and pediments form between the mountain fronts with bajada and valley floor deposits towards the center of the valley basins.

Concurrent with the Cenozoic uplifting and volcanism are episodes of erosion and deposition of sediments derived from the volcanic and granitic rocks. Thompson and White give evidence and discuss several pediments, particularly on the east flanks of the Carson Range. A unique structure of the region is the Steamboat Hills and the Steamboat Springs geothermal hot spring area. The Steamboat Hills are uplifted, faulted, granitic and overlain with volcanics ranging from rhyolite to andesitic basalt. The Steamboat Springs KGRA is a site with continuing subsurface geothermal discharges. Surface (hot

spring) discharges disappeared in the late 1980's, prior to the SB 2/3 and YCJV geothermal operations.

Most faulting within the South Truckee Meadows has been identified as trending north south (Cordova, 1969; Thompson and White, 1964) and are presently active. Recent work (van de Kamp, this report) has identified northeasterly trending faults (see Figure 5) that are associated with thermal fluid movement through the system. The north-south trending faults are probably related to extensional forces resulting in both normal and reverse faults. Localized grabens have been identified (Bonham and Rogers, 1983; Widmer, 1991).

4.1) Generalized Geology of the Steamboat Hills and Steamboat Springs Areas

Faulting and fracture patterns mapped in the Steamboat Hills and Steamboat Springs areas are shown in Figure 5. In general, the northeast trending Steamboat Hills are a part of the Carson section of the Walker Lane Structural Belt and are within the Basin and Range physiographic and geologic province. Gross structure of the Steamboat Hills is folded metavolcanics intruded to the north by Cretaceous granodiorite. The Alta and Kate Peak volcanics unconformably overly the granodiorite to the west and northeast of Steamboat Hills. The whole block comprising Steamboat Hills is bounded to the north and south by N50-60E trending normal faults and to the east and west by north-northeast to north-south normal faults. This yields a parallelogram shaped block, in map view, which is 2,000 feet to 3,000 feet higher, structurally, than the adjacent areas to the east, west and north. This parallelogram also forms the boundaries to the high and moderate temperature geothermal system, as shown in Figure 5. A third prominent normal fault pattern occurs in a northwesterly direction in the Steamboat Springs area.

In and adjacent to Steamboat Hills, the most recent tectonic movement occurred along northerly trending faults which extend through the hills 5+ miles south to Washoe Valley and 5+ miles north to Huffaker Hills. However, the northeast trend may have been active in the recent past as indicated by offsets in the Lousetown volcanic formation. The northeast and northwest trending faults were conduits for volcanic extrusions. Pleistocene

rhyolite domes occur for five miles along this same northeast trend. This is strongly suggestive of a deep reaching fault zone through which lava rose from their mantle source. The heat source for the geothermal system is most likely associated with these volcanics and deep-seated faults. no

Figure 6 is a schematic geologic representation of the Steamboat Springs KGRA geothermal system. This figure is a north-south cross section through Steamboat Hills, Steamboat Springs and the alluvial valley-fill areas located to the north and south of the Steamboat Springs KGRA.

4.2) Detailed Geology of the Steamboat Hills and Steamboat Springs Area

Granodiorite is the oldest rock unit present in the northern Steamboat Hills. This granodiorite is of Jurassic-Cretaceous age, estimated as >80 million years old by apatite fission track analysis (Duddy ET al., 1995). The older (Triassic?) Peavine Sequence of metamorphic rocks, into which the granodiorite is intruded in central Steamboat Hills, is not found in the Steamboat Springs area. The Peavine Sequence is noted on the southern flank of Steamboat Hills and is the primary producing formation for geothermal fluids in the Steamboat Hills area. Several wells in the Steamboat Hills production area penetrate an alternating sequence of metamorphic and granodiorite rocks, indicative of tonguing along an intrusive contact. Outcroppings also suggest a steeply dipping contact between the Peavine Sequence and the intrusive granodiorite.

The granodiorite which underlies the Steamboat Springs area is a younger intrusive, about 22 million years old to 16 million years old (Duddy ET al., 1995). This sequence of granodiorite is penetrated by numerous wells drilled in the Steamboat Springs area. The granodiorite serves as the reservoir for geothermal fluid production in the Steamboat Springs area of the SBS KGRA. Younger sediments, hot spring deposits, volcanic rocks and alluvial deposits overlie the granodiorite. The surface of the granodiorite in the northern Steamboat Hills area slopes northward, the surface declining in depth approximately 15° to 20°.

The granodiorite in the Steamboat Springs area ranges from very fine to coarse-grained and generally shows little internal structure other than faults, fractures, and joints. Within it, there are quartz veins and aplite and pegmatite dikes. Major minerals in the granodiorite are quartz, plagioclase, and K-feldspar with variable biotite, muscovite, chlorite, and amphibole with accessory sphene, zircon, apatite, epidote, pyrite, and magnetite. In some rock samples, plagioclase is zoned ranging from fresh to intensely sericitized with some grains partially replaced by calcite. K-feldspar includes orthoclase, microcline, and perthites.

In surface outcrops, the granodiorite is fractured and faulted. These features are also found in cores and are evidenced in drill cuttings from the subsurface by fragments of protomylonite and calcite and silica veins (fracture fillings) in rock fragments. Hydrothermal alteration in and adjacent to fractures is shown by intense sericitization +/- clay alteration (montmorillonite or kaolin) of plagioclase, in some cases accompanied by calcite replacement of feldspar as well as altered biotite. The biotite is more or less "bleached" to pale tan from deep brown or green and contains numerous minute grains of opaque material, probably iron oxides. The clay alteration yields "chalky" whitish feldspar in the less intensely altered rocks. Highly altered granodiorite is a crumbly white clay and quartz aggregate with many minute pyrite grains. Noted in several cores in the Steamboat Springs area are intervals, up to 30 cm to 40 cm long, of moist dark grey clay, likely developed by intense alteration of the granodiorite, apparently in fractured zones. Cores in this area also contain many steeply dipping open fractures lined with common calcite. Below 3,000 feet in depth, fractures are lined by quartz with only minor calcite.

An unconformity between the granodiorite and the overlying Miocene Alta Fm. represents a time hiatus. The hiatus represents a mid-Tertiary uplift (Laramide uplift), an erosional event which removed the rocks into which the granodiorite was intruded, exposing the granodiorite. Subsequently, volcanoclastic sediments and volcanic flows of the Alta Fm. and the Kate Peak Fm. were deposited on the eroded granodiorite. These volcanic units and the younger granodiorite represent igneous activity which accompanied the late Oligocene-Miocene (25±10 Mya) tectonic extension in the Basin

and Range Province. In the Steamboat Springs area, these volcanics and volcanoclastic sediments are up to 500 feet thick. Since deposition, the Tertiary volcanics have been uplifted and subsequently eroded from higher areas in the Steamboat Hills. The Tertiary volcanics are now found in a northward thickening wedge in the Steamboat Springs area.

The Alta Fm. is an early to mid-Miocene soda trachyte occurring mostly as lava flows and pyroclastics. Where fresh, the volcanics are black, glassy rocks with plagioclase and hornblende phenocrysts. More commonly, the rock is altered and is grey to purple.

For simplicity, in the subsurface of the Steamboat Springs area all volcanic rocks in depositional contact with the granodiorite are classified in the Kate Peak Fm. The following description covers the volcanics penetrated by various wells in the Steamboat Springs area.

The Kate Peak Fm., overlying the Alta Fm., is late Miocene to Pliocene age and is composed of thin to thick-bedded andesitic pyroclastics and tuff-breccias. This formation is up to 400 feet thick in the Steamboat Springs area, thinning southwestward into the Steamboat Hills. In cores, these volcanoclastics range from relatively fresh, hard, grey and grey-green rocks to very soft, highly altered rocks in which clays have replaced the original minerals while retaining the clastic textures. Thus, mechanically, these altered rocks are more like soft shales than the original pyroclastic deposits. The Kate Peak volcanics lie on top of the granodiorite at depositional contact as evidenced in cores from the Steamboat Springs area. In some cores, a poorly sorted conglomeratic deposit represents the contact with fresh to weathered granodiorite and volcanic clasts. A 300-foot thick interval of red-brown to grey-green soft, clay-rich clastics were encountered in one injection well drilled in the Steamboat Springs area.

Above the Tertiary volcanics, there is an erosional unconformity representing late Pliocene and Pleistocene uplift and subsequent erosion. This event caused erosion of volcanics and granodiorite toward the south. Alluvium now covers the erosionally