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# USING SLIM HOLES FOR LONG-TERM MONITORING OF GEOTHERMAL RESERVOIR PERFORMANCE AT STEAMBOAT SPRINGS, NEVADA, U.S.A.

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**ABSTRACT**

Four slim holes were drilled into the producing geothermal reservoir, a highly fractured granodiorite, at the Steamboat Hills Geothermal Field in northwestern Nevada, U.S.A. These slim holes have been used for monitoring subsurface geothermal reservoir pressures and temperatures as a function of time. Static spinner surveys have also been performed. Since the slim holes are not produced, accurate water level elevations versus time can be measured. From these data, pressure in the slim holes exhibit strong correlation with local rainfall, and thus, imply a hydrological connection between the shallow groundwater system and the geothermal reservoir. The produced geothermal fluid temperatures versus time data from Steamboat Hills indicate a gradual reservoir cooling. Periodic temperature versus depth measurements, in the slim holes, indicate that there has been a gradual cooling, followed by a gradual heating, as a function of time in the shallow portion of the reservoir. Deeper portions of the geothermal reservoir exhibit temperature decreases. These temperature decreases are related to injection of cooled geothermal fluids into the geothermal reservoir. Because of the areal distribution of the slim holes relative to the production and injection wells, it has been possible to determine the relative temperature decrease and fluid flow patterns in the reservoir. These slimhole data have been used to recommend appropriate modifications to some well completions and suggest modifications to the injection system.

## 1.0) INTRODUCTION

The Steamboat Hills Geothermal Area is a part of the Steamboat Springs Geothermal Area, which was classified as a Known Geothermal Resource Area (KGRA) by the United States Geological Survey. The KGRA is located about 15 km south of Reno, Nevada along side of Highway 395 (see Figure 1). The Steamboat Hills geothermal reservoir is a fracture-controlled resource hosted in granitic rocks.

United States Geological Survey (USGS) geothermal investigators, principally Donald E. White (1967, 1968), conducted scientific studies of the Steamboat Hills Geothermal Area beginning in 1945. USGS personnel continued research activities through the 1960s and 1970s (Thompson and White, 1964; White, et al., 1964; Silberman, et al., 1979) and into the 1990s (Janik and Mariner, 1993).

Commercial geothermal development in the Steamboat Springs area began in the early 1900s. Initial development used geothermal fluids from hot spring discharge for heated baths and swimming pools. The first geothermal well was drilled in 1920 to augment swimming pool temperatures. This well is located directly north of the Far West Capital, Inc. (FWC) geothermal electric power development area (see Figure 2). Total combined electrical power generation from the FWC SB 1/1A and SB 2/3 air–cooled binary power plants is currently 31 MW (net).

Twelve production wells use downhole shaft driven pumps to supply a total geothermal brine production of 1,700 kg/s. All of the produced fluid is injected through five injection wells to dispose of the spent geothermal brine. Average produced fluid temperature is 160°C. Production and injection areas are closely spaced within the development area (see Figure 2).

A chronological account of the development of geothermal power plant facilities at the Steamboat Hills Geothermal Area was presented by Combs and Goranson (1994) based primarily on earlier work by Goranson and coworkers (1990; 1991).

Prior to the development of the FWC SB 2/3 Towne Lease Geothermal Area, three slim holes were drilled to determine whether productive geothermal fluids could be found at depths suitable for well pumping equipment and at temperatures required for electrical power production

The locations of the slim holes (see Figure 3) were chosen to investigate the subsurface conditions along a series of northwest and north-northeast trending surface lineaments noted on air photos and later confirmed during surface geologic investigations (van de Kamp, 1991). The three TH-series slim holes (TH#1, TH#2, and TH#3) were drilled and injection tested during 1991 to investigate the geologic conditions, thermal regime, and productive characteristics of the liquid-dominated geothermal system in the northeastern portion of the Steamboat Hills. These TH–series slim holes were subsequently discharge tested in 1992. The test data and analysis of these tests are not discussed here (see Combs and Goranson 1995). Two additional slim holes GTH 87-29 and MTH 21-33 were drilled in 1993 and 1994, respectively, to investigate other portions of the FWC lease area. Data for slimhole MTH 21-33 are not discussed in this paper.

## 2.0) HYDROGEOLOGIC AND STRUCTURAL SETTING

A detailed description of the hydrogeologic and hydrothermal characteristics is beyond the scope of this paper. However, a general description of the hydrogeology and structure of the Steamboat Hills Geothermal Area is provided based on the work of van de Kamp (1991). The geology of the Steamboat Springs area was first mapped and discussed in detail by

Thompson and White (1964) and White, et al. (1964). These two publications formed the basis for the geological evaluation of the geothermal system beneath the FWC leases.

The moderate-temperature geothermal system covers about 6.5 $km^2$, including defunct hot springs and numerous dormant fumaroles associated with siliceous sinter surface deposits. The geothermal fluid in the reservoir has a total dissolved solids content of approximately 2,000 mg/l with maximum downhole temperatures of 165°C. Geothermal fluids are produced from sub-hydrostatic fractured granodiorite at depths between 175 m to 275 m. All produced fluid is injected back into the geothermal reservoir at depths below 330 m.

The oldest rock unit present in the northeast Steamboat Hills, and the geothermal reservoir host, is granodiorite of Mesozoic age (estimated as 150 to 80 Ma, (Silberman, et al., 1979). Younger Tertiary sedimentary rocks, volcanic rocks and alluvial deposits overlie the granodiorite. Fracturing and faulting in the granodiorite is apparent in outcrops. A fine- to medium-grained granodiorite is the major portion of the rocks penetrated by wells drilled in the area. The granodiorite has no intrinsic permeability, nor is there any appreciable rock matrix porosity. Therefore, the granodiorite has essentially no fluid storage capacity and all fluid flow within the granodiorite is confined to fractures. The rock is generally hard and only slightly altered to chlorite and clay minerals with abundant minute pyrite crystals located in fracture zones. Apparently, there was an early stage of chloritic alteration and fracturing in the granodiorite, followed much later by fracturing related to geothermal processes. In the later stage of fracturing, chloritic alteration and filling of fractures with calcite, chlorite, silica, and minor amounts of heavy-metal mineralization occurred.

van de Kamp (1991) has described in detail the structural setting of the northeastern Steamboat Hills, a portion of the larger Steamboat Hills structural block. The existing mountainous topography in the Steamboat Hills area was formed in late Tertiary and Recent times when the Steamboat Hills were uplifted relative to areas to the east, north and west.

The uplifted area is bounded by steeply dipping north-northeast and east-northeast trending normal faults with displacement of tens to hundreds of meters or more. Fault and fracture strikes range from northeast to northwest, with measured dips ranging from 45° to 90°.

Three systems of faulting (see Figure 3) have been recognized in the Steamboat Hills (van de Kamp, 1991). One set strikes northeast, parallel to the axis of the Steamboat Hills. A second set, essentially at right angles to the first, strikes northwest. A third set of faults and fractures strike north–northeast and are prominent on the sinter terrace associated with dormant hot springs. In the distant past, this fault zone issued geothermal fluids to the surface where active hot springs and associated siliceous sinter precipitation occurred, similar to the modern situation at the Steamboat Hot Springs located southeast of the FWC leases. Additionally, based on the results of a tracer test (Adams, et al., 1993), there is clear evidence of anisotropy within the reservoir. The primary faults controlling fluid circulation in the geothermal reservoir appear to be the northeast trending series of steep normal faults. The abundance of fractures appears to increase with depth. Near-vertical, open fractures in the granodiorite control movement of geothermal fluids.

## 3.0) DRILLING AND COMPLETION DATA

Prior to the SB 2/3 development, three production wells and two injection wells, PW-1, PW-2 and PW-3; IW-2 and IW-3, respectively, (see Figure 2) had been in operation, on offsetting acreage, for approximately five years supplying the 9-MW (gross) Steamboat 1/1A power plants. Although production characteristics were available for the wells on the offsetting acreage, little data, due to loss-of-circulation drilling conditions, were available on subsurface geologic conditions. Therefore, drilling and completion of slim-holes TH#1, TH#2 and TH#3 utilized a small diameter core-drilling rig. The use of the core rig allowed for determination of subsurface geologic conditions during loss-of-circulation drilling conditions. Thermal and productive characteristics of the slim holes were also measured and used in the development program for the FWC Towne lease.

### 3.1) Slim Holes

The depths and completion programs for the TH-series slim holes were designed to obtain reservoir data for fracture sets in the subsurface between depths of 175 m to 300 m. The slim holes were cased and cemented to a depth of about 180 m in order to eliminate vertical interzonal flow from the fractures above this depth. The depths of the TH-series slim holes vary from 262 m to 277 m with open-hole diameters of 70-mm (e.g., see Figure 4).

Each of the slim holes, as well as the large-diameter production and injection wells, was drilled through a sequence of alluvium and sinter, volcaniclastic materials, and granodiorite (see Figure 4). The final completion of the slim holes typically consisted of a 115-mm diameter surface casing, an intermediate casing of 89.8-mm diameter, and a 70-mm open-hole section to total depth. For each of the slim holes, a 101-mm hole was drilled and cored to about 30 m and was then opened to 190-mm with a tri-cone rotary drill bit. Only partial core recovery was obtained above 30 m in each of the slim holes. After coring to depths ranging from 30 m in TH#1 and TH#2 and 49 m in TH#3, a 115-mm diameter, schedule 40, steel-threaded pipe was set and cemented to surface. Well control consisted of a 140-mm Hydril spherical blowout preventor (BOP) with a 122–mm gate valve located below the BOP.

The slim holes were originally planned to have only a 115-mm casing set to about 30 m and then completed with a 101-mm (HQ size) open-hole to total depth. However, due to numerous open fractures encountered between 82 m and 152 m in TH#1, it was decided to set and cement an intermediate casing of 89.8-mm diameter to about 169 m depth. Casing to this depth allowed for an injection test, to determine reservoir permeability characteristics, to be performed on open fractures encountered below 169 m. The depth of the intermediate casing was 169 m in TH#1, 183 m in TH#2, and 201 m in TH#3. Only partial returns were obtained during cementing of the casing for each of the TH-series slim holes.

After setting the 89.8-mm casing, partial to complete loss of circulation was encountered during drilling in the granodiorite. The open-hole section of the slim holes were drilled using a 74-mm (NQ size) core bit to total depths of 272m in TH#1, 262 m in TH#2, and 277 m in TH#3.

To investigate deeper sections of the geothermal system slim hole GTH 87-29 was drilled to a total depth of 1,220 m in 1993. This slim hole was drilled with funding from the US DOE through Sandia National Laboratory to investigate the use of slim holes for reducing costs associated with the exploration of geothermal systems. Details of the drilling, completion and testing activities are beyond the scope of this paper but are discussed in other reports (Goranson, 1994; Finger, et al, 1994). The upper casing completion of slim hole GTH 87-29 is similar to completions of the TH-series holes except that 11.5-cm casing was set to a depth of 160 m. The slim hole was completed with a 9.89-cm open-hole section to a total depth of 1,220 m. Several discharge and injection tests were performed at various stages of the drilling operations. In addition, pressure, temperature and spinner (PTS) surveys were obtained during discharge, injection and static wellbore conditions (Goranson, 1994).

Essentially 100% core recovery was obtained through the lower section of each of the slim holes. Slimhole drilling and completion activities required about 10 days for the TH-series slim holes, with an average drilling rate of about 2 m/h and at a cost of about $280 per meter. Slim hole costs and drilling times for slimhole GTH 87-29 are given in the previously mentioned report.

### 3.2) Production and Injection Wells

The data obtained from the slim holes was used to assist in the casing design and surface locations of large-diameter production and injection wells on the Towne lease. Three production wells, with open-hole diameters of 311-mm and ranging in total depths from 180 m to 302 m, were drilled within about 5 m from each of the three slim holes. In total, nine production wells and three injection wells were completed into the granodiorite formation for the SB 2/3 power plants. Production well depths vary between 180 m and 670 m, with the majority completed to less than 300 m. Injection wells were also completed into the granodiorite formation. IW-5 was completed at 325 m. The two additional injection wells are completed to depths greater than those of the majority of the production wells with the total depth of IW-1 at 825 m and IW-4 at 550 m (see, Goranson and Combs, 1995, for a detailed description of the injection wells).

Although varying in depths, completion of the nine production and three injection wells were similar to production well PW 2-1, shown in Figure 4. The completion of the large-diameter wells consisted of a surface casing of 51-cm diameter, an intermediate casing of 34-cm diameter, and a 31-cm open-hole section to total depth. The wells were drilled during the time period of January 1992 to September 1992. The large-diameter wells were completed in about 20 days each with an average drilling rate of about 3 m/h and at a cost of approximately $890 per meter.

## 4.0) SLIMHOLE RESERVOIR MONITORING DATA

Reservoir pressure data, static temperature versus depth surveys and static spinner (wellbore fluid velocity) versus depth surveys have been obtained for the TH-series slimholes and slim hole GTH 87-29. Given that all of the production wells in the FWC operations area are produced with downhole shaft driven pumps, these slim holes are the only cost effective and technically feasible mode for obtaining data on reservoir conditions during field operations.

### 4.1) Reservoir Pressure Monitoring

Water level elevations in the TH-series slim holes have been monitored since SB 2/3 power plant operations began in October 1992 (see Figure 5). The actual water level elevations for each of the TH-series slim holes are identical and data shown in the Figure 5 are offset vertically for presentation purposes. As noted in the figure, water level elevations were declining when monitoring operations began in 1992. Water levels continued to decline until spring 1996. Water levels began to rebound in summer 1996. Water level elevations continue to rebound to 1992 levels in mid-1999.

Stream discharge data for Steamboat Creek, an ephemeral creek located directly east of the FWC SB 2/3 power plants, are also shown in Figure 5. The Steamboat Hills geothermal area is located in the South Truckee Meadows area and Steamboat Creek is a major drainage feature for the South Truckee Meadows. Steamboat Creek, channels snowmelt and run-off from the Carson Range to the Truckee River, near Reno. The Carson Range is a major topographic feature in the area and is located approximately 3 km west of Steamboat Hills.

Discharge rates of Steamboat Creek have been shown to correlate with precipitation in the Carson Range and, therefore, subsurface recharge to the shallow groundwater systems surrounding Steamboat Hills (van de Kamp and Goranson, 1990). This groundwater recharge source may also be the recharge source for the Steamboat Hills geothermal system.

Water level elevations decreased during a drought period that began in 1986(?). This period of lower than normal precipitation is reflected in the discharge of Steamboat Creek as low discharge rates during the months of April through August for years 1992 to 1995. The April through August period is, typically, the period of maximum discharge due to snowmelt in the Carson Range. Steamboat Creek returned to normal discharge conditions after March 1995.

### 4.2) Reservoir Temperature Monitoring

Temperatures versus depth data have been obtained for the TH-series slim holes beginning in 1992. These temperature data illustrate convective thermal reservoir conditions (see Figure 6). The temperature data obtained in 1992 (pre-power plant operations) indicate that a shallow high–temperature reservoir zone, with temperatures of approximately 166°C, exists at depths between 106 m to 137 m. This upper zone overlies a cooler zone with average temperatures of 161°C.

This lower zone was chosen for power plant production operations because the upper zone is at or near saturated liquid conditions (including non-condensable gases) and pump cavitation during wellfield operations was a major development concern. For reasons mentioned above, all of the production wells supplying the SB 2/3 power plant were cased to depths of approximately 183 m.

Downhole temperature versus depth data for years 1996, 1997 and 1998 are also shown in Figure 6. These data indicate that the lower zone, at depths below 183 m, has cooled over time. This cooling is attributed to injection of spent brine. In addition, the temperature data indicate that the maximum temperature measured in the shallow high temperature zone decreased during the period between 1992 to 1996. The maximum measured temperature in the shallow zone increased for years 1997 and 1998.

### 4.3) Interzonal Wellbore Flow Characteristics

Static spinner (fluid velocity) versus depth data has been obtained for the slim holes. Slim hole GTH 87-29 spinner data (see Figure 7) has allowed for some insight into subsurface interzonal flow characteristics. Slim hole GTH 87-29 is completed to a total depth of 1,220 m. The slim hole is cased to a depth of 160 m with the bottom portion of the wellbore completed open-hole. It has not been possible, since completion of the hole, to obtain well logs below a depth of about 800 m. However, drill bits have readily passed this depth.

The spinner survey data shown in Figure 7 was obtained during static well conditions while logging down the hole. Maximum depth logged was 795 m, due to wellbore conditions mentioned above. The plotted data indicate fluid velocity increases below a depth of 650 m. The fluid velocity increases indicate that thermal fluids are flowing up the wellbore from depths below 795 m. While the tool was stopped, and at the total logged depth of 795 m, the spinner was revolving at approximately 3 revolutions per second (rps). The temperature at this depth was 140°C. During logging down the wellbore at 30-m/min, and while still within the cased portion of the well, the spinner reading was 5 rps. This indicates that the velocity of fluids moving-up the wellbore is approximately 18 m/s at a depth of 795 m. This indicates an upward vertical flow rate, for a 9.9-cm hole, of □2.2 kg/s of thermal fluids at a temperature of 140°C.

## 5.0) RESULTS AND DISCUSSION

The water level elevation data and Steamboat Creek discharge data indicate that a hydrological connection exists between the Steamboat Hills Geothermal system and the surrounding groundwater systems. Thermal fluids are noted in groundwater wells at locations up to 2 miles to the northeast of the Steamboat Hills area. Thermal fluids may extend beyond this point. It is not clear, at this time, whether the groundwater system act as a pressure, and therefore flow, boundary to the outflow area of the geothermal system or as a pressure restriction on the inlet of fluid to the geothermal system. Most likely, the groundwater system effects both the inlet and outlet conditions of the geothermal resource.

With respect to the temperature versus depth data obtained from the slim holes it can be noted that as the water elevations and therefore, the pressure in the geothermal reservoir, decreased the maximum observed temperature in the shallow thermal reservoir zone decreased. As the geothermal water level elevations rebound, the maximum temperatures in the shallow reservoir zone increase. In fact, simple calculations indicate that the temperature decrease or increase is approximately equal to the measured change in pressure along the saturated liquid portion of the pure water pressure-enthalpy saturation curve.

The deeper portions of the slim holes indicate some reservoir cooling. At first glance, the deeper cooling may be considered as a factor in the cooling of the shallow reservoir zone. However, this seems unlikely. Injection rates have increased by about 25% to maintain constant power plant electrical output and the shallow reservoir temperature has increased. In addition, the injection locations have not changed since operations began in 1992.

The spinner surveys obtained for slim hole GTH 87-29 have allowed for some practical results. Production well HA#4 is located approximately 10 m from slim hole GTH 87–29 (see Figure 4). Well HA#4 is completed to a depth of 222 m and cased to a depth of 160 m. The static bottom hole temperature was 163°C after completion in 1990. During production in 1996, measured discharge fluid temperature was 155°C during a 6-month flow period. The data obtained from GTH 87-29 suggested that cool fluids may be entering the HA#4 production zone. A downhole packer was run into GTH 87-29 and set at a depth of 765 m in July 1998. The produced fluid temperatures of HA#4 returned to 161°C and have remained at this temperature as of mid-1999.

The temperatures at depths below 180 m indicate that reservoir cooling is taking place. The development plan included deep injection of thermal fluids, making use of the influx of thermal fluids into the system at depths of about 110 m. The slimhole data indicate that deeper injection, than that currently used, will be required to maintain current production temperatures. The GTH 87-29 spinner data, along with the temperature recovery of HA#4 during production, indicate that deep injection can reduce cooling in the reservoir zones being produced as of mid-1999.

## 6.0) CONCLUSIONS

The slim holes at Steamboat Hills, Nevada have been invaluable in monitoring subsurface reservoir conditions during power plant operations. The wells used to supply thermal fluids to the power plants require downhole pumps, thereby eliminating the possibility of obtaining downhole pressure, temperature and spinner versus depth data during operating conditions. The slim holes allow for subsurface data acquisition in undisturbed portions of the reservoir to be obtained while production of geothermal fluids for electricity generation is on going.

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**REFERENCES**

Adams, M.C., J.N. Moore, P.C. van de Kamp and C. Goranson (1993), “Rhodamine WT as a Geothermal Tracer - A Field Test at Steamboat Hills, Nevada,” *Geothermal Resources Council 1993 Annual Meeting,* Burlingame, California, 10-13 October, poster presentation.

Combs, J. and C. Goranson (1994), “Use of Slim Holes for Reservoir Evaluation at the Steamboat Hills Geothermal Field, Nevada, U.S.A.,” *Proceedings of the Nineteenth Workshop on Geothermal Reservoir Engineering*, Stanford University, Stanford, California, Vol. 19, pp. 131-138.

Combs, J. and Goranson, C. (1995), “Reservoir Evaluation Using Discharge and Injection Test Data from Slim Holes and Large-Diameter Production Wells at the Steamboat Hills Geothermal Field, Nevada, USA”, *World Geothermal Congress*, Florence, Italy, Vol. 3, pp. 1517-1524.

Finger, J. T., C. E. Hickox, R. R. Eaton, and R. D. Jacobson (1994), “Slim-hole Exploration at Steamboat Hills Geothermal Field,” *Geothermal Resources Council Bulletin,* Vol. 23, no. 3, pp. 97-104.

Garg, S.K. and J. Combs (1993), “Use of Slim Holes for Geothermal Exploration and Reservoir Assessment: A Preliminary Report on Japanese Experience,” *Proceedings Eighteenth Workshop on Geothermal Reservoir Engineering*, Stanford University, Stanford, California, 26-28 January, Vol. 18, pp. 173-179.

Goranson, C. (1994), “Drilling, Completion and Testing of Intermediate-Depth Slim Hole 87-29”, report for Far West Capital, Salt Lake City, Utah, 160 pp.

Goranson, C., P. C. van de Kamp, and T. DeLong (1990), “Geothermal Injection and Monitoring Program History at the Caithness Power, Inc. Flash Steam Power Plant Steamboat Springs”, Nevada: *Proceedings of the Symposium on Subsurface Injection of Geothermal Fluids*, Santa Rosa, CA, 29-30 October, pp. 101-124.

Goranson, C., P. C. van de Kamp, and E. Call (1991), “Summary and Interpretation of Six Years of Groundwater Monitoring Data at the SB GEO, Inc. Geothermal Power Plant Steamboat Springs,” NV: *Proceedings of the Underground Injection Practices Council Meeting*, Reno, NV, 28-31 July, pp. 77-94.

Goranson, C. and J. Combs, (1995), "Characterization of Injection Wells in a Fractured Reservoir Using PTS logs, Steamboat Hills Geothermal Field, Nevada, USA" *Proceedings of the Twentieth Workshop on Geothermal Reservoir Engineering*, Stanford University, Stanford, California, Vol. 20, pp. 47-53.

Janik, C.J., and R.H. Mariner (1993), “Geochemical Investigation of Hydrothermal Systems and Geochemical Aspects of Geothermal Reservoir Depletion,” in *Geothermal Reservoir Technology Research Program Abstracts of Selected Research Projects*, edited by M. R. Reed, U. S. Dept. of Energy, March, 1993, Washington, D.C., pp. 75-76.

Silberman, M.L., D.E. White, T.E.C. Keith, and R.D. Docker (1979), “Duration of Hydrothermal Activity at Steamboat Springs, Nevada, from Ages of Spatially Associated Volcanic Rocks,” *U. S. Geol. Survey Prof. Paper 458-D*, 14pp.

Thompson, G.A., and D.E. White (1964), “Regional Geology of the Steamboat Springs area, Washoe County, Nevada,” *U.S. Geol. Survey Prof. Paper 458-A*, 52pp.

van de Kamp, P.C. (1991), “Geothermal Geology of the Northern Steamboat Hills, Nevada,” report submitted to Far West Capital, Inc., Salt Lake City, Utah, August, 5pp and 9 plates.

White, D.E. (1967), “Some Principles of Geyser Activity, Mainly from Steamboat Springs, Nevada,” *American Journal Science*, v. 265, pp. 641-648.

White, D.E. (1968), “Hydrology, Activity, and Heat Flow of the Steamboat Springs Thermal System, Washoe County, Nevada,” *U.S. Geol. Survey Prof. Paper 458-C*, 109pp.

White, D.E. (1973), “Characteristics of Geothermal Resources,” in *Geothermal Energy: Resources, Production, Stimulation*, ed. by P. Kruger and C. Otte, Stanford University Press, Stanford, CA, pp. 69-94.

White, D.E., G.A. Thompson, and G.A. Sanberg (1964), “Rocks, Structure, and Geologic History of the Steamboat Springs Thermal Area, Washoe County, Nevada,” *U.S. Geol. Survey Prof. Paper 458-B*, 63pp.

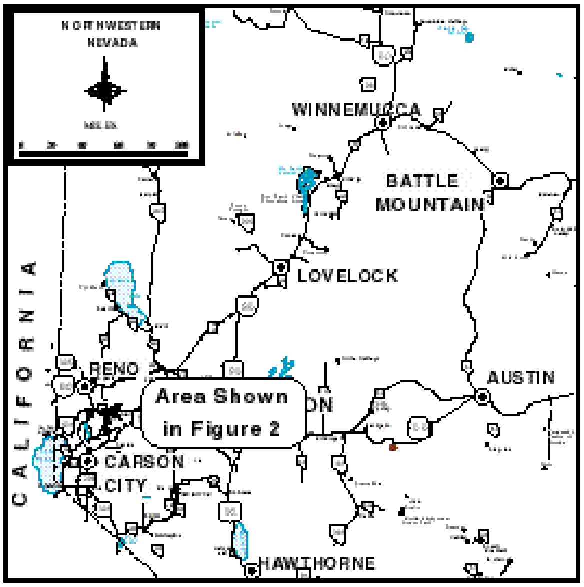


**Figure 1.** Regional location map of the Steamboat Hills Geothermal Field, Nevada

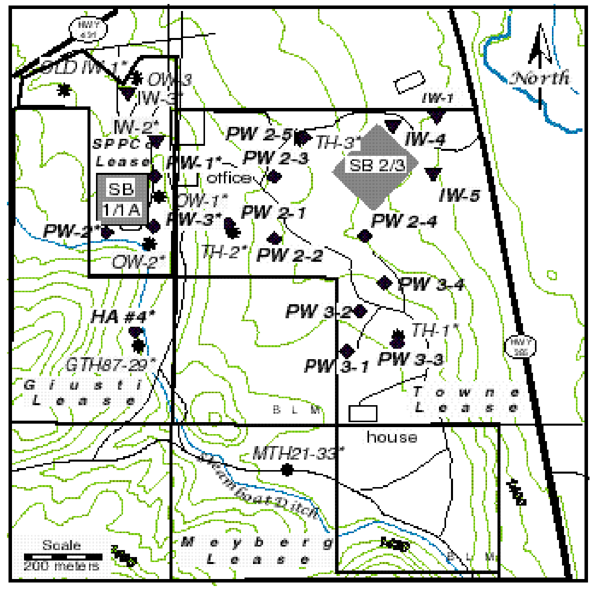


**Figure 2.** Location of slim holes, production and injection wells at the Steamboat Hills Geothermal Field.

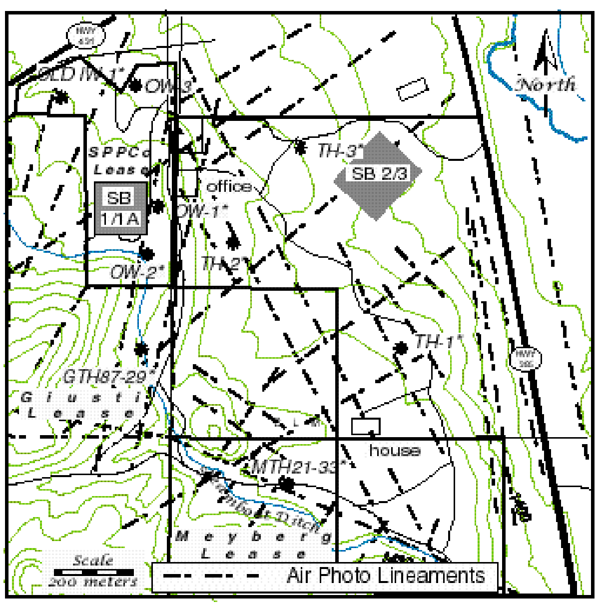


**Figure 3.** Steamboat Hills Geothermal Field showing location of air photo lineaments and slim holes.

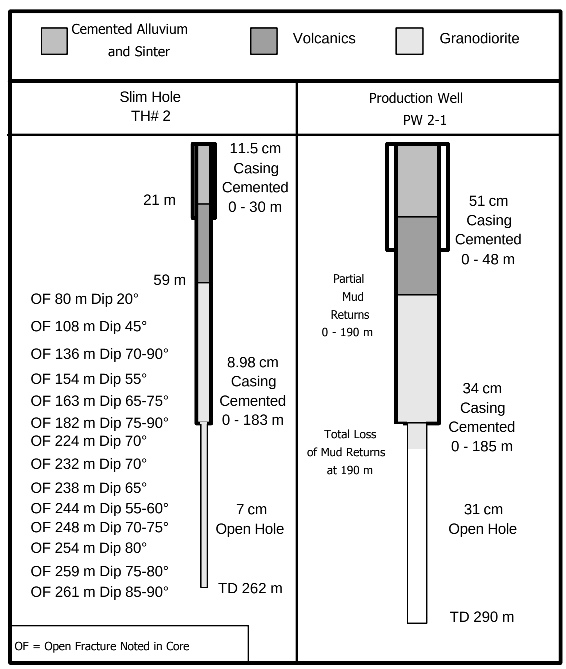


**Figure 4.** Geological data and completion for slim hole TH#2 and production well PW 2-1.

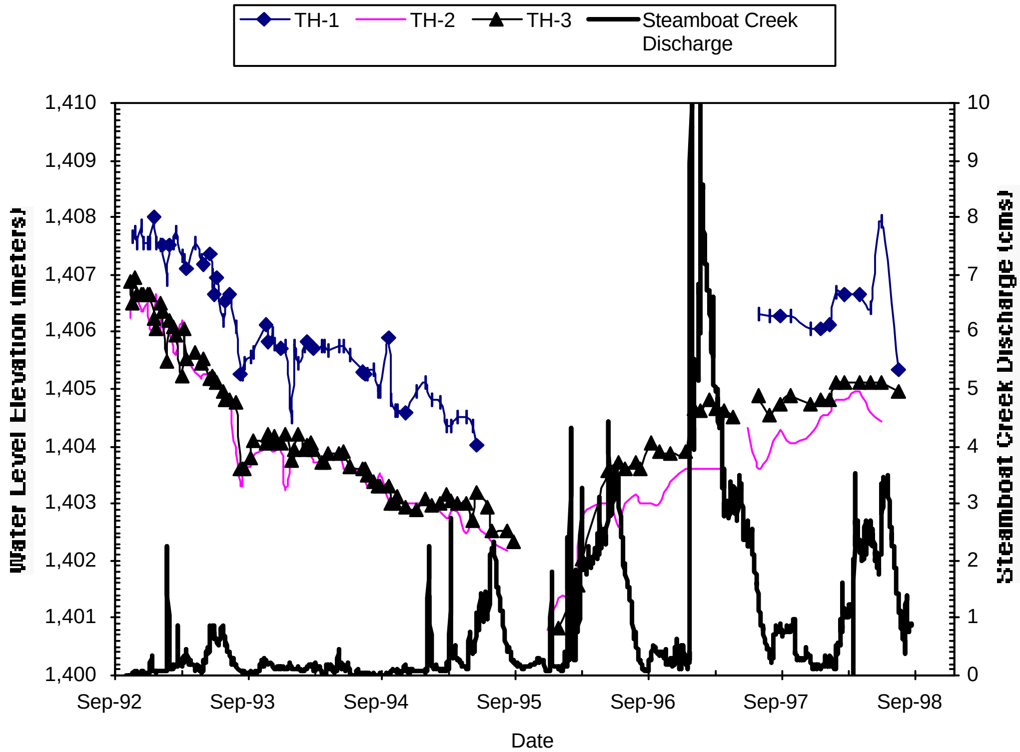


**Figure 5.** TH-series slim hole water level elevations and Steamboat Creek discharge.

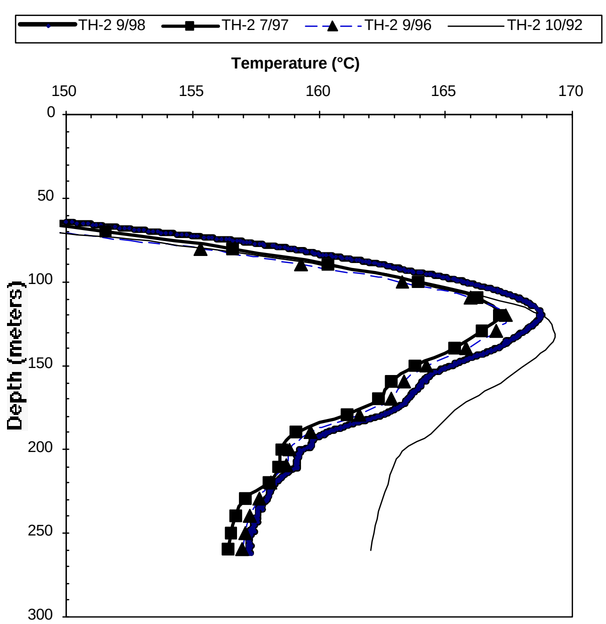


**Figure 6.** Temperature versus depth data for slim hole TH-2 for years 1992, 1996, 1997 and 1998.

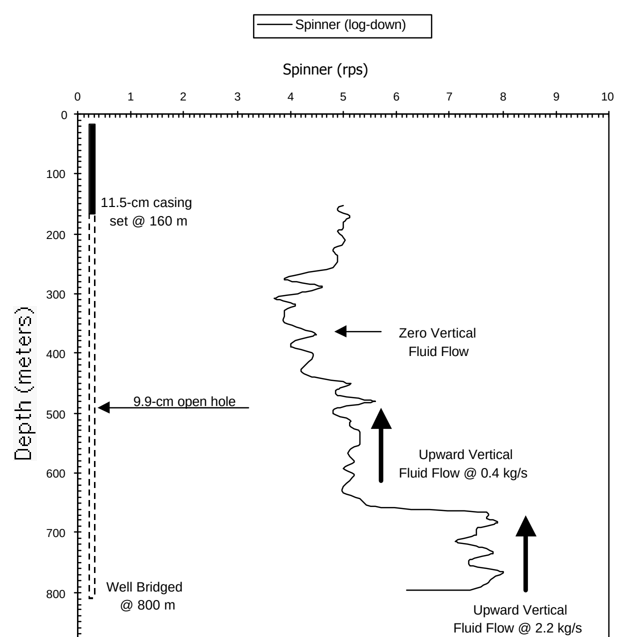


**Figure 7.** Spinner (wellbore fluid velocity) versus depth for slim hole GTH 87-29 while logging-down the wellbore under static conditions.