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Development of a Geothermal Resource in a Fractured Volcanic Formation: Case Study of the Sumikawa Geothermal Field, Japan

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Development of a Geothermal Resource in a Fractured Volcanic Formation: Case Study of the Sumikawa Geothermal Field, Japan

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This work performed under Sandia Contract AG-4388

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ABSTRACT

The principal purpose of this case study of the Sumikawa Geothermal Field is to document and to evaluate the use of drilling logs, surface and downhole geophysical measurements, chemical analyses, and pressure transient data for the assessment of a high temperature volcanic geothermal field. The work accomplished during Year 1 of this ongoing program is described in the present report. A brief overview of the Sumikawa Geothermal Field is given. The drilling information and downhole pressure temperature, and spinner surveys are used to determine feedzone locations, pressures and temperatures. Available injection and production data from both slim holes and large-diameter wells are analyzed to evaluate injectivity/productivity indices and to investigate the variation of discharge rate with borehole diameter. Finally, plans for future work are outlined.

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1 Introduction

The next major geothermal area in the United States (U.S.) to be developed is likely to be the Cascade volcanic zone in the Pacific Northwest region of the country (northern California/Oregon/Washington/Idaho). At present, detailed practical information pertinent to the development of geothermal resources in fractured volcanic rocks is scarce in the United States. Geothermal resources in Japan, however, are located in volcanic zones and the development of the Cascade region of the U.S. would likely be expedited by providing American developers with information concerning the Japanese experience in geothermal exploration and reservoir assessment.

During the past year, S-Cubed—under a contract with the U.S. Department of Energy (DOE)/Sandia National Laboratories (Sandia)—approached Mitsubishi Materials Corporation (MMC) for release of their proprietary data from the Sumikawa Geothermal Field for use in a case study of a high temperature volcanic field. As a result of these negotiations, MMC gave permission to S-Cubed to use pertinent Sumikawa data obtained prior to 1990 (MMC, 1985, 1986, 1987, 1988 and 1989). (MMC has also indicated its willingness to release more recent data at a future date.) The Sumikawa field is an especially good candidate for a case study of a high temperature volcanic field. The Sumikawa Geothermal Field is located on the northern slope of the Mount Yake volcano (Hachimantai volcanic region, Akita Prefecture, Japan), and is situated about 1.5 km to the west of the Ohnuma geothermal power station. An extensive exploration (and later field development) program was initiated at Sumikawa in October 1981 by MMC. The construction and commission-

ing of a 50 MWe power plant at Sumikawa will be completed some time in 1995.

The main thrust of the present case study of the Sumikawa Geothermal Field is on documenting and evaluating the use of drilling logs, surface and downhole geophysical measurements, chemical analyses, and pressure transient data for reservoir assessment purposes. While no large-scale numerical simulations of the Sumikawa reservoir will be performed under this case study, S-Cubed plans to analyze available geochemical and pressure transient data. Because of funding limitations at DOE, the case study will be conducted over several years.

The Sumikawa data set is being incorporated into an interactive computerized data base system (GEOSYS: Geothermal Reservoir Data Management System). GEOSYS incorporates a relational data base with a graphical user interface for the input, analysis and display of geothermal and geophysical data. The data base system will provide convenient accesses to the data, and at the completion of the study, copies will be made available to qualified users at nominal cost. During the past year, surface maps (including well locations, topography, tectonic features), well histories, drilling data, and downhole pressure/temperature/spinner logs were incorporated into the data base. In future years, other relevant data (surface geophysical and geological surveys, pressure transient and geochemical data, production data) will be included in the data base.

Under its drilling research program, the DOE through Sandia National Laboratories (Sandia) has

initiated a research effort to demonstrate that slim holes can be used (1) to provide reliable geothermal reservoir parameter estimates comparable to those obtained from large-diameter wells, and (2) to predict the behavior of large-diameter wells (Combs and Dunn, 1992). As part of this research effort, DOE/Sandia plan to drill and test pairs of small-diameter slim holes with large-diameter production wells in several geothermal fields in the western United States; the first of these tests was completed in mid-1993 at the Steamboat Hills Geothermal Field, Nevada (Finger, *et al.*, 1994). In addition, DOE/Sandia are supporting the examination of existing Japanese data on the use of slim holes in geothermal exploration and reservoir assessment; in the first of these studies, Garg, *et al.* (1994) analyzed production and injection data from the Oguni Geothermal Field, Japan. As part of its work under the subject contract during the past year, S-Cubed was also tasked to examine the existing production and injection flow test data for both small-diameter boreholes and large-diameter production wells at the Sumikawa Geothermal

Field. The major thrust of this work is to determine the feasibility of predicting the discharge characteristics of large-diameter production wells on the basis of test data from slim holes.

The present report describes the work accomplished during Year 1 of the contract between S-Cubed and DOE/Sandia. A brief overview of the Sumikawa Geothermal Field is presented in Section 2. The drilling information and downhole pressure, temperature and spinner surveys for eighteen Sumikawa boreholes are analyzed in Section 3 to determine feedzone locations, pressures and temperatures. Available injection and production data from both slim holes and large-diameter production wells are analyzed in Section 4 to determine injectivity/productivity indices. In Section 5, the injectivity/productivity indices for Sumikawa boreholes are compared with those for the Oguni Geothermal Field boreholes. The variation of discharge rate with borehole diameter is also discussed in Section 5. Finally in Section 6, plans for work during Year 2 are outlined.

2 An Overview of Sumikawa Geothermal Field

2.1 Introduction

The Sumikawa Geothermal Field is located in the Hachimantai volcanic area in northern Honshu, Japan, about 1.5 kilometers to the west of Ohnuma geothermal power station operated by Mitsubishi Materials Corporation (MMC). The Hachimantai area also includes the Matsukawa and Kakkonda Geothermal Fields (Figure 2.1). After the completion of the Ohnuma power station (~ 10 MWe) in 1973, MMC began to conduct exploratory investigations of the Sumikawa geothermal prospect. An extensive well drilling and testing program was initiated in October 1981 with the spudding of boreholes S-1 and S-2 by MMC and the Mitsubishi Gas Chemical Corporation (MGC). The New Energy and Industrial Technology Development Organization (NEDO) became involved in the field characterization effort with the drilling of borehole N59-SN-5 (~ 2 km west of S-1 and S-2) in 1984–1985. During the years 1986–1990, under NEDO sponsorship, S-Cubed carried out geothermal reservoir engineering studies of the Sumikawa Geothermal Field. All aspects of the five-year study of the Sumikawa Geothermal Field performed by S-Cubed have been summarized by Pritchett, *et al.* (1990). Much of the material presented in Sections 2 and 3 of this report is derived from the earlier study by Pritchett, *et al.* (1990). The field exploration and characterization program at Sumikawa was successfully concluded in 1990 with a decision to build a 50 MWe power plant.

The Sumikawa geothermal power plant is expected to be commissioned some time in 1995.

2.2 Geological Setting and Subsurface Stratigraphic Structure

The Sumikawa/Ohnuma geothermal area is shown in Figure 2.2. The area depicted is about 42 km²; the Sumikawa Geothermal Field lies in the western part of the area. The terrain is extremely irregular. Mt. Yake lies to the southwest of the Sumikawa area, and Mt. Hachimantai is just to the southeast (outside the area illustrated in Figure 2.2). To the north of these volcanic peaks, the terrain drops away rapidly. Between the Sumikawa prospect (which may be regarded as centered in the neighborhood of the S-series boreholes, S-1, S-2, S-3, and S-4) and the Ohnuma borefield is a north-south region of relatively low ground surface elevation where natural hot springs and fumaroles are found.

The Sumikawa/Ohnuma area lies within a north-south oriented regional graben structure which extends many kilometers both north and south of the Sumikawa area (see Figure 2.1). Indeed, the Sumikawa field itself appears to be located along the western edge of the graben. An east-west cross section corresponding to line A-A' is depicted in Figure 2.3. A similar north-south section (B-B') is depicted in Figure 2.4. These struc-

Figure 2.1. Tectonic map of the Hachimantai volcanic area. The origin of the local co-ordinate system is 40°N latitude and 140°50'E longitude.

Figure 2.2. The Sumikawa/Ohnuma area, showing locations of wells and cross-sections A-A' and B-B'. The origin of the local co-ordinate system is 40°N latitude and 140°50'E longitude.

Figure 2.3. East-west A-A' (total length = 3 km) geological cross-section through the Sumikawa area.

Figure 2.4. North-south B-B' (total length = 3.5 km) geological cross-section through the Sumikawa area.

tural interpretations are based almost exclusively upon drilling experience—the only available seismic survey was far too regional in scope to be useful for local structure interpretation, and the results of a gravity survey are difficult to interpret because of a lack of density contrast among the various deep formations in the area.

Extensive faulting has rendered the detailed geological structure at Sumikawa somewhat obscure, but the abundance of drilling logs from the various boreholes in the area has revealed an underlying geological sequence which applies to most of the area illustrated in Figure 2.2. In order of increasing depth, these formations are:

ST formation. Surficial andesitic tuffs, lavas, and pyroclastics of recent origin (from Mt. Yake).

LS formation. Lake sediments; Pleistocene tuffs, sandstones, siltstones, and mudstones.

DA formation. Pliocene dacites, dacitic tuffs, and breccias.

MV formation. “Marine/volcanic complex”; interbedded Miocene dacitic volcanic rocks and “black-shale” oxygen-poor marine shales and sediments.

AA formation. Altered andesitic rocks that apparently are extensively fractured.

BA formation. Crystalline intrusive (?) rocks (mainly granodiorite and diorite).

The BA formation is the deepest so far encountered by drilling (well SC-1 bottomed in this formation at 2486 m depth), but the pre-Tertiary basement, which presumably underlies the above sequence, has not yet been reached. Little evidence exists for significant permeability deep within the

BA formation, however, so that it may be permissible to regard this layer as the “basement” from a hydrological standpoint.

2.3 Fluid State

2.3.1 Fluid Temperatures

At Sumikawa, underground temperatures are highest to the south and decline to the north and northwest. The estimated temperatures at sea level (~700–1100 m depth) in the area (based mainly on temperature surveys in shut-in boreholes) are shown in Figure 2.5. The highest temperature so far measured in the field is at the bottom of well SA-2 (320°C at 840 m below sea level); this is also the southernmost deep borehole at Sumikawa.

Temperatures are significantly higher at Sumikawa (near the S-series boreholes) than at the nearby operating Ohnuma borefield. On the whole, temperatures appear to increase monotonically with depth; large-scale temperature inversions (with the exception of well SC-1) are not observed. The existence of a positive self-potential anomaly in the neighborhood of the S-series boreholes (Ishido, *et al.*, 1987) is indicative of the presence of upwelling deep hot water in this vicinity. The relatively low temperatures encountered to the north and west of the Sumikawa field have been interpreted by Kubota (1988) to indicate the downward flux of cold water in these areas. Observed surface manifestations of hot-water upflow (hot springs) are generally located along a north-south axis lying between Sumikawa and Ohnuma.

2.3.2 Fluid Pressures

Pritchett, *et al.* (1990) have examined the various downhole feedpoint pressure determinations

Figure 2.5. Temperatures at sea-level elevation in the Sumikawa/Ohnuma area (adapted from Kubota 1988).

available from boreholes in the Sumikawa/Ohnuma area in detail. Evidence from a series of thirty-two shallow (80 m) heat-flow holes drilled throughout the area (but not shown in Figure 2.2) indicates that near-surface pressures are cold-water hydrostatic relative to a water table depth that follows the local surface very closely; the water table is approximately 45 (± 21) m below ground. At great depth, however, pressures are surprisingly uniform throughout the area; apart from a small region immediately adjacent to the Ohnuma power station, deep shut-in pressures may be determined from the empirical correlation

$$P(\text{bars}) = 61.170 - 79.985Z - 6.492Z^2$$

where Z is elevation, measured in kilometers with respect to sea level (km ASL). The standard deviation of this correlation from the measurements is only 0.88 bars (comparable to the reliability of the pressure determinations themselves).

This "deep pressure correlation" is in excellent agreement with measurements (see Figure 2.6). This dependence of deep pressures on elevation (Z) and not on depth (D) is in sharp contrast to the situation at shallow depths, where the reverse is true (see above). The pressure data from several boreholes in the Ohnuma borefield (0-1R, 0-2R, 0-3R-a, 0-3R-b), obtained prior to the startup of Ohnuma power plant, are also in good agreement with the deep correlation obtained above.

The Ohnuma geothermal power plant started producing electric power in 1973. The sparse pressure data available for the Ohnuma boreholes suggest that the pressures at Ohnuma have fallen by several bars during the last 17 years. Since the pressure measurements upon which the deep pressure correlation is based were made between 1968 and 1988 (average date = 1980), it is apparent that any

pressure disturbance induced by operations associated with the Ohnuma power station must be of limited areal extent. According to Pritchett *et al.* (1990), the influence of Ohnuma operations is confined to a north-south channel which extends 1.5 km north of the power station and an undetermined distance south of Ohnuma, but which appears to be only about one kilometer wide in the east-west direction.

It is virtually certain that a two-phase (water and steam) flow region is present in the southern part of the reservoir system at depth, extending from the lower part of the lake sediment layer (600 m ASL to 800 m ASL) down to a considerable depth. Slim hole S-1 (feedpoint elevation ~ 580 m ASL) discharged nothing but dry steam. Furthermore, it appears that the two-phase region in the neighborhood of borehole S-3 reaches at least as deep as +400 m ASL. Since temperatures generally increase to the south in the Sumikawa area, it would appear that the depth of the bottom of the two-phase zone will likewise increase to the south.

The deep pressure correlation yields one atmosphere pressure at $Z = +711$ m ASL; it follows that in regions with lower ground surface elevation, underground pressures must be lower than the above. Indeed, measured pressures in boreholes in the extreme northern part of the area are less than the above correlation. The clear implication is that a deep reservoir boundary must be present, oriented roughly east-west, at about the location of the 750 m ASL ground surface elevation contour.

2.3.3 Fluid Salinity and Gas Content

Samples collected from discharging Sumikawa boreholes indicate that the reservoir fluid is of low salinity (<3000 ppm) and that the

Figure 2.6. Selected deep feedpoint pressures and algebraic fit (from Pritchett, *et al.* 1990).

noncondensable gas content is very low (typically < 0.1 percent by volume of the steam). The reservoir fluids are mainly of the Na-Cl type with a near neutral pH.

Acidic zones are encountered only infrequently at Sumikawa. According to Ueda, *et al.* (1991), only a single acidic zone was struck by slim hole S-2 at ~130 m ASL. In general, drilling along the flanks of young volcanoes (*e.g.*, Mt. Yake) can be expected to result in encounters with acidic zones (Hedenquist, 1991). Future work under the present research program will include a reexamination of the geochemical data for the Sumikawa field; special emphasis will be placed on deriving a better understanding of acidic zones in high temperature volcanic geothermal fields.

2.4 Reservoir Permeability

The vertical permeabilities at Sumikawa are small in comparison with horizontal permeabilities. Permeability in the field is due primarily to the pervasive network of fractures. Both the volcanic and sedimentary country rocks between the fractures appear to be essentially impermeable.

The lake sediments are nearly impermeable and act as a caprock for the underlying geothermal reservoirs. Pressure transient tests have been

interpreted (see *e.g.*, Pritchett, *et al.*, 1990; Garg, *et al.*, 1991) to imply the presence of two high-transmissivity geothermal aquifers within the "altered andesite" and the deeper "granodiorite" formations. The shallower of these two reservoirs (in the andesite formation) is usually encountered between 1000 and 1800 meters depth, and has been penetrated by several wells. At present, only well SC-1 produces a substantial quantity of hot fluid from a permeable horizon in the "granodiorite" formation. Pressure interference data have also been used to confirm the presence of a moderately transmissive layer in the "marine-volcanic complex" formation. Because of its low vertical permeability, the "marine-volcanic complex" formation will be used for injecting waste brine.

Discharge tests have shown that production wells SA-2 and SA-4 produce essentially dry steam from entries in the "altered andesite" formation. This is somewhat puzzling in that pressure interference data indicate (see above) that the "altered andesite" formation is characterized by high transmissivity. Perhaps, the production of dry steam is associated with the nature of permeability (*i.e.*, high permeability fractures separated by low permeability matrix blocks) encountered in the "altered andesite" layer. In our future work, we will re-examine existing pressure transient data using fractured formation models (*e.g.*, double-porosity, MINC or gradient-flow).

3 Analysis of Downhole Data

As of early-1990, MMC and NEDO had drilled and tested thirteen slim holes (diameter ≤ 6 inches) and eleven large-diameter (diameter > 6 inches) wells. With the exception of four slim holes (0-3T, Y-1T, Y-2T, and Y-3T) and two large-diameter wells (SD-2, SN-8R), some injection and/or production data are available for all of the Sumikawa boreholes. In this section, we will analyze available drilling (circulation losses, well completion and geologic data) and downhole PTS (*i.e.*, pressure, temperature, and spinner) surveys to obtain feedzone depths, pressures and temperatures for the eighteen wells listed in Table 3.1. The essential drilling and well completion data, required in the interpretations, are given in Appendix A.

At the Sumikawa Geothermal Field, downhole pressures are usually measured with Kuster gauges. Since these Kuster gauges are not recalibrated in the field, it is highly desirable to have repeat measurements with different tools. It is also possible to utilize the water level and temperature gradient data to deduce the downhole pressure distribution in the borehole; this pressure distribution can in turn be used to verify the accuracy of downhole pressure measurements. The importance of ensuring the accuracy and reliability of measuring tools cannot be overemphasized. It appears that the downhole pressure measurements made with a Kuster pressure tool (KPG-29846) during 1987 at Sumikawa are incorrect. We were also advised by MMC that many of the pressure/temperature measurements taken by an experimental PTS tool (PTS 350) during 1988 are suspect.

Some of the Sumikawa boreholes were directionally drilled; because of borehole deviation the measured depths along the borehole (MD) do not necessarily indicate true vertical depths (TVD) from the surface. To derive true vertical depths from the measured depths, it is thus necessary to correct for borehole deviation. Depths will also be sometimes given in terms of elevation (meters) above sea level; thus -800 ASL denotes an elevation of 800 meters below sea level. Casing, liner and borehole dimensions are generally given in mm for slim holes (borehole diameter ≤ 6 inches) and in inches for large-diameter (borehole diameter > 6 inches) wells.

3.1 Slim Hole 50-HM-3

The borehole appears to heat up conductively (Figure 3.1) and temperature surveys provide no clear indications of permeability. A temperature profile at a nominal shutin time of three hours recorded on November 27, 1975 shows a change in temperature gradient at ~ 460 m; if real, this may indicate the permeable horizon for 50-HM-3. The latter depth (~ 460 m) corresponds to a sandstone stringer embedded in the black shales.

Selected water level data and computed downhole pressures are shown in Figure 3.2. The water level stood at 14 m on November 22, 1975 (ST ~ 3 hours); it then fell to 139 m on December 2, 1975 (ST ~ 120 hours). Since it is not known if the water level at 120 hours represents the stable water level for 50-HM-3, we can only place an upper

Continued on page 3-5

Table 3.1. Sumikawa boreholes with production or injection data.

Borehole Name	Measured Depth (meters)	Vertical Depth (m TVD)	Feedzone Depth (m TVD)	Final Diameter (mm)	Feedzone Temperature (°C)	Production/ Injection Data
50-HM-3	501	501	460?	79	—	I
N60-KY-1	1604	1604	1560	101	205	I
O-5T	749	749	747?	64	>210	I
S-1	448	448	436	143	—	P,I
S-2*	905	905	900	101	>225	P,I
S-2	1065	1065	940	101	240	P,I
S-3	805	805	700	101	240	P,I
S-4	1552	1552	1520	159	295	P,I
SA-1	2001	1832	1800	216	305	P,I
SA-2	2005	1943	1450	216	≥300	P,I
SA-4	2009	1739	1240	216	≥290	P,I
SB-1	2086	2006	1600	216	>260	P,I
SB-2	1384	1308	1270	216	~250	I
SB-3	1542	1366	880	216	~210	I
SC-1	2486	2472	2310	216	246	P,I
SD-1	1704	1691	1550	216	250	P,I
52E-SM-1	1003	1003	730?	79	—	I
52E-SM-2*	803	803	550	101	>170	P,I
52E-SM-2	1001	1001	980	79	>230	P
N59-SN-5	1701	1701	1600	101	>260	I

*Partially-drilled hole

Figure 3.1. Temperature profiles for 50-HM-3.

Figure 3.2. Pressure profiles computed from water level and temperature data for 50-HM-3.

bound on the formation pressure. The pressure at a depth of 460 m is:

$$p(460 \text{ m}) = p(514 \text{ ASL}) < 31 \text{ bars}$$

3.2 Slim Hole N60-KY-1

Heat up surveys in the partially drilled hole (drilled depth ~ 880 meters) show a thermal feature in the depth interval from 500 to 540 meters (Figure 3.3); this probably corresponds to the lost circulation zone at 530 meters. After over four months of shutin, the water level in the partially drilled borehole was recorded on April 26, 1986; the computed pressure profile is shown in Figure 3.4. The pressure at 530 meters is ~ 38.5 bars. It is significant that the heatup surveys in the completed borehole (Figure 3.5) do not show any thermal feature at 500 to 540 meters; in addition, the pressures in the completed borehole are much lower than those implied by the water level measurements in the partially drilled borehole.

The completed borehole heats up very slowly below the casing shoe at ~ 1001 meters; available temperature profiles provide no clear indications of formation permeability. Only two mud loss zones (at 1160 m and at 1562 m) were encountered in the uncased interval for this borehole. We will tentatively assume that the major feedzone for KY-1 is located at ~ 1560 meters. Like the temperatures, water levels did not show much variation during the heat up period; representative computed pressure profiles are shown in Figure 3.6. The pressure at 1560 meters is ~ 104 bars. The latter pressure value is in substantial agreement with that (~ 103 bars) recorded on May 10, 1988 (Figure 3.7). The stable pressure at 1560 meters is, therefore, 103.5 (± 0.5) bars. The stable temperature at 1560 meters is about 205°C.

3.3 Slim Hole O-5T

The heatup profiles (Figure 3.8) show marked features at ~ 260 m and ~ 380 m; also a small break in temperature gradient is seen at ~ 450 m. The break in temperature gradient at ~ 260 m is probably associated with the water level in the well; the feature at ~ 450 m corresponds to the change from cased to open hole. Temperature data, however, fail to show any thermal anomaly at the lost circulation horizon at ~ 747 m. Maximum temperature occurs towards bottomhole and exceeds 210°C (shutin time ~ 76 hours).

Well logs indicate that the water level in the borehole stood at 261.5 m at a shutin time of ~ 3 hours (8/13/77); it then fell to 262.5 m at ~ 4 hours and stayed at this level until the end of the observation period (shutin time ~ 76 hours). The above water level for 76 hours cannot be correct since the corresponding temperature profile would imply the presence of superheated steam below the water level. Table 6-3-1 (MMC, 1985) gives a water level of 150 m at the same time. Assuming that the latter water level is correct, the pressure at 750 m (see Figure 3.9) is about 54.5 bars.

3.4 Slim Hole S-1

During the drilling of S-1, partial circulation losses were recorded at 436 m and 438 m. While drilling at 448 m, a blowout occurred and no further drilling was undertaken. The blowout was probably caused by total circulation loss at 448 m. These mud loss and drilling data suggest that the fluid entry for this borehole is located at 436 to 448 m.

Prior to setting the 6-inch casing at 305 m, heat up surveys (shutin time 3 to 12 hours) were

Continued on page 3-13

Figure 3.3. Temperatures in partially drilled borehole N60-KY-1 (drilled depth ~ 880 meters).

Figure 3.4. Pressures computed from water level and temperature data in partially drilled borehole N60-KY-1.

Figure 3.5. Temperatures in borehole N60-KY-1.

Figure 3.6. Pressures computed from water level and temperature data for borehole N60-KY-1.

Figure 3.7. Measured pressure profile in borehole N60-KY-1 on May 10, 1988.

Figure 3.8. Heatup profiles for O-5T.

Figure 3.9. Pressure profile computed from water level and temperature data in O-5T at a shut-in time of ~76 hours.

recorded on November 4 and 5, 1981 (see Figure 3.10). The 12-hour temperature survey suggests the possibility of an entry at ~ 270 m; this is, however, not confirmed by the temperature survey at 3 hours. No heat up profiles deeper than 305 m are available.

The temperature survey made while injecting cold water at a rate of 5.8 kg/s (May 5, 1982, Figure 3.10) showed anomalously high temperatures below the first measurement point at ~ 70 m. This temperature log indicates a break in the casing at 70 to 100 m depth, and an upflow with a steam component which is rapidly quenched on mixing with the injected cold water (KRTA, 1985).

The pressure survey of April 30, 1982 (see Figure 3.11) was run to a maximum depth of 300 m. The interval from 100 m to 300 m depth is certainly two-phase; extrapolating the pressure gradient over the interval 150 m to 300 m, a bottomhole (448 m) pressure of ~ 20.3 bars is obtained. This pressure is only approximate since (1) the pressure gradient below 300 m may not be the same as that above 300 m and (2) the borehole is discharging internally.

The borehole was flow tested for several days in April 1982. The well output consisted entirely of dry steam with no water phase present. It appears that the reported wellhead enthalpies were determined by assuming that the steam is saturated at the measured wellhead pressure. The steam flow rate declines linearly with pressure and can be extrapolated to give a pressure of ~ 20.1 bars at zero flow rate. Allowing for the weight of the steam column, this suggests a bottomhole (~ 448 m) pressure of ~ 20.5 bars. The latter pressure value agrees closely with that obtained from an extrapolation of the pressure survey of April 30, 1982. Assuming that the reservoir in the neighborhood of S-1

contains saturated steam, the reservoir temperature is estimated to be ~ 213°C (corresponding to a reservoir pressure of ~ 20.4 bars).

The above inferred value for reservoir pressure is, however, at considerable variance with the pressure value given in Table II-3-1 of MMC (1986). According to the latter, a pressure survey run on December 17, 1981 (shutin time ~ 1 hour, 9 minutes) indicated a pressure of 25.3 bars at 436 m. The corresponding water level (pressure ~ 0.9 bars) depth in the borehole was ~ 187 meters (*i.e.*, 249 meters above the pressure measurement depth). These water level and pressure data imply the presence of a very dense fluid (density ~ 1000 kg/m³) in the borehole at the time of pressure survey on December 17, 1981. The drilling operations were completed on or about November 20, 1981. We are unable to explain the presence of a dense fluid (density ~ 1000 kg/m³) in the borehole on December 17, 1981. It is therefore, suggested that the pressure measurement of December 17, 1981 is unreliable.

3.5 Slim Hole S-2

The borehole was originally (October 1981) drilled to a total depth of ~ 905 meters. The bottom of the 4-inch casing was set at 703 meters, and an open hole completion was used below this depth. In October 1982, the hole was sidetracked at 747 meters, and drilled to a depth of ~ 1065 meters. The redrilled hole (like the original hole) was left open below 703 meters.

The single shutin survey (Figure 3.12) in the original hole was recorded during swabbing operations on July 2, 1982; the temperature at 900 meters depth exceeds 225°C. A spinner survey recorded during an injection test on July 16, 1982

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Figure 3.10. Temperature surveys in slim hole S-1.

Figure 3.11. Pressure survey recorded in slim hole S-1 on April 30, 1982 shortly after a production test.

Figure 3.12. Temperature surveys in partially-drilled slim hole S-2 (drilled depth = 904.6 m).

(Figure 3.13) indicates that the major feedzone for the original S-2 is located at 900 meters. Temperature (Figure 3.12) and pressure surveys (Figure 3.14) taken during a production test on July 11, 1982 show two-phase conditions in the borehole at the feedzone depth; apparently, production is accompanied by *in situ* boiling. MMC (1986; Table II-3-1) lists a pressure (computed from water level and temperature data) of 49.5 bars (June 24, 1982; shutin time ~ 13.3 hours) at 903.4 meters. The temperature and water level data recorded on June 24, 1982 are unavailable for the present study.

Selected heat up surveys in the redrilled hole are plotted in Figure 3.15. The persistence of low temperatures at ~ 600 m, ~ 735 m and ~ 880 m indicates the presence of permeable horizons. Also, an abrupt change in temperature gradient at ~ 940 m implies a fluid entry at this depth. The temperature at ~ 940 m (see temperature surveys taken on May 10, 1983 and November 10, 1982) is ~ 240°C. The fluid entry at ~ 600 m is also confirmed by several flow meter surveys (see Figure 3.16). It is therefore likely that there is a break in casing at this depth. All of the flow meter surveys in the redrilled hole indicate that most of the injected water is lost over the depth interval 900 to 940 m; this is clearly the most permeable horizon for S-2.

Several water level readings are available for the redrilled S-2. The water level reading corresponding to a shutin time of 179 days appears to be incorrect; this is probably due to boiling in the upper part of S-2 at this time. The pressure profiles (Figure 3.17) other than that for a shutin time of 179 days appear to coincide at ~ 900 to 1000 m. The pressure at a depth of 940 m is 52.5 bars. The latter value is close to the pressure of ~ 51 bars

(depth ~ 935 m) recorded on November 6, 1982 (Table II-3-1, MMC, 1986). The slight discrepancy (~ 1 bar) between the two values may be due to borehole deviation. The saturation temperature corresponding to a pressure of 51 bars is ~ 265°C. Since it is unlikely that the stable temperature at ~ 940 m exceeds 250°C, we conclude that the reservoir fluid at this depth is single-phase liquid. The reservoir at shallower depths may, however, contain a two-phase fluid.

Temperature (Figure 3.15) and pressure (Figure 3.18) surveys taken in the redrilled hole during a production test on November 10, 1982 show the presence of single-phase liquid in the borehole at the feedzone (900–940 meters) depth. During the November 1982 production test, the redrilled S-2 discharged fluid with an enthalpy of about ~ 250 (± 10) kcal/kg; this is consistent with production from a liquid reservoir of about 240 to 250°C at a depth of ~ 940 m.

3.6 Slim Hole S-3

The available temperature surveys for S-3 are shown in Figure 3.19. A pronounced feature in temperature profiles 2 and 3 identifies a permeable zone at ~ 450 m. Temperature surveys 2 to 4 also show permeable zones at 650 to 750 m and at ~ 780 m. The permeable zone at 650 to 750 m may not be a continuous zone; the isothermal interval indicates permeability at both the endpoints and interzonal flow. Two flow-meter surveys conducted on June 13, 1983 (Figure 3.20) show that most of the injected water is lost over the depth interval 650 to 750 m; thus it would seem that the principal feed point for S-3 is located in this depth interval.

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Figure 3.13. Spinner survey (interpreted by MMC) run in partially-drilled slim hole S-2 (drilled depth = 904.6 m) during an injection test on July 16, 1982.

Figure 3.14. Pressure survey recorded in partially-drilled slim hole S-2 (drilled depth = 904.6 m) during a production test on July 11, 1982.

Figure 3.15. Temperature surveys in slim hole S-2 (drilled depth = 1065.1 m).

Figure 3.16. Spinner surveys (interpreted by MMC) in slim hole S-2 (drilled depth = 1065.1 m) taken during an injection test on October 24, 1982.

Figure 3.17. Pressure profiles computed from temperature and water level data in slim hole S-2 (drilled depth = 1065.1 m).

Figure 3.18. Pressure survey in slim hole S-2 (drilled depth = 1065.1 m) run during a production test on November 10, 1982.

Figure 3.19. Selected temperature profiles for slim hole S-3.

Figure 3.20. Spinner surveys (interpreted by MMC) in S-3 taken during an injection test on June 13, 1983.

Temperature surveys conducted after long standing times (see profiles 7 and 10, Figure 3.19) appear to follow the boiling point versus depth curve down to ~ 650 m; the water levels associated with these profiles (see profiles 7 and 10, Figure 3.21) are useless for determining reservoir pressures due to boiling in the borehole. The maximum temperature in S-3 measured on May 16, 1983 was ~ 236°C at ~ 620 m. The enthalpy of the fluid produced from S-3 is approximately equal to the enthalpy of liquid water at ~ 240°C. Thus, it is likely that the main feed zone for S-3 (depth ~ 650 to 750 m) contains liquid water at ~ 240°C.

Several bottomhole pressure surveys are available for S-3. Two of these surveys (September 2, 1982, $p = 27.6$ bars at 428 m; May 16, 1983, $p = 32.6$ bars at 648 m) were made in the partially drilled hole (see Table II-3-1 in MMC, 1986). Since the reservoir is most likely two-phase down to a depth of ~ 650 m, these pressure values may be used to estimate the corresponding formation temperatures ($T = 229^\circ\text{C}$ at 428 m, and $T = 238^\circ\text{C}$ at ~ 648 m). We note that for borehole S-1, the estimated temperature at 436 m depth is at least 213°C .

Pressure profiles computed from water level and temperature data are shown in Figure 3.21. Pressure profiles (7 and 10) cannot be used to determine the feedzone pressure due to the presence of two-phase conditions in the wellbore. The pressure at the midpoint (700 m) of the permeable zone at 650 to 750 m can be estimated from profiles 2 and 4, and is ~ 33.5 bars. The latter pressure value is in substantial agreement with that obtained (~ 32.5 bars) from downhole pressure surveys (see e.g., pressure survey 3, Figure 3.22) conducted prior to June 1986. Later downhole pressure surveys (surveys 4 and 5, Figure 3.22) give substantially higher pressures; these higher pressures may be the result of a shallow casing leak in S-3.

3.7 Well S-4

Selected temperature profiles for S-4 are shown in Figure 3.23. Temperature profile 1 was measured in the partially drilled hole, and indicates a temperature of ~245°C at a depth of 650 m. The measured temperature implies two-phase (or even steam) conditions at this depth in the reservoir. The shape of the temperature profile (i.e., linear gradient above ~550 m) suggests that two-phase conditions may extend up to ~550 m.

The short-time heat-up profiles (see profiles 2 through 4) indicate permeable zones at 1120 to 1180 m and at ~1525 m. These permeable zones are also confirmed by a flow-meter test carried out on November 7, 1983. The flow-meter also indicates water loss at 1200 to 1300 m (Figure 3.24). Temperature profile 12 (Figure 3.23) shows an isothermal zone from 1250 to 1350 m; an isothermal zone implies permeability at both its end points. The maximum temperature (Profile 6) occurs towards bottomhole and is ~300°C.

Pressure profiles calculated from water level and temperature data are shown in Figure 3.25. Pressure profiles 2 and 4 (corresponding to temperature profiles 2 and 4, Figure 3.23) coincide towards bottomhole; this indicates that the primary permeable zone for S-4 is at ~1520 to 1530 m. The computed pressure at ~1520 m is ~94 bars, and is in good agreement with a bottomhole pressure survey ($p = 94.9$ bars at 1523 m) made on June 29, 1984 (MMC, 1986; Table II-3-1). It is noteworthy that the water level and temperature data recorded on the latter date yield a higher pressure value (see profile 6 in Figure 3.25). The water level data of June 29, 1984, and April 3, 1989 (Figure 3.25), cannot be used to calculate downhole pressures due to the presence of boiling conditions in the wellbore at that time. The measured pressure profiles

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Figure 3.21. Pressure profiles computed from water level and temperature data for slim hole S-3.

Figure 3.22. Measured pressure profiles for slim hole S-3.

Figure 3.23. Temperature surveys for well S-4.

Figure 3.24. Spinner surveys (interpretation by MMC) recorded in well S-4 during an injection test on November 7, 1983.

Figure 3.25. Pressure profiles computed from water level and temperature data for well S-4.

for well S-4 are shown in Figure 3.26; these pressure profiles indicate a pressure of ~92 bars at ~1520 m. Based on the preceding discussion, the stable pressure at ~1520 m is estimated to be 93 (± 1) bars.

3.8 Well SA-1

Selected temperature surveys for well SA-1 are displayed in Figure 3.27. The temperature survey recorded on October 10, 1986 while injecting cold water shows an anomalously warm interval from ~1250 m TVD to ~1450 m TVD. This anomaly is most likely associated with the particular liner arrangement (slotted/blank/slotted/blank/slotted) employed in the hole over the latter depth interval. A spinner survey taken during an injection test on October 15, 1987 (Figure 3.28) shows a complex flow pattern in the well from ~1250 m TVD to ~1450 m TVD. All the available spinner surveys (Figures 3.28 and 3.29) indicate that the major permeable zone for SA-1 is located at ~1790 m TVD. The maximum temperature occurs towards bottomhole and exceeds 305°C.

Pressures computed from measured temperature profiles and water level data are shown in Figure 3.30. Interestingly, the pressures appear to increase with increasing shutin time, and do not form a pivot. This may be indicative of poor formation permeability; alternatively, it could be due to inaccuracies in water level data. It is often difficult to measure water levels accurately in wells which are boiling. The computed pressure (Figure 3.30) at 1800 m TVD is $\sim 114.5 \pm 2$ bars. This value is in good agreement with that (~113 bars) recorded on April 22, 1988 with a downhole pressure gauge (see Figure 3.31).

3.9 Well SA-2

A temperature survey taken during cold water injection on September 28, 1987 (Figure 3.32) shows that part of the injected fluid is lost into a fracture zone at ~1450 m TVD, and that the rest of the injected fluid travels down the hole. Heat up surveys (Figure 3.32, profiles 1 and 2) indicate additional permeable zones at ~1150 m TVD and at ~1900 m TVD. The permeable zone at ~1900 m TVD is probably associated with the lost circulation zone recorded near this depth. A spinner survey taken during cold water injection on September 28, 1987 (Figure 3.33) indicates that most of the water loss occurs from ~1380 m TVD to ~1500 m TVD. Thus, it would appear that the major feed point for Well SA-2 is located at ~1450 m TVD. The maximum temperature occurs towards bottomhole and is ~320°C. The feedzone temperature exceeds 300°C.

No reliable downhole pressure measurements are available for this well. (Downhole pressure measurements were made with KPG-29846 and PTS-350. As discussed elsewhere in this report, these measurements are not reliable.) Pressure profiles computed from water level and temperature data are shown in Figure 3.34. The water level for profile 1 was obtained from an electric survey, and may be in substantial error. The pressure survey conducted with Kuster tool KPG-29846 (Figure 3.35) was used to determine the water level for profile 8. Although the two pressure profiles in Figure 3.34 appear to pivot at ~1220 m TVD, we do not attach any significance to this observation; a pressure pivot should be an intersection of at least three pressure profiles. Assuming that pressure profile 8 represents stable pressures, the pressure at 1450 m TVD is ~95.5 bars; by comparison, the

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Figure 3.26. Measured pressure profiles for well S-4.

Figure 3.27. Temperature surveys in well SA-1.

Figure 3.28. A spinner survey recorded (tool moving up wellbore) while injecting cold water in well SA-1 on October 15, 1987.

Figure 3.29. Spinner surveys recorded in well SA-1 during a discharge test in September 1989.

Figure 3.30. Pressures (computed from water level and temperature data) in well SA-1.

Figure 3.31. A measured pressure profile in well SA-1.

Figure 3.32. Temperature surveys in well SA-2. Breaks in injection temperature profile of September 28, 1987 indicate stops at these locations.

Figure 3.33. A spinner survey (tool moving up the hole) recorded in well SA-2 during an injection test on September 28, 1987.

Figure 3.34. Pressures computed from water level and temperature data in well SA-2.

Figure 3.35. Pressure surveys in well SA-2.

downhole pressure recorded directly by KPG-29846 (see Figure 3.35) is ~94.5 bars. At present, the feedpoint pressure for Well SA-2 must be regarded as uncertain. The available estimates for feedzone pressure and temperature imply that two-phase conditions may be present at the feedzone.

3.10 Well SA-4

Temperature surveys taken during and shortly after injection (see profiles 9 and 3, Figure 3.36) imply that most of the water loss occurs from ~1240 m TVD to ~1420 m TVD; this depth interval is characterized by numerous lost circulation zones. Rapid temperature recovery at ~1240 m TVD (profiles 2 and 6, Figure 3.36) indicates that the major feed zone for SA-4 is located at this depth. A spinner survey recorded in the discharging well (Figure 3.37) supports the conclusion that the major permeable horizon is situated at ~1240 TVD. Offsets in the spinner and temperature survey at ~920 TVD (Figures 3.38 and 3.39) indicate the presence of a casing break and a minor inflow zone at this depth. The pressure and temperature surveys in the discharging well indicate that the entry at ~920 TVD supplies steam to the well. The maximum temperature occurs towards bottomhole and exceeds 300°C. The feedzone temperature exceeds 290°C.

Shutin pressure surveys of June 11, 1988 and June 26, 1988 (Figure 3.40) were both made with tool PTS-350. Pressure profiles computed from water level and temperature data are displayed in Figure 3.41. The pressure (Figure 3.41) at 1240 m TVD is ~80 bars, and is not too different from that (~81.5 bars) recorded downhole by PTS-350. The estimated feedzone temperature and pressure values indicate that two-phase conditions are likely at the feedzone depth.

3.11 Well SB-1

Selected temperature surveys in well SB-1 are shown in Figure 3.42. Short-time heat up surveys after cold water injection (see Profiles 2, 3 and 4) indicate permeable horizons at ~1520 m TVD and at ~1650 m TVD. A minor entry may also be present just below the casing shoe at ~1060 m TVD. The persistence of a low temperature zone at ~1520 m TVD may imply that the major permeable horizon for SB-1 is located at this depth. The maximum temperature occurs towards bottomhole and is ~300°C. By comparison with measured temperatures above and below the feedzone, the temperature at 1600 m TVD is estimated to be at least 260°C.

Pressure profiles computed from water level and temperature data are displayed in Figure 3.43; profiles 5, 8 and 9 (Figure 3.43) intersect at about ~1600 m TVD. The pressure at 1600 m TVD is ~103 bars. Measured pressure profiles for SB-1 are displayed in Figure 3.44. The pressure survey of May 7, 1988 – conducted with PTS-350 – exhibits strange behavior below ~1650 m TVD. Pressure surveys 2 and 3 (Figure 3.44) give a pressure of ~103 bars at 1600 m TVD; the latter value is identical with that computed from temperature and water level data.

3.12 Well SB-2

Brief shutin time heatup surveys (see profiles 1, 2 and 3, Figure 3.45) indicate several permeable horizons (740 m TVD, 1020 m TVD, 1160 m TVD and 1270 m TVD). The permeable horizons at 1020 m TVD, 1160 m TVD and 1270 m TVD correspond closely to lost circulation zones. The persistence of a cold zone at ~1270 m TVD even at late times (profiles 4 and 5, Figure 3.45) implies

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Figure 3.36. Selected temperature surveys in well SA-4.

Figure 3.37. A spinner survey recorded during a discharge test in well SA-4 on September 23, 1989.

Figure 3.38. An expanded view of the spinner survey taken on September 23, 1989. See Figure 3.37 for complete record.

Figure 3.39. An expanded view of the temperature survey taken on September 23, 1989. See Figure 3.36 for the complete profile.

Figure 3.40. Pressure surveys recorded in well SA-4 with an experimental pressure/temperature/spinner tool (PTS-350).

Figure 3.41. Pressure profiles computed from water level and temperature data for well SA-4.

Figure 3.42. Selected temperature surveys in well SB-1.

Figure 3.43. Pressure profiles computed from water level and temperature data for well SB-1.

Figure 3.44. Measured pressure profiles in well SB-1.

Figure 3.45. Temperature profiles for well SB-2.

that the major feed point for SB-2 is located at about this depth. By comparison with the temperatures measured above the feedzone, the temperature at 1270 m TVD is estimated to be about 250°C.

Pressure profiles computed from water level and temperature data are shown in Figure 3.46. The computed pressure at 1270 m TVD is ~77.5 bars. The measured pressure (see Figure 3.47) at 1270 m TVD is ~78.5 bars. Thus, the best estimate for feed point (1270 m TVD) pressure is ~78 bars.

3.13 Well SB-3

Selected heatup surveys for well SB-3 are displayed in Figure 3.48. Temperature surveys taken shortly after cold water injection (Profiles 2 and 4, Figure 3.48) suggest that most of the water loss occurs from ~800 m TVD to ~960 m TVD. Relatively rapid heatup at ~1100 m TVD may be evidence of a minor feed zone at this depth. The feedzone temperature is estimated to be about 210°C.

Pressure profiles computed from water level and temperature data are shown in Figure 3.49, the pressure at 880 m TVD is ~46.5 bars. This pressure value is in substantial agreement with that (~45.5 bars) recorded downhole by a pressure gauge (Figure 3.50). Accordingly, the pressure at 880 m TVD is estimated to be ~46 bars.

3.14 Well SC-1

(original well name: N61-SN-7D)

Selected temperature surveys for well SC-1 are shown in Figures 3.51 and 3.52. The temperature profile measured during cold water injection on June 7, 1988 shows a water loss zone at

~2300 m TVD. Heat up surveys 4, 10, and 14 (Figures 3.51 and 3.52) show large temperature gradients at ~1740 m TVD and at ~1900 m TVD; these thermal features do not denote the presence of permeable horizons. It appears that rapid heatup at ~1740 m TVD and ~1900 m TVD is the direct result of well completion. During cold water injection or fluid production (see below), part of the fluid flows in the annulus between the 7-inch liner and the 9⁵/₈-inch casing (or 12¹/₄-inch hole) from 1740 m TVD to 1900 m TVD. Temperature profile 14 (Figures 3.51 and 3.52) also implies a permeable zone at ~2030 m TVD. Temperature profile 11 (Figures 3.51 and 3.52) was recorded after the well had been shut in for approximately 6 months. It is significant that the cold zone at ~2300 meters has not disappeared even after 6 months; the recorded temperature at ~2300 m TVD is ~246°C. The maximum temperature (~310°C) occurs in the depth range 1800 m TVD to 1900 m TVD. The temperature inversion is confirmed by pressure/temperature/spinner (PTS) surveys taken while the well was discharging.

The PTS logs taken during a production test in November 1988 are displayed in Figure 3.53. The spinner logs clearly confirm fluid flow behind the liner between ~1740 m MD and ~1900 m MD. Temperature logs imply permeable horizons at 1950–1970 m MD (1947–1967 m TVD), 2030–2050 m MD (2026–2046 m TVD), 2120–2130 m MD (2114–2124 m TVD), 2230–2250 m MD (2222–2242 m TVD), and 2320 m MD (2310 m TVD). Since the temperature distribution below the shallowest feedpoint does not depend upon the flow rate, it would appear that the fraction of fluid contributed by each feed zone is essentially independent of the pressure drawdown inside the wellbore. To estimate the flow fractions emanating from the various feed zones, we need stable feedpoint temperatures. For present

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Figure 3.46. Pressure profiles computed from water level and temperature data for well SB-2.

Figure 3.47. Measured pressure profiles for well SB-2.

Figure 3.48. Selected heatup surveys for well SB-3.

Figure 3.49. Pressure profiles computed from water level and temperature data for well SB-3.

Figure 3.50. Measured pressures in well SB-3.

Figure 3.51. Selected temperature surveys for well SC-1.

Figure 3.52. Deep portion of selected temperature surveys for well SC-1 (see Figure 3.51 for complete profiles).

Figure 3.53. Pressure/temperature/spinner logs taken during production testing of well SC-1.

purposes, we shall assume that the feed zone temperatures are given sufficiently accurately by the temperature survey taken on May 11, 1988 (Figure 3.51). Given feedpoint temperatures (T_i , $i = 1, 2, \dots, 5$) and the temperature distribution in the wellbore, the fluid fractions (x_i , $i = 1, 2, \dots, 5$) contributed by the various feed zones can be obtained by solving the following set of linear algebraic equations:

$$\begin{aligned}(x_1 + x_2 + x_3 + x_4)H(T_{-5}) + x_5H(T_5) &= \\ &= (x_1 + x_2 + x_3 + x_4 + x_5)H(T_{+5}) \\ (x_1 + x_2 + x_3)H(T_{-4}) + x_4H(T_4) &= \\ &= (x_1 + x_2 + x_3 + x_4)H(T_{+4}) \\ (x_1 + x_2)H(T_{-3}) + x_3H(T_3) &= (x_1 + x_2 + x_3)H(T_{+3}) \\ x_1H(T_{-2}) + x_2H(T_2) &= (x_1 + x_2)H(T_{+2}) \\ (x_1 + x_2 + x_3 + x_4 + x_5) &= 1,\end{aligned}$$

where index i increases from the deepest to the shallowest feedpoint and

$H(T)$ = Fluid enthalpy at temperature T ,

$T_{-i}(=T_{+(i-1)})$ = Fluid temperature just below
(just above) feedzone $i(i-1)$.

The numerical results for x_i are given in Table 3.2. Almost two-thirds of the total flow is contributed by the deepest feed zone at or below 2320 m MD (2310 m TVD), and most of the remainder comes from the two feed zones at 1950–1970 m MD and 2030–2050 m MD.

Selected pressure profiles computed from water level and temperature data are displayed in Figure 3.54. The pressure profiles tend to coincide in the depth range from ~2200 m TVD to ~2400 m TVD. The computed pressure at 2310 m TVD is ~148 bars and is in reasonable agreement with that (~150 bars) recorded with downhole gauges (Figure 3.55).

3.15 Well SD-1

(original well name: N61-KY-2)

Temperature surveys taken during a break in drilling of well SD-1 (drilled depth ~700 meters) are shown in Figure 3.56; the change in temperature gradient at about 380 meters is most likely associated with the lost circulation zone at 387 meters. Since the water level did not stabilize prior to the restart of drilling (see profiles 4 and 6 in

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Table 3.2. Fluid fractions x_i contributed by the various feedzones in well SC-1.

Feedpoint Depth (m MD)	Fluid Temp. Below Feedpoint (°C)	Fluid Temp. Above Feedpoint (°C)	Feedzone Temperature (°C)	Fluid Fraction x_i
1950—1970	262	268	307.4	0.13
2030—2050	250.5	262	306.8	0.17
2120—2130	249.5	250.5	303.8	0.01
2230—2250	246	249.5	286.4	0.06
2320	—	246	246	0.64

Figure 3.54. Pressure profiles computed from water level and temperature data for well SC-1.

Figure 3.55. Measured pressures in well SC-1.

Figure 3.56. Temperature surveys in partially drilled well SD-1.

Figure 3.57), it is only possible to place an upper limit on shallow pressures. Thus, the pressure at a depth of 400 meters does not exceed 37 bars.

Temperature surveys in the completed well are displayed in Figures 3.58 and 3.59. The injection survey of October 17, 1986 (Figure 3.58) shows sharp changes in temperature gradient at ~650 m, ~800 m, ~930 m and ~1100 m. A spinner survey taken while injecting at a low flow rate (~500 liters/min) indicates that not all of these depth intervals correspond to water loss zones; the gradient changes at ~650 m and ~1100 m are very likely associated with variations in pipe conditions (diameter; slotted versus cased interval, *etc.*). The injected water is lost in the depth intervals from 783 to 926 meters and from 1445 to 1526 meters (Table 3.3). Interestingly, the temperature survey taken during high rate injection on October 26, 1988 shows no clear indication of water loss in the zone at 783 to 926 meters; instead, it appears that the water is now lost at or below a depth of ~1500 meters. Apparently, the water injection rate during the latter test was high enough to cool the hole down to a depth of 1500 meters, and thus obscure the upper water loss zone. The deep water loss zone at ~1500 meters is also confirmed by a break in temperature gradient at this depth in heat up surveys (see profiles labeled 11 and 12 in Figure 3.59).

Long-term heatup surveys in the completed well show a boiling point temperature profile down to a depth of ~620 meters. The boiling point to depth (BPTD) profile represents the highest temperature that a liquid water column can attain, and thus cannot reflect the effects of a higher formation temperature outside the well. Presumably, the temperature of the formation outside the well in this region exceeds that inside the well. Temperature surveys 11 and 12 (Figure 3.59) show an essentially isothermal region in the depth range

from ~800 meters to ~1500 meters. This indicates interzonal flow between these two feed zones in well SD-1.

Because of interzonal flow in well SD-1, shut-in temperature surveys provide no information regarding permeability and temperature distributions in the depth interval from ~800 to ~1500 m. During a discharge test of well SD-1 in September 1989, two pressure/temperature/spinner surveys were run. These PTS surveys (Figures 3.60–3.62) are invaluable for deciphering the permeability and thermal structure in the vicinity of well SD-1. An examination of spinner surveys indicates fluid entries at 1550–1570 m, 1530–1550 m, 1450–1490 m, 1300–1360 m, 1040–1060 m and 800–900 m. In the absence of calibration data for the spinner logs, we shall assume that the fluid velocity v_f is linearly related to the spinner revolutions R as follows:

$$R = m(v_s + v_f) \quad ,$$

where v_s is the line speed and m is a constant. Assuming that there are no fluid entries below 1570 m ($v_f \equiv 0$), the two spinner surveys yield:

$$m \sim 4.07 \text{ RPM/m/min.}$$

The fluid velocity (v_f) and temperature distribution in the wellbore can be combined to yield feedzone temperatures (see Tables 3.4 and 3.5). Temperature and pressure surveys (Figures 3.60 and 3.62) indicate the presence of boiling conditions at shallow depths (~1200 meters on September 18, 1989, and ~900 meters on September 19, 1989). In the two-phase zone, the fluid speed v_f (and hence R) increases due to a decrease in fluid density. Therefore, no attempt was made to analyze the spinner data in the boiling region. The temperature of the liquid in the wellbore above the shallowest single-phase entry is (Tables 3.4 and

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Figure 3.57. Pressures computed from water level and temperature data in partially drilled well SD-1.

Figure 3.58. Temperature surveys during cold water injection in well SD-1.

Figure 3.59. Temperature surveys in well SD-1 prior to, and after an injection test performed on October 17, 1986.

Table 3.3. Results of a spinner test conducted in well SD-1 (MMC, 1988).

(Flow Rate , q ~0.5 m³/min.; Cable Velocity, v_c ~29 m/min.)

Depth Interval	Inside Pipe/Well Diameter	Spinner (RPM)	Flow Velocity (v_f , m/min)
~641 m	0.224 m	280	12.7
641 ~ 783 m	0.162 m	370	24.3
783-926 m	Loss Zone		
926-1045 m	0.162 m	340 ± 10	
1045-1394 m	Flow in Annulus	(No Net Fluid Loss)	
1394-1445 m	0.162 m	340 ± 10	
1445-1526 m	Loss Zone		
1526 ~ m	0.162 m	0

Figure 3.60. Temperature surveys run under discharge conditions in well SD-1 in September 1989. For corresponding spinner and pressure surveys, see Figures 3.61 and 3.62, respectively.

Figure 3.61. Spinner surveys run under discharge conditions in well SD-1 in September 1989. For corresponding temperature and pressure surveys, see Figures 3.60 and 3.62, respectively.

Figure 3.62. Pressure surveys recorded in well SD-1.

Table 3.4. Results of spinner test conducted on September 18, 1989 (discharge rate ~84.5 tons/hour, flowing enthalpy ~1100 kJ/kg).

Feedpoint Depth (m)	Spinner Revolutions Above Feedzone (RPM)	Line Speed v_s (m/min)	Fluid Speed v_f (m/min)	Temp. Below Feedzone T_- (°C)	Temp. Above Feedzone T_+ (°C)	Fluid Mass Flux M_+ (tons/hour)	Formation (Feedzone) Temp. (°C)
1550—1570	111	26.4	0.9	250.9	250.4	1.5	250.4
1530—1550	125	26.7	4.0	250.4	244.3	7.3	242.7
1450—1490	189	27.8	18.6	233.1	216.4	34.4	211.9
1300—1360	239	28.7	30.0	218.5	221.8	55.4	227.2
1040—1060	Two-Phase Flow						
800—900	Two-Phase Flow						

Notes: 1. $v_f = \frac{\text{RPM}}{4.07} - v_s$

2. $M \sim A v_f \rho_{T_+}$; A (well cross-section) $\sim 0.0366 \text{ m}^2$, ρ_{T_+} = water density at T_+

3. Formation Temperature, $T = (T_+ M_+ - T_- M_-) / (M_+ - M_-)$; $M_+(M_-)$ = Mass Flux above (below) feedzone.

Table 3.5. Results of spinner test conducted on September 19, 1989 (discharge rate ~62.5 tons/hour, flowing enthalpy ~1010 kJ/kg).

Feedpoint Depth (m)	Spinner Revolutions Above Feedzone (RPM)	Line Speed v_s (m/min)	Fluid Speed v_f (m/min)	Temp. Below Feedzone T_- (°C)	Temp. Above Feedzone T_+ (°C)	Fluid Mass Flux M_+ (tons/hour)	Formation (Feedzone) Temp. (°C)
1550—1570	162	36.5	3.3	249.6	249.1	5.8	249.1
1530—1550	172	36.2	6.1	249.1	240.2	11.0	230.3
1450—1490	196	35.9	12.3	227.0	215.6	22.6	204.8
1300—1360	242	37.2	22.3	218.2	221.0	41.1	224.4
1040—1060	284	38.3	31.5	220.4	220.4	58.1	220.4
800—900	Two-Phase Flow						

Notes: 1. $v_f = \frac{\text{RPM}}{4.07} - v_s$

2. $M \sim A v_f \rho_{T_+}$; A (well cross-section) $\sim 0.0366 \text{ m}^2$, ρ_{T_+} = water density at T_+

3. Formation Temperature, $T = (T_+ M_+ - T_- M_-) / (M_+ - M_-)$; $M_+(M_-)$ = Mass Flux above (below) feedzone.

3.5) $\sim 220^{\circ}\text{C}$ (enthalpy ~ 940 kJ/kg). Since the enthalpy of the produced fluid is greater than 940 kJ/kg, it follows that the fluid entering SD-1 from the uppermost feedzone(s) is two-phase. The estimated feedzone temperatures (Table 3.6) imply a temperature inversion in the vicinity of well SD-1. The minimum temperature ($\sim 208^{\circ}\text{C}$) occurs in the depth interval 1450–1490 m.

Table 3.6. Feedzone temperatures (see Tables 3.4, 3.5).

Feedzone Depth (meters)	Temperature ($^{\circ}\text{C}$)
1550–1570	250
1530–1550	236 ± 6
1450–1490	208 ± 3
1300–1360	226 ± 1
1040–1060	220
800–900	$219 \pm 2^*$

*Estimated from shutin temperature profiles

Pressure profiles computed from the water level and temperature data are shown in Figure 3.63. Because of boiling in the wellbore (see Figure 3.59), downhole pressures calculated from water level data are not reliable. The pressures recorded by downhole gauges are displayed in Figure 3.62. The pressure at 800 m TVD (top of upper feedzone) is ~ 44 (± 1) bars, and the pressure at 1200 m TVD (middle of permeable interval 800–1570 m) is ~ 77 bars.

3.16 Slim Hole 52E-SM-1

The borehole appears to heat up conductively in the upper part (Figure 3.64); no heat up below ~ 730 m is observed. A break in temperature gradi-

ent at the latter depth indicates the presence of a permeable horizon at ~ 730 m.

The water level in 52E-SM-1 stood at the wellhead at a shutin time of ~ 3 hours on September 27, 1978. It then fell to 19 m at a shutin time of 12 hours (9/27/78) and to 42 m at a shutin time of 36 hours (9/28/78). It is unlikely that a stable water level was attained during the observation period. Consequently, it is only possible to place an upper limit on the reservoir pressure. The pressure at a depth of 730 m is (Figure 3.65) less than 63.5 bars.

3.17 Slim Hole 52E-SM-2

Temperature surveys 1 and 2 (Figure 3.66) were recorded in the partially-drilled hole (depth = 803 m) on August 21, 1978. The change in temperature gradient at ~ 550 m corresponds to a lost circulation horizon, and represents the principal feedzone for the partially-drilled hole. The feedzone temperature exceeds 170°C . Pressure profiles computed from water level and temperature data are shown in Figure 3.67. The pressure at 550 m (profiles 1, 2; Figure 3.67) is less than 38.5 bars.

Temperature surveys recorded on October 15 and 16, 1978 in the completed borehole (Figure 3.68) show a sharp increase in temperature at ~ 470 m; this feature is absent from the temperature profiles recorded in the partially drilled hole on August 21, 1978 (see Figure 3.66). We speculate that a casing break is present at ~ 470 m. A break in temperature gradient at ~ 980 m identifies the permeable horizon for the completed 52E-SM-2. The feedzone temperature is at least 230°C . During the observation period in October 1978, the water level (Profiles 3–5, Figure 3.67) continued to rise; it is impossible to tell whether a stable water level

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Figure 3.63. Selected pressure profiles computed from water level and temperature data in well SD-1.

Figure 3.64. Selected temperature profiles for 52E-SM-1.

Figure 3.65. Pressure profiles computed from water level and temperature data for 52E-SM-1.

Figure 3.66. Temperature profiles in partially-drilled (depth = 803 m) 52E-SM-2 recorded on August 21, 1978.

Figure 3.67. Pressure profiles computed from water level and temperature data for 52E-SM-2.

Figure 3.68. Temperature surveys in completed 52E-SM-2 taken on October 15 and 16, 1978.

was reached. The pressure at 980 meters is estimated to be ~69 bars (see Profile 5, Figure 3.67).

3.18 Slim Hole N59-SN-5

The temperature survey of November 7, 1985 (Figure 3.69) was taken after the hole had reached 1700 m. An injection test was performed on November 13, 1985. Heat-up surveys subsequent to the injection test show a large change in temperature at ~750 m; this temperature feature is absent from the temperature survey of November 7, 1985. We therefore speculate that injection caused a break in casing at ~750 m. Temperature profiles recorded on November 13, 1985 (Figure 3.69) show depressed temperatures at ~1425 m and ~1600 m. An abrupt break in temperature gradient at ~1600 m identifies the principal feedzone for N59-SN-5.

Only three short shutin time (ST ~5 and 8 hours on November 13, 1985 and ST ~16 hours

on November 14, 1985) water level readings are available. The borehole has poor permeability, and it is almost certain that the water level did not attain its stable value at these early times; these water levels are, therefore, useless for determining reservoir pressures.

On November 20 and 21, 1985, two pressure gradient surveys were taken with a Kuster gauge. Unfortunately, these surveys were confined to the upper 800 m of the hole. There appears to be something wrong with these pressure data since the measured pressure gradients imply the presence of two-phase fluid in the depth interval 200 to 800 m. (The temperatures in this depth interval are simply too low to sustain two-phase conditions). In any case, the measured pressure at 800 m depth was 34 to 38 bars. Assuming that the pressure at 800 m is indeed 34 to 38 bars and taking the average temperature between 800 m and 1600 m to be ~238°C (see Figure 3.69), the pressure at 1600 m is estimated to be 99 to 103 bars.

Figure 3.69. Selected temperature surveys in N59-SN-5.

4 Injection and Production Tests

Injection tests have been performed on eighteen Sumikawa boreholes. It is a standard practice at Sumikawa to perform a short (a few hours) injection test soon after the (usually within a few days) drilling and completion of a borehole. In an effort to improve the productivity and injectivity of wells SA-1, SA-2, SA-4, S-4, SB-1, SB-2 and SB-3, MMC injected large amounts of cold river water in these wells in April and May 1989; step rate injection tests were performed (with downhole pressure gauges) both prior to (wells SA-1, SA-2, and SA-4 only) and subsequent to (all 7 wells) the river water injection. A typical injection test at Sumikawa consists of injecting cold water into a borehole at several different rates and simultaneously monitoring pressure (and temperature) downhole. While exceptions do exist, in most of the tests, the pressure tool was placed substantially above the feedzone depth. Because of wellbore cooling, the measured change in pressure at the gauge depth (gauge depth $\ll$ feedzone depth) will underestimate the change in pressure at the feedzone depth. The discrepancy in rates of change at the gauge and feedzone depths will decline with continued injection. After the injection of a few wellbore volumes (say 2 or 3), the rates of pressure change at the two depths should be similar. Since in most of the Sumikawa injection tests several wellbore volumes of cold water were injected, the measured pressures can be used to infer the injectivity index (II). The injectivity index (II) is defined as follows:

$$II = \frac{\Delta M}{\Delta P}$$

Here $\Delta M/\Delta P$ is the slope of the straight-line fit to the multi-step injection rate versus injection pressure (at gauge depth) data.

The available injection test data are, however, less useful for inferring formation transmissivity. During the injection phase, the pressures (at a constant rate) are often observed to decline due to borehole cooling and/or borehole washing effects. The fall-off pressure data from most of the tests are corrupted by borehole heating. Borehole heating causes the apparent pressure decline rate at the gauge depth to be smaller than the corresponding decline rate at the feedzone depth. It would be worthwhile to analyze pressure fall-off data from those tests in which the pressure gauge was placed in close proximity to the feedzone. Because of funding limitations, these pressure fall-off data were not analyzed during this contract period.

The determination of injectivity indices for individual Sumikawa boreholes is described in Section 4.1. The injectivity data are summarized in Table 4.1.

A total of four slim holes and seven large-diameter Sumikawa wells have been discharged at one time or another. Five of the Sumikawa boreholes (slim holes S-2, S-3 and 52E-SM-2, large diameter wells SB-1 and SC-1) produce from all liquid feedzones. Discharge from other Sumikawa boreholes (slim hole S-1, partially-drilled slim holes S-2 and 52E-SM-2, large-diameter wells S-4, SA-1, SA-2, SA-4 and SD-1) is accompanied by *in situ* boiling. As part of the discharge tests, the characteristic output curves (*i.e.*, mass and enthalpy versus wellhead pressure) were also obtained. These characteristic data are discussed in Section 4.2.

During the discharge tests of seven boreholes (slim hole S-2, partially-drilled slim hole S-2,

Table 4.1. Injectivity indices for Sumikawa boreholes.

Borehole Name	Final Diameter (mm)	Feedzone Depth (m TVD)	Test Date	Pressure Gauge Depth (m TVD)	Injectivity Index (kg/s-bar)	Remarks
50-HM-3	79	460	12-02-75	0	0.016	After well completion
N60-KY-1	101	1560	08-07-86	1177	0.012	After well completion
O-5T	64	747	09-22-78	280	0.28	
S-1	143	436	05-20-82 05-26-82	250 300	1.3 6.8	Injection into a shallow horizon (70–100 meters) through a casing break
S-2	101	900 900 ? 940 940	06-23-82 07-16-82 10-04-82 10-16-82 10-23-82	400 500 450 500 500	0.76 0.76 0.52 1.62 1.76	Partially-drilled, hole depth = 904.6 m Partially-drilled, hole depth = 904.6 m Partially-drilled, hole depth = ? After well completion After well completion
S-3	101	? ? ? 700	09-02-82 10-06-82 05-16-83 06-12-83	400 300 600 600	0.79 0.43 0.25 1.4	Partially-drilled, hole depth = 603 m? Partially-drilled, hole depth = 603 m? Partially-drilled, hole depth = 656 m After well completion
S-4	159	1520	11-06-83 11-07-83 05-19-89	700 700 700	1.4 1.4 4.9	After well completion After well completion After 1989 injection
SA-1	216	1800	10-11-86 04-16-89 05-16-89	1057 1726 1726	1.5 0.90 2.0	After well completion Before 1989 injection After 1989 injection
SA-2	216	1450	09-22-87 09-22-87 04-16-89 05-17-89	968 968 1062 1061	1.0 1.2 1.3 1.7	After well completion After well completion Before 1989 injection After 1989 injection
SA-4	216	1240	05-30-88 04-17-89 05-18-89	1127 1262 1262	0.31 0.88 1.0	After well completion Before 1989 injection After 1989 injection
SB-1	216	1600	10-25-87 10-26-87 11-08-87 05-27-88 08-15-88 05-28-89	0 0 965 965 1665 1626	0.98 1.5 0.37 0.49 0.44 2.0	After well completion After well completion After well completion After well completion After well completion After 1989 injection
SB-2	216	1270	06-22-88 05-29-89	674 684	1.8 1.6	After well completion After 1989 injection
SB-3	216	880	08-05-88 05-30-89	678 678	0.41 1.5	After well completion After 1989 injection
SC-1	216	2310	11-15-87 06-07-88	2290 2329	5.5 4.9	After well completion
SD-1	216	? 1550 1550	09-04-86 10-12-86 10-17-86	387 700 799	2.7 0.65 0.92	Partially-drilled; hole depth = 396 m After well completion After well completion
52E-SM-1	79	730	09-30-78	0	0.002	After well completion
52E-SM-2	101	550	08-26-78	0	0.068	Partially-drilled; hole depth = 803 m
N59-SN-5	101	1600	11-12-85	0	0.068	After well completion

- Notes: 1. After well completion = within 1 month of drilling and well completion.
 2. 1989 injection test: cold river water was injected into SA-1, SA-2, SA-4, S-4, SB-1, SB-2 and SB-3 during April and May 1989

large-diameter wells S-4, SA-1, SA-4, SC-1 and SD-1), pressure and temperature (or pressure, temperature and spinner) surveys were run. These pressure/temperature surveys are used to calculate the productivity indices for the Sumikawa boreholes in Section 4.1. Productivity index, PI, is defined as follows:

$$PI = \frac{M}{P_{ns} - P_{fp}}$$

where M is the mass discharge rate, P_{ns} is the stable (static) feedzone (or gauge depth) pressure, and P_{fp} is the flowing feedzone (or gauge depth) pressure. The static feedzone (or gauge depth) pressure was estimated from shutin pressure surveys discussed in Section 3. The pressure surveys in the discharging boreholes were used to obtain the flowing pressures. The productivity indices for individual Sumikawa boreholes are summarized in Table 4.2.

Following the discharge tests, pressure buildup was recorded in some of the Sumikawa boreholes; these data may be analyzed to obtain formation transmissivity. Because of funding limitations, no attempt was made to analyze these data during this contract period.

4.1 Injectivity and Productivity Indices

The injection rates are usually given as volume injection rates (m^3/s or liters/s). For present purposes, it is satisfactory to assume that the density of injected water is $1000 \text{ kg}/\text{m}^3$; therefore, a volume flow rate of 1 liter/s equals a mass flow rate of 1 kg/s.

Slim Hole 50-HM-3

A multi-rate injection test was performed on December 2, 1975; the pressures were recorded at

the wellhead. The straight-line fit to the pressure versus injection rate data (Figure 4.1) yields an injectivity index of 0.016 kg/s-bar . Slim hole 50-HM-3 is located in a low-permeability zone to the north of the Sumikawa field.

Slim Hole N60-KY-1

A single multi-rate injection test was performed shortly after drilling and completion of the borehole on August 7, 1986; the pressures were recorded at 1177 m TVD. The straight-line fit to the pressure and injection rate data (Figure 4.2) gives an injectivity index of 0.012 kg/s-bar . The poor injectivity exhibited by N60-KY-1 is rather surprising in view of the results of later pressure interference tests. During discharge from wells S-4 and SB-1 and injection into wells S-4, SB-1 and SB-2, strong pressure interference was observed in N60-KY-1. These pressure interference data have been interpreted to imply the existence of a high permeability zone in the "altered andesite" formation (N60-KY-1 has feedzones in the altered andesite and marine-volcanic complex formations), and a modest permeability dacite layer in the "marine-volcanic complex" formation. In view of these pressure interference results, we hypothesize that the poor injectivity for N60-KY-1 is caused by the plugging of permeable fractures by the drilling mud.

Slim Hole O-5T

An injectivity test for slim hole O-5T was carried out on September 22, 1978 with the pressure gauge set at 280 m TVD. Slim hole O-5T is located to the east of the Sumikawa field (*i.e.*, between the Sumikawa and Ohnuma Geothermal Fields). The pressure and injection data shown in Figure 4.3 give an injectivity index of 0.28 kg/s-bar .

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Table 4.2. Productivity indices for Sumikawa boreholes.

Borehole Name	Final Diameter (mm)	Feedzone Depth (m TVD)	Test Date	Total Flow Rate (kg/s)	Static Pressure (bars)	Flowing Pressure (bars)	Productivity Index (kg/s-bar)	Remarks
S-1	143	436	04-25-82 04-27-82 04-30-82	—	—	—	0.86	Produced dry-steam. PI estimated from mass flow rate and wellhead pressure (see text).
S-2	101	900	07-11-82	1.10	47.3*	7.26	0.027	Partially-drilled, hole depth = 904.6 m Two-phase feed
	101	940	11-10-82	13.4	51.0	40.5	1.3	Liquid feed
S-4	159	1520	10-04-84 10-31-84 10-12-85	37.5 39.1 35.1	93.0	51.3 49.4 58.2	0.90 0.90 1.01	Two-phase feed. Flowing pressure extrapolated from pressure surveys to 1050, 1050 and 1070 meters depth (see text).
SA-1	216	1800	09-21-89 09-22-89	13.6 13.7	114.0	26.5 34.6	0.16 0.17	Well produces mostly steam Two-Phase feed
SA-4	216	1240	09-23-89	8.06	81.0	10.8	0.11	Well produces dry steam from a two-phase feed
SC-1	216	2310	11-04-88 11-06-88 11-07-88	48.1 55.2 86.1	149.0	139.7 140.1 133.6	5.2 6.2 5.6	Liquid feeds (several entries)
SD-1	216	1200 (middle of permeable interval)	09-18-89 09-19-89	23.5 17.4	77.0	23.8 47.0	0.44 0.58	Several entries. Shallowest (800-900 m) two-phase; deeper entries liquid.

*Estimated from a fit to feedzone pressures for Sumikawa wells

Figure 4.1. Injectivity test for slim hole 50-HM-3 performed on December 2, 1975. The pressure gauge was set at wellhead.

Figure 4.2. Injectivity test for slim hole N60-KY-1 performed on August 7, 1986. The pressure gauge was set at 1177 m MD (1177 m TVD).

Figure 4.3. Injectivity test for slim hole O-5T performed on September 22, 1978. The pressure gauge was set at 280 m MD (280 m TVD).

Slim Hole S-1

The pressure and flow rate data obtained during the two injection tests of S-1 in May 1982 (approximately six months after drilling and completion of S-1) are displayed in Figures 4.4a and 4.4b. It is apparent from Figures 4.4a and 4.4b that the pressures fluctuated considerably during these injection tests. The principal feedzone for S-1 is located at ~436 meters. A downhole temperature survey run in S-1 during cold water injection on May 5, 1982 indicates (1) a break in the casing at 70–100 m depth, and (2) an upflow with a steam component which is quenched on mixing with injected cold water (see Section 3.4). Thus, cold water injection takes place into a shallow zone; production, however, is derived from the zone at 436 meters. For this reason, productivity and injectivity indices for S-1 are not expected to be correlated. The two injection tests (Figures 4.4a,b) yield rather disparate values (1.3 kg/s-bar and 6.8 kg/s-bar) for the injectivity index.

Slim hole S-1 was discharged for several days in April 1982 (*i.e.*, prior to injection tests discussed above). The slim hole produced dry steam. No downhole pressure and temperature surveys were taken in the discharging borehole. The discharge rate versus wellhead pressure data (Figure 4.5) can be fit closely by a straight-line; the discharge rate is inversely proportional to the wellhead pressure. The slope of the straight-line gives a value of 0.86 kg/s-bar for the productivity index.

Slim Hole S-2

After the borehole had been drilled to 904.6 m, both injection and discharge tests were performed. The major feedpoint for the partially-drilled S-2 (drilled depth = 904.6 m) is located a depth of about 900 m. The injectivity tests per-

formed on June 23, 1982 and July 16, 1982 (Figures 4.6a and b) both yield an injectivity index of 0.76 kg/s-bar. During discharge tests from July 8 to July 12, 1982 of the 904.6 m hole, two-phase fluids with an enthalpy well above that of liquid water at reservoir temperature were produced. The amount of excess enthalpy decreased with increasing wellhead pressure. It is, therefore, likely that the excess enthalpy is the result of production induced flashing in the formation. An alternative explanation is that the borehole taps a two-phase reservoir at shallow depths. A pressure survey run in the discharging hole on July 11, 1982 gave a pressure of 7.26 bars at 900 m depth. Assuming a stable feedzone pressure of 47.3 bars (pressure computed from Sumikawa pressure correlation, Section 2) and a discharge rate of 1.10 kg/s, a productivity index of 0.027 kg/s-bar is obtained. The large difference between the productivity and injectivity indices is due to *in situ* boiling induced by borehole discharge; the formation transmissivity is severely reduced by two-phase flow.

Injectivity tests of October 16 and October 23, 1982 (Figures 4.6d,e) were performed on the completed hole (final depth = 1065.1 m). The feedzone for the completed hole is at ~940 m. The injectivity index for S-2 (Figures 4.6d,e) is ~1.7 kg/s-bar. During a discharge test in November 1982, slim hole S-2 produced fluid with an enthalpy of about 250 (± 10) kcal/kg; this is consistent with production from a liquid reservoir of about 240 to 250°C. A pressure survey run in discharging S-2 on November 10, 1982, gave a pressure of 40.5 bars at 940 m. With a stable feedzone pressure of 51.0 bars (Section 3.5) and a discharge rate of 13.4 kg/s, a productivity index of 1.3 kg/s-bar is obtained. Unlike the partially-drilled hole, the productivity and injectivity indices for the completed hole are not all that different. Both the injection and production tests imply that the completed hole has higher transmissivity than the partially-drilled hole.

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Figure 4.4a. Injectivity test for slim hole S-1 performed on May 20, 1982. The pressure gauge was set at 250 m MD (250 m TVD).

Figure 4.4b. Injectivity test for slim hole S-1 performed on May 26, 1982. The pressure gauge was set at 300 m MD (300 m TVD).

Figure 4.5. Productivity test for slim hole S-1 performed from April 25, 1982 to April 30, 1982. S-1 discharged dry steam.

Figure 4.6a. Injectivity test for partially-drilled slim hole S-2 (drilled depth = 904.6 m) performed on June 23, 1982. The pressure gauge was set at 400 m MD (400 m TVD).

Figure 4.6b. Injectivity test for partially-drilled slim hole S-2 (drilled depth = 904.6 m) performed on July 16, 1982. The pressure gauge was set at 500 m MD (500 m TVD).

Figure 4.6c. Injectivity test for partially-drilled slim hole S-2 (drilled depth = ?) performed on October 4, 1982. The pressure gauge was set at 450 m MD (450 m TVD).

Figure 4.6d. Injectivity test for slim hole S-2 performed on October 16, 1982. The pressure gauge was set at 500 m MD (500 m TVD).

Figure 4.6e. Injectivity test for slim hole S-2 performed on October 23, 1982. The pressure gauge was set at 500 m MD (500 m TVD).

Slim Hole S-3

Injectivity tests of September 2, 1982, October 6, 1982 and May 16, 1983 (Figures 4.7a-c) were performed in the partially drilled hole. After the hole was drilled to the target depth (805.1 m) and completed, another injectivity test was carried out on June 12, 1982 (Figure 4.7d). The injectivity index for the completed hole is 1.4 kg/s-bar.

During discharge tests carried out in October 1983, slim hole S-3 produced fluids with an enthalpy equal to that of liquid water at ~240°C. This suggests that the main feedzone for S-3 contains liquid water. Slim hole S-3 exhibited some cycling of steam and water flows and wellhead pressure. The period of the cycle is ~10 minutes. Considering the low discharge rate (< 15 tons/hour) and the absence of a two-phase zone in the open part (601 to 805 meters) of the hole, it is likely that the cycling was induced by the wellbore. Apparently, no downhole pressure surveys were carried out in S-3 under discharge conditions; it is, therefore, not possible to compute a productivity index for S-3.

Production Well S-4

Injectivity tests of November 6 and 7, 1983 (Figures 4.8a,b), carried out shortly after well drilling and completion, both gave an injectivity index of 1.4 kg/s-bar. A sharply higher value of injectivity index (4.9 kg/s-bar) is implied by an injectivity test performed on May 19, 1989 (Figure 4.8c) after the injection of cold river water in April and May 1989. Discharge tests carried out prior to and after the May 1989 injection test, however, failed to show any increase in well productivity. As a matter of fact, the maximum discharge rate for S-4 did not exhibit any substantial variation during the years 1984 to 1990.

Well S-4 produces a two-phase mixture from several feedzones in the depth interval from 1071 to 1552 m. The wellhead enthalpies indicate some *in situ* boiling. During discharge tests in October 1984 and December 1985, pressure surveys were run in the cased part of the hole; these pressure surveys imply the upflow of a two-phase mixture above 1070 meters. The principal feedzone for S-4 is at a depth of 1520 meters; the stable feedzone pressure (Section 3.7) is 93.0 bars. The measured pressure gradients in the shallow part of the hole (*i.e.*, above ~1050 meters) were used to estimate the flowing pressures at 1520 meters. The estimates of productivity index for S-4 range from 0.90 to 1.01 kg/s-bar (Table 4.2). *In situ* boiling during discharge is most likely responsible for the productivity index being lower than the injectivity index.

Production Well SA-1

An injectivity test was performed on well SA-1 on October 11-12, 1986 shortly after well drilling and completion; the pressure gauge was set 1057 m TVD (~750 meters above the principal feedzone at 1800 m TVD). The October 1986 injection test (Figure 4.9a) gave an injectivity index of 1.5 kg/s-bar. In April and May 1989 (Figures 4.9b,c), two additional injectivity tests were performed; the pressure gauge in these tests was set at 1726 m TVD (*i.e.*, ~75 meters above the principal feedzone). The injectivity test carried out prior to cold river water injection (Figure 4.9b) gave an injectivity index of 0.90 kg/s-bar. Injection of cold river water resulted in a large increase in the injectivity index; the injectivity index after cold water injection (Figure 4.9c) is seen to be 2.0 kg/s-bar. Apparently, injection of cold river water also resulted in a large increase in well productivity. The maximum discharge rate for SA-1 prior to

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Figure 4.7a. Injectivity test for partially-drilled slim hole S-3 (drilled depth = 603 m?) performed on September 2, 1982. The pressure gauge was set at 400 m MD (400 m TVD).

Figure 4.7b. Injectivity test for partially-drilled slim hole S-3 (drilled depth = 603 m?) performed on October 6, 1982. The pressure gauge was set at 300 m MD (300 m TVD).

Figure 4.7c. Injectivity test for partially-drilled slim hole S-3 (drilled depth = 656 m?) performed on May 16, 1983. The pressure gauge was set at 600 m MD (600 m TVD).

Figure 4.7d. Injectivity test for slim hole S-3 performed on June 12, 1983. The pressure gauge was set at 600 m MD (600 m TVD).

Figure 4.8a. Injectivity test for production well S-4 performed on November 6, 1983. The pressure gauge was set at 700 m MD (700 m TVD).

Figure 4.8b. Injectivity test for production well S-4 performed on November 7, 1983. The pressure gauge was set at 700 m MD (700 m TVD).

Figure 4.8c. Injectivity test for production well S-4 performed on May 19, 1989 after injection of cold river water. The pressure gauge was set at 700 m MD (700 m TVD).

Figure 4.9a. Injectivity test for production well SA-1 performed on October 11–12, 1986. The pressure gauge was set at 1100 m MD (1057 m TVD).

Figure 4.9b. Injectivity test for production well SA-1 performed on April 16, 1989 just prior to injection of cold river water. The pressure gauge was set at 1879 m MD (1726 m TVD).

Figure 4.9c. Injectivity test for production well SA-1 performed on May 16, 1989 after injection of cold river water. The pressure gauge was set at 1879 m MD (1726 m TVD).

injection was ~34 tons/hour at a wellhead pressure of ~4.9 bars. After cold water injection, the maximum discharge rate increased to ~62 tons/hour at a wellhead pressure of ~4.2 bars.

Production well SA-1 produces a two-phase mixture (steam is over 80 percent by mass at atmospheric pressure) from a feedzone at ~1800 m TVD. The stable feedzone pressure is 114.0 bars (Section 3.8). During a discharge test in September 1989, two downhole pressure/temperature/spinner surveys were run in SA-1; these surveys show the existence of two-phase conditions in the wellbore above the feedzone. Using the measured values for flowing feedzone pressure, the productivity index for SA-1 is estimated to be 0.16–0.17 kg/s-bar (Table 4.2). The large discrepancy between the productivity and injectivity indices is due to *in situ* boiling during discharge tests.

Production Well SA-2

The two injectivity tests performed on September 22 and 23, 1987 just after well completion (Figure 4.10a,b) gave injectivity indices of 1.0 and 1.2 kg/s-bar. These injectivity indices are in substantial agreement with that (1.3 kg/s-bar) obtained from a test carried out on April 16, 1989 prior to the injection of cold river water (Figure 4.10c). The injectivity did not improve much with the injection of cold river water in April and May 1989; the injectivity index after cold water injection was 1.7 kg/s-bar (Figure 4.10d). Like the injectivity index, production from SA-2 showed little or no increase as a result of injection.

Production well SA-2 produces essentially all steam from a feedzone at 1450 m TVD. No downhole pressure surveys were run in the discharging

well; consequently, it is not possible to calculate the productivity index for SA-2.

Production Well SA-4

The injection test performed on May 30, 1988 shortly after well completion (Figure 4.11a) gave a relatively low value (0.31 kg/s-bar) for the injectivity index. The injectivity tests carried out on April 17, 1989 (prior to cold river water injection) and May 18, 1989 (after cold river water injection) imply substantially higher values for the injectivity index (0.88 kg/s-bar and 1.0 kg/s-bar, respectively). Apparently, injection of cold river water in April and May 1989 (Figure 4.11b,c) resulted in a modest improvement in well productivity. The maximum discharge rate increased from ~24 tons/hour (prior to injection) to ~30 tons/hour (after injection).

Production well SA-4 produces dry steam from a feedzone at about 1240 m TVD. The stable shutin pressure at 1240 m TVD is 81.0 bars (Section 3.10). A pressure/temperature/spinner survey run in the discharging well on September 23, 1989 gave a pressure of 8.06 bars. With a mass discharge rate of 10.8 kg/s, the productivity index is estimated to be 0.11 kg/s. The productivity index is an order of magnitude smaller than the injectivity index.

Production Well SB-1

Five injection tests of production well SB-1 (Figures 4.12a–e) were conducted in the period from October 25, 1987 to August 15, 1988. The best estimate for the injectivity index prior to April/May 1989 cold river water injection is provided by the test run on August 15, 1988. In the latter

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Figure 4.10a. Injectivity test for production well SA-2 performed on September 22, 1987. The pressure gauge was set at 1000 m MD (968 m TVD).

Figure 4.10b. Injectivity test for production well SA-2 performed on September 22–23, 1987. The pressure gauge was set at 1000 m MD (968 m TVD).

Figure 4.10c. Injectivity test for production well SA-2 performed on April 16–17, 1989 prior to injection of cold river water. The pressure gauge was set at 1100 m MD (1062 m TVD).

Figure 4.10d. Injectivity test for production well SA-2 performed on May 17, 1989 after the injection of cold river water. The pressure gauge was set at 1099 m MD (1061 m TVD).

Figure 4.11a. Injectivity test for production well SA-4 performed on May 30, 1988. The pressure gauge was set at 1200 m MD (1127 m TVD).

Figure 4.11b. Injectivity test for production well SA-4 performed on April 17–18, 1989 prior to cold river water injection. The pressure gauge was set at 1366 m MD (1262 m TVD).

Figure 4.11c. Injectivity test for production well SA-4 performed on May 18, 1989 after cold river water injection. The pressure gauge was set at 1366 m MD (1262 m TVD).

Figure 4.12a. Injectivity test for production well SB-1 performed on October 25, 1987. The pressure gauge was set at wellhead.

Figure 4.12b. Injectivity test for production well SB-1 performed on October 26, 1987. The pressure gauge was set at wellhead.

Figure 4.12c. Injectivity test for production well SB-1 performed on November 8, 1987. The pressure gauge was set at 1000 m MD (965 m TVD).

Figure 4.12d. Injectivity test for production well SB-1 performed on May 27, 1988. The pressure gauge was set at 1000 m MD (965 m TVD).

Figure 4.12e. Injectivity test for production well SB-1 performed on August 15, 1988. The pressure gauge was set at 1740 m MD (1665 m TVD).

test, the pressure gauge was set 65 meters below the main feedzone at 1600 m TVD; in all other tests (Figure 4.12a–d) the pressure gauge was set hundreds of meters above the feedzone.

Injection of cold water in April and May 1989 appears to have improved the well injectivity. The injectivity index increased from 0.44 kg/s-bar on August 15, 1988 (prior to river water injection) to 2.0 kg/s-bar on May 28, 1989 (after river water injection, Figure 4.12f). Since no discharge tests of SB-1 were performed prior to cold river water injection in April/May 1989, it is not possible to ascertain the effect of cold water injection on well productivity.

A discharge test of well SB-1 was conducted from June 4, 1989 to November 26, 1989. Well SB-1 produces liquid water from a feedzone at 1600 m TVD; the feedzone temperature is ~280°C. No downhole pressure surveys were made in the discharging well. It is, therefore, not possible to compute a value for the productivity index.

Injection Well SB-2

An injectivity test of well SB-2 was performed on June 22, 1988 shortly after well drilling and completion (Figure 4.13a). After cold river water injection in April/May 1989, a second injectivity test was performed on May 29–30, 1989 (Figure 4.13b). The two injection tests yield essentially the same value (1.8 and 1.6 kg/s-bar) for the injectivity index.

Injection Well SB-3

An injection test of well SB-3 was performed on August 5, 1988 shortly after well drilling and

completion; an injectivity index of 0.41 kg/s-bar is inferred for this test (Figure 4.14a). Apparently, the injection of cold river water in April/May 1989 was accompanied by a large increase in well injectivity. A test performed on May 30–31, 1989 (Figure 4.14b) yields an injectivity index of 1.5 kg/s-bar.

Production Well SC-1

An injection test was performed on November 15, 1987 soon after well drilling and completion. A second injectivity test was carried out several months later on June 7, 1988. The pressure gauge in both the tests was set fairly close to the principal feedzone at 2310 m TVD. Both the tests (Figure 4.15a,b) gave essentially the same value (5.5 and 4.9 kg/s-bar) for the injectivity index.

Production well SC-1 is by far the most productive well at Sumikawa. The well produces liquid water from several feedzones between 1950 m MD (temperature = 307°C) and 2320 m MD (temperature = 246°C). Over 60 percent of the production is derived from the feedzone at 2320 m MD (2310 m TVD). The stable pressure at 2310 m TVD is 149.0 bars (Section 3.14). During a discharge test in November 1988, three downhole pressure/temperature/spinner surveys were run. Using the flowing pressures measured in the latter surveys, the productivity index for SC-1 is estimated to be 5.7 (± 0.5) kg/s-bar.

The productivity and injectivity indices for SC-1 are more or less equal. Furthermore, the productivity (injectivity) index for SC-1 is substantially larger than for other Sumikawa wells. It is interesting to note here that no altered andesite layer was encountered in SC-1; instead, an unusually thick layer of "marine volcanic complex"

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Figure 4.12f. Injectivity test for production well SB-1 performed on May 28–29, 1987. The pressure gauge was set at 1700 m MD (1626 m TVD).

Figure 4.13a. Injectivity test for injection well SB-2 performed on June 22, 1988. The pressure gauge was set at 690 m MD (674 m TVD).

Figure 4.13b. Injectivity test for injection well SB-2 performed on May 29–30, 1989 after the injection of cold river water in April/May 1989. The pressure gauge was set at 700 m MD (684 m TVD).

Figure 4.14a. Injectivity test for injection well SB-3 performed on August 5, 1988. The pressure gauge was set at 700 m MD (678 m TVD).

Figure 4.14b. Injectivity test for injection well SB-3 performed on May 30–31, 1989 after cold river water injection. The pressure gauge was set at 700 m MD (678 m TVD).

Figure 4.15a. Injectivity test for production well SC-1 performed on November 15, 1987. The pressure gauge was set at 2300 m MD (2290 m TVD).

Figure 4.15b. Injectivity test for production well SC-1 performed on June 7, 1988. The pressure gauge was set at 2340 m MD (2329 m TVD).

formation was found to overlie the "granodiorite" formation. No other Sumikawa well has been drilled (as of early 1990) through this unusual geologic structure.

Injection Well SD-1

The injectivity test of September 4, 1986 (Figure 4.16a) was run in the partially-drilled (hole depth = 396 m) well. Shortly after reaching target depth and completing the well, two other injectivity tests (Figure 4.16b,c) were run. The pressure gauge in the latter two tests was set at the top of the permeable interval. The injectivity test run on October 17, 1986 gave a slightly higher value (0.92 kg/s-bar) for the injectivity index than that (0.65 kg/s-bar) obtained from the test of October 12, 1986. The improvement in well injectivity between the two tests may be due to borehole washing.

During a discharge test run from August 8, 1989 to December 1, 1989, injection well SD-1 produced from several feedzones in the depth interval from 800 m MD to 1570 m MD. At the start of the production test, *in situ* boiling was limited to the shallowest feedzone at 800 m MD; as production continued, boiling conditions extended to the deeper feedzones. The stable feedzone pressure at 1200 m TVD (approximately the middle of the permeable interval) is 77.0 bars (Section 4.15). During the 1989 production test, two downhole pressure/temperature/spinner surveys were run in SD-1 on September 18 and 19, 1989. At the time of these pressure/temperature/spinner surveys, *in situ* boiling was limited to the shallowest feedzone (800–900 meters). Using the flowing pressures measured in these pressure/temperature/spinner surveys, the productivity index for SD-1 is estimated to be ~0.51 (± 0.07) kg/s-bar (Table 4.2). It is almost certain that the productiv-

ity index for SD-1 goes down with continued production as boiling extends to deeper feedzones.

Slim Hole 52E-SM-1

Slim hole 52E-SM-1, located to the northeast of the Sumikawa Geothermal Field, did not encounter any circulation losses during drilling; this indicates poor formation permeability. An injection test was performed shortly after well completion on September 30, 1978 (Figure 4.17). The very small value (0.002 kg/s-bar) of the injectivity index obtained from this test is consistent with indications of poor permeability provided by the absence of circulation losses while drilling.

Slim Hole 52E-SM-2

After slim hole 52E-SM-2 had been drilled to a depth of 803 m, an injection test was performed on August 26, 1978 (Figure 4.18). The injectivity index inferred from the latter test is rather small (0.068 kg/s-bar). The partially-drilled hole was also discharged on September 23, 1978. The measured wellhead enthalpies suggest *in situ* boiling. The maximum discharge rate was about 5 tons/hour. No downhole pressure surveys were made in the discharging borehole.

No injection data are available for the completed 52E-SM-2. The principal feedzone for the completed slim hole is at a depth of 980 meters. The measured wellhead enthalpies during a discharge test performed in October 1978 suggest that the borehole feeds from a liquid zone at about 230–240°C. (Later discharge tests indicate some *in situ* boiling.) The maximum discharge rate during the October 1978 test was ~35 tons/hour.

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Figure 4.16a. Injectivity test for partially-drilled (drilled depth = 396 m) injection well SD-1 performed on September 4, 1986. The pressure gauge was set at 387 m MD (387 m TVD).

Figure 4.16b. Injectivity test for injection well SD-1 performed on October 12, 1986. The pressure gauge was set at 700 m MD (700 m TVD).

Figure 4.16c. Injectivity test for injection well SD-1 performed on October 17, 1986. The pressure gauge was set at 800 m MD (799 m TVD).

Figure 4.17. Injectivity test for slim hole 52E-SM-1 performed on September 30, 1978. The pressure gauge was set at the wellhead.

Figure 4.18. Injectivity test for the partially-drilled (drilled depth = 550 m) slim hole 52E-SM-2 on August 26, 1978. The pressure gauge was set at the wellhead.

The absence of downhole pressure measurements makes it impossible to compute the productivity index for either the partially-drilled or the completed slim hole. The measured discharge rates/enthalpies do, however, imply that the completed hole has higher transmissivity and productivity than the partially-drilled borehole. Slim hole 52E-SM-2 is located to the south of O-5T (*i.e.*, between the Ohnuma and Sumikawa fields).

Slim Hole N59-SN-5

Slim hole N59-SN-5 is located to the west of the Sumikawa field. No circulation losses were encountered in the open part of the borehole. An injection test performed shortly after drilling and completion on November 12, 1985 (Figure 4.19) implies that the injectivity index for N59-SN-5 is small (0.068 kg/s-bar). The small injectivity index is consistent with low formation permeability indicated by the absence of circulation losses during drilling.

4.2 Characteristic Tests

A total of eleven Sumikawa boreholes (slim holes S-1, S-2, S-3, and 52E-SM-2; production wells S-4, SA-1, SA-2, SA-4, SB-1, and SC-1; injection well SD-1) have been discharged at one time or another. In addition, two partially-drilled slim holes (S-2 and 52E-SM-2) were discharged for brief periods. The discharge test data are needed to define the characteristic output curves (*i.e.*, mass and enthalpy versus wellhead pressure). Wellhead enthalpy measurements suggest that slim holes S-2 (final completion), S-3 and 52E-SM-2 (final

completion), and production wells SB-1 and SC-1 produced from all liquid feedzones with little or no *in situ* boiling. Production from all the other Sumikawa boreholes is accompanied by *in situ* boiling. Slim hole S-1 and production wells SA-2 and SA-4 discharge only steam. The mass output curves for the various Sumikawa boreholes are shown in Figures 4.20 through 4.32 (tables of data are given in Appendix B). Interestingly, production from partially-drilled slim holes S-2 and 52E-SM-2 causes *in situ* boiling; final completions of these slim holes discharge fluid with an enthalpy equal to that of liquid water in the reservoir. In an attempt to stimulate well productivity, cold river water was injected into wells S-4, SA-1, SA-2, SA-4 and SB-1 in April and May 1989. Cold water injection was ineffective in raising the productivity of wells S-4 and SA-2. Production from well SA-1 nearly doubled and that from SA-4 increased by about 25 percent. In as much as SB-1 was not discharged prior to cold river water injection, it is impossible to evaluate the efficacy of cold water injection for this well.

The measured maximum mass discharge rates for the various Sumikawa boreholes are presented in Table 4.3. It is apparent from Table 4.3 that the maximum discharge for Sumikawa production wells varies over a wide range (from 28 tons/hour for SA-2 to 490 tons/hour for SC-1). Even for wells with liquid feeds and/or wells with limited *in situ* boiling, the discharge rate varies widely (from < 100 tons/hour for SD-1 to 490 tons/hour for SC-1). This large variation in discharge rates underscores the heterogeneous character of formation permeability at Sumikawa.

Figure 4.19. Injectivity test for slim hole N59-SN-5 performed on November 12, 1985. The pressure gauge was set at the wellhead.

Figure 4.20. Discharge rate versus wellhead pressure for slim hole S-1 (April 1982).

Figure 4.21. Discharge rate versus wellhead pressure for partially-drilled (drilled depth = 904.6 m) slim hole S-2 (July 1982).

Figure 4.22. Discharge rate versus wellhead pressure for slim hole S-2 (final completion) (November, 1982).

Figure 4.23. Discharge rate versus wellhead pressure for slim hole S-3 (July and October 1983). The discharge rate for S-3 fluctuates with a cycle time of ~10 minutes (see Section 4.1).

Figure 4.24. Discharge rate versus wellhead pressure for production well S-4 (1984, 1985, 1986, and 1988).

Figure 4.25. Discharge rate versus wellhead pressure for production well SA-1 (November 1988 and August 1989). The two highest discharge rates (~62 tons/hour) represent the August 1989 data.

Figure 4.26. Discharge rate versus wellhead pressure for production well SA-2 (November 1988 and August 1989).

Figure 4.27. Discharge rate versus wellhead pressure for production well SA-4 (November 1988 and August 1989). The two highest discharge rates (29–30 tons/hour) represent the August 1989 data.

Figure 4.28. Discharge rate versus wellhead pressure for production well SB-1 (July 1989–December 1989).

Figure 4.29. Discharge rate versus wellhead pressure for production well SC-1 (1988 and 1989).

Figure 4.30. Discharge rate versus wellhead pressure for injection well SD-1 (August 1989–November 1989).

Figure 4.31. Discharge rate versus wellhead pressure for partially-drilled (drilled depth = 803 m) slim hole 52E-SM-2 (September 23, 1978).

Figure 4.32. Discharge rate versus wellhead pressure for slim hole 52E-SM-2 (final completion) (October and November 1978).

Table 4.3. Measured maximum discharge rates for various Sumikawa boreholes.

Borehole Name	Final Diameter (mm)	Feedzone Depth (m TVD)	Measured Discharge Rate (T/hour)	Remarks
S-1	143	436	35	Produces only steam
S-2	101	900	4.1	Partially-drilled; hole depth = 904.6 m <i>In situ</i> boiling
S-2	101	940	52	Liquid feed, final completion
S-3	101	700	16	Liquid feed
S-4	159	1520	180	Limited <i>in situ</i> boiling
SA-1	216	1800	62	<i>In situ</i> boiling; produces mostly steam
SA-2	216	1450	28	<i>In situ</i> boiling; produces mostly steam
SA-4	216	1240	30	<i>In situ</i> boiling; produces steam
SB-1	216	1600	105	Liquid feed
SC-1	216	2310	490	Liquid feeds
SD-1	216	1200	100	Limited <i>in situ</i> boiling
52E-SM-2	101	550	5.1	Partially-drilled; hole depth = 803 m <i>In situ</i> boiling
52E-SM-2	79	980	27	Liquid feed, final completion

5 Discussion and Conclusions

5.1 Productivity and Injectivity Indices

Apart from transient effects associated with the initiation of production (or injection) from a borehole, the flow resistance (*i.e.*, pressure losses) of the reservoir rocks can be represented by the productivity (or injectivity) index. Injectivity indices are available for eighteen Sumikawa boreholes (Table 4.1). Five of the boreholes listed in Table 4.1 (50-HM-3, O-5T, 52E-SM-1, 52E-SM-2, and N59-SN-5) are located outside the permeable zone of the Sumikawa field. Slim hole N60-KY-1 within the Sumikawa field displays excellent pressure communication with several Sumikawa wells (S-4, SB-1, and SB-2); this slim hole has, however, very limited injectivity (Table 4.1). As mentioned elsewhere in this report, slim hole N60-KY-1 was injection tested only once (shortly after drilling); it is likely that the permeable fractures at the time of the test were laden with drilling mud and/or rock flour. In the following discussion, we will not further consider injectivity data for the aforementioned six boreholes. Of the remaining twelve boreholes (S-1, S-2, S-3, S-4, SA-1, SA-2, SA-4, SB-1, SB-2, SB-3, SC-1, SD-1), productivity indices (Table 4.2) are available for seven boreholes (S-1, S-2, S-4, SA-1, SA-4, SC-1, SD-1). The productivity and injectivity indices for the latter seven boreholes are compared in Table 5.1.

The injectivity indices for ten of the twelve boreholes (the two exceptions are S-1 and SC-1) are all of the order of unity. Injectivity index for SC-1 is significantly larger than that for other Sumikawa boreholes. Apparently, the injected fluid in S-1 enters the formation through a casing break

at 70–100 meters; thus the injectivity index for S-1 listed in Tables 4.1 and 5.1 is not representative of conditions at depth. The injectivity indices for Sumikawa boreholes do not depend in any systematic manner on the borehole diameter. This result is in agreement with theoretical results of Pritchett (1993) and of Hadgu, *et al.*, (1994). Both of these authors have suggested that apart from any differences associated with differences in wellbore skin (*i.e.*, near wellbore formation damage or stimulation), the productivity (or injectivity) should exhibit only a weak dependence on borehole diameter. The Sumikawa results are, however, at variance with results for the Oguni Geothermal Field (Garg, *et al.*, 1994). Both the productivity and injectivity indices for the Oguni wells display a strong dependence on borehole diameter. We suggest that the difference between the Oguni and Sumikawa results is due to the differences in drilling practice at the two fields. At Oguni, most of the slim holes were drilled with a complete loss of circulation; the drilling mud and/or rock flour apparently plugged some of the permeable fractures. In the case of Sumikawa slim holes, no blind drilling was necessary. Rotary drilling—employed to drill large-diameter holes in both the Sumikawa and Oguni Geothermal Fields—is rarely carried out with complete loss of circulation. Thus, it is likely that formation plugging is responsible for the apparent variation of productivity/injectivity indices with diameter at Oguni; apparently, formation plugging does not vary with diameter at Sumikawa. Data from other geothermal fields should be examined to determine the frequency of the occurrence of excess formation plugging with core drilling.

Table 5.1. Comparison of productivity and injectivity indices for Sumikawa boreholes.

Borehole Name	Final Diameter (mm)	Feedzone Depth (m TVD)	Injectivity Index (kg/s-bar)	Productivity Index (kg/s-bar)	Remarks
S-1	143	436	1.3–6.8	0.86	Borehole produces dry steam. Injection and production depths are different.
S-2	101	900	0.76	0.027	Partially-drilled, hole depth = 904.6 m. <i>In situ</i> boiling on discharge.
	101	940	1.7	1.3	Liquid feed.
S-4	159	1520	1.4	0.94	<i>In situ</i> boiling on discharge; 1983 Injectivity Index
SA-1	216	1800	1.5	0.16	<i>In situ</i> boiling on discharge; 1989 Injectivity Index
SA-4	216	1240	0.94	0.11	1989 Injectivity Index; <i>in situ</i> boiling on discharge.
SC-1	216	2310	5.2	5.7	Liquid feeds.
SD-1	216	1200 (middle of permeable interval)	0.78	0.51	Shallowest feedzone two-phase; deeper feeds liquid.

The injectivity indices for Sumikawa boreholes ($\sim 0(1)$) are significantly smaller than productivity/injectivity indices for Oguni production wells (productivity indices for Oguni wells range from 4 kg/s-bar to 15 kg/s-bar). Liquid conditions prevail at the feedzone depth during production from Sumikawa boreholes S-2 (completed hole only) and SC-1; the productivity indices for these boreholes are more or less the same as the corresponding injectivity indices. The latter conclusions are in accord with results from the Oguni boreholes (Garg, *et al.*, 1994). Production from Sumikawa boreholes other than S-2 (completed hole only) and SC-1 is accompanied by *in situ* boiling. Low formation permeability and high formation temperatures ($250^{\circ}\text{C} < T < 320^{\circ}\text{C}$) are responsible for *in situ* boiling on discharge. The forma-

tion transmissivity for two-phase flow is always smaller than that for liquid flow. For Sumikawa boreholes with *in situ* boiling (S-1, S-4, SA-1, SA-4 and SD-1), the productivity index is, as expected, smaller than the corresponding injectivity index.

5.2 Effect of Borehole Diameter on Discharge Rate

Discharge characteristics of a geothermal borehole are principally controlled by (1) pressure losses associated with flow in reservoir rocks, and (2) pipe friction and heat losses in the wellbore. At Sumikawa, pressure losses in the reservoir constitute the bulk of pressure losses in boreholes for which discharge is accompanied by *in situ* boil-

ing. Even for boreholes with liquid conditions at the feedzone depth, the pressure loss in the formation exceeds 10 bars (see Table 4.2 for boreholes S-2 and SC-1). This situation is quite different from that prevailing in the case of the Oguni Geothermal Field. At Oguni, the formation permeability is sufficiently high such that the pressure losses in the reservoir are insignificant compared to pressure losses in the borehole. The discharge behavior of an Oguni borehole is principally determined by pipe friction and heat losses in the wellbore. Pressure losses in the formation cannot, however, be neglected in the case of Sumikawa boreholes.

Pritchett (1993) employed numerical simulation to investigate the fluid-carrying capacity of boreholes of varying size. In the work by Pritchett (1993), the pressure losses in the formation were assumed to be negligible. Furthermore, the feedzone was assumed to contain single-phase liquid. Based on numerical simulations, Pritchett (1993) suggests that the maximum discharge rate $M_{\max}$ will increase at a rate somewhat greater than the square of borehole diameter.

$$M_{\max} = M_o (d/d_o)^{2+n}, \quad n \geq 0$$

where M_o is the actual borehole discharge rate, and d and d_o are the internal borehole diameters (mm). The exact value of n will most likely vary with feedzone conditions (depth, pressure, enthalpy, and gas content). For the conditions assumed by Pritchett (depth = 1500 m, pressure 80 bars, single phase liquid at 250°C, uniform borehole diameter), n is approximately equal to 0.56. The conditions assumed in Pritchett's work do not hold for Sumikawa boreholes. There is a need to extend Pritchett's work to investigate the effects of pressure losses in the reservoir and of *in situ* boiling on the flow capacity of geothermal boreholes.

The "area-scaled discharge rate" M^* is defined as follows:

$$M^* = M_o (d/d_o)^2$$

The "area scaled" and "scaled maximum ($n = 0.56$)" discharge rates for the Sumikawa slim holes are compared with measured discharge rates from large-diameter Sumikawa wells in Table 5.2. The discharge rates for wells SB-1 (liquid feed) and SD-1 (limited boiling) are approximately equal to the scaled maximum discharge rate for slim hole S-3. The discharge rates for wells SB-1, SD-1 and S-3 (scaled maximum discharge rate) are unusually small for wells with liquid feedzones; the discharge rate in this case is limited by low formation permeability and not by pressure losses in the borehole. The scaled maximum discharge rates for slim holes S-2 and 52E-SM-2 (liquid feeds) provide an adequate prediction for discharge from well S-4 (limited *in situ* boiling). The measured discharge rate for well SC-1 (liquid feeds), however, exceeds the scaled maximum discharge rate for slim holes S-2 and 52E-SM-2 by about 25 percent. The maximum discharge (scaled to a nominal 216 mm diameter) rates for Sumikawa boreholes with little or no *in situ* boiling (52E-SM-2, S-2, S-3, SB-1, SC-1, S-4, SD-1) range from 100 tons/hour (well SD-1) to 490 tons/hour (well SC-1). The comparable range for Oguni wells extends from 227 ton/hour (slim hole GH-7) to 488 ton/hour (slim hole GH-8). The upper limit for the discharge rates is about the same for both the Sumikawa and Oguni boreholes. The Sumikawa boreholes do, however, display considerably more variability in discharge rates than the Oguni boreholes. In any event, the above-discussed data for Sumikawa boreholes taken in conjunction with Oguni data (Garg, *et al.*, 1994), imply that the "scaled-maximum discharge rate" provides a reasonable first prediction of the discharge performance of large-diameter geothermal wells (with little or no *in situ* boiling).

The measured maximum discharge rates for Sumikawa boreholes with extensive *in situ* boil-

Table 5.2. Measured and predicted discharge rates for Sumikawa boreholes.

Borehole Name	Final Diameter (mm)	Measured Discharge Rate (tons/hour)	Area-Scaled Discharge* (tons/hour)	Scaled Maximum Discharge** (tons/hour)	Remarks
(A) Boreholes with liquid feeds and no <i>in situ</i> boiling					
52-E-SM-2	79	27	202	355	Final completion
S-2	101	52	238	364	Final completion
S-3	101	16	73	112	
SB-1	216	105			
SC-1	216	490			
(B) Boreholes with limited <i>in situ</i> boiling					
S-4	159	180	332	394	
SD-1	216	100			
(C) Boreholes with extensive <i>in situ</i> boiling					
52E-SM-2	101	5.1	23	36	Partially-drilled
S-2	101	4.1	19	29	Partially-drilled
S-1	143	35	80	101	
SA-1	216	62			
SA-2	216	28			
SA-4	216	30			

* Area Scaled Discharge Rate = Measured Discharge Rate $\times$ (216/well dia. in mm)²

** Scaled Maximum Discharge Rate = Measured Discharge Rate $\times$ (216/well dia. in mm)^{2.56}

ing are substantially lower than for boreholes with liquid feedzones. The average scaled maximum discharge rate for slim holes 52E-SM-2, S-2, and S-1 is 55 tons/hour. By comparison, the average measured discharge rate for production wells SA-1, SA-2 and SA-4 is 40 tons/hour. The latter value for discharge rate (40 tons/hour) is not too different from that for Oguni well GH-15 (36 tons/hour). Oguni slim hole HH-2 has a scaled maximum discharge rate of 72 tons/hour. Based upon the available data from Oguni and Sumikawa boreholes (four slim holes, four large-diameter wells) with extensive *in situ* boiling, it appears that the "scaled maximum discharge rate" provides too high a prediction for the discharge rate of large-diameter wells. In all likelihood, the scaling rule ($n = 0.56$) derived for boreholes with liquid feeds and with little or no pressure loss in the formation, is not

applicable to boreholes with two-phase feeds. Additional theoretical work is needed to examine the scalability (or lack thereof) of discharge data from slim holes to predict the performance of large-diameter wells.

5.3 Conclusions

Discharge and injection data from slim holes and large-diameter wells at the Sumikawa Geothermal Field, Japan, were examined in an effort to establish relationships (1) between productivity of slim holes and large-diameter wells, (2) between injectivity and productivity indices of slim holes and large-diameter wells, and (3) between productivity/injectivity indices and borehole diameter. The injectivity indices for Sumikawa bore-

holes do not depend in any systematic manner on the borehole diameter as was the case with the Oguni boreholes. Secondly, the productivity and injectivity indices for the Sumikawa boreholes are equal to first order as was the case with the Oguni boreholes. Finally, the Sumikawa borehole data imply that the "scaled-maximum discharge rate" provides a reasonable prediction of the production rate of large-diameter geothermal wells based on discharge data from slim holes.

The Sumikawa and Oguni borehole data (especially for boreholes with liquid feeds) provide

support for the premise that the discharge performance of large-diameter production wells may be forecast using production/injection data from slim holes. The utility (and applicability) of any prediction scheme can only be established by examining actual discharge data from a statistically significant number of slim holes and production wells from several geothermal fields. The set of geothermal fields should include both single- and two-phase reservoirs. A wide range of permeabilities is also needed to delineate the effect of pressure losses in the reservoir on the discharge performance of boreholes.

6 Future Plans

The principal purpose of the present work is to document and evaluate the use of drilling logs, surface and downhole geophysical measurements, chemical analyses and pressure transient data for reservoir assessment purposes at the Sumikawa Geothermal field, Japan. To provide convenient access to the Sumikawa data base, it is planned to incorporate the pertinent Sumikawa data into S-Cubed's Geothermal Reservoir Data Management System (GEOSYS). During the past year, the following data were entered (and checked for errors) into GEOSYS:

- Surface tectonic and topographic maps.
- Well drilling (circulation loss, deviation, stratigraphy) and completion data.
- Well histories.
- Downhole logs (pressure/temperature/spinner) in shutin and flowing wells.

With very few exceptions, the above data sets (for the period prior to mid-1990) are now available as part of GEOSYS. These data are discussed in detail in Section 3 of this report.

A limited amount of chemical data from analyses of well fluids and hot springs have also been entered in the database; these data have, however, not been checked for accuracy. Surface geophysical/geological data, core test data, well testing (see *e.g.*, Section 4), and pressure transient data have yet to be entered into the computerized data base. As already mentioned, MMC has expressed its willingness to supply some post-1989/1990 data for this study; these data will also need to be incorporated into GEOSYS.

Because of DOE's budget constraints, it appears that it will be necessary to significantly curtail work planned for the second year of this project. (DOE has decided to fund the second year of this project through Idaho National Engineering Laboratory.) During the coming year, work will be completed on incorporating (and verifying) geochemical data into GEOSYS. Work on digitizing other pertinent Sumikawa data will also be continued within the available budget constraints. The major thrust of the work in Year 2 will, however, be concerned with the analyses of available pressure transient and geochemical data. The latter sets of data are critical to the formulation of a conceptual model of the natural state of the Sumikawa Geothermal Field.

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Appendix A

Drilling and Completion Data for Sumikawa Area Boreholes

Drilling and Completion Data for Sumikawa Area Boreholes

50-HM-3 -- Borehole Summary

Surface Elevation: 974.0 mASL
 Coordinates: East= -4315.0
 North= -1490.0
 Vertical Borehole? T
 Vertical depth: 500.7 meters
 Total depth: 500.7 meters

History:

Start Time	End Time	Status
30sep75 00:00	19nov75 00:00	Drilling
25oct75 00:00		ShutIn
19nov75 00:00		ShutIn
27nov75 00:00		ShutIn
02dec75 13:30	02dec75 16:50	Injection
02dec75 16:50		ShutIn
31jan86 00:00		ShutIn

50-HM-3 -- Lost circulation

starting depth*	ending depth*	starting rate#	ending rate#	
25.0	25.0	250	250	total loss
45.0	45.0	250	250	total loss
93.0	93.0	250	250	total loss
108.1	108.1	250	250	total loss
109.6	109.6	56	56	
116.9	116.9	250	250	total loss
140.0	140.0	250	250	total loss
146.0	146.0	30	30	

* Vertical Depth (m)
 # l/min

50-HM-3 -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	11.5	7 5/8"	6"	cemented
0.0	120.0	146mm	4"	cemented
0.0	294.7	100mm	3"	cemented
290.9	500.7	79mm	73mm	uncemented

slotted regions:
 350.9 500.7

* Vertical Depth (m)

50-HM-3 -- Stratigraphy data

starting depth*	ending depth*	maj.code	maj.name	min.code	min.name
0.0	81.8	L	Andesitic lavas & pyro.	-	-
81.8	229.5	K	lake sediments	-	-
229.5	348.0	X	Dacitic lava	-	-
348.0	349.0	E	Black shales	-	-
349.0	410.0	F	Dacitic tuff & breccia	-	-
410.0	500.7	E	Black shales	-	-

* Vertical Depth (m)

Drilling and Completion Data for Sumikawa Area Boreholes

N60-KY-1 -- Borehole Summary

Surface Elevation: 991.0 mASL
 Coordinates: East= -4558.5
 North= -1610.5
 Vertical Borehole? T
 Vertical depth: 1604.0 meters
 Total depth: 1604.0 meters

History:

Start Time	End Time	Status
20oct85 00:00	13dec85 00:00	Drilling
14dec85 12:00		ShutIn
01may86 00:00	26jul86 00:00	Drilling
03aug86 00:00		ShutIn
03aug86 15:00	03aug86 16:00	Injection
03aug86 16:00		ShutIn
07aug86 13:20	07aug86 19:00	Injection
07aug86 19:00		ShutIn
10aug86 12:00		ShutIn

N60-KY-1 -- Lost circulation

starting depth*	ending depth*	starting rate#	ending rate#	
5.5	5.5	200	200	
12.9	12.9	300	300	
16.7	16.7	380	380	
38.8	38.8	202	202	
40.3	40.3	800	800	
346.5	346.5	76	76	
382.9	382.9	23	23	
530.0	530.0	35	35	
996.7	996.7	100	100	total loss
1160.0	1160.0	14	14	
1562.1	1562.1	7	7	

* Vertical Depth (m)
 # l/min

N60-KY-1 -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	42.5	14 3/4"	12"	cemented
0.0	290.7	10 5/8"	8 5/8"	cemented
0.0	501.0	7 5/8"	6"	cemented
0.0	1001.0	5 5/8"	4"	cemented
993.5	1604.0	101mm	3"	uncemented

slotted regions:

1140.8	1178.9
1271.6	1347.8
1380.6	1462.3
1467.8	1489.6
1511.3	1604.0

* Vertical Depth (m)

N60-KY-1 -- Stratigraphy data

starting	ending
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Drilling and Completion Data for Sumikawa Area Boreholes

depth*	depth*	maj.code	maj.name	min.code	min.name
0.0	130.0	L	Andesitic lavas & pyro.	-	-
130.0	305.0	K	lake sediments	-	-
305.0	593.7	F	Dacitic tuff & breccia	-	-
593.7	1432.0	C/E	Black shales & Dacitic tu	-	-
1432.0	1604.0	B	Andesites	-	-

* Vertical Depth (m)

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Drilling and Completion Data for Sumikawa Area Boreholes

O-5T -- Borehole Summary

Surface Elevation: 835.0 mASL
 Coordinates: East= -3046.0
 North= -1589.0
 Vertical Borehole? T
 Vertical depth: 749.1 meters
 Total depth: 749.1 meters

History:

Start Time	End Time	Status
26jul68 00:00	23oct68 00:00	Drilling
31jul72 00:00		ShutIn
04aug77 00:00	12aug77 00:00	Drilling
13aug77 00:00		ShutIn
22sep78 16:22	22sep78 18:20	Injection
22sep78 18:20		ShutIn
05oct85 00:00		ShutIn
30sep87 00:00		ShutIn
26apr88 00:00		ShutIn

O-5T -- Lost circulation

starting depth*	ending depth*	starting rate#	ending rate#	
383.0	383.0	120	120	total loss
437.0	437.0	120	120	total loss
747.0	747.0	84	84	total loss

* Vertical Depth (m)

l/min

O-5T -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	51.0	7 5/8"	6"	cemented
0.0	152.2	146mm	4"	cemented
0.0	251.4	92mm	86mm	cemented
233.7	446.7	92mm	73mm	uncemented
446.7	749.1	64mm	open hole	

slotted regions:

233.7 446.7

* Vertical Depth (m)

O-5T -- Stratigraphy data

starting depth*	ending depth*	maj.code	maj.name	min.code	min.name
0.0	51.0	L	Andesitic lavas & pyro.	-	-
51.0	459.8	F	Dacitic tuff & breccia	-	-
459.8	492.1	D	Andesitic tuff & black sh	-	-
492.1	646.7	C/E	Black shales & Dacitic tu	-	-
646.7	749.1	X	Dacitic lava	-	-

* Vertical Depth (m)

Drilling and Completion Data for Sumikawa Area Boreholes

S-1 -- Borehole Summary

Surface Elevation: 1015.6 mASL
Coordinates: East= -3700.3
North= -2105.0
Vertical Borehole? T
Vertical depth: 448.4 meters
Total depth: 448.4 meters

History:

Start Time	End Time	Status
06oct81 00:00	20nov81 00:00	Drilling
04nov81 20:00		ShutIn
17nov81 00:00		ShutIn
30apr82 00:00		ShutIn
05may82 00:00		Injection
20may82 17:05	20may82 18:19	Injection
26may82 03:26	26may82 04:14	Injection

S-1 -- Lost circulation

starting depth*	ending depth*	starting rate#	ending rate#	
436.0	436.0	250	250	total loss
437.5	437.5	250	250	total loss

* Vertical Depth (m)

l/min

S-1 -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	31.0	9 5/8"	8"	cemented
0.0	304.8	7 5/8"	6"	cemented
304.8	448.4	5 5/8"	open hole	

* Vertical Depth (m)

S-1 -- Stratigraphy data

starting depth*	ending depth*	maj.code	maj.name	min.code	min.name
0.0	196.0	L	Andesitic lavas & pyro.	-	-
196.0	200.0	K	lake sediments	-	-
200.0	484.4	F	Dacitic tuff & breccia	-	-

* Vertical Depth (m)

Drilling and Completion Data for Sumikawa Area Boreholes

S-2 -- Borehole Summary

Surface Elevation: 1071.1 mASL
 Coordinates: East= -3702.7
 North= -2589.1
 Vertical Borehole? T
 Vertical depth: 1065.1 meters
 Total depth: 1065.1 meters

History:

Start Time	End Time	Status
20oct81 00:00	20may82 00:00	Drilling
23jun82 22:05	23jun82 23:02	Injection
24jun82 06:00		ShutIn
07jul82 00:00	08jul82 00:00	Production
16jul82 15:55	16jul82 16:55	Injection
04oct82 19:50	04oct82 21:38	Injection
06oct82 00:00	21oct82 00:00	Drilling
16oct82 17:23	16oct82 19:10	Injection
22oct82 00:00		ShutIn
23oct82 16:31	23oct82 18:05	Injection
24oct82 00:00		Injection
26oct82 00:00		ShutIn
10nov82 00:00		Production
12nov82 00:00		ShutIn
16may83 00:00		ShutIn
06aug84 00:00		Injection
02sep86 11:20	03nov86 16:30	Injection
30sep88 10:30	18oct88 00:00	Injection
03jul89 10:00	30nov89 12:00	Injection

S-2 -- Lost circulation

starting depth*	ending depth*	starting rate#	ending rate#	
771.4	771.4	120	120	total loss
797.2	798.5	60	60	
862.9	862.9	93	93	total loss
897.1	897.1	110	110	total loss
903.4	903.4	110	110	total loss
720.0	720.0	?	?	
914.8	914.8	120	120	total loss
935.0	935.0	?	?	

* Vertical Depth (m)

l/min

? missing data

S-2 -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	30.5	9 5/8"	8"	cemented
0.0	305.6	7 5/8"	6"	cemented
0.0	703.3	5 5/8"	4"	cemented
703.3	1065.1	101mm	open hole	

* Vertical Depth (m)

S-2 -- Stratigraphy data

starting	ending
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Drilling and Completion Data for Sumikawa Area Boreholes

depth*	depth*	maj.code	maj.name	min.code	min.name
0.0	280.0	L	Andesitic lavas & pyro.	-	-
280.0	430.0	K	lake sediments	-	-
430.0	570.0	F	Dacitic tuff & breccia	-	-
570.0	1065.1	C	Dacitic tuff	-	-

* Vertical Depth (m)

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Drilling and Completion Data for Sumikawa Area Boreholes

S-3 -- Borehole Summary

Surface Elevation: 1048.5 mASL
 Coordinates: East= -4248.6
 North= -2162.3
 Vertical Borehole? T
 Vertical depth: 805.1 meters
 Total depth: 805.1 meters

History:

Start Time	End Time	Status
22jul82 00:00	11jun83 00:00	Drilling
02sep82 12:51	02sep82 13:52	Injection
06oct82 16:13	06oct82 17:13	Injection
08dec82 00:00		ShutIn
16may83 13:46	16may83 16:35	Injection
12jun83 09:35	12jun83 14:30	Injection
16jun83 06:00		ShutIn
28jan84 00:00		ShutIn
15jun89 09:00	15jul89 15:00	Injection

S-3 -- Lost circulation

starting depth*	ending depth*	starting rate#	ending rate#	
112.0	112.0	20	20	
208.7	208.7	12	12	
419.0	419.0	55	55	
427.6	427.6	600	600	total loss
432.5	440.3	25	25	
441.3	450.0	125	125	
474.0	481.0	21	21	
508.8	508.8	325	325	
547.0	547.0	400	400	total loss
644.0	644.0	23	23	
647.5	647.5	90	90	total loss
755.0	755.0	?	?	

* Vertical Depth (m)

1/min

? missing data

S-3 -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	38.1	12 1/4"	10"	cemented
0.0	254.8	9 5/8"	7 5/8"	cemented
1.9	601.3	5 5/8"	4"	cemented
4.9	804.5	101mm	3"	uncemented
804.5	805.1	101mm		open hole

slotted regions:

602.8 804.5

* Vertical Depth (m)

S-3 -- Stratigraphy data

starting depth*	ending depth*	maj.code	maj.name	min.code	min.name

Drilling and Completion Data for Sumikawa Area Boreholes

0.0	290.0	L	Andesitic lavas & pyro.	-	-
290.0	410.0	K	lake sediments	-	-
410.0	610.0	F	Dacitic tuff & breccia	-	-
610.0	805.1	C/E	Black shales & Dacitic tu	-	-

* Vertical Depth (m)

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Drilling and Completion Data for Sumikawa Area Boreholes

S-4 -- Borehole Summary

Surface Elevation: 1106.7 mASL
 Coordinates: East= -4322.0
 North= -2763.0
 Vertical Borehole? T
 Vertical depth: 1552.0 meters
 Total depth: 1552.0 meters

History:

Start Time	End Time	Status
01jul83 00:00	01nov83 00:00	Drilling
11aug83 00:00		ShutIn
06nov83 19:50	06nov83 21:20	Injection
07nov83 09:11	07nov83 11:46	Injection
07nov83 11:46	07nov83 11:46	ShutIn
19nov83 00:00		ShutIn
30nov83 00:00		ShutIn
08nov84 00:00		ShutIn
24nov85 00:00		ShutIn
02sep86 11:20	03nov86 16:30	Production
03nov86 16:30		ShutIn
25oct88 09:05	24nov88 16:50	Production
24nov88 16:50		ShutIn
16may89 19:00	19may89 14:00	Injection
10jun89 08:51	23nov89 17:35	Production
23nov89 17:35		ShutIn

S-4 -- Lost circulation

starting depth*	ending depth*	starting rate#	ending rate#	
5.7	5.7	1000	1000	total loss
33.0	33.0	800	800	total loss
81.5	81.5	1845	1845	total loss
174.3	174.3	1394	1394	total loss
975.0	975.0	130	130	
1101.8	1108.3	140	140	
1172.4	1172.4	60	60	
1522.6	1522.6	800	800	total loss

* Vertical Depth (m)

l/min

S-4 -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	37.0	26"	20"	cemented
0.0	291.6	17 1/2"	13 3/8"	cemented
1.1	695.3	12 1/4"	9 5/8"	cemented
7.9	1071.0	8 1/2"	7"	cemented
1071.0	1552.0	6 1/4"	open hole	

* Vertical Depth (m)

S-4 -- Stratigraphy data

starting depth*	ending depth*	maj.code	maj.name	min.code	min.name
0.0	420.0	L	Andesitic lavas & pyro.	-	-

Drilling and Completion Data for Sumikawa Area Boreholes

420.0	550.0	K	lake sediments	-	-
550.0	730.0	F	Dacitic tuff & breccia	-	-
730.0	840.0	E	Black shales	-	-
840.0	1160.0	C	Dacitic tuff	-	-
1160.0	1552.0	B	Andesites	-	-

* Vertical Depth (m)

=====

Drilling and Completion Data for Sumikawa Area Boreholes

SA-1 -- Borehole Summary

Surface Elevation: 1107.1 mASL
 Coordinates: East= -4369.2
 North= -2794.2
 Vertical Borehole? F
 Vertical depth: 1831.8 meters
 Total depth: 2002.0 meters

History:

Start Time	End Time	Status
29jul86 00:00	10oct86 00:00	Drilling
11oct86 20:56	12oct86 01:17	Injection
14oct86 00:00		ShutIn
16oct87 00:00		ShutIn
22oct88 09:45	25nov88 19:50	Production
15apr89 17:35	16may89 14:43	Injection
01jun89 09:10	29nov89 16:30	Production

SA-1 -- Lost circulation

starting depth*	ending depth*	starting rate#	ending rate#	
37.0	37.0	80	80	
122.0	122.0	200	200	
213.9	213.9	933	933	
1655.9	1655.9	130	130	
1726.4	1726.4	1660	1660	total loss
1735.8	1831.8	?	?	blind drilling

* Vertical Depth (m)
 # l/min
 ? missing data

SA-1 -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	33.7	840mm	20"	cemented
0.0	367.3	17 1/2"	13 3/8"	cemented
0.0	1056.4	12 1/4"	9 5/8"	cemented
991.6	1830.9	8 1/2"	7"	uncemented
1830.9	1831.8	8 1/2"	open hole	

slotted regions:

991.6	1056.4
1089.3	1116.1
1255.6	1281.3
1323.8	1358.1
1435.9	1830.7

* Vertical Depth (m)

SA-1 -- Stratigraphy data

starting depth*	ending depth*	maj.code	maj.name	min.code	min.name
0.0	434.8	L	Andesitic lavas & pyro.	-	-
434.8	573.8	K	lake sediments	-	-
573.8	756.4	F	Dacitic tuff & breccia	-	-
756.4	1276.2	C/E	Black shales & Dacitic tu	-	-

Drilling and Completion Data for Sumikawa Area Boreholes

1276.2 1593.1 B Andesites - -
1593.1 1831.8 Z Granodiorite and diorite - -

* Vertical Depth (m)

SA-1 -- Deviation data (m)

Meas.depth	Vert.depth	E_dev.	N_dev.
100.0	100.0	0.00	0.00
360.0	359.9	-1.63	7.60
446.5	446.3	-2.13	10.69
476.5	476.3	-3.62	11.33
512.0	511.6	-7.12	11.32
550.0	549.2	-12.66	10.59
604.0	602.3	-22.18	9.30
666.0	662.8	-35.69	8.56
712.0	706.8	-49.00	9.10
767.0	758.3	-68.25	10.63
806.0	794.0	-83.92	12.07
842.0	826.7	-98.98	13.66
879.0	860.0	-114.98	15.34
933.0	908.4	-138.70	17.83
987.0	956.7	-162.80	20.36
1042.0	1005.8	-187.28	22.94
1125.0	1079.3	-225.89	25.18
1206.0	1150.1	-265.25	24.69
1300.0	1229.9	-314.82	23.82
1444.0	1351.0	-392.69	21.61
1644.0	1521.9	-496.39	16.72
1790.0	1650.2	-565.66	9.44
2002.0	1831.8	-672.44	-14.02

Drilling and Completion Data for Sumikawa Area Boreholes

SA-2 -- Borehole Summary

Surface Elevation: 1107.1 mASL
 Coordinates: East= -4355.8
 North= -2786.9
 Vertical Borehole? F
 Vertical depth: 1943.1 meters
 Total depth: 2004.6 meters

History:

Start Time	End Time	Status
19oct86 00:00	16nov86 00:00	Drilling
03aug87 00:00	25sep87 00:00	Drilling
22sep87 00:00		ShutIn
22sep87 16:45	22sep87 18:45	Injection
22sep87 18:45		ShutIn
22sep87 22:25	23sep87 01:00	Injection
23sep87 01:00		ShutIn
29sep87 00:00		ShutIn
24oct88 12:40	26nov88 11:50	Production
16apr89 17:53	17may89 13:36	Injection
07jun89 09:07	02dec89 14:05	Production

SA-2 -- Lost circulation

starting depth*	ending depth*	starting rate#	ending rate#	
107.0	107.0	250	250	
214.0	214.0	127	127	
270.0	270.0	74	74	
311.0	311.0	73	73	
676.9	676.9	2451	2451	total loss
1084.6	1943.1	?	?	Aerated Mud drilling
1903.5	1903.5	2077	2077	total loss

* Vertical Depth (m)

1/min

? missing data

SA-2 -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	33.6	750mm	20"	cemented
0.0	334.0	17 1/2"	13 3/8"	cemented
0.0	1060.6	12 1/4"	9 5/8"	cemented
989.6	1941.5	8 1/2"	7"	uncemented
1941.5	1943.1	8 1/2"	open hole	

slotted regions:

1343.4 1941.5

* Vertical Depth (m)

SA-2 -- Stratigraphy data

starting depth*	ending depth*	maj.code	maj.name	min.code	min.name
0.0	434.7	L	Andesitic lavas & pyro.	-	-
434.7	571.1	K	lake sediments	-	-
571.1	767.4	F	Dacitic tuff & breccia	-	-

Drilling and Completion Data for Sumikawa Area Boreholes

767.4	897.2	C/E	Black shales & Dacitic tu	-	-
897.2	1069.4	C	Dacitic tuff	-	-
1069.4	1152.8	C/E	Black shales & Dacitic tu	-	-
1152.8	1941.5	C	Dacitic tuff	-	-

* Vertical Depth (m)

SA-2 -- Deviation data (m)

Meas.depth	Vert.depth	E_dev.	N_dev.
360.0	360.0	0.00	0.00
384.0	384.0	0.11	-0.45
403.0	403.0	0.50	-1.56
424.0	423.8	0.94	-3.73
442.0	441.7	1.08	-6.05
457.0	456.5	1.35	-8.45
466.0	465.3	1.56	-10.07
475.0	474.2	1.84	-11.84
524.0	521.9	3.50	-22.81
561.0	557.7	4.97	-31.96
607.0	601.7	7.37	-45.02
661.0	652.7	9.78	-62.80
715.0	703.0	11.14	-82.39
769.0	752.6	11.42	-103.56
827.0	806.0	11.16	-126.25
899.0	872.8	11.96	-153.03
990.0	958.1	13.14	-184.88
1040.0	1005.2	13.59	-201.57
1128.0	1088.3	14.35	-230.41
1168.0	1126.6	16.04	-241.81
1186.0	1144.1	17.01	-246.13
1269.0	1224.9	22.30	-264.02
1349.0	1303.1	28.97	-280.00
2004.6	1943.1	82.31	-411.48

Drilling and Completion Data for Sumikawa Area Boreholes

SA-4 -- Borehole Summary

Surface Elevation: 1107.1 mASL
 Coordinates: East= -4342.3
 North= -2779.6
 Vertical Borehole? F
 Vertical depth: 1738.6 meters
 Total depth: 2009.0 meters

History:

Start Time	End Time	Status
01oct87 00:00	15nov87 00:00	Drilling
13nov87 00:00		ShutIn
05may88 00:00	01jun88 00:00	Drilling
29may88 00:00		ShutIn
30may88 00:00		ShutIn
30may88 07:05	30may88 08:50	Injection
30may88 08:50		ShutIn
30may88 12:00		ShutIn
31may88 00:00		ShutIn
23oct88 09:20	27nov88 15:35	Production
28nov88 00:00		ShutIn
17apr89 19:20	18may89 13:10	Injection
29apr89 00:00	30apr89 14:32	ShutIn
04jun89 09:00	26nov89 10:30	Production

SA-4 -- Lost circulation

starting depth*	ending depth*	starting rate#	ending rate#	
123.0	123.0	35	35	
140.0	140.0	318	318	
754.4	754.4	2490	2490	total loss
782.1	782.1	308	308	
819.2	819.2	73	73	
841.9	841.9	137	137	
922.3	922.3	2108	2108	total loss
925.8	925.8	2108	2108	total loss
976.6	976.6	408	408	
1238.5	1738.6	?	?	Aerated Mud drilling

* Vertical Depth (m)
 # l/min
 ? missing data

SA-4 -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	33.6	750mm	20"	cemented
0.0	401.7	17 1/2"	13 3/8"	cemented
0.0	1129.7	12 1/4"	9 5/8"	cemented
1089.8	1731.3	8 1/2"	7"	uncemented
1731.3	1738.6	8 1/2"	open hole	

slotted regions:

1174.0	1426.4
1454.9	1497.5
1541.2	1645.6
1699.9	1723.5

* Vertical Depth (m)

Drilling and Completion Data for Sumikawa Area Boreholes

SA-4 -- Stratigraphy data

starting depth*	ending depth*	maj.code	maj.name	min.code	min.name
0.0	432.7	L	Andesitic lavas & pyro.	-	-
432.7	577.2	K	lake sediments	-	-
577.2	780.3	F	Dacitic tuff & breccia	-	-
780.3	906.5	C/E	Black shales & Dacitic tu	-	-
906.5	1261.4	C	Dacitic tuff	-	-
1261.4	1587.9	B	Andesites	-	-
1587.9	1738.6	Z	Granodiorite and diorite	-	-

* Vertical Depth (m)

SA-4 -- Deviation data (m)

Meas.depth	Vert.depth	E_dev.	N_dev.
100.0	100.0	-0.17	0.85
300.0	299.8	-4.40	6.77
515.0	511.5	-39.44	15.32
700.0	685.2	-101.68	25.92
926.0	889.9	-196.06	40.63
1113.0	1053.7	-282.31	65.39
1307.0	1217.2	-370.88	119.67
1516.0	1376.2	-495.86	170.30
1724.0	1524.1	-635.63	213.15
1900.0	1654.6	-746.16	254.63
2009.0	1738.6	-810.40	281.01

Drilling and Completion Data for Sumikawa Area Boreholes

SB-1 -- Borehole Summary

Surface Elevation: 1048.7 mASL
 Coordinates: East= -4289.9
 North= -2179.9
 Vertical Borehole? F
 Vertical depth: 2006.2 meters
 Total depth: 2086.1 meters

History:

Start Time	End Time	Status
11aug87 00:00	23oct87 00:00	Drilling
23oct87 00:00		ShutIn
25oct87 20:18	25oct87 22:40	Injection
25oct87 22:40		ShutIn
26oct87 11:41	26oct87 13:30	Injection
26oct87 13:30		ShutIn
08nov87 11:11	08nov87 17:50	Injection
08nov87 17:50		ShutIn
27may88 11:10	27may88 13:20	Injection
15aug88 04:30	15aug88 07:30	Injection
17nov88 10:20	22nov88 13:17	Injection
22nov88 13:17		ShutIn
25apr89 10:25	29may89 13:50	Injection
15jun89 09:07	01dec89 15:03	Production

SB-1 -- Lost circulation

starting depth*	ending depth*	starting rate#	ending rate#	
89.3	89.3	1990	1990	total loss
101.0	101.0	1990	1990	total loss
409.0	409.0	1590	1590	total loss
580.1	580.1	1990	1990	total loss
621.9	621.9	195	195	
646.3	646.3	1930	1930	total loss
1370.7	2006.2	?	?	Aerated Mud drilling

* Vertical Depth (m)

l/min

? missing data

SB-1 -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	38.8	800mm	20"	cemented
0.0	274.9	17 1/2"	13 3/8"	cemented
0.0	1062.1	12 1/4"	9 5/8"	cemented
1062.1	2006.2	8 1/2"	open hole	

* Vertical Depth (m)

SB-1 -- Stratigraphy data

starting depth*	ending depth*	maj.code	maj.name	min.code	min.name
0.0	279.9	L	Andesitic lavas & pyro.	-	-
279.9	449.6	K	lake sediments	-	-
449.6	670.7	F	Dacitic tuff & breccia	-	-
670.7	1001.7	C/E	Black shales & Dacitic tu	-	-

Drilling and Completion Data for Sumikawa Area Boreholes

1001.7 1753.3 B Andesites - -
1753.3 2006.2 Z Granodiorite and diorite - -

* Vertical Depth (m)

SB-1 -- Deviation data (m)

Meas.depth	Vert.depth	E_dev.	N_dev.
140.0	140.0	0.69	0.91
350.0	349.9	6.26	1.10
436.0	435.8	3.20	-1.21
485.0	484.2	-3.30	-4.60
523.0	521.4	-9.37	-9.26
561.0	558.2	-16.70	-15.24
608.0	603.1	-27.60	-23.76
675.0	666.1	-45.82	-37.67
760.0	744.8	-72.84	-54.88
818.0	798.5	-93.14	-63.18
874.0	850.0	-114.13	-69.60
931.0	902.2	-136.03	-75.98
988.0	954.0	-159.08	-82.16
1055.0	1015.5	-185.14	-87.33
1111.0	1067.7	-205.37	-89.57
1168.0	1120.7	-226.26	-90.12
1225.0	1174.2	-248.02	-90.60
1283.0	1227.3	-269.29	-90.87
1340.0	1280.6	-289.41	-92.53
1397.0	1334.3	-308.33	-95.36
1474.0	1407.7	-331.45	-98.51
1562.0	1492.3	-354.75	-104.40
1675.0	1602.0	-381.39	-110.44
1788.0	1712.1	-405.89	-116.73
1873.0	1795.4	-421.26	-123.48
1981.0	1902.1	-438.05	-123.89
2058.0	1978.4	-447.07	-120.70
2086.1	2006.2	-449.87	-118.74

Drilling and Completion Data for Sumikawa Area Boreholes

SB-2 -- Borehole Summary

Surface Elevation: 1048.7 mASL
 Coordinates: East= -4275.6
 North= -2173.0
 Vertical Borehole? F
 Vertical depth: 1308.0 meters
 Total depth: 1384.2 meters

History:

Start Time	End Time	Status
01nov87 00:00	10nov87 00:00	Drilling
28may88 00:00	23jun88 00:00	Drilling
21jun88 12:00		ShutIn
22jun88 10:43	22jun88 15:00	Injection
22jun88 15:00	22jun88 15:00	ShutIn
22oct88 12:18	24nov88 16:50	Injection
24nov88 16:50		ShutIn
29apr89 13:55	30may89 12:50	Injection
01jun89 12:45	29nov89 16:30	Injection

SB-2 -- Lost circulation

starting depth*	ending depth*	starting rate#	ending rate#	
95.0	95.0	1841	1841	total loss
120.0	120.0	487	487	
437.9	437.9	44	44	
472.7	472.7	199	199	
559.8	559.8	2240	2240	total loss
636.3	636.3	92	92	
828.9	1308.0	?	?	Aerated Mud drilling

* Vertical Depth (m)

1/min

? missing data

SB-2 -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	38.8	750mm	20"	cemented
0.0	273.5	17 1/2"	13 3/8"	cemented
0.0	678.4	12 1/4"	9 5/8"	cemented
678.4	1308.0	8 1/2"	open hole	

* Vertical Depth (m)

SB-2 -- Stratigraphy data

starting depth*	ending depth*	maj.code	maj.name	min.code	min.name
0.0	283.4	L	Andesitic lavas & pyro.	-	-
283.4	446.6	K	lake sediments	-	-
446.6	653.9	F	Dacitic tuff & breccia	-	-
653.9	1109.9	E	Black shales	-	-
1109.9	1239.4	C/E	Black shales & Dacitic tu	-	-
1239.4	1306.9	C	Dacitic tuff	-	-

* Vertical Depth (m)

Drilling and Completion Data for Sumikawa Area Boreholes

SB-2 -- Deviation data (m)

Meas.depth	Vert.depth	E_dev.	N_dev.
0.0	0.0	0.00	0.00
220.0	219.9	-0.71	2.65
323.0	322.0	-5.31	14.86
440.0	436.9	-11.77	35.93
582.0	574.3	-16.69	71.26
709.0	691.9	-22.93	118.68
820.0	792.0	-35.01	164.92
936.0	896.4	-56.88	211.99
1048.0	997.1	-86.43	248.96
1125.0	1068.2	-107.99	269.18
1264.0	1197.0	-149.33	301.05
1384.2	1308.0	-189.04	324.42

Drilling and Completion Data for Sumikawa Area Boreholes

SB-3 -- Borehole Summary

- Surface Elevation: 1048.7 mASL
 Coordinates: East= -4262.1
 North= -2166.5
 Vertical Borehole? F
 Vertical depth: 1365.9 meters
 Total depth: 1541.9 meters

History:

Start Time	End Time	Status
27jun88 00:00	05aug88 00:00	Drilling
16jul88 00:00		ShutIn
03aug88 00:00		ShutIn
05aug88 12:30	05aug88 15:30	Injection
05aug88 15:30		ShutIn
18nov88 13:18	22nov88 13:14	Injection
22nov88 13:14		ShutIn
25apr89 14:01	31may89 13:30	Injection
15jun89 09:07	01dec89 15:30	Injection

SB-3 -- Lost circulation

starting depth*	ending depth*	starting rate#	ending rate#	
101.0	101.0	192	192	
790.5	790.5	355	355	
804.9	1365.9	?	?	Aerated Mud drilling

* Vertical Depth (m)
 # l/min
 ? missing data

SB-3 -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	16.9	26"	20"	cemented
0.0	278.5	17 1/2"	13 3/8"	cemented
0.0	681.6	12 1/2"	9 5/8"	cemented
681.6	1365.9	8 1/2"	open hole	

* Vertical Depth (m)

SB-3 -- Stratigraphy data

starting depth*	ending depth*	maj.code	maj.name	min.code	min.name
0.0	283.3	L	Andesitic lavas & pyro.	-	-
283.3	441.2	K	lake sediments	-	-
441.2	665.7	F	Dacitic tuff & breccia	-	-
665.7	1304.3	C/E	Black shales & Dacitic tu	-	-
1304.3	1366.0	B	Andesites	-	-

* Vertical Depth (m)

SB-3 -- Deviation data (m)

Meas.depth	Vert.depth	E_dev.	N_dev.
0.0	0.0	0.00	0.00

Drilling and Completion Data for Sumikawa Area Boreholes

130.0	130.0	0.17	-1.12
233.0	232.9	2.45	1.16
354.0	352.6	7.14	17.53
471.0	466.5	18.52	41.53
584.0	573.6	37.72	71.78
696.0	674.7	64.76	111.47
806.0	770.2	94.33	157.45
918.0	865.0	130.94	204.33
1020.0	950.0	175.14	239.12
1134.0	1047.7	228.66	262.65
1243.0	1138.6	287.31	275.97
1355.0	1226.7	354.41	292.56
1454.0	1299.8	419.33	307.72
1541.9	1365.9	473.40	328.40

Drilling and Completion Data for Sumikawa Area Boreholes

SC-1 -- Borehole Summary[†]

Surface Elevation: 1086.6 mASL
 Coordinates: East= -3885.5
 North= -2663.8
 Vertical Borehole? F
 Vertical depth: 2471.6 meters
 Total depth: 2486.0 meters

History:

Start Time	End Time	Status
27jul87 00:00	10nov87 00:00	Drilling
04oct87 00:00		ShutIn
05nov87 00:00		ShutIn
11nov87 00:00		ShutIn
15nov87 14:30	15nov87 17:05	Injection
16nov87 12:00		ShutIn
12may88 06:00		ShutIn
07jun88 12:45	07jun88 14:50	Injection
07jun88 14:50		ShutIn
30sep88 10:00	09oct88 10:00	Production
17oct88 10:00	15nov88 12:00	Production
15nov88 12:00		ShutIn
06oct89 09:08	28nov89 13:10	Production
28nov89 13:10		ShutIn
07apr90 16:00		ShutIn

SC-1 -- Lost circulation

starting depth*	ending depth*	starting rate#	ending rate#	
74.6	74.6	210	210	
1045.8	1045.8	100	100	
1080.7	1080.7	83	83	
1358.1	1358.1	190	190	
1380.0	1380.0	2100	2100	total loss
1387.9	1387.9	650	650	
1410.6	1410.6	583	583	
1430.6	1430.6	400	400	
1436.6	1436.6	1000	1000	
1448.6	1448.6	667	667	
1454.1	1454.1	1667	1667	
1499.5	1499.5	2000	2000	total loss
1703.3	1703.3	250	250	
1835.5	1835.5	600	600	
1861.3	1861.3	500	500	
1871.7	1871.7	750	750	
1977.5	2092.6	?	?	Aerated Mud drilling
2092.6	2471.6	?	?	blind drilling
2095.6	2095.6	1400	1400	total loss

* Vertical Depth (m)

l/min

? missing data

SC-1 -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	40.7	1200mm	660mm	cemented
0.0	502.9	24"	18 5/8"	cemented
0.0	1018.4	17 1/2"	13 3/8"	cemented

Drilling and Completion Data for Sumikawa Area Boreholes

960.7	1799.3	12 1/4"	9 5/8"	cemented
1741.0	2466.8	8 1/2"	7"	uncemented
2466.8	2471.6	8 1/2"	open hole	

slotted regions:

1799.3 2466.8

• Vertical Depth (m)

SC-1 -- Stratigraphy data

starting depth*	ending depth*	maj.code	maj.name	min.code	min.name
0.0	339.9	L	Andesitic lavas & pyro. -	-	-
339.9	494.9	K	lake sediments -	-	-
494.9	654.9	F	Dacitic tuff & breccia -	-	-
654.9	2079.9	C/E	Black shales & Dacitic tu -	-	-
2079.9	2470.7	Z	Granodiorite and diorite -	-	-

* Vertical Depth (m)

SC-1 -- Deviation data (m)

Meas.depth	Vert.depth	E_dev.	N_dev.
50.0	50.0	-0.76	-0.83
150.0	150.0	-2.07	-2.39
250.0	249.9	-3.08	-3.85
350.0	349.9	-3.80	-5.19
450.0	449.9	-4.22	-6.42
550.0	549.9	-4.35	-7.54
650.0	649.9	-4.17	-8.55
750.0	749.8	-3.71	-9.44
850.0	849.8	-2.95	-10.22
950.0	949.8	-1.89	-10.89
1050.0	1049.8	-0.53	-11.44
1150.0	1149.7	0.55	-11.96
1250.0	1249.7	0.73	-12.52
1350.0	1349.7	0.76	-13.02
1450.0	1449.6	0.65	-13.46
1550.0	1549.4	0.54	-14.36
1650.0	1649.0	0.53	-16.01
1750.0	1748.6	0.52	-18.05
1850.0	1848.0	0.49	-20.48
1950.0	1947.0	3.53	-18.00
2050.0	2045.5	11.83	-6.83
2150.0	2143.7	22.91	8.73
2250.0	2241.5	36.76	28.68
2350.0	2339.1	48.44	49.18
2450.0	2436.6	57.15	69.60
2486.0	2471.6	60.11	77.37

†Original name: NG1-SN-7D

Drilling and Completion Data for Sumikawa Area Boreholes

SD-1 -- Borehole Summary†

Surface Elevation: 1015.9 mASL
 Coordinates: East= -3752.8
 North= -2139.4
 Vertical Borehole? F
 Vertical depth: 1691.3 meters
 Total depth: 1704.3 meters

History:

Start Time	End Time	Status
27aug86 00:00	10oct86 00:00	Drilling
31aug86 00:00		ShutIn
04sep86 18:40	04sep86 18:55	Injection
12sep86 12:00		ShutIn
12oct86 12:30	12oct86 16:20	Injection
12oct86 16:20		ShutIn
17oct86 15:30	17oct86 22:56	Injection
17oct86 22:56		ShutIn
03dec86 00:00		ShutIn
05oct87 00:00		ShutIn
17oct88 10:10	15nov88 12:00	Injection
15nov88 12:00		ShutIn
08aug89 09:15	01dec89 11:06	Production

SD-1 -- Lost circulation

starting depth*	ending depth*	starting rate#	ending rate#	
387.0	387.0	2800	2800	total loss
487.0	487.0	36	36	
799.7	799.7	400	400	
977.3	1691.3	?	?	Aerated Mud drilling

* Vertical Depth (m)

l/min

? missing data

SD-1 -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	39.5	840mm	20"	cemented
0.0	183.9	17 1/2"	13 3/8"	cemented
0.0	706.9	12 1/4"	9 5/8"	cemented
641.0	1687.1	8 1/2"	7"	uncemented
1687.1	1691.3	8 1/2"	open hole	

slotted regions:

781.6	922.7
1043.5	1134.0
1154.0	1244.7
1274.9	1385.4
1435.8	1496.0
1515.6	1686.6

* Vertical Depth (m)

SD-1 -- Stratigraphy data

starting depth*	ending depth*	maj.code	maj.name	min.code	min.name
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Drilling and Completion Data for Sumikawa Area Boreholes

0.0	190.0	L	Andesitic lavas & pyro.	-	-
190.0	200.0	K	lake sediments	-	-
200.0	475.0	F	Dacitic tuff & breccia	-	-
475.0	1242.9	C/E	Black shales & Dacitic tu	-	-
1242.9	1371.2	B/E	Black shales & andesitic	-	-
1371.2	1691.3	B	Andesites	-	-

* Vertical Depth (m)

=====

SD-1 -- Deviation data (m)

Meas.depth	Vert.depth	E_dev.	N_dev.
0.0	0.0	0.00	0.00
700.0	700.0	0.00	0.00
1704.3	1691.3	101.24	101.81

=====

†Original name: N61-KY-2

Drilling and Completion Data for Sumikawa Area Boreholes

52E-SM-1 -- Borehole Summary

Surface Elevation: 780.0 mASL
Coordinates: East= -3177.0
North= -1240.0
Vertical Borehole? T
Vertical depth: 1002.6 meters
Total depth: 1002.6 meters

History:

Start Time	End Time	Status
01jul78 00:00	24sep78 00:00	Drilling
23sep78 00:00		ShutIn
27sep78 00:00		ShutIn
30sep78 13:08	30sep78 14:17	Injection

52E-SM-1 -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	44.5	10 5/8"	8"	cemented
0.0	147.5	7 5/8"	6"	cemented
0.0	399.5	5 5/8"	4"	cemented
0.0	618.5	101mm	3"	cemented
609.4	1002.6	79mm	73mm	uncemented

slotted regions:
799.6 1002.6

* Vertical Depth (m)

52E-SM-1 -- Stratigraphy data

starting depth*	ending depth*	maj.code	maj.name	min.code	min.name
0.0	423.0	F	Dacitic tuff & breccia	-	-
423.0	752.0	C	Dacitic tuff	-	-
752.0	993.1	E	Black shales	-	-
993.1	1002.6	B	Andesites	-	-

* Vertical Depth (m)

Drilling and Completion Data for Sumikawa Area Boreholes

52E-SM-2 -- Borehole Summary

Surface Elevation: 897.0 mASL
 Coordinates: East= -3105.0
 North= -1880.0
 Vertical Borehole? T
 Vertical depth: 1001.0 meters
 Total depth: 1001.0 meters

History:

Start Time	End Time	Status
01jul78 00:00	09sep78 00:00	Drilling
21aug78 00:00		ShutIn
26aug78 17:00	26aug78 19:52	Injection
26sep78 00:00	16oct78 00:00	Drilling
15oct78 00:00		ShutIn

52E-SM-2 -- Lost circulation

starting depth*	ending depth*	starting rate#	ending rate#	
111.8	111.8	500	500	total loss
187.8	187.8	8	8	
500.7	500.7	70	70	
548.5	548.5	70	70	
549.7	549.7	100	100	total loss
637.2	637.2	70	70	
979.1	979.1	500	500	total loss

* Vertical Depth (m)

l/min

52E-SM-2 -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	20.7	12 1/4"	10"	cemented
0.0	66.0	9 7/8"	8"	cemented
0.0	147.4	7 5/8"	6"	cemented
0.0	399.8	5 5/8"	4"	cemented
0.0	803.2	101mm	3"	cemented
793.8	1001.0	79mm	73mm	uncemented

slotted regions:

510.4	586.2
793.8	1001.0

* Vertical Depth (m)

52E-SM-2 -- Stratigraphy data

starting depth*	ending depth*	maj.code	maj.name	min.code	min.name
0.0	400.0	F	Dacitic tuff & breccia	-	-
400.0	462.5	D	Andesitic tuff & black sh	-	-
462.5	594.6	C	Dacitic tuff	-	-
594.6	770.5	C/E	Black shales & Dacitic tu	-	-
770.5	894.7	X	Dacitic lava	-	-
894.7	914.7	E	Black shales	-	-
914.7	1001.0	X	Dacitic lava	-	-

* Vertical Depth (m)

Drilling and Completion Data for Sumikawa Area Boreholes

N59-SN-5 -- Borehole Summary

Surface Elevation: 1040.0 mASL
 Coordinates: East= -5711.0
 North= -2462.0
 Vertical Borehole? T
 Vertical depth: 1700.5 meters
 Total depth: 1700.5 meters

History:

Start Time	End Time	Status
31oct84 00:00	13dec84 00:00	Drilling
13dec84 00:00		ShutIn
28apr85 00:00	20sep85 00:00	Drilling
01jun85 00:00		ShutIn
01aug85 00:00		ShutIn
20sep85 00:00		ShutIn
14oct85 00:00	07nov85 00:00	Drilling
07nov85 00:00		ShutIn
12nov85 16:17	12nov85 20:44	Injection
13nov85 12:00		ShutIn

N59-SN-5 -- Lost circulation

starting depth*	ending depth*	starting rate#	ending rate#	
6.0	6.0	520	520	
99.6	99.6	93	93	total loss
111.0	111.0	93	93	total loss
118.0	118.0	93	93	total loss
235.3	235.3	53	53	
263.7	263.7	92	92	total loss
272.0	272.0	500	500	total loss
273.7	273.7	93	93	total loss
277.9	277.9	1100	1100	total loss
281.1	281.1	700	700	total loss
287.3	287.3	93	93	total loss
334.5	334.5	90	90	total loss
337.9	337.9	90	90	total loss
340.6	340.6	56	56	
343.6	343.6	1000	1000	total loss
347.2	347.2	90	90	total loss
351.7	351.7	90	90	total loss
357.3	357.3	90	90	total loss
368.6	368.6	100	100	total loss
377.8	377.8	100	100	total loss
384.4	384.4	1000	1000	total loss
390.6	390.6	1000	1000	total loss
394.0	394.0	800	800	total loss

* Vertical Depth (m)

l/min

N59-SN-5 -- Hole/Casing data

starting depth*	ending depth*	hole_size	casing_size	
0.0	48.5	14 3/4"	12"	cemented
0.0	301.4	10 5/8"	8 5/8"	cemented
0.0	702.5	7 5/8"	6"	cemented
0.0	1002.0	5 5/8"	4"	cemented
998.6	1700.5	101mm	3"	uncemented

Drilling and Completion Data for Sumikawa Area Boreholes

slotted regions:

1302.4	1379.5
1417.6	1488.3
1510.1	1531.9
1580.8	1618.9
1651.5	1689.6

* Vertical Depth (m)

=====

N59-SN-5 -- Stratigraphy data

starting depth*	ending depth*	maj.code	maj.name	min.code	min.name
0.0	455.0	L	Andesitic lavas & pyro.	-	-
455.0	758.9	K	lake sediments	-	-
758.9	1051.7	B	Andesites	-	-
1051.7	1700.5	Z	Granodiorite and diorite	-	-

* Vertical Depth (m)

Appendix B

Characteristic Mass Output Data for Sumikawa Boreholes

Slim Hole S-1

Test Interval: APRIL 25-30, 1982

Date	Wellhead Pressure (bars)	Total Flow Rate (T/HR)
04-25-82	8.07	34.70
	10.03	31.80
	11.70	25.90
	13.66	19.80
	15.62	15.20
	18.56	4.60
04-27-82	8.37	35.70
	10.23	32.00
	11.70	27.20
	13.37	22.00
	16.11	12.40
	18.27	5.70
04-30-82	8.66	34.40
	11.21	27.80
	13.17	21.40
	14.94	15.70
	17.49	7.00
	18.76	3.70

Note: The slim hole produces only steam. The feedzone (436 m TVD = 580 m ASL) temperature is at least 213°C. The feedzone pressure is at least 20 bars (i.e., saturation pressure at 213°C).

Characteristic Mass Output Data for Sumikawa Boreholes

Slim Hole S-2

Test Interval: July 8-12, 1982

Date	Wellhead Pressure (bars)	Total Flow Rate (T/HR)
07-08-82	0.90	4.08
	1.10	4.08
	1.59	4.03
	2.28	3.94
	3.06	3.99
	4.24	4.02
	6.30	3.47
	9.04	1.37
07-10-82	0.90	3.97
	2.28	3.97
	3.45	3.87
	5.32	3.73
	7.47	3.39
	9.34	2.95
	10.02	1.45
07-12-82	0.90	4.28
	0.89	4.06
	0.89	4.00
	2.46	3.95
	4.62	3.79
	7.66	3.17
	9.52	2.09
	9.72	2.09

Note: Discharge test of the partially drilled hole (Total depth = 904.6 m). Enthalpy of the produced fluid suggests a two-phase entry. Circulation loss data/spinner survey (07-16-82) imply fluid entries at ~800 m and at ~900 m.

Characteristic Mass Output for Sumikawa Boreholes

Slim Hole S-2

Test Interval: November 3-11, 1982

Date	Wellhead Pressure (bars)	Total Flow Rate (T/HR)
11-03-82	4.04	53.86
	5.27	50.89
	6.20	44.83
	7.28	29.24
	7.57	23.93
11-11-82	4.02	48.20
	4.81	50.19
	5.98	45.19
	6.86	42.16
	7.55	30.38

Note: Discharge test of the redrilled hole (Total depth = 1065.1 m). The borehole feeds from a liquid zone (pressure = 52.5 bars, temperature = $245 \pm 5^{\circ}\text{C}$) at a depth of 940 m.

Characteristic Mass Output Data for Sumikawa Boreholes

Slim Hole S-3

Test Interval: July and October, 1983

Date	Wellhead Pressure (bars)	Total Flow Rate (T/HR)
07-14-83	2.41	15.07
	2.41	15.80
	2.95	13.33
	3.54	12.10
	4.32	10.95
	4.28	10.02
	5.21	7.06
10-22-83	2.10	14.73
	2.93	15.73
	4.11	14.32
	5.21	13.62
	6.48	12.52

Note: The borehole produces from a liquid feedzone (temperature ~240°C) at a depth of 700 ± 50 meters (349 ± 50 m ASL).

Characteristic Mass Output for Sumikawa Boreholes

Well S-4

Test Interval: 1984, 1985, 1986, 1988

Date	Wellhead Pressure (bars)	Total Flow Rate (T/HR)
09-13-84	9.14	145.33
	13.16	143.03
	17.28	139.03
	21.20	130.50
	24.93	88.16
	26.89	49.32
10-20-84	9.24	162.79
	13.16	156.31
	16.10	151.16
	20.03	125.86
	23.95	59.18
11-06-84	9.33	164.66
	13.44	158.29
	17.56	150.44
	20.02	116.75
	22.76	40.97
11-16-85	10.01	175.79
	15.80	166.43
	19.92	148.03
	23.45	90.04
11-03-86	10.22	179.53
	16.40	174.31
	21.50	133.63
	24.44	107.57
11-24-88	6.15	172.62
	10.27	175.39
	14.68	174.60
	20.17	146.38
	21.94	84.10

Note: Completed hole (drilled depth: 1552 m) produces from several feedzones in the open interval (1071-1552 m) of the well. Wellhead enthalpies imply *in situ* boiling.

Characteristic Mass Output Data for Sumikawa Boreholes

Well SA-1

Test Interval: November 25, 1988 and August 6, 1989

Date	Wellhead Pressure (bars)	Total Flow Rate (T/HR)
11-25-88	4.87	33.59
	10.56	31.79
	21.45	26.68
	28.31	13.10
08-06-89	3.66	61.70
	4.21	61.81

Note: Completed hole (drilled depth: 2002 m MD or 1832 m TVD) produces from a feedzone at about 1800 m TVD. The maximum temperature at bottomhole exceeds 305°C. In 1989, cold water was injected into SA-1 in order to improve the productivity of this well; the 1989 flowrates are substantially higher than 1988 flowrates. The produced fluid is mostly (over 80% by mass at atmospheric conditions) steam.

Characteristic Mass Output for Sumikawa Boreholes

Well SA-2

Test Interval: November 26, 1988 and August 9, 1989

Date	Wellhead Pressure (bars)	Total Flow Rate (T/HR)
11-26-88	4.19	22.00
	5.02	27.50
	7.44	25.09
	10.86	22.10
08-09-89	3.65	25.99
	4.05	27.40

Note: Completed hole (drilled depth: 2005 m MD or 1943 m TVD) produces steam from a feedzone at about 1450 m TVD. The maximum temperature at bottomhole is 320°C. In 1989, cold water was injected into SA-2 in order to improve the productivity of this well; the 1989 flowrates are about the same as 1988 flowrates.

Characteristic Mass Output Data for Sumikawa Boreholes

Well SA-4

Test Interval: November 27, 1988 and August 3, 1989

Date	Wellhead Pressure (bars)	Total Flow Rate (T/HR)
11-27-88	3.50	24.08
	4.87	23.69
	10.15	23.00
	15.17	22.28
	19.78	21.38
08-03-89	3.64	29.09
	4.18	29.59

Note: Completed hole (drilled depth: 2009 m MD or 1739 m TVD) produces steam from a feedzone at about 1240 m TVD. The maximum temperature at bottomhole exceeds 300°C. In 1989, cold water was injected into SA-4 in order to improve the productivity of this well; the 1989 flowrates are somewhat higher than 1988 flowrates.

Characteristic Mass Output for Sumikawa Boreholes

Well SB-1

Test Interval: June 30 - December 1, 1989

Date	Wellhead Pressure (bars)	Total Flow Rate (T/HR)
07-15-89	2.63	105.50
07-31-89	2.89	108.00
08-15-89	2.94	105.80
08-24-89	3.16	102.60
08-25-89	5.07	94.60
09-15-89	2.99	102.80
09-30-89	2.91	101.40
10-15-89	2.86	96.40
10-30-89	2.72	91.40
11-15-89	2.52	86.20
11-29-89	2.72	89.60
11-30-89	4.78	78.10
12-01-89	7.37	48.10

Note: Completed hole (drilled depth: 2086 m MD or 2006 m TVD) produces mainly liquid water from a depth of about 1600 m TVD. The bottomhole temperature is about 300°C; by comparison, the feedzone temperature is estimated to be about 280°C.

Characteristic Mass Output Data for Sumikawa Boreholes

Well SC-1 (SN-7D)

Test Interval: Oct. & Nov. 1988; Oct. & Nov. 1989

Date	Wellhead Pressure (bars)	Total Flow Rate (T/HR)
10-01-88	19.49	182.90
10-09-88	18.80	134.30
10-18-88	14.78	281.90
10-18-88	13.60	409.80
10-31-88	12.23	446.70
11-04-88	19.09	171.70
11-06-88	19.29	198.20
11-06-88	17.23	349.60
11-08-88	18.21	309.40
11-11-88	15.76	382.90
11-13-88	18.80	290.20
11-15-88	16.84	116.70
11-15-88	13.90	62.60
10-06-89	12.72	490.70
10-09-89	12.43	477.20
10-12-89	12.62	491.80
10-16-89	12.33	472.20
10-20-89	17.33	109.60
10-26-89	19.88	252.40
10-31-89	12.43	481.10
11-05-89	12.62	484.60
11-10-89	13.01	489.50
11-15-89	13.01	487.20
11-20-89	13.11	487.60
11-23-89	13.31	496.80
11-25-89	15.37	461.10
11-26-89	17.52	422.20
11-27-89	20.07	352.30
11-28-89	17.13	80.70

Note: Completed hole (drilled depth: 2486 m MD or 2472 m TVD) produces mainly liquid water from several feedzones between 1950 m MD (temp = 307°C) and 2320 m MD (temp ~246°C). The well has a pronounced temperature inversion. SC-1 is the most prolific producer at Sumikawa.

Characteristic Mass Output for Sumikawa Boreholes

Well SD-1 (KY-2)

Test Interval: August 8 - December 1, 1989

Date	Wellhead Pressure (bars)	Total Flow Rate (T/HR)
08-10-89	2.42	96.90
08-20-89	2.32	87.50
08-24-89	2.47	84.90
08-25-89	4.17	79.80
08-26-89	5.36	50.70
08-31-89	2.37	98.30
09-10-89	2.23	81.40
09-20-89	2.42	81.50
09-30-89	2.32	78.00
10-10-89	2.37	79.60
10-20-89	2.42	81.10
10-31-89	2.40	78.50
11-10-89	2.40	80.70
11-20-89	2.28	76.60
11-27-89	2.81	87.00
11-28-89	3.94	69.70
11-29-89	5.12	53.80
11-30-89	2.62	82.00

Note: Completed hole (drilled depth: 1704 m MD or 1691 m TVD) produces from several feedzones in the depth interval from 800 m MD to 1570 m MD. At the start of the production test, in situ flashing is limited to the shallowest feedzone; eventually, flashing extends to the deepest feedzone. The decline in production rate is probably due to the spread of flashing conditions to deeper feedzones. The feedzone temperatures range from ~210°C (1450-1490 m MD) to ~250°C (1550-1570 m MD).

Characteristic Mass Output Data for Sumikawa Boreholes

Slim Hole 52-E-SM-2

Test Interval: September 23, 1978

Date	Wellhead Pressure (bars)	Total Flow Rate (T/HR)
09-23-78	1.11	5.18
	1.15	5.15
	1.18	5.11
	1.25	4.90
	1.36	5.00
	1.44	4.79
	1.59	4.72
	1.79	4.57
	2.06	4.36
	2.23	3.89
	2.37	2.77

Note: Partially-drilled hole (drilled depth: 803 m). Feedzone depth: 550 m (?). Wellhead enthalpies suggest *in situ* boiling.

Characteristic Mass Output for Sumikawa Boreholes

Slim Hole 52E-SM-2

Test Interval: October 1978 - October 1978⁹

Date	Wellhead Pressure (bars)	Total Flow Rate (T/HR)
10-19-78	2.68	26.14
10-20-78	2.68	35.50
11-02-78	2.97	26.68
11-17-78	2.85	25.52
	3.83	24.44
	4.82	24.08
	5.80	23.62
	6.78	22.68
	9.23	20.34
	11.68	19.37
	13.15	17.32
06-26-79	2.86	18.97
08-24-79	2.86	20.56
10-27-79	3.07	20.09

Note: Completed hole (drilled depth: 1001 m). Feedzone depth: 980 m (?). Wellhead enthalpies suggest that the slim hole feeds from a liquid zone at a temperature of about 230-240°C. Flow data for 06-26-79 and later indicate some *in situ* boiling.

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