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PRESSURE-INTERFERENCE TESTING OF THE SUMIKAWA GEOTHERMAL FIELD

S.K. Garg*, J.W. Pritchett*, K. Ariki+, and Y. Kawano•

*S-CUBED, +Mitsubishi Materials Corporation (MMC), •New Energy and Industrial Technology Development Organization (NEDO)

Abstract

Pressure interference tests have been used to determine the permeability structure of the Sumikawa reservoir. Interference tests between wells S-4 and KY-1 have indicated the presence of a very high permeability (140 md) north-south channel in the altered andesite layer. Pressure buildup data from well SN-7D have provided indications of a high transmissivity (kh ~ 18 darcy-meters) reservoir located in the granodiorite layer; lack of pressure response in nearby shutin Sumikawa wells implies that the reservoir penetrated by SN-7D is isolated from the shallower reservoir in the altered andesites. The "altered andesite" and the "granodiorite" formations constitute the principal geothermal aquifers at Sumikawa. Pressure interference tests (wells KY-1 and SB-2, and wells KY-2 and SB-3) have also confirmed the presence of moderately high transmissivity (~ 2 darcy-meters) dacitic layers in the "marine-volcanic complex" formation. Because of its low vertical permeability, the "marine volcanic complex" formation constitutes an attractive target for the reinjection of waste geothermal fluids.

Introduction

The Sumikawa geothermal field is located in the Hachimantai volcanic area in northern Honshu, Japan. Figure 1 shows the region of particular interest. The area depicted is about 42 square kilometers; the Sumikawa geothermal field lies in the western part of the area. To the east, the Ohnuma geothermal power station has been producing about 10 MW of electrical power for several years using a small borefield immediately surrounding the power station. The terrain is extremely irregular; Mt. Yake lies in the southwest part of the illustrated area and Mt. Hachimantai is just to the southeast. 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 wells: 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 area shown in Figure 1. Indeed, the Sumikawa field itself appears to be located along the western edge of the graben. Figure 2 shows an east-west cross-section corresponding to line A–A′ in Figure 1. Figure 3 shows a similar north-south section (B–B′). These structural interpretations are based almost exclusively upon drilling experience. The major formations in order of increasing depth 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.

"DI" Formation: Dacitic dike located generally north of the Kumazawa river.

"MV" Formation: "Marine/Volcanic Complex"; interbedded Miocene dacitic volcanic rocks and "black shale" oxygen-poor marine shales and sediments.

"AA" Formation: Altered andesitic rocks which are apparently extensively fractured.

"GR" Formation: Crystalline intrusive rocks (mainly granodiorite and diorite).

The lake sediments act as a caprock for the geothermal reservoir (see Pritchett *et al.*, 1989). The "GR" formation is the deepest so far encountered by drilling, but the pre-Tertiary basement which presumably underlies the above sequence has not yet been reached. The "DI" formation (known only from outcrops) is located north of the Kumazawa river (i.e. outside the main Sumikawa geothermal field) and is believed to extend to great depth.

In this paper, we discuss the pressure-interference testing of the Sumikawa geothermal field. The various pressure transient tests performed to-date have helped in clarifying the permeability structure of the Sumikawa reservoir. Interference tests have indicated the presence of (1) a very high permeability north-south channel in the altered andesite layer, and (2) moderately high transmissivity dacitic layers in the "marine/volcanic complex" formation. In addition, it appears that the deep "granodiorite" reservoir penetrated by well SN-7D is isolated from the overlying altered andesite reservoir.

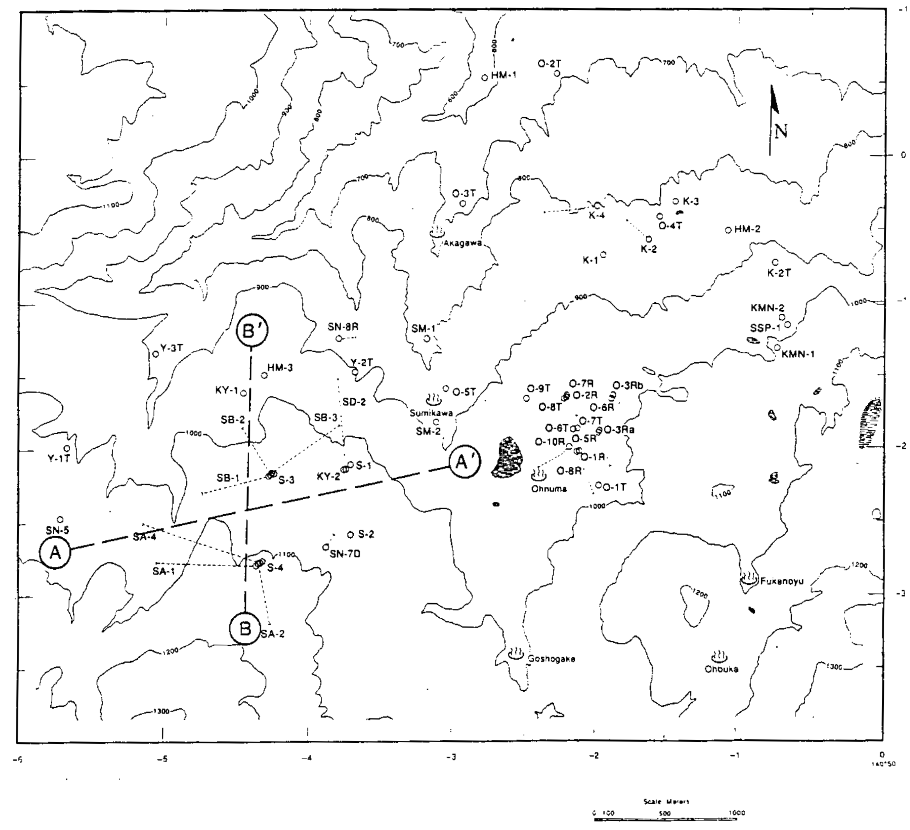

Figure 1. The Sumikawa/Ohnuma area, showing locations of wells and cross-sections A–A′ and B–B′

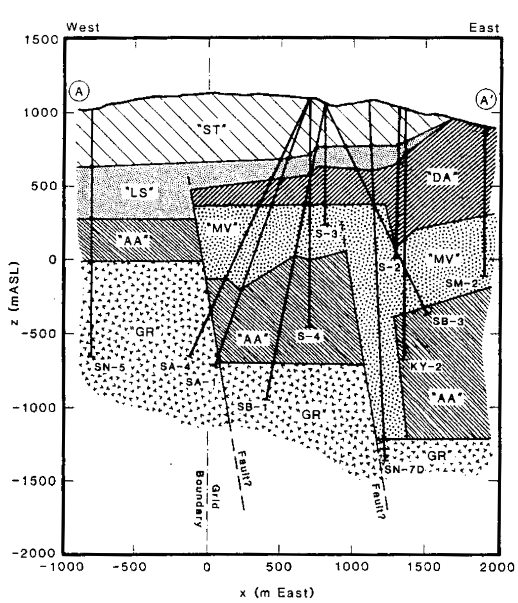

Figure 2. East-west A–A′ geological cross-section through the Sumikawa area.

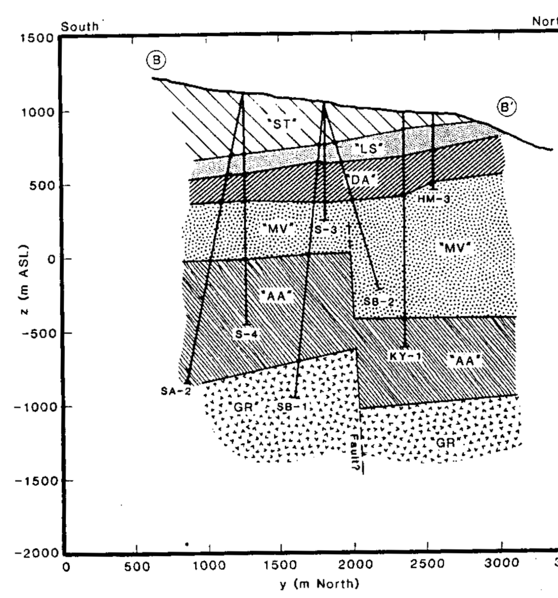

Figure 3. North-south geological cross-section B–B′ through the Sumikawa area.

Pressure Disturbances in Observation Well KY-1

In 1986, a large-scale pressure-interference experiment was carried out at Sumikawa. Deep well S-4 was discharged starting on September 2 and was subsequently shut in on November 3; the liquid fraction of the discharge was simultaneously reinjected into nearby shallow well S-2. Four shut-in observation wells (O-5T, S-3, KY-1 and KY-2) were equipped with downhole pressure gauges of the capillary-tube type. No signals attributable to the S-4 discharge were recorded in O-5T, KY-2 or S-3, but a clear and immediate response was observed in deep well KY-1, located 1.1 km north of S-4. Only two mud loss zones were encountered in the uncemented part of well KY-1: at –166 m ASL and at –568 m ASL. The deeper of these mud loss zones lies in the "altered andesite" layer and corresponds to the major feedpoint for well KY-1. The major feedpoint for well S-4 is located at –413 m ASL in the "altered andesite" layer.

All four "A" pad wells (SA-1, SA-2, SA-4, S-4) were discharged, essentially simultaneously, between October 22 and November 27, 1988. Except for a brief period in November, all of the liquid separated from SA-1 and S-4 (SA-2 and SA-4 discharged only dry steam) was reinjected into well SB-2. From November 17 to November 22, 1988, part of the separated liquid was also reinjected into wells SB-1 and SB-3. During the 1988 discharge test, well KY-1 was equipped with a downhole capillary tube pressure gauge. Based on the flow histories of various wells, it is concluded that the pressure signal recorded in KY-1 reflects the effects of production/reinjection into wells S-4, SB-1 and SB-2. The major feedpoint for well SB-1 is located at –551 m ASL in the altered andesite layer. The fluid injected into well SB-2 enters the reservoir at its major entry (–221 m ASL) located in a dacite layer within the "marine/volcanic complex". Thus S-4 and SB-1 apparently communicate with well KY-1 through the altered andesite layer; well SB-2 is connected to well KY-1 through the dacites (see Figure 4). Analysis of 1988 test data is severely handicapped by extremely sparse data concerning flow rates in various wells, and the reservoir parameter values inferred are not considered to be very reliable.

In April and May 1989, MMC injected cold water into several wells (SA-1, SA-2, SA-4, S-4, SB-1, SB-2 and SB-3). During the injection period, several shutin wells (KY-1, KY-2, S-3, S-4 and SN-7D) were equipped with downhole capillary-tube pressure gauges. No definite evidence of pressure interference was found in the records obtained from wells S-3, S-4 or SN-7D. Well KY-2 exhibited a pressure response to injection into well SB-3; these interference data are discussed in a later section. Figure 5 shows the pressure signal recorded in well KY-1 during April and May 1989. The pressure record (Figure 5) shows significant oscillations even prior to the start of injection at ~ 1098 hours (April 16, 1989). Besides the fictitious oscillations, the pressure record contains a number of gaps and apparently discontinuous shifts in pressure. Despite these difficulties with the KY-1 pressure record, it is possible to identify pressure changes attributable to injection into wells S-4, SB-1 and SB-2. These pressure changes are considered in detail in the following subsections.

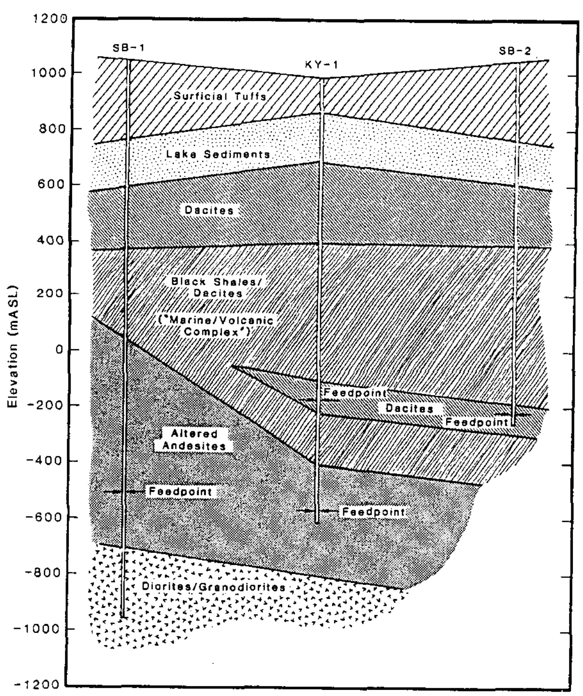

Figure 4. Correlations between stratigraphic logs in wells SB-1, SB-2 and KY-1.

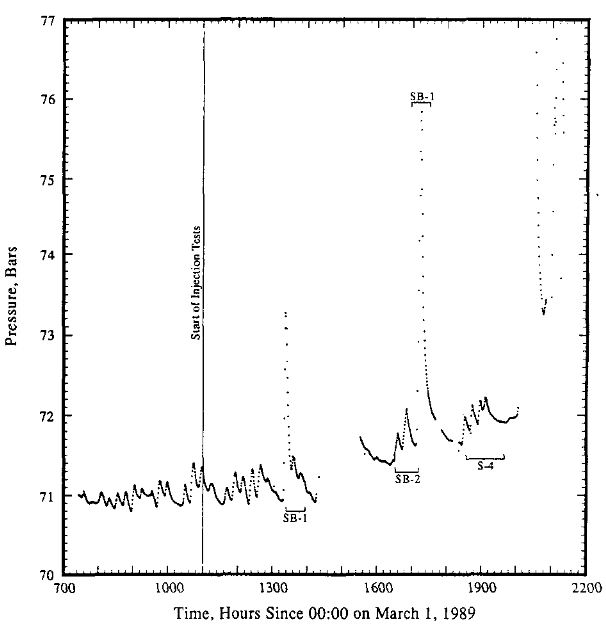

Figure 5. Measured pressure response in KY-1 during April and May 1989. Also indicated are the pressure responses believed to be associated with injection into wells S-4, SB-1 and SB-2.

As noted above, well KY-1 appears to be connected to two aquifers (a dacite layer in the "marine/volcanic complex" formation, and the altered andesites). The net pressure disturbance measured within well KY-1 at any time is the weighted average of the pressure distribution within the two aquifers outside the well; the weighting factors are the injectivities of the two feedzones involved. Assuming that the characteristic relaxation time for the well is small compared to the time scale associated with aquifer pressure disturbances, the time rate of change in well pressure $\dot{p}_w$ is given by:

$$\dot{p}_w = W_u \dot{p}_u + (1 - W_u)\dot{p}_l$$

where

W_u = fractional injectivity of the upper feedzone

$\dot{p}_u(\dot{p}_l)$ = time rate of change in pressure within the upper (lower) aquifer.

ϕ (porosity) = 0.15

The pressure disturbance within the upper aquifer is presumably that due to injection into well SB-2, and the disturbance in the lower aquifer is a linear combination of the disturbances caused by injection into (or production from) wells SB-1 and S-4. An estimate for W_u (≈ 0.2) is presented in the next subsection.

Wells SB-2 and KY-1

The recorded KY-1 pressure signal shows influence of cold water injection into well SB-2 on May 8 and May 9, 1989 (see Figure 6). We treat the dacite aquifer intercepted by wells KY-1 and SB-2 as characterized by the following uniform properties:

$$\phi \text{ (porosity)} = 0.15$$

$$\mu \text{ (fluid viscosity)} = 1.2 \times 10^{-4} \text{ Pa-s}$$

$$C_T \text{ (total compressibility)} = 1.2 \times 10^{-9}/\text{Pa}$$

The spatial separation between the SB-2 feedpoint and the upper KY-1 feedpoint is 243 meters.

The classical line-source solution was utilized; well SB-2 was treated as a fully penetrating well for purposes of the analysis of interference at KY-1. Provision was made for a constant pressure linear aquifer boundary. A single interference signal cannot uniquely establish the orientation of the "constant pressure" boundary; only the following parametric relationship may be obtained;

$$(R \sin\theta)X + (R\cos\theta - A)Y = 2B^2$$

where

$$R^2 = A^2 + 4B^2$$

θ = any angle from 0 to 2π

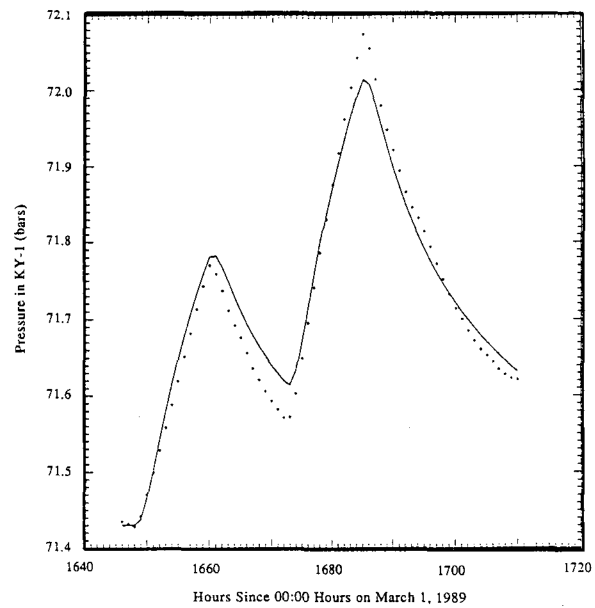

Figure 6. Comparison of pressure measurements in well KY-1 with computed response due to cold water injection into well SB-2 on May 8 and May 9, 1989 (t = 1647.7 to 1664.3 hours and t = 1672.1 to 1688.2 hours). —computed, • measurements

and where the "y" axis coincides with a line connecting the two feedpoints, the "x" axis is perpendicular to y, "A" represents the spatial separation between the two feedpoints (243 meters), the KY-1 feedpoint is located at $x = y = 0$, the SB-2 feedpoint is located at $x = 0$, $y = A = 243$ meters, and the boundary is represented by the locus of points with $x = X$, $y = Y$. The unknown parameters in the model (p_i, initial reservoir pressure, k, dacite aquifer permeability; h, the aquifer thickness; B, the boundary distance) were varied in order to minimize deviations between calculations and observations. The values finally obtained were:

p_i (initial reservoir pressure) = 71.430 bars

k (permeability) = 25.2×10^{-15} m^2 = 25.2 millidarcies

h (thickness) = 647 W_u meters

B (boundary distance) = 567.6 meters

φ (rock porosity) = 0.05

The proper value for the aquifer thickness (h) depends upon the value selected for the relative injectivity of the upper feedzone in well KY-1 (W_u) This permits W_u to be estimated, at least approximately. Well logs indicate that the thickness of the dacite aquifer involved is in the neighborhood of 150 meters. Therefore, if we impose h =150 m, we obtain W_u= 0.232. Of course, h is not precisely known; accordingly, we have simply adopted the rounded value: W_u = 0.2. The permeability-thickness product of the dacite layer connecting the upper feedzone of well KY-1 with the feedpoint of well SB-2 is ~ 3.3 darcy-meters.

Wells KY-1 and S-4

Starting at 19:00 hours on May 16, 1989 ($t \sim 1843$ hours), cold water was intermittently injected into well S-4 until 14:00 hours on May 19, 1989; well KY-1 responded (see e.g. Figure 7) quickly to each change in the injection rate. For the sake of simplicity, we ignore the slight difference in elevation between the feedpoints of well S-4 (–413 m ASL) and well KY-1 (–566 m ASL), and treat well KY-1 as if it were located directly north of well S-4. Assuming that the coordinates of the S-4 feedpoint coincide with the origin ($x = y = z = 0$), the coordinates of the feedpoint of well KY-1 are ($x = 0$, $y = 1120$ meters, $z = 0$). A variety of geometrical flow models were considered in an attempt to interpret the measured pressure response in well KY-1. The best fit was obtained by assuming that well S-4 fully penetrates an areally infinite anisotropic reservoir with the following properties:

φ (rock porosity) $= 0.05$

μ (fluid viscosity) $= 10^{-4}$ Pa - s

C_T (formation compressibility) $= 1.7 \times 10^{-9}$ Pa^{-1}

ρ (*in situ* fluid density) $= 800$ kg/m^3

k_y (north - south permeability): 141 md

k_x (east - west permeability): 3.36 md

h (formation thickness): 500 $(1 - W_u)$ meters

p_i (initial pressure): 71.599 bars

As noted above, a pressure response was also recorded in well KY-1 during a 1986 discharge test of well S-4. Although no downhole pressure measurements in well S-4 were made during the 1986 discharge test, it is certain that two-phase (water/steam) boiling flow was induced locally in the reservoir adjacent to the S-4 feedpoint by the pressure reduction associated with discharge. Well test pressure transient analysis is traditionally based on assumptions of single phase isothermal flow. As discussed by Garg and Pritchett (1988), these linear single-phase analysis techniques may be applied for interference test interpretation so long as the discharge rate history used in the analysis is suitable modified to reflect the influence of the two-phase zone in the vicinity of the production well. According to Pritchett *et al.* (1989), the effective discharge rate history for well S-4 may be represented as follows:

Time Interval	Effective Discharge Rate
prior to 09/02/86 11:20	0 kg/s
09/02/86 11:20 to 09/03/86 12:00	50 kg/s
09//03/86 12:00 to 09/07/86 00:00	42 kg/s
09/07/86 00:00 to 11/03/86 16:30	34 kg/s
11/03/86 16:30 to 11/29/86 09:00	4 kg/s

We next attempted to match the 1986 pressure interference response in KY-1 with an "anisotropic line-source model". Figure 8 compares the computed pressure response with the measurements. The following parameters were utilized in computing the pressure disturbance shown in Figure 8.

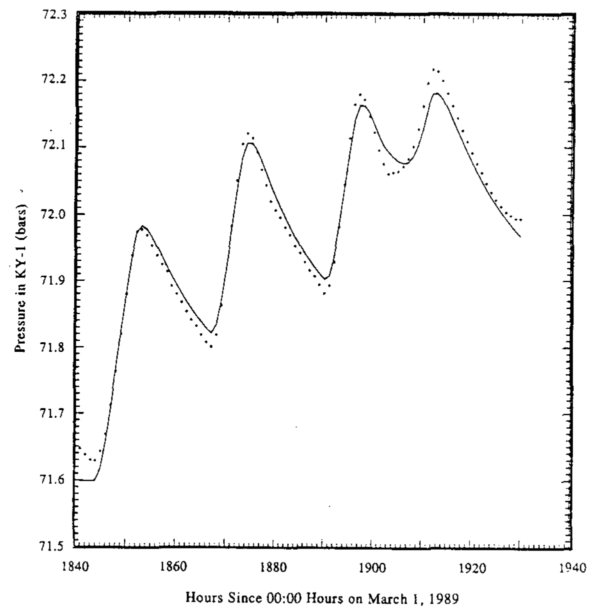

Figure 7. Comparison of computed (anisotropic line-source model) pressure response of KY-1 with measurements due to cold water injection into well S-4 (—computed, •measurements).

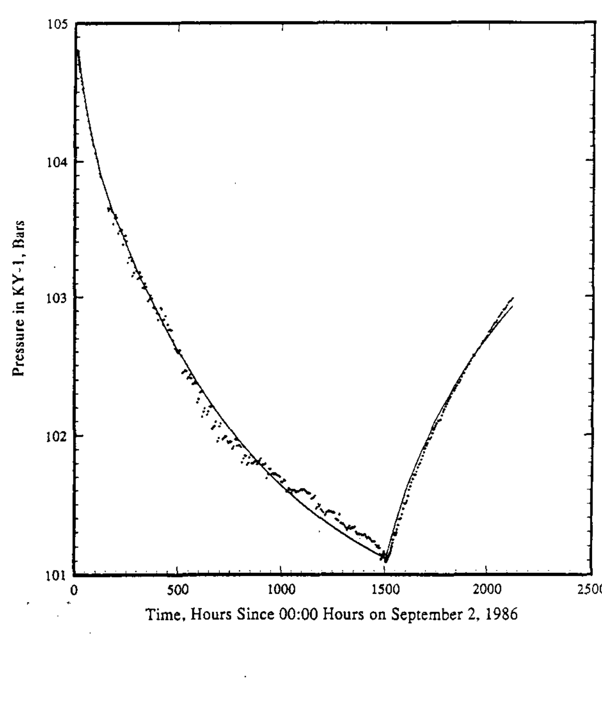

Figure 8. Comparison of computed (anisotropic line-source with boundaries) 1986 pressure disturbance in well KY-1 to measurements (—computed, •measurements).

k_y (north-south permeability): 139 md

k_x (east-west permeability): 28.2 md

h (formation thickness) = 498 m

distance to eastern (western) impermeable boundary, $\Delta x_e(\Delta x_w) = 630 \times (1-W_u)$ meters $\cong$ 504 meters

distance to northern impermeable boundary Δy_n = 2030 meters

distance to southern constant pressure boundary, Δy_s = 8710 meters

The reservoir cross-section ($0.498 \times 1.008 \sim 0.50$ km^2) and the distance to the northern and southern boundaries given by the above model is not too different from that presented earlier by Prichett *et al.* (1989). Within certain limits, the computed pressure response is not very sensitive to the exact value for the east-west permeability. Considering the uncertainty associated with the 1986 flow data, it is not possible to claim any great precision for the east-west permeability (28.2 md) needed to obtain the computed pressure response in Figure 8.

Figure 9 compares the measured pressures in KY-1 (April and May 1989) with the pressure response computed using the above described anisotropic line-source model with boundaries. All the parameter values, with the exception of k_x and initial pressure p_i, were held constant. The following values for k_x and p_i were utilized in computing the pressure response:

$$k_x = 5.82 \text{ md}, \qquad p_i = 71.614 \text{ bars}$$

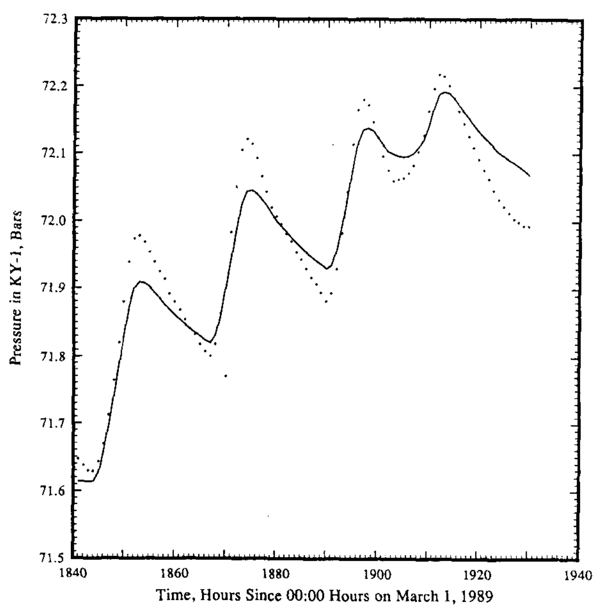

Figure 9. Comparison of pressure measurements in well KY-1 with computed (anisotropic line-source model with boundaries) response due to cold water injection into well S-4 (—computed, •measurements).

The agreement between the measured and computed response, while not as good as that shown in Figure 7, is certainly adequate. Furthermore, the east-west permeability value (5.82 md) is within a factor of three to five of that required to match the 1986 pressure response.

In conclusion, our interpretation of the pressure interference data shows that wells KY-1 and S-4 penetrate a north-south channel of high permeability; the permeability in the transverse (i.e. east-west) direction is, however, low (5 to 30 md). The cross-section of the north-south channel is ~ 0.5 km^2. The permeable channel is bounded to the north by an impermeable boundary. The inferred southern constant pressure boundary most likely corresponds to the two-phase water-steam zone in the reservoir.

Wells KY-1 and SB-1

Because of gaps in the recorded pressure response for well KY-1, it was possible to clearly identify pressure interference from only two episodes (April 25, 1989 and May 11, 1989) of cold water injection into well SB-1. In each case, the signal strength at well KY-1 was extremely high (several bars) despite the relatively small quantity of fluid injected into well SB-1 and despite the large separation between the well feedpoints.

The best fit to the pressure interference observations (see e.g. Figure 10) between wells SB-1 and KY-1 was obtained by using the conventional line-source model with a constant pressure boundary. Well SB-1 is apparently connected to well KY-1 by a single fracture. The permeability-thickness product of this fracture is only about ~ 0.11 darcy-meter and the porosity-thickness is only about 14 centimeters. This suggests that the aquifer volume involved is very small. As established by the interpretation of the pressure interference tests between wells KY-1 and S-4, the "altered andesite" formation is very permeable, and the cross-section area of the channel is substantial. This permeability is presumably due to the presence of a system of fractures (probably oriented approximately north-south); although well S-4 intersected only one of these fractures at its primary feedpoint, the frequent intersections of the individual fractures within the channel served to distribute the pressure signal from S-4 throughout the entire fracture network in the formation such that the apparent cross-section area and aquifer volume were substantial. In the case of well SB-1, however, the very high ratio of pressure disturbance to injection flowrate suggest that only a limited part of the fracture network was accessed by the pressure disturbance before it was felt at well KY-1. For example, it is possible that well SB-1 injects fluid into a single fracture which either intersects well KY-1 or passes very near the dominant KY-1 feedpoint; this fracture presumably eventually intersects the remainder of the fracture network, but only at considerable distance. The constant pressure boundary indicated by our analysis most likely implies that the fracture connecting wells KY-1 and SB-1 joins the rest of the fracture network at some indeterminate distance from well SB-1.

Pressure Disturbances in Well KY-2

Well KY-2 has several feedpoints between ~ 200 m ASL and ~ –500 m ASL. The top two feedzones (216 to 86 m ASL, and –24 to –44 m ASL) are located in dacite layers within the "marine/volcanic complex". The major

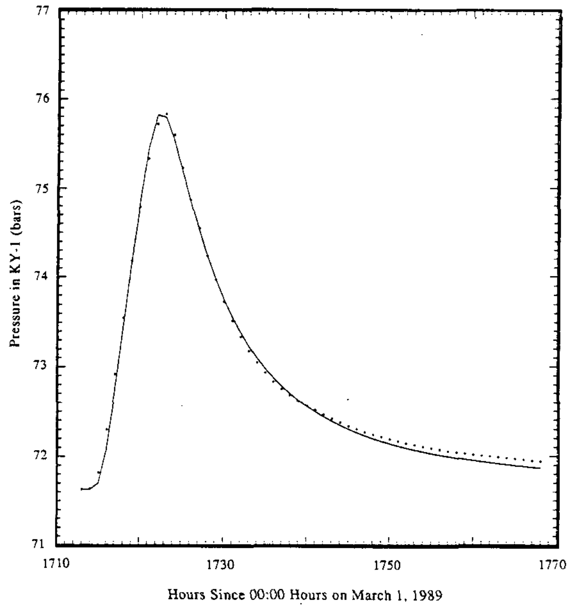

Figure 10. Comparison of pressure measurements in well KY-1 with computed response due to cold water injection into well SB-1 during the time interval from 9:16 hours (t = 1713.267 hours) on May 11, 1989 to 15:50 hours (t = 1719.833 hours) on May 11, 1989 (—computed, •measurements).

feedzone for well SB-3 occurs in the depth interval 249 to 89 m ASL; this depth interval contains the "marine/volcanic complex". During April and May 1989, cold water was intermittently injected into well SB-3, and a pressure interference response was observed in well KY-2 (see Figure 11). It is likely that wells SB-3 and KY-2 communicate through the upper feedpoint of well KY-2.

To analyze the pressure interference response of well KY-2, we assume that well SB-3 can be treated as a classical line-source in an aquifer with the following properties:

formation porosity, $\varphi = 0.15$

fluid viscosity, $\mu = 1.2 \times 10^{-4}$ Pa-s

total formation compressibility, $C_T = 1.2 \times 10^{-9}$ Pa^{-1}

Ignoring the slight difference in feedpoint elevations, the distance between KY-2 and SB-3 is ~ 414.3 meters. The unknown parameters are (1) initial formation pressure, p_i (2) formation permeability, k and (3) formation thickness, h. Minimization of error gives the following values for the model parameters:

initial formation pressure, $p_i = 44.0$ bars

formation permeability, $k = 12.8 \times 10^{-15}$ m^2 = 12.8 md

formation thickness, $h = 203$ meters

The computed pressure response is compared with the measurements in Figure 11. The permeability-thickness value of 2.6 darcy-meters for the dacite layer intercepted by wells KY-2 and SB-3 is comparable to that (3.3 darcy-meters) inferred for the dacite layer connecting wells KY-1 and SB-2.

Well SN-7D

Well SN-7D is the deepest well (total depth ~ 2486 m; true vertical depth ~ 2472 m) at Sumikawa. The major feedpoint for well SN-7D is located in the crystalline granodiorite/granite/diorite rocks at about −1230 m ASL; several minor feedzones are to be found in the overlying "marine/volcanic complex" formation. Well SN-7D is by far the best producer at Sumikawa; total (water plus steam) flow rates up to 500 tons/hour were recorded during a 1989 discharge test.

Downhole pressures were monitored using a gauge of the capillary tube type in at least three separate (two in 1988 and one in 1989) discharge tests. The pressure buildup data from these tests have been interpreted to indicate a very high transmissivity (permeability × thickness ~ 18 darcy-meters). It also appears that the volume of the deep zone tapped by well SN-7D is at least a few cubic kilometers. During the SN-7D discharge tests, five other wells (S-3, S-4, KY-1, KY-2, SN-8R) were, at one time or another, equipped with downhole pressure gauges. No signal attributable to the discharge of SN-7D was observed in any of these wells; this implies that the deep reservoir penetrated by well SN-7D is probably isolated from the shallower reservoir in the "altered andesites".

Structural Interpretation of "Channel Model"

The feedpoints of both wells S-4 and KY-1 are located within a deep altered andesite layer. Above this layer lies a thick formation consisting of alternating marine sediments (black shales) and dacite volcanic flows; because of the presence of the shales it is likely that the average vertical permeability is rather low. Below the andesite layer, a crystalline granitic layer (granodiorite formation) is to be found. The thickness of the permeable (andesite) layer, sandwiched between the marine/volcanic complex and the crystalline granitic basement, is about 0.5 to 0.6 kilometers. Since the cross-section area of the channel is ~ 0.5 km^2, it follows that the width (east-west) of the channel is about 1 km. It is noteworthy that, about 2 km farther to the east, a similar north-south permeable channel of ~ 1 km width (permeable zone III in Figure 12) was identified associated with the Ohnuma Geothermal Field based on stable shutin pressure evidence.

The granodorite formation appears to rise abruptly ~ 0.7 km west of well S-4 ; this geological discontinuity is an obvious candidate for the western boundary of the deep flow channel (permeable zone I in Figure 12). If this geometric interpretation is valid, the implication is that another north-south vertical barrier is present ~ 0.2 to 0.3 km east of well S-4. Such a flow barrier would lie between wells S-4, S-3, N60-KY-1 and 50-HM-3 (to the west) and wells S-2, S-1, N61-KY-2 and Y-2T (to the east). This eastern boundary most likely consists of "MV" black shale, as evidenced by drilling logs from well SN-7D.

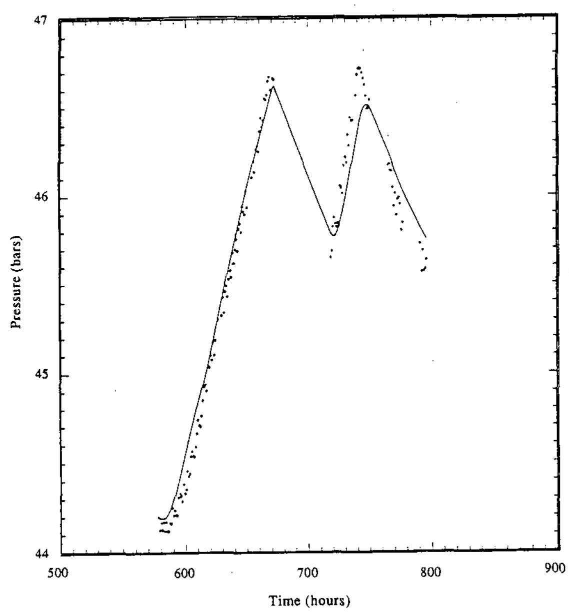

Figure 11. Pressure response of well KY-2 to cold water injection into well SB-3 from April 25, 1989 to May 25, 1989 (—computed, •measurements).

An east-west reservoir boundary located north of wells 0-3T and 0-4T was identified based on static pressure evidence (Pritchett *et al.*, 1989). The presence of this northern boundary is confirmed by the above interpretation of the signal observed in well KY-1 from the S-4 discharge test. This boundary is probably associated with the dacitic dike along the Kumazawa river.

The channel flow model also suggests the presence of a constant-pressure boundary located some 8.7 km south of well S-4. It seems implausible that the flow channel could extend so far south. The explanation for this peculiar result is intrinsic in the linear character of the flow model. In particular, it was assumed that the flow channel contains single-phase liquid. It is likely that two-phase conditions prevail under undisturbed conditions in the flow channel a short distance (less than 1 km) south of well S-4. This suggests that the actual position of the southern boundary is probably much closer to well S-4 than the 8.7 km indicated by the single-phase treatment.

Conclusions

Pressure transient tests have been invaluable in delineating the permeability-strucutre of the Sumikawa reservoir. Interference tests between wells S-4 and KY-1 have indicated the presence of a very high permeability (140 md) north-south channel in the altered andesite layer. Pressure buildup data from well SN-7D have provided

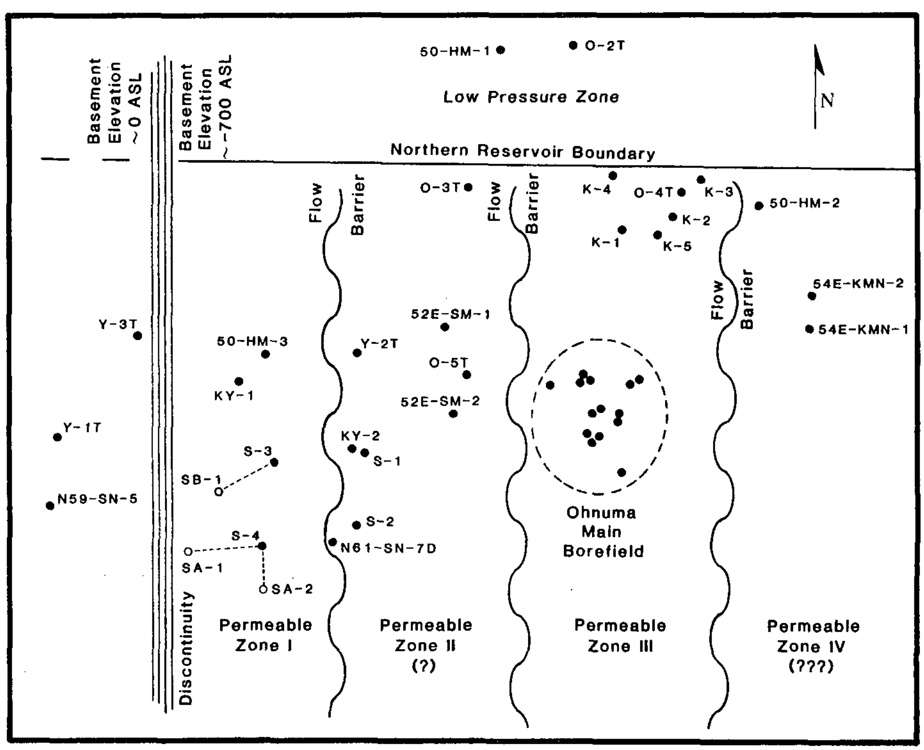

Figure 12. Estimated locations of deep permeable channels in Sumikawa/Ohnuma area.

indications of a high transmissivity (permeability × thickness ~ 18 darcy-meters) reservoir located in the crystalline rocks underlying the altered andesite layer. Lack of pressure response in shutin wells, however, indicates that the deep reservoir encountered by SN-7D is hydraulically isolated from the overlying "altered andesite" formation. At present, the "altered andesite" and the "granodiorite" formations are believed to constitute the principal geothermal aquifers at Sumikawa.

Pressure interference tests (wells KY-1 and SB-2, and wells KY-2 and SB-3) have also confirmed the presence of moderately high transmissivity (~ 2 darcy-meters) dacitic layers in the "marine/volcanic complex" formation. Because of its low vertical permeability, the "marine/volcanic complex" formation constitutes an attractive target for reinjection of waste geothermal fluids.

Acknowledgement

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