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DOE/ET/27040--T1

DRILLING, LOGGING AND PRELIMINARY WELL TESTING
OF GEOTHERMAL WELL SUSAN 1,
SUSANVILLE, LASSEN COUNTY
CALIFORNIA

MASTER

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for
CITY OF SUSANVILLE,
SUSANVILLE, CALIFORNIA

DOE/ET/27040--T1

DE82 010444

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SUMMARY AND CONCLUSIONS

Susan 1, a hot water production well, was drilled late in 1980 for the City of Susanville, California, as part of its geothermal space-heating project. This report presents a history of drilling, logging, completion and pump testing of this well. Susan 1 was drilled to 930 feet using local river water with a 17-1/2-inch bit from 50-540 feet and a 12-1/2-inch bit from 540-927 feet. A 12-3/4-inch solid casing was set from surface to 350 feet, a slotted casing from 350-538 feet, and a 8-5/8-inch slotted casing from 520-925 feet.

Interpretations of the following logs and test data from this well are presented:

1. drilling logs (penetration rate, water loss and gain, return temperatures);
2. formation logs (description of well cuttings, caliper, spontaneous potential, electrical resistivity, gamma ray, neutron);
3. production logs (temperature, spinner); and
4. pump test data.

Based on these interpretations the following stratigraphic sequence was identified in this well:

alluvial section	-	0-75 feet
lake beds(?)	-	75-280 feet
tuffs(?)	-	280-700 feet
lake beds(?)	-	700-750 feet
basaltic andesite	-	750-815 feet
lake beds(?)	-	815-895 feet
basalt	-	895-915 feet
lake beds(?)	-	915-930 feet

Drilling conditions were more severe than anticipated, resulting in numerous partial cave-ins of the uncased hole. Future drilling will require a modified casing and completion program.

Permeable zones in the interval 350-460 feet constitute the aquifer, within the probable tuff interval. Permeable zones appear to exist below 825 feet from mud return temperatures; this could not be confirmed because of the inability to run logs below this depth.

The transmissivity value from the pump test is on the order of 1.5×10^6 md·feet/cp and agrees with that from the wells in the southern part of the city. The storativity value from the pump test is on the order of 3×10^{-5} ft/psi and is about one-tenth of that from the wells in the southern part of the city. Despite this, deliverability is comparable to that of other thermal wells in the area, at 10.5-12.6 gpm/ft. Maximum flow temperature of 174°F is some 10°F above the temperature anticipated prior to drilling.

The observed high flow rates (up to 650 gpm for short intervals, and sustainable at 350 gpm with just over 30 feet of drawdown), high temperature (flow at 174°F, extrapolated equilibrium of at least 180°F), and high deliverability at least equal to the pre-drilling expectations, and categorize Susan 1 as a successful geothermal well.

RECOMMENDATIONS

1. Conduct at least a month-long, carefully designed interference test in which Susan 1 is flowed and the water level is monitored in a number of strategically selected wells in the city.
2. Develop a detailed correlation of logs, well data and pump test data from all wells in the city and develop a geological model of the reservoir.
3. Interpret the interference test data based on above geological model, and develop a quantitative reservoir model based from this. Use this reservoir model to assess reservoir capacity and to forecast long-term well performance.
4. Based on the reservoir model and operational constraints, decide on the need for and siting of (1) a second production well and (2) an injection well. Redesign drilling, casing and completion programs to satisfy anticipated conditions of caving formations.

INTRODUCTION

Susan 1 is a hot water production well drilled as part of the City of Susanville Geothermal Energy Project (DE AC03 79ET 27040). It is located in SE1/4 NE1/4 SE1/4 Sec. 31, T. 30 N., R. 12 E. (Figure 1). Ground elevation is 4,210 feet; the hole is 925 feet deep. Susan 1 is about 15 feet northeast of Suzy 9A and about 50 feet southwest of Suzy 9, which were drilled to 818 and 445 feet respectively in 1979.

The drilling contractor was the Water Development Corporation of Woodland, California. A trailer-mounted Failing JED-A reverse-circulation drilling rig was used. Unlike a conventional system, drilling fluid in a reverse circulation drilling rig flows downward by gravity from the surface around the drill stem, passes through the drill bit, and is pumped up inside the drill stem (Figure 2). Lift is provided by compressed air injected into the top 20-200 feet of the drill string. Reverse-circulation drilling provides very clean samples with little contamination from up-hole slough.

Water for drilling was pumped from the Susan River into a pit located next to the rig. This water, and the entrained sand- and silt-sized drill cuttings in the circulation loop, was the only drilling fluid used; no mud, gel, foam or lost-circulation material was added. Water flowed by gravity from the pit through a short horizontal pipe into an 8-inch porthole cut into the surface casing, and thence down the hole (Figure 2). This pipe and porthole were about 4 feet below ground level.

Susan 1 was drilled in the period October 15-December 2, 1980. Drilling operations were conducted 24-hours per day until October 31, with either 2 or 3 two-man crews per day. Well clean-out, setting of casing, and rig repair was done only during daylight hours after October 31. The drilling supervisor was Roger Weidemeir of the Water Development Corporation.

GeothermEx, Inc. was responsible for the specification, monitoring and supervision of drilling, logging, completion and flow testing. Carol A. Petersen of GeothermEx performed geologic logging during drilling operations, examined local surface geology and conducted temperature logging of Susan 1 and Suzy 9A. Dr. Subir K. Sanyal and Dr. James R. McNitt were present during geophysical logging of Susan 1, provided well-site interpretation of the logs, and selected the interval to be completed with slotted 12-3/4-inch casing. Following completion, GeothermEx personnel conducted further logging and flow testing, interpreted the logs and tests, and prepared this report.

FIGURE 2. Schematic diagram of reverse drilling process.

DRILLING HISTORY

Activities carried out during the drilling and casing period (October 15-December 2) are shown graphically in Figure 3. The final hole dimensions, as well as casing, slotted liner, cementing, and gravel pack intervals, are shown in Figure 4.

The hole was spudded on October 15 and drilled through fine-grained to very coarse fluvial sediments to a 50-foot depth with a 26-inch-diameter drag bit. Fifty feet of 20-inch conductor pipe was inserted and cemented into the hole. Coarse, poorly cemented fluvial gravels, cobbles and boulders were encountered to a depth of 75 feet. These coarse sediments caved into the hole beneath, and eventually from behind, the surface conductor, until finally the conductor was swinging free, suspended only by chains from the rig. Caving of the top 75 feet of poorly cemented sediments eventually produced a large hole (10x3x5 feet) at the ground surface, fortuitously on the side away from the drill rig. If this hole had developed beneath a wheel or jack support, the rig would have overturned and the hole would have been lost.

If more holes are drilled near the Susan River, drilling specifications should allow flexibility in choosing the depth at which surface conductor is set. Experience at Susan 1 shows that caving results if river gravels are not cased off.

The hole was drilled below 50 feet with a 17-1/2-inch rock bit. Drilling rates were slow until lake beds(?) were encountered below the fluvial gravels. Drilling proceeded steadily to a depth of 360 feet, when caving uphole in the interval 240-260 feet began to endanger the drill string. Cleaning and circulating at 240-260 feet did not succeed in stabilizing the hole, so a cement plug was set. This plug is thought to cover the interval 235-260 feet, but there are no data to determine the actual interval covered by the cement.

After cleaning out the hole from 260-360 feet, drilling proceeded smoothly with the 17-1/2-inch bit. This was changed to a 12-1/2-inch rock bit at 540 feet, primarily because of drill string weight considerations and also because drilling specifications permitted a smaller diameter in the bottom of the hole. There was no lithologic break nor other geological consideration that required a change in drilling practices.

While drilling ahead with the 12-1/2-inch bit, a very large lost-circulation zone developed when the hole was 475 feet deep. Water losses in previous intervals had been increasing steadily, as

FIGURE 3. Susan 1--Time elapsed during drilling and completion.

FIGURE 4. Susan 1 -- Final well dimensions.

shown on Plate 1, but the total-loss zone which developed at this depth absorbed the entire capacity of the pump bringing drilling water from the Susan River. Over the next 6 days, more than 275,000 gallons of cold river water were lost down the hole. Unfortunately, data are not available to determine how much of this water moved through the permeable river gravels at the top of the hole, and how much entered deeper permeable zones.

The hole was drilled ahead to 930 feet on October 29 even though large water losses continued almost continuously (data regarding water loss and gain are discussed in another section). However, at this depth several things occurred nearly simultaneously:

- (1) fine-grained altered volcanics at the bottom of the hole clogged the circulation loop, preventing further drilling and also producing some caving at the bottom of the hole;
- (2) coarse fluvial gravels began to cave from the top of the hole; and
- (3) fine-grained altered volcanics accumulated in the hole from 530 to approximately 600 feet; these may have caved below the cement plug at 235-260 feet (or that plug may not have completely covered the unstable interval).

The hole was cleaned easily through the zone 530-600 feet. Both volcanic rocks and sloughed alluvium were cleaned below 800 feet; however, the latter zone did not stabilize. The drilling rods were pulled and the hole was left overnight (October 29-30) while water was injected continuously. On October 30-31, various logs were run. More fill gradually accumulated during this time, filling the bottom of the hole from 820 up to 800 feet.

The hole was left during October 31-November 3 without additional water being injected. On November 4, small to moderate amounts of fill (altered fine-grained volcanics) were cleaned in several intervals, including 730-740 feet; but overall the hole above 800 feet was in good condition.

On November 5, a combined string of solid and slotted 12-3/4-inch casing was run to 538 feet, in order to protect the hole from additional caving at shallow levels and to complete and protect production zones in the interval from 350-540 feet. The interval to be completed with slotted liner had been selected by the authors of this report from interpretation of cuttings, temperature and geophysical logs.

On November 6, the annulus between slotted liner and hole wall was gravel-packed from 538-320 feet. It had been intended to stop the gravel at 350 feet, but additional gravel was added accidentally. The gravel behind the solid casing is not expected to affect well performance. On November 7, cement was pumped into the annulus from 320 feet, with returns visible at about 4 feet below ground level (bottom of "porthole"). After the casing and cement were in place and there was no danger from additional caving in the fluvial section, the 26-inch conductor pipe was pulled.

Cleaning below the 12-3/4-inch casing was carried out from November 11-December 1, with delays caused by rig repair, difficulty in obtaining supplies, and holidays. The level of fill at the bottom of the hole had stabilized at about 800 feet, with a large part being gravel slough from the top of the hole.

Finally, on December 2, 8-5/8-inch slotted casing was run in the interval 520-925 feet, with the casing landed on bottom. The lower casing string was not gravel packed, and the lap (520-538 feet) between the two casing strings was not cemented.

LOGGING

Drilling Logs

Penetration Rate

Average drilling rates are shown on Plate 1. These values were calculated from the driller's time records of footage, with allowances made for interruptions to drilling. Drilling rates greater than 20 feet per hour show good correlation with lithology; slower drilling rates are more common.

Water Loss and Gain

Circulation water was lost to permeable zones throughout the drilling period. The variation of the rate of water loss with depth is shown on Plate 1. These rates are calculated from the data contained in Appendix A and are only approximate because individual values represent losses averaged over a period of several hours, during which time the hole was deepened several tens of feet. Nevertheless, consistent results were obtained, showing a gradual loss ranging from 0.2 to 20 gallons per minute (gpm) up to 450 feet, and then rapidly increasing through the 450-475-foot interval. Because the maximum capacity of the water delivery pump was about 80 gpm, no additional data could be obtained below 475 feet.

Susan 1 was observed to produce water briefly on two occasions (Appendix A) before the 12-3/4-inch casing was run. On both of these occasions, the hole was open below 800 feet.

After the 12-3/4-inch casing was run (isolating permeable surficial gravels from the open section at the bottom of the hole), the hole produced water through the casing-drill pipe annulus while circulating at 700-830 feet. On the morning of November 21, the hole flowed spontaneously at a temperature of 138°F (58°C). Circulation history in the hole before this spontaneous flow was established is as follows: the hole had been cleaned once to 835 feet on the previous afternoon but had caved again to 820 feet during the night. The hole continued to flow with a small head until the porthole in the surface casing was closed on December 6. This porthole and the connecting horizontal pipe were about 4 feet below ground level. Static water level stabilized at 23 inches below ground level, this being sufficient to balance the head in the permeable strata communicating with the borehole.

During the time that Susan 1 flowed spontaneously, the temperature rose from 138°F to 164°F (on November 23), and an odorless gas (believed to be CO₂) evolved from the water. Temperature dropped slightly to 162°F on November 25 with lower rate of gas evolution, and to 158°F on December 1, with very little accompanying gas. A water sample was taken on November 23 and the resulting analysis is given in Appendix B.

The rate of water flow was estimated at 25 gpm on November 24 and somewhat greater on December 1 and 2.

Return Temperatures

Temperature of the returning drilling fluid was measured at the exit of the mud-circulation loop by means of a dial-type thermometer set into the flow line. During most of the drilling the inlet mud temperature was 45-50°F due to the large volumes of river water being lost downhole.

Circulation return temperatures observed while drilling to 930 feet are plotted on Plate 1; they mostly range from 50-66°F. A sharp increase in return temperature, from 62-72°F, occurred at 920 feet. This may indicate an inflow of warm water at that depth.

Circulation return temperatures during cleaning-out operations were extremely variable, depending largely on the length of time the hole had been undisturbed. However, on November 10, while cleaning out from 770-800 feet, the flow-line temperature rose from 135-147°F. This part of the hole had been undisturbed for 20 days.

Formation Logs

Formation logging of Susan 1 included the examination and description of drill cuttings by the GeothermEx well-site geologist, and the running of caliper, spontaneous potential, resistivity, gamma ray and neutron logs by a subcontractor logging service, Welenco of Bakersfield, California. The order of formation logging and production logging is given in Table 1.

The geophysical logs were run soon after the hole was drilled to total depth, but because of partial caving, the bottom 100 feet of the hole could not be logged. Temperature logs also were run at various times.

Table 1. Sequence of logs in Susan 1.

<u>October 30</u>		<u>Depth reached, feet</u>
10:00 AM	Differential temperature in static hole	825
10:45 AM	Electric log (SP, long normal and short normal resistivity)	815
12:30 PM	3-arm caliper	800
1:00 PM	Radioactivity log (gamma ray and neutron)	805
2:00 PM	4-arm caliper	819
2:40 PM	Spinner log in static hole	800
<u>October 31</u>		
8:15 AM	Differential temperature in static hole.	815
9:10 AM	Spinner log while water is injected	800
10:00 AM	Differential temperature while water is injected	800

Well Cuttings

Samples from Susan 1 were collected and labeled by the driller at approximately 5-foot intervals, and some additional samples were taken at intermediate points.

Descriptions of the samples are based on examination of the cuttings by binocular microscope. Detailed descriptions are given in Appendix C and are shown graphically on Plate 1. Some work was done by examination of crushed fragments in oil immersion mounts using a petrographic microscope. This involved a small number of samples and was done to check mineral identifications. Because of the fine-grained nature of most of the rocks, additional petrographic examination by thin-section and X-ray diffraction studies may prove useful.

The log of Suzy 9A is comparable with the log of Susan 1, when allowance is made for sloughing in Suzy 9A.

The top 75 feet of the hole penetrated silt, clay, sand, gravel and boulders of a typical fluvial deposit. The coarse fraction included well-rounded basalt, andesite and rhyolite.

In the sedimentary units identified as lake beds(?), two particle size-fractions predominate: very fine ash or clay matrix, similar in mineralogy to the ash/clay matrix described below, and very fine (0.1 mm) sand. The ash/clay matrix ranges from cream to dark brown in color, probably reflecting differences in oxidation conditions, and ranges in hardness from soft and sticky to relatively hard. The sand particles appear mainly to be red, orange and black (non-magnetic) iron oxide, but occasional flakes of biotite also were observed.

These sediments probably were derived from volcanic uplands and perhaps also contain an air-fall ash component, especially in the interval 240-260 feet. Difference in hardness and oxidation observed in these samples may reflect in situ hydrothermal alteration and oxidation.

The most common lithology encountered in Susan 1 is very fine-grained, relatively homogeneous volcanic ash or clay. These rocks have a very fine-grained matrix (typically <0.1 mm) and are of variable hardness. In some zones, overall hardness is greater than 5; in other zones, the rocks can easily be rubbed into silt-sized paste. Nowhere in the hole could the mineralogy of the matrix be determined at the highest available magnification by binocular microscope (30x). No small crystals of plagioclase or other typical volcanic phenocrysts were noted at this magnification.

Composition of the matrix was checked by petrographic microscope using oil immersion mounts of crushed fragments. At magnifications as great as 400x, the matrix remains homogeneous. No pumice shards or other textures typical of volcanic glass were noted in the very small sample volumes examined. The matrix is composed of cloudy brown isotropic glass or low birefringent minerals, probably clay. Very small (0.02 mm) plagioclase crystals were observed in a few instances.

Several color phases of the altered volcanic ash/clay are present. The most common is soft to very hard gray-green rock, typical in the interval 300-480 feet. A gray-brown, soft, very fine-grained, very homogenous phase is nearly ubiquitous through the hole below 240 feet, as can be seen from the lithologic log. However, because of the mechanics of the reverse drilling operation, there is very little likelihood that these small percentages of the gray-brown phase are slough from uphole. Other color variations in the volcanic ash/clay sequence are noted in the lithologic log (Appendix C); these probably are caused mainly by changes in conditions of oxidation during alteration.

It is believed that most of the rocks penetrated by Susan 1 are weakly altered and perhaps silicified (because of their hardness) fine-grained volcanics, termed here tuffs. The original mode of deposition may have been as ash-flow units, mud flows, and/or air-fall volcanic ash.

In general, cuttings descriptions in Susan 1 in the interval 300-700 feet are similar to descriptions published for Suzy 9A (Hollinger and Turner, in Benson et al., 1980). Several cores were taken in the corresponding intervals of Suzy 9A (detailed descriptions are given in Appendix C). Cores at 390-394.3 feet and 507-511.5 feet correspond moderately well with these intervals in Susan 1, although naturally much more detail is visible in the core. The description of core from 682.5-687 feet, however, is rather dissimilar to cuttings returned in Susan 1. It is possible that the core was taken through a boulder.

The depth interval 700-750 feet contains a larger percentage of soft ash/clay matrix, including the gray-brown phase and white, very soft clay matrix, than do the overlying rocks. Thus, although the overall mineralogy is not markedly different from the overlying tuff(?) units, this segment is more likely to be a sedimentary deposit, perhaps of lacustrine origin. Some andesitic boulders may also be present.

Very hard, medium-gray aphanitic basaltic andesite or basalt is present in the interval 750-815 feet. Although virtually no phenocrysts are visible in this unit, greater hardness and overall texture serves to distinguish the basaltic andesite from the volcanic ash/clay (tuff?) units. No thin-sections of this rock have been prepared; therefore the compositional name is based only on the color of the rock and should be considered provisional. The texture of the basaltic andesite is very dense, unlike the porous texture of nearby andesite outcrops.

Very thin intervals (2-3 feet) of similar-appearing dark-gray rocks were penetrated at 465 and 482 feet; these are thought to be erratic boulders.

The depth interval 815-895 feet contains rocks composed primarily of the ash/clay matrix; they are lighter in color and more bleached-appearing than in upper parts of the section. Soft gray-brown phase ash/clay matrix also is present throughout this interval, as is soft, tan to orange, partially oxidized ash/clay matrix.

Because the lithologies show some variability with depth (see Appendix C) and because they are similar overall to the 700-750 foot interval, this interval also is interpreted to be lacustrine sediments(?). However, because the unit is harder than in the 700-750 foot interval, and because the ash/clay matrix fraction resembles that found in the tuffs(?), it is possible that these are bleached and altered tuffs.

Dark gray, dense-textured glassy basalt with small (0.5-1 mm) plagioclase phenocrysts is found in the interval 895-910 feet. Numerous small fractures within individual chips of the cuttings are partially to completely filled with calcite.

The basalt may be interbedded with ash units, because several phases of the volcanic ash/clay are present in these samples.

Calcite is present in fractures throughout most of Susan 1; major occurrences are noted on Plate 1. Most of these are 1-5 mm cleavage rhombs, although pyramidally terminated crystals also are present.

Pyrite is sparsely present in many intervals. Commonly it forms small (<0.5 mm) brass-colored cubes.

Bright orange to orange-red iron oxide coloration is present in several intervals (Appendix C); major intervals also are noted on Plate 1.

The volcanic ash/clay (tuff) unit shows films and patches of a yellow-green alteration mineral, probably epidote, in the interval 600-660 feet. This interval of the hole appears to be relatively impermeable.

Caliper Log

The caliper log shows two washout zones: 225-270 feet and 705-740 feet. These washouts are within the intervals interpreted to be lake beds(?). Thin zones of hole enlargement at 335, 380, 430 and 475 feet may indicate the presence of fractures.

Spontaneous Potential-Resistivity Log

This log was run from 60-830 feet. The following units can be recognized on the resistivity log:

- 60-75 feet: relatively high resistivity and negative SP
- 75-300 feet: relatively low resistivity with a resistive interval of low SP peaks
- 300-630 feet: alternating zones of relatively high to moderate resistivity with relatively featureless SP
- 630-710 feet: moderate resistivity, but featureless SP
- 710-740 feet: relatively low resistivity, featureless SP
- 740-810 feet: highly variable resistivity, featureless SP
- 810-830 feet: low resistivity, featureless SP

The poor SP response reflects the lack of resistivity contrast between the formation fluid and drilling fluid and the presence of a clayey matrix. In general, high resistivity denoted basalts and andesites, and low resistivity denoted clay, ash and tuff.

Gamma Ray-Neutron Log

This log was run from 60-810 feet. The gamma ray log is relatively featureless (except for background noise), reflecting the relatively uniform chemical composition of the dominantly volcanic

section. The gamma ray log from Suzy 9A (Benson et al., 1980), however, displays relatively low values in the upper 300 feet of hole.

The neutron log shows very low counts (high hydrogen content in the rocks of the logged interval) down to 250 feet; a gradual build-up in the 250-300 foot interval, and variably moderate to high counts below 300 feet.

Production Logs

Two types of production logs were run: temperature and spinner. Temperature logs were run by Welenco with continuous recording equipment and by GeothermEx with dial-indicator equipment. The spinner logs were run by Welenco.

Temperature Logs

Non-equilibrium (injecting) and partial temperature recovery logs of Susan 1 are given in Plate 2 and Figures 5 and 6. Those taken before November 1 are in the uncased hole, while later logs are in partially cased hole.

Equilibrium temperature logs of Suzy 9A are available from October 1979 (taken in 2-inch water-filled pipe 3 months after drilling); non-equilibrium (flowing) logs and partial temperature recovery logs of Suzy 9A were taken in October and November 1980 (Plate 2 and Figure 5). The configuration of Suzy 9A during the latter logging consisted of 8-inch blank casing from 0-78 feet, 4-inch blank steel pipe from 2 feet above ground level to 333 feet depth, cemented at the surface to the 8-inch casing, and open hole (drilled at 6-1/2-inch diameter) from 313-818 feet. The 2-inch gradient pipe had been pulled and the 4-inch pipe had been installed in preparation for flow tests during January 1980.

The temperature logs run in Suzy 9A during the drilling of Susan 1 were particularly helpful in determining the location of permeable zones and consequently in determining the proper depth for setting blank and slotted casings.

On October 24, when Susan 1 was 413 feet deep, water began to flow from the 4-inch pipe in Suzy 9A and from leaks in the cement between the 4-inch and 8-inch pipes. This water initially was at 71°F, but rose to 80°F within 8 hours. Suzy 9A continued to flow through

FIGURE 5. Temperature logs of Susan 1 and Suzy 9A, 10/8/79 through 11/4/80.

FIGURE 6. Temperature logs of Susan 1 and Suzy 9A, 11/4/80 through 11/15/80.

November 25 in response to changes in head in Susan 1 long after the top 350 feet of Susan 1 had been hydrologically isolated by casing and cement. On many occasions, Suzy 9A would begin to flow when circulation in Susan 1 was turned off, but flow from Suzy 9A would cease within 2-3 minutes of the resumption of circulation. However, the water flowing from Suzy 9A was always much warmer than the water being circulated in Susan 1, with the highest observed outflow temperature being 127°F on October 31.

Logs of Suzy 9A

Temperature logs of Suzy 9A not only demonstrated that there are several permeable zones below 350 feet, but in addition, equilibrium logs from Suzy 9A taken in 1979 provide the best data presently available on deep temperatures at this site, because no equilibrium temperature data are available below about 400 feet in Susan 1.

The most detailed and informative log from Suzy 9A was run under flowing conditions on October 29 by Welenco. This log shows sharp changes in temperature below 350 feet, which undoubtedly are caused by water moving in permeable zones. However, it is not known how many zones of entry contributed to the surface flow of 107°F (flow rate estimated at 25 gpm). The flow could represent about 85% water at 110°F mixed with about 15% water at 88°F. However, other proportions of mixing could produce the observed outflow temperatures.

Logs of Susan 1

Three detailed temperature logs were run in Susan 1 by Welenco as part of the suite of geophysical logs; they are shown on Figure 5 and are given on Plate 2 for ease in comparison with the other types of logs. The temperature logs were made under different injection conditions and give important data concerning down-hole permeability.

Later, logs were run to partial depth in Susan 1; they are shown in Figure 6.

The first log (10:15 AM, 10/30/80) was run immediately after stopping injection; it shows that the hole was thoroughly chilled as a result of long-term injection of cold water. Cold water entered fractures or other permeable zones in the interval 100-490 feet to keep the hole nearly isothermal at 42-44°F.

From 490-755 feet, the profile is a nearly straight-line gradient at 8.9°F/100 feet. This smooth profile results from lower permeability in the hole below 490 feet.

A small bump on the profile at 775-785 feet and also the sharp increase in temperature from 790-825 feet indicates even less permeability in this zone as compared with the 490-775 foot interval.

The second log (8:15 AM, 10/31/80) was taken 22 hours after injection ceased, and the temperature increase throughout the hole is dramatic. In the interval 335-475 feet the temperature rose some 80°F from the previous log; and the jagged nature of the profile clearly indicates warm water flowing into the hole. The temperature reversal from 475-640 feet and the nearly isothermal profile from 640-814 feet probably indicates little water inflow, with temperature recovery controlled by conductive heat transfer; but even here the temperature increased a minimum of 50°F.

The third log (10:00 AM, 10/31/80) shows that permeable zones in the interval 335-475 feet are invaded by cold water, because they have been chilled to 52°F after less than 2 hours injecting. The lower part of the hole is less affected, with the interval 705-800 feet still isothermal and slightly warmer than during the second logging. The part of the profile from 600-800 feet is somewhat warmer during the third logging run than during the second.

Comparison of these three logs with equilibrium temperature profiles of Suzy 9A shows that the hydrologic and thermal response of Susan 1 is rapid. This is confirmed by the fact that 174°F water was pumped from the initial flow tests on December 4-5, 1980.

Figure 6 shows temperature logs of Suzy 9A and Susan 1 taken before the latter had been completely cleaned out and cased to total depth. These logs were measured by GeothermEx using several different instruments, which could reach various depths before becoming stopped by irregularities in the hole.

They show that equilibrium temperatures below 300 feet in both Susan 1 and Suzy 9A are consistently higher than 150°F under static conditions; but that the water flowing from Suzy 9A, at about 120°F, is a mix of hot and cold components. This is in contrast to the flowing temperature of Susan 1, which ranges between 150° and 175°F, depending on duration of flow. Clearly, this difference in flowing temperature between the two wells is due to the mixing of drilling fluid in the outflow of Suzy 9A.

The static temperature logs taken on November 4, 1980 represent about 100 hours since last circulation of water in the hole. The log on November 10 represents about 135 hours since last circulation, and the log on November 15 represents about 60 hours since last disturbance of Suzy 9A.

It should also be noted that in a chemical analysis of water sampled on November 23, 1980 from Susan 1, SiO_2 was reported at 82.6 mg/l (Appendix B). This corresponds to a chalcedony solubility temperature of almost 208°F, and to a conductive quartz temperature of 260°F. It is reasonable to assume that temperatures approaching 200°F, or even significantly higher, are to be found within the thermal aquifer supplying Susan 1. The observed 174°F flow temperature and the equilibrium value of 180°F for Suzy 9A are taken as minimum equilibrium values for Susan 1.

Spinner Log

Four spinner logs were run by Welenco; one up-run and one station run under static (shut in) conditions; and one up-run and one down-run under injection conditions.

Although there is considerable noise on the traversing log taken under static conditions, neither this log nor the station log shows evidence for fluid movement within the hole under shut-in conditions.

The up-run taken under injection conditions gave no interpretable results, probably because the tool velocity was too high (50 ft/min) in comparison with fluid velocities: that is, the differential velocity was too small to be detected. Larger injection rates or slower tool speeds would be needed in order to obtain interpretable results.

The down-run also gave very noisy results, but because both the fluid and the tool were moving in the same direction, the differential velocity was smaller than in the up-run, and a tentative interpretation can be made. If it is assumed that the tool had a higher velocity than the fluid over the entire depth of the hole, it appears that most of the injected fluid leaves the hole before reaching the depth of 375 feet; all of it appears to leave before reaching 500 feet.

STRATIGRAPHIC SEQUENCE AND
RESERVOIR CHARACTERISTICS
AS INTERPRETED FROM WELL LOGS

Stratigraphic Sequence

The alluvial section at the top of the hole is identified to extend from 0-75 feet, on the basis of :

- (1) Cuttings log.
- (2) Drilling rate.
- (3) Caliper log.
- (4) Resistivity log, where there is a sharp decrease in resistivity at the base of the unit.

Lake beds(?) are interpreted to occupy the interval 75-280 feet, with the bottom boundary based primarily on the caliper and cuttings log. Factors that contributed to this interpretation are:

- (1) Cuttings log, with mixed fine-grained, apparently clay-rich components within the interval, including homogeneous units of possibly water-laid or air-fall ash at 235-260 feet.
- (2) Caliper log showing large wash-outs, corresponding to the softest zones.
- (3) Resistivity log showing very low resistivity, indicating a high clay content.
- (4) Neutron log indicating a high water content.

Tuffs(?) are interpreted to occupy the interval 280-700 feet. This name is applied on the basis of:

- (1) The cuttings log, which shows the rocks to be relatively homogeneous very fine-grained altered volcanic ash/clay.
- (2) The caliper log showing relatively competent rock, with a few possible fractures.
- (3) Regular variations in the resistivity log, which may indicate large-scale differences in bedding, welding, or alteration.
- (4) The neutron log showing relatively low water content.

Lake beds(?) are interpreted in the interval 700-750 feet, based mainly on:

- (1) Caliper log and drilling rates indicating the degree of softness.
- (2) Neutron log showing high water content.
- (3) Cuttings log showing a high concentration of possible air-fall or water-laid ash.

The basaltic andesite interval from 750-815 feet is identified chiefly from:

- (1) Cuttings log.
- (2) Relatively hard rocks, shown by drilling rate and caliper logs.
- (3) Resistivity log showing relatively high, variable resistivity.

Lake beds(?) in the interval 815-895 and 915-930 feet are interpreted on the basis of similarity of cuttings with the 700-750 foot interval. Geophysical logs do not extend below 815 feet because the bottom of the hole was filled with slough.

The basalt interval from 895-915 feet is identified from:

- (1) Cuttings log.
- (2) Drilling rate and caliper logs indicating relatively hard rocks.

Nature and Thickness of Permeable Zones

The permeable zones in Susan 1 have been identified from temperature logs of Susan 1 and Suzy 9A; and from the spinner log. It should be noted that neither temperature logs nor geophysical logs are available below 825 feet in either hole, but circulation return temperatures gave a sharp increase at 920 feet in Susan 1. If permeable zones exist below 825 feet (limit of temperature log) in Susan 1, they should contribute to total flow through the 8-5/8-inch slotted casing.

Permeable zones in the interval 350-460 feet in Susan 1 constitute the aquifer. Three zones at 350, 400 and 460 feet have especially high permeability. These three zones clearly are visible on the 23-hour build-up temperature log (Figure 5; 8:15 AM, 10/31/80).

The aquifer occurs within the stratigraphic interval identified as tuff(?); no particular differences in component grain size, hardness or mineralogy are noted in the very permeable zones and surrounding samples.

Available cuttings did not permit the identification of bedding planes, rubble zones, zones of partial welding or other stratigraphically controlled intervals of higher or lower permeability in the tuff(?) unit. If sandy or pebbly interbeds occur in the tuff(?) unit, they were not identified in the cuttings.

Fractures may contribute to permeability in the aquifer. Numerous hairline fractures, which were partially to completely filled with calcite, were observed in cuttings in the tuff(?), as well as elsewhere in the hole.

Several cores were taken in Suzy 9A in the unit identified here as tuff(?). That from 390-394.3 feet showed no natural fractures; that from 507-511.5 feet showed fractures, most of which were healed with calcite, and that from 682.5-687 feet showed fractures and voids which are reported to be healed or partially filled with calcite, possibly representing two events of secondary mineralization (Hollinger and Turner, in Benson et al., 1980).

These data show that despite variable degrees of hardness, the tuff(?) units are sufficiently brittle to fracture. However, the present-day permeability of the fractures is not known; nor is it known whether they contribute significantly to production in the aquifer.

PRELIMINARY PUMP TEST

A preliminary, short-term pump test of Susan 1 was conducted on December 4-6, 1980. The hole was pumped at various rates ranging from 150-700 gpm. Appendix D gives data from this test. The largest period of pumping was 6 hours at 350 gpm. For the 150 gpm rate, the flow measurement was deemed wrong; and for the 700 gpm rate, the duration of flow was too short to have achieved a stabilized drawdown. Figure 7 is a deliverability plot for Susan 1 based on flow rate versus observed drawdown, excluding the 150 and 700 gpm cases. Although there are only 3 reliable points to the line, Figure 7 can be used to estimate the expected drawdown at any given flow rate.

From the pump test, the drawdown data at both 250 and 350 gpm were analyzed by standard semilog plotting (Figure 8) as well as by type-curve matching, to yield values of permeability-thickness product (kh), storativity (ϕch) of the aquifer, and the skin factor. The build-up data at both 250 and 350 gpm were analyzed by Horner plot (Figures 9 and 10) to calculate kh and the skin factor. Table 2 presents the results.

The difference between the kh values calculated by various methods (Table 2) is due to the short-term nature of the flow test, with its inherently limited interpretative approaches. This pump test has obtained a valid approximation of the well's capability; the formation characteristics should be calculated from a long-term interference test to be conducted in the near future.

The calculated range of kh values of $1.10-2.01 \times 10^6$ md-ft/psi compares well with the range of 0.43-3.6 md-ft/psi reported by LBL (1979) from interference tests on several wells in the southern part of the City of Susanville. The range of storativity values ($2.45-3.06 \times 10^{-5}$ ft/psi) in Table 2 is much less than the range of $23-72 \times 10^{-5}$ ft/psi reported by LBL (1979). This difference may arise because: (1) wells tested by LBL are in the southern part of the city, where sediments are more sandy and hence have higher storativity; (2) the net permeable zone in Susan 2 is less than in wells in the south, for wells Suzy 9, 9A and 11 in the northern part of the city show very few permeable zones.

The deliverability of geothermal well Susan 1 is of the same order as the other thermal wells in the city because their kh values are similar. For example, U. S. Bureau of Reclamation (1976) reported a "transmissivity" of 16,000 gpd/ft from a well in the southern edge of the city (North State Growers' well). This value of deliverability

FIGURE 7. Deliverability of Susan 1.

FIGURE 8. Drawdown Test Analysis--Susan 1.

FIGURE 9. Pressure Buildup Test--250 gpm Case

FIGURE 10. Pressure Buildup Analysis--350 gpm Case

Table 2. Results of Preliminary Pump Test of Susan 1

<u>Analysis Basis</u>	<u>Storativity, ϕch (ft/psi)</u>	<u>Transmissivity, kh/μ (md.ft/cp)</u>	<u>Skin Factor, S</u>
1. Drawdown during production at 250 gpm			
a. Semi-log plot	-	1.66×10^6	2.0
b. Type-curve matching	2.45×10^{-5}	1.33×10^6	-
2. Build-up after production at 250 gpm	-	1.10×10^6	-2.0
3. Drawdown during production at 350 gpm			
a. Semi-log plot	-	1.85×10^6	5.8
b. Type-curve matching	3.06×10^{-5}	1.11×10^6	-
4. Build-up after production at 350 gpm	-	2.01×10^6	6.0

equals 11.1 gpm/ft of drawdown. By comparison, from Figure 7 we find that for a 250 gpm flow the drawdown is 19.8 ft, giving a deliverability of 12.6 gpm/ft. Figure 7 also shows that at 350 gpm the deliverability is 10.5 gpm/ft. Thus, the deliverability of Susan 1 compares favorably with that reported by U. S. Bureau of Reclamation (1976).

CONTINUED TESTING

As stated above, it will be necessary to perform longer-term tests (1) to confirm the initial observations and calculations, and (2) to develop a quantitative reservoir model for continued developmental forecasts. Stages of testing should be as follows.

1. A carefully designed interference test should be run on Susan 1, using a number of strategically selected wells in other parts of the city as monitor wells. The exact location and number can be determined later this year. Test duration should be a minimum of 30 days. Flow rates would be established in Susan 1, and drawdown monitored both in Susan 1 and the selected monitor wells.
2. Simultaneously, there should be a detailed correlation of geological, geophysical and drilling data from all thermal wells in the City of Susanville, leading to the establishment of a geological model of the thermal reservoir. This would involve construction of subsurface structure maps and cross-sections and calculation of volumes of sediment available to serve as thermal aquifers. Faults and 3-dimensional circulation patterns would be described.
3. Based on the geological model and the interference test data, a quantitative reservoir model should be developed. This reservoir model will be used to assess reservoir capacity and to forecast long-term well performance.
4. From this, it can be decided whether and where to drill a second production well and/or an injection well for wastewater disposal. Various operational constraints must be considered, including land availability, and the need for a revised drilling, casing and completion program to satisfy anticipated conditions of caving formations.

NOMENCLATURE

- c = Effective compressibility of the reservoir
rock/fluid systems, psi^{-1}
- h = Net reservoir thickness, feet
- k = Permeability, millidarcy
- S = Skin Factor, dimensionless
- ϕ = Porosity, fraction
- μ = Fluid viscosity, centipoise

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APPENDIX A

Summary of Water Loss and Gain in Susan 1

Appendix A

Summary of Water Loss and Gain in Susan 1.

Date	Hole Depth, (feet)	Time to begin adding water to pit (expressed in 24-hour clock)	Duration of Pumping (minutes)		Estimated ¹ Water Volume Added (hundreds of gallons)	Calculated Rate of Water Loss (gal/min)
			Timed	Estimated		
10/18	50-60	3 times during night		15	12	
	60	1030	22		18	.15
		1335	11		9	
10/19	---	?				
10/20	123	1150	11		9	
	225	1800		5	4	3.17
	275	2045		5	4	
10/21	315	0045		5	4	
	330	0315		5	4	
	345	0600		5	4	3.8
	350	0700		5	4	
	360	1113	12		10	
10/22	---					
10/23	cleaning out from 240- 360	1700		5	4	
		1930		5	4	
		2055	10		8	5.6
		2140	3		2	
	375	2330		5	4	
10/24	382	0024	6		5	
	383	0100	10		8	19.5
	388	0151	5		4	
	390-400	0230-0445 (4 times)		20	16	21.3
	400-410	0545-0645 (3 times)		15	12	20.0
	410-420	0740-0900 (3 times)		15	12	15.0
	420-430	0930-1035 (3 times)		15	12	18.5
	430-440	1120-1305 (3 times)		15	12	11.4
	440-450	1400-1500 (2 times)	10	5	12	20.0
	450-460	1523-1609 (2 times)	17		14	30.4
	460-470	1630-1730 (2 times)	33		26	43.3
	480	1845 (continuous)		120	96	80.0

Note: Very large loss of circulation sucked pit dry during connection.

Appendix A (continued)

Date	Hole Depth, (feet)	Time to begin adding water to pit (expressed in 24-hour clock)	Duration of Pumping (minutes)		Estimated ¹ Water Volume Added (hundreds of gallons)	Calculated Rate of Water Loss (gal/min)
			Timed	Estimated		
	480	2155		50	40	
		1135		15	12	
10/25	480-530	0010-0813 (11 times) 0955-1630 (continuous) Note: Pit sucked dry within 20 minutes when water pump interrupted and circulation stopped.	395	165	132 316	
Pit refilled numerous times on 10/25 PM and during 10/26; times not recorded.						
10/27	at 620	0005-0700 (7 times)		100	80	
	630-730	0710-1530 (continuous)	480		384	
	740-750	1610-1700 (continuous)	50		40	
	750-800	0810-1115 (continuous)	180		144	
10/28	800-805	0000-0430 (continuous)	270		216	
Note: Water circulation turned off at 0130 in order to trip out of hole. However, pit volume held relatively steady, and even increased at 0300-0400. By contrast, hole had sucked pit dry when circulation was temporarily stopped 5 hours earlier.						
	at 805	0630-0910 (3 times)	85		68	
	805-810	0930-1025 (2 times)	60		48	
	810-820	1130	35		28	
	830	1235	15		12	
	840	1330	40		32	
	845	1345	40		32	
	850	1500	20		16	
	860	1609	16		13	
	865	1644	71		57	
	880	1820	45		36	
	895	1937	49		39	
	905	2130	40		32	
10/29	920	0000	30		24	
	930	0200	150		120	

Appendix A (continued)

<u>Date</u>	<u>Hole Depth, (feet)</u>	<u>Time to begin adding water to pit (expressed in 24-hour clock)</u>	<u>Duration of Pumping (minutes)</u>		<u>Estimated¹ Water Volume Added (hundreds of gallons)</u>	<u>Calculated Rate of Water Loss (gal/min)</u>
			<u>Timed</u>	<u>Estimated</u>		
Note: Stopped drilling (TD) at because of plugged bit and caving problems. Hole continued to take water as shown through 10/31.						
		0450		150	120	
		0745		65	52	
		0915		75	60	
		1100		20	16	
		1130		50	40	
		1250		75	60	
Note: At 1410 hole begins to make water; possibly because casing in alluvial section displaces water in hole						
		1445		150	120	
Note: Hole begins to take water again when pump is shut off.						
		1825		20	16	
Water additions during night not recorded; but pit kept full prepara- tory to temperature logging of hole.						
10/30	Cleaned out to 825 feet	0830		75	60	
Note: Hole sucked pit dry; static water level 11 feet 7 inches below drilling table (7 feet below ground level).						
10/31	820	0900		?	_____	
TOTAL -					2,798	

Appendix A (continued)

<u>Date</u>	<u>Hole Depth, (feet)</u>	<u>Time to begin adding water to pit (expressed in 24-hour clock)</u>	<u>Duration of Pumping (minutes)</u>		<u>Estimated¹ Water Volume Added (hundreds of gallons)</u>	<u>Calculated Rate of Water Loss (gal/min)</u>
			<u>Timed</u>	<u>Estimated</u>		

Note: From Nov. 1-Nov. 20 pit was dry most of the time while rig was repaired and casing was run. However, it was filled occasionally when attempts were made to clean out the hole.

On Nov. 21, after hole had been cleaned to 835 feet, hole began to flow. Continues to flow through Nov. 25; rate estimated 25 gpm. Outflow temperature = 164°F.

¹No metered flow rate available. Pump rate estimated 80-90 gpm; assumed 80 gpm for computation.

APPENDIX B

Chemical analyses of water from Susan 1, Suzy 9A,
and nearby wells.

Appendix B. Chemical analyses of water from Susan 1, Suzy 9A, and nearby wells.

Sample Number	Sample Date	Temperature, °F	Concentration, in parts per million											Calculated TDS	Field pH	Lab pH	Water Type
			Na ⁺	Ca ⁺⁺	Mg ⁺⁺	K ⁺	Cl ⁻	SO ₄	HCO ₃	CO ₃	OH ⁻	B	SiO ₂				
Suzy 9A-1	2/15/80 ³	165	215	76	2	5	120	320	34	0		2.00	-	757	6.5	8.1	
Suzy 9A-3	2/27/80 ³	165	205	32	1	6	120	294	37	1		3.08	-	680	6.5	8.4	
Suzy 9A-4	2/27/80 ³	165	203	30	1	6	119	294	35	1		2.46	-	674	6.5	8.4	Na>>Ca>>K SO ₄ >Cl>>HCO ₃
Suzy 9A-5	2/27/80 ³	165	207	36	1	6	120	307	35	0		3.04	-	698	6.5	8.2	
Suzy 9A-6	2/27/80 ³	165	205	34	1	6	119	301	37	0		3.04	-	688	6.5	8.3	
Susan 1	11/23/80 ⁴	164	245	30	0.351	6.80	127	379		7.80	2.52		82.6	881		8.91	Na >>Ca>>K SO ₄ >Cl>>CO ₃

Notes to Appendix B:

¹HCO₃ calculated from total alkalinity reported as 18 mg/l CaCO₃

²Value reported for CO₃ inconsistent with reported pH of 7.1.

³Source of data: U. S. Bureau of Reclamation pump test.

⁴Source of data: Sampled by GeothermEx, Inc., Analyst: American Technical Laboratories, Inc.

Appendix B, Part 2. Ionic ratios of water from Susan 1, Suzy 9A, and nearby wells.

Sample Number	Sample Date	Na/Ca	Na/K	SO ₄ /Cl
9A-1	2/15/80	2.829	43.00	2.667
9A-3	2/27/80	6.406	34.17	2.450
9A-4	2/27/80	6.767	33.83	2.471
9A-5	2/27/80	5.750	34.50	2.558
9A-6	2/27/80	6.029	34.17	2.529
Susan 1	11/23/80	8.167	36.03	2.984
Susan 1	12/16/80	1.113	2.073	not determined

Roosevelt Swimming Pool	7/18/73	1.053	5.882	5.500
LDS Church	7/18/73	5.833	30.43	2.969

APPENDIX C

Lithologic log of Susan 1

LITHOLOGIC LOG

SUSAN 1

<u>Depth of Sample, Feet</u>	<u>Rock Type</u>	<u>Description</u>
10	<u>Alluvium</u>	Well-rounded to semi-rounded sand, gravel, and small cobbles. Mixed lithologies present, including basalt, andesite, and rhyolitic volcanics.
20	<u>Unit as above</u>	Consisting of 70% fine sand (<0.5 mm) and dark brown clay 20% gravel of mixed lithology 10% medium sand.
30	<u>Unit as above</u>	Consisting of 60% fine sand 20% medium sand 20% gravel
40	<u>Unit as above</u>	Consisting of 60% coarse sand 30% fine to medium gravel 10% coarse gravel and cobbles, of mixed lithology.
50	<u>Unit as above</u>	Consisting of 40% coarse sand 30% medium to fine gravel 30% coarse gravel and cobbles, of mixed lithology (Much larger cobbles and small boulders also are present-- 14" subangular boulder fished from 52').
60	<u>Unit as above</u>	Consisting of 40% coarse sand 40% fine to medium gravel 20% coarse gravel and cobbles
63	As above	

65	<u>Unit as above</u>	50% coarse sand 40% fine to medium gravel 10% coarse gravel and pebbles
68	<u>Unit as above</u>	40% coarse sand 50% fine to medium gravel 10% coarse gravel and cobbles
70	<u>Unit as above</u>	50% fine to medium gravel, of mixed lithologies 20% coarse gravel and cobbles 10% coarse sand 30% ash or partially hydrated clay
		Ash/clay is tan or pinkish-brown or white. Ranges from soft to moderately firm and brittle and relatively dry. Contains admixture of very fine (<0.1 mm) sand grains; red, brown, and orange.
73	<u>Unit as above</u>	50% ash/clay, as above 30% very fine sand, mixed lithology 20% coarse sand to pebbles.
80	<u>Lacustrine Deposits(?)</u>	[Alternative identification-- altered ash or mud flow] Consisting of: 70% ash/clay matrix. Pinkish brown in color, fairly firm, slightly sticky. Component particles not resolvable at 30x magnification. 20% very fine sand, contained in ash component. Mostly black, brown, or orange non-magnetic, some black or bronze-colored mica flakes. 10% medium to coarse sand.

- 85 Unit as above Overall color is pink-brown to rusty yellow. Consisting of:
 50% ash/clay matrix; in pebble-size, firm to very firm chips.
 40% very fine sand, similar to previous interval.
 10% medium to coarse sand.
- 87 Unit as above Very firm cuttings, consisting of:
 40% ash/clay matrix with very fine sand.
 40% medium to coarse sand.
 20% fine to medium gravel.
- 90 As above.
- 100 Unit as above Pebble sized, relatively hard cuttings, consisting of:
 50% very fine sand
 40% ash/clay matrix
 10% medium to coarse sand
- 110 As above.
- 120 Unit as above. Much softer.
- 123 Unit as above Soft cuttings, consisting of:
 60% ash/clay matrix with very fine sand. Tan color, very soft.
 20% fine sand
 20% ash/clay. Dark green color, hard, contains very fine sand component.
- 130 Unit as above Proportions of components about the same as above, but there is variability in overall color, ranging from oxidized red to gray-green.

- 140 Lacustrine deposits (?) Similar to unit above, but
persistent for many feet in color and
hardness. [Matrix composition checked by
oil immersion mount.] Sample composed of:
60% clay/ash matrix
40% very fine sand
Pebble-sized firm cuttings. Blue-gray
color predominates, but tan and brown
chips also present.
- 150 As above.
- 160 Unit as above
40% clay/ash matrix
40% fine sand
20% medium sand
- 170 Unit as above
- 180 Unit as above Greater variability of color, with both
dark green and brick red coloration in
same chip.
- 186 Unit as above Increase in iron oxide color. Trace of
clear calcite crystals. [Checked matrix
by oil immersion mount; matrix appears
identical to 140' sample.]
- 190 Unit as above Medium brown cuttings, slightly softer
than above.
- 200 Unit as above
- 210 Unit as above Includes both medium-hard, blue-gray
gravel-size cuttings and somewhat softer,
medium-brown cuttings. Observed one
possible pumice lump (much oxidized).
- 218 Unit as above Medium hard cuttings; much iron-oxide
staining.
- 220 Unit as above Very oxidized. Trace of clear calcite
fragments.
- 227 Unit as above Considerably softer.
80% clay/ash matrix
10% very fine sand
10% medium sand

230	<u>Unit as above</u>	Very soft. 90% clay/ash matrix, blue-gray color. 10% very fine sand
240	<u>Unit as above</u>	Chips very soft; easily disaggregated to soft, white paste.
245	Homogeneous clay/altered ash (water-laid or airfall ash?)	Gray-brown color, very soft (can easily be disaggregated to <0.01 mm). [Inspection by oil immersion mount at 400x magnification shows virtually no components >0.02 mm. Low birefringence; texture and mineralogy apparently same as previous samples. Darker color caused by slightly higher proportion (to 10%) of opaques.]
250	As above.	
260	<u>Lacustrine deposits(?)</u>	Similar to 190-240' interval. Very fine-grained clay-ash matrix of variable colors, ranging from dark blue-green to orange-red. Traces of clear calcite crystals; rare small (0.1 mm) pyrite crystals.
263	As above.	
270	<u>Unit as above</u>	Medium-hard cuttings, variable color; but where disaggregated, makes bright red mud.
280	<u>Unit as above</u>	Cuttings of variable hardness and color, including relatively soft, silvery-green and hard red-brown chips. Accessory small (1mm) clear calcite rhombs.
290	<u>Unit as above</u>	Predominantly medium blue-gray cuttings. Higher proportion of very fine sand. Some calcite veins.
295	<u>Unit as above</u>	Disaggregates to white paste.

- 300 Tuff(?) (Altered volcanic ash/clay). Cuttings are predominantly blue-green in color, very fine-grained, harder to disaggregate with steel pick. Trace of tiny pyrite crystals; small calcite veins. [Inspection by oil immersion mount at 400x magnification shows that about 50% of sample is composed of cloudy glass, but no pumice shards or other original textures are visible. 45% of sample is low birefringent clay, easily crushed to <0.01 mm. Scarce very small (0.02 mm) partially altered plagioclase crystals. Few clear very small (0.02 mm) higher birefringent chips; probably calcite.]
- 310 Unit as above All cuttings are very fine grained.
Sample composed of:
 90% blue-green phase, hard to very hard

 10% gray-brown phase, medium soft.
- 320 Unit as above Primarily blue-green, hard phase. Accessory small (2mm) translucent calcite cleavage fragments; trace small (0.5 mm) pyrite crystals.
- 330 Unit as above
- 340 Unit as above Composed of:
 90% green to white very fine-grained phase; medium hard.
 10% gray-brown phase; soft
- 350 Unit as above Composed of:
 70% gray-green phase, as in 320-330' interval. Hard.
 30% gray-brown phase. Soft. Slightly less homogeneous-contains tiny soft white patches.
- 360 No sample.

365

Unit as above Composed of:

80% gray-green phase,
medium hard to hard.
20% pink to red-oxidized
fine-grained phase.
Soft to medium hard.
Contains abundant very
fine (<0.1mm) multico-
lored lithic frag-
ments.
Accessory calcite
fragments; trace
pyrite.

370

As above.

373

As above.

380

Unit as above Composed of:

80% gray-green phase, hard
to medium hard.
10% gray-brown phase, soft
10% pink to tan phase.
Soft, mainly fine-
grained phase but con-
tains very fine
multicolored lithic
fragments.
Accessory clear calcite
crystals.

[Inspection of oil immersion mount at
400x shows gray-green phase composed of
60% very fine (0.01 mm) low birefringence
clay, 40% cloudy structureless glass.]

386

As above.

- 390 Unit as above Composed of:
- 80% gray-green phase,
hard.
 - 20% soft gray paste.
Disaggregated
clay/ash?
- [Core from Suzy 9A at 390-394.3 feet was reported to be medium-gray to gray-green to green; har, dense, but could be scratched with knife. Groundmass: medium gray-green, fine-grained. Clasts: light-gray to medium gray-green, fine-grained, angular to subrounded, size fine to up to 3". Common calcite veins and vein fillings; common pyrite.]
- 400 Unit as above Composed of:
- 70% gray-green phase;
medium hard to hard.
 - 20% gray-brown phase; soft
 - 10% tan to orange oxidized
phase; medium soft.
 - Accessory vein calcite,
with pyramidally termina-
ted crystals.
- 410 Unit as above Composed of:
- 50% gray-green phase;
hard to medium hard.
 - 30% tan to orange oxi-
dized phase
 - 20% vein-filling calcite
 - Accessory gray-brown
phase; soft
- 420 Unit as above Composed of:
- 90% gray-green phase;
medium hard to hard
 - 10% tan to orange oxidized
phase
 - Accessory calcite
- 430 Unit as above Composed of:
- 70% gray-green phase;
hard to medium hard
 - 20% tan to orange oxi-
dized phase
 - 10% vein calcite.

440	<u>Unit as above</u>	Composed of:	90% gray-green phase; hard 10% tan to orange oxi- dized phase Accessory calcite
445	<u>Unit as above</u>	Composed of:	80% gray-green phase; hard 10% tan to orange oxi- dized phase 10% gray paste; soft. Disaggregated clay/ash? Accessory calcite
450	<u>Unit as above</u>	Composed of:	80% gray-green phase; hard 20% gray-brown phase; soft
454	<u>Unit as above</u>	Composed of:	70% gray-green phase; medium hard to hard 30% gray paste; soft. Disaggregated clay/ash?
460	<u>Unit as above</u>	Composed of:	60 gray-green phase; medium hard to hard 20% tan to orange oxi- dized phase 10% gray-brown phase; soft 10% calcite

- 465 Altered andesite. (erratic boulder?) Sample composed of:
90% andesite. Dark gray,
very hard cuttings.
10% tan to brown phase;
altered volcanics.
[Inspection of oil immersion mount
at 100x and 400x shows some small
hornblende crystals. Ground mass
partially glassy; partially altered
to clay.] Probably erratic boulder
because of small thickness.
- 468 Tuff(?) (Altered volcanic ash/clay) Composed of:
70% gray-green phase;
hard. Similar to
400-450' interval.
20% soft gray paste.
Disaggregated
clay/ash.
10% tan to brown phase.
Clay/ash.
- 470 Unit as above Composed of:
60% soft gray paste.
Disaggregated
clay/ash.
40% gray-green phase;
hard. Similar to
468' interval.
- 475 Unit as above Composed of:
90% gray-green phase;
medium hard to hard.
Thin film of yellow-
green alteration
mineral (epidote?)
10% tan to brown phase.
Accessory calcite
- 482 Unit as above Composed of:
40% dark gray andesite,
similar to 465'
interval
50% soft clay/ash of
various colors,
including white, tan,
sulfur-yellow.
10% calcite.

483	<u>Unit as above</u>	Composed of:	60% gray-green phase; hard 30% tan to orange oxi- dized phase 10% calcite
487	<u>Unit as above</u>	Composed of:	90% gray-green phase; hard 10% soft gray clay/ash
490	<u>Unit as above</u>	Composed of:	90% gray-green phase; hard 10% tan phase; soft Accessory calcite
500	<u>Unit as above</u>	Composed of:	50% gray-green phase; hard 20% tan phase; soft 20% tan to orange oxidized phase; hard 10% calcite [Core from Suzy 9A at 507-511.5 feet was reported to be light to medium gray to gray-green, dense to fractured, fractures mostly healed with white calcite; some slickens apparent. Groundmass: light gray to gray-green, very soft and flaky to moderately firm; can be scratched in places with fingernail, others only with knife. Fine to medium-grained, common hornblende and recrystallized calcite. Clasts: light to medium gray, usually hard and aphanitic; angular to subrounded, up to 3" in size. Large voids filled with white calcite. Common pyrite.]
510	<u>Unit as above</u>	Composed of:	90% gray-green phase; hard 10% soft gray paste (disaggregated clay/ash)
515	As above		

520	<u>Unit as above</u>	Composed of:	60% gray-green phase; hard 20% tan clay/ash phase; soft 20% soft gray paste (disaggregated clay/ash)
525	As above		
530	<u>Unit as above</u>	Composed of:	80% gray-green phase; hard 10% tan clay/ash phase; soft 10% red and brown oxidized phase
540	No sample		
550	<u>Unit as above</u>	Composed of:	80% gray-green phase; hard 20% gray-brown to tan phase; soft (includes some paste-- disaggre- gated clay/ash)
560	<u>Unit as above</u>	Composed of:	90% gray-green phase; hard 10% soft gray paste (disaggregated clay/ash) Accessory calcite; trace pyrite
570	<u>Unit as above</u>	Composed of:	80% gray-green phase; hard 10% gray-green to tan phase; soft 10% soft gray paste (disaggregated clay/ash)
580	<u>Unit as above</u>	Composed of:	90% gray-green phase; hard 10% brown phase; soft Trace calcite

585	<u>Unit as above</u>	Composed of:	80% gray-green phase; hard 10% gray-green phase; soft 10% gray-brown phase; soft Trace calcite
590	<u>Unit as above</u>	Composed of:	90% gray-green phase; hard 10% gray-brown phase; soft (Sample covered with soft gray paste-- disaggregated clay/ash)
600	<u>Unit as above</u>	Composed of:	90% gray-green phase; hard. About 1/2 of chips have thin patches of yellow- green, amorphous alteration mineral. 10% tan to orange oxidized phase; hard Accessory calcite
605	<u>Unit as above</u>	Composed of:	90% gray-green phase; hard 10% gray-brown phase; soft Accessory calcite
610	<u>Unit as above</u>	Composed of:	90% gray-green phase; hard. Films of yellow-green altera- tion mineral common (epidote?) 10% calcite. Translucent cleavage fragments, probably vein-filling.
615	<u>Unit as above</u>	Composed of:	80% gray-green phase; hard. Yellow-green alteration mineral (epidote?) is common. 20% calcite-- clear vein- fillings.

620	<u>Unit as above</u>	Composed of:	90% gray-green phase; hard. Yellow-green alteration common. 10% red-brown phase; soft. Contains some lithic fragments. Accessory calcite
625	<u>Unit as above</u>	Composed of:	80% gray-green phase; hard. Yellow-green alteration less com- mon. 15% calcite 5% red-brown phase; hard
630	<u>Unit as above</u>	Composed of:	90% gray-green phase; hard. Yellow-green alteration mineral sparse. 5% calcite 5% gray-brown phase; soft
640	As above		
650	<u>Unit as above</u>	Composed of:	90% gray-green phase; medium hard. 10% gray-brown phase; soft
656	<u>Unit as above</u>	Composed of:	90% gray-green phase; hard. Sparse yellow- green alteration 10% gray-brown or tan soft clay/ash Accessory calcite
660	<u>Unit as above</u>	Composed of:	95% gray-green phase; hard 5% soft tan clay/ash

- 670 Unit as above Composed of:
 90% gray-green phase;
 medium hard to hard
 10% soft gray paste
 (disaggregated
 clay/ash)
- 675 Unit as above Composed of:
 90% gray-green phase; hard
 10% soft red-brown,
 orange, and gray-brown
 ash/clay
- 680 As above
- 685 Unit as above Composed of:
 90% gray-green phase;
 medium hard to hard.
 Sparse yellow-green
 alteration
 10% soft brown and orange
 ash/clay
 [Core from Suzy 9A at 682.5-687 feet
 reported to be light to dark gray to
 black, hard, but can be scratched locally
 with a knife. Dense but locally frac-
 tured. Fractures and voids healed or
 partially filled from two events of
 secondary mineralization: white calcite
 first and white to clear, crystalline
 quartz secondly. Matrix aphanitic, dark
 gray to black with vug fillings of
 feldspar and calcite. Clasts light to
 dark gray, hard, angular to subrounded,
 fine up to 1 "]
- 690 Unit as above Composed of:
 80% gray-green phase;
 medium-hard to hard
 10% gray-brown phase; soft
 10% tan to orange ash/clay
 Accessory calcite

695	<u>Unit as above</u>	Composed of:	80% gray-green phase; medium hard to hard 10% gray-brown phase; soft 10% soft gray paste
700	<u>Unit as above</u>	Composed of:	90% gray-green phase; hard. Sparse yellow- green alteration. 10% gray-brown phase; soft Accessory calcite
705	<u>Unit as above</u>	Composed of:	80% gray-green phase; hard. As above. 10% tan to brown ash/clay and soft gray paste 10% gray-brown phase; soft
710	<u>Lake beds(?)</u>	Composed of:	50% soft gray paste (disaggregated ash) 40% gray-green phase; hard 10% gray-brown phase; soft
715	<u>Unit as above</u>	Composed of:	40% gray-green phase; hard 40% hard dark gray to black andesite, simi- lar to 465' interval 10% soft red, tan, brown clay/ash
720	<u>Unit as above</u>	Composed of:	80% gray-green phase; hard 20% soft white paste
725	<u>Unit as above</u>	Composed of:	40% gray-brown phase; soft. Contains some fine sand. 40% gray-green phase; hard 20% soft white paste

730	<u>Unit as above</u>	Composed of: 40% gray-green phase; hard 40% white paste and fine sand 20% gray-brown phase; soft, as above Trace pyrite crystals
740	<u>Unit as above</u>	Composed of: 50% soft gray paste 30% gray-green phase; hard 20% gray-brown phase; soft
745	<u>Unit as above</u>	Composed of: 70% gray-green phase; hard. Some pyrite. 20% soft to medium hard red ash/clay 10% white paste
750	<u>Basaltic Andesite</u> , medium gray.	90% medium hard, medium gray andesite, containing 1 mm altered plagioclase phenocrysts. Also fine pyrite crystals and some dark green alteration. 10% soft sandy red-brown ash/clay. Accessory calcite, including veins in andesite
755	<u>Unit as above</u>	90% hard medium-gray andesite with pyrite and sparse yellow-green alteration (epidote?) 10% gray-brown phase; soft Accessory calcite
760	As above	

765	<u>Unit as above</u>	Composed of:	90% light gray to pale green ash/clay. Common tiny pyrite crystals, little or no epidote or dark green alteration minerals. No phenocrysts noted. 10% tan to red-brown ash/clay, medium hard.
770	<u>Unit as above</u>		90% andesite, hard, medium gray. Common yellow-green alteration (epidote?) 10% soft tan ash/clay
775	<u>Unit as above</u>		90% andesite, hard, medium gray. Sparse yellow-green alteration. 5% calcite 5% gray-brown phase; soft
780	<u>Unit as above</u>		80% andesite as above 10% calcite 10% tan to orange clay/ash
785	<u>Unit as above</u>		70% gray-green ash/clay, as in 765' interval. 20% tan to orange ash/clay 10% calcite
790	<u>Unit as above</u>		50% andesite as in 770-780' interval 20% tan to orange ash/clay, soft 20% gray-brown phase; soft 10% calcite Accessory pyrite

795	As above	
800	As above	Andesite contains a few elongate black phenocrysts-hornblende?
805	<u>Unit as above</u>	50% andesite, hard, medium gray. (Some plagioclase phenocrysts noted). 40% gray-brown phase; soft 10% tan to orange-stained clay/ash; soft to medium hard
810	<u>Unit as above</u>	80% andesite, as above 20% tan to orange-stained clay/ash, as above Accessory calcite
813	<u>Lacustrine deposits(?)</u>	80% light gray to gray-green phase; medium hard to hard. No phenocrysts, no lithic fragments noted. 20% gray-brown phase; soft Some soft gray paste (disaggregated ash/clay)
815	<u>Unit as above</u>	70% light gray to gray-green phase; medium hard to hard. Has tiny pyrite crystals. 30% gray-brown phase; soft
820	<u>Unit as above</u>	Very soft. 50% soft gray paste (disaggregated ash/clay) 30% light gray to gray-green phase; soft to medium hard

825	<u>Unit as above</u>	<p>70% light gray to gray-green phase; medium hard to hard.</p> <p>20% gray-brown phase; soft</p> <p>10% tan to orange-stained clay/ash</p>
830	<u>Unit as above</u>	<p>80% light gray to gray-green phase; medium hard to hard.</p> <p>10% gray-brown phase; soft</p> <p>10% tan to orange-stained clay/ash</p> <p>Accessory pyrite</p>
835	<u>Unit as above</u>	<p>70% light gray to gray-green phase; medium hard to hard.</p> <p>20% gray-brown phase; soft</p> <p>10% tan to orange-stained clay-ash</p>
840	<u>Unit as above</u>	<p>80% light gray to gray-green phase; medium hard to hard.</p> <p>10% gray-brown phase; soft</p> <p>10% soft gray paste (disaggregated clay/ash)</p>
842	<u>Unit as above</u>	<p>60% light gray to gray-green phase; medium hard to hard. Some yellow-green alteration.</p> <p>10% yellow to tan soft ash/clay</p> <p>10% andesite, hard, dark gray</p> <p>10% calcite</p> <p>10% gray-brown phase; soft</p>

845	<u>Unit as above</u>	50% light gray to gray-green phase; medium hard to hard. 20% gray-brown phase; soft 20% yellow to tan soft ash/clay 10% calcite
850	<u>Unit as above</u>	90% light gray to gray-green phase; medium hard to hard. Abundant pyrite crystals but not yellow-green alteration noted. 10% calcite
855	<u>Unit as above</u>	90% light gray to gray-green phase; medium hard to hard. Some yellow-green alteration and some pyrite. 10% gray-brown phase; soft
860	<u>Unit as above</u>	60% light gray to gray-green phase; medium hard to hard. 40% gray-brown phase; soft Accessory calcite
870	<u>Unit as above</u>	70% light gray to gray-green phase; medium hard to hard. Sparse pyrite. 30% gray-brown phase; soft
880	<u>Unit as above</u>	60% light gray to gray-green phase; medium hard to hard. 40% gray-brown phase; soft

885	<u>Unit as above</u>	100% tan to gray ash/clay phase; medium hard to hard. Common pyrite. Color facies of previous units?
890	<u>Unit as above</u>	80% tan to gray phase, as above 20% gray-brown phase; soft
895	<u>Basalt or basaltic andesite</u>	80% dark gray basaltic andesite or basalt. Classy, dense-textured, contains plagioclase phenocrysts with carlsbad twinning (0.5-1 mm). Calcite and pyrite on fracture surfaces. 20% tan to gray phase, as above.
897	<u>Unit as above</u>	50% dark gray basalt, as above 30% light gray ash/clay phase 10% gray-brown phase; soft
900	<u>Unit as above</u>	70% dark gray basalt, as above. Many healed fractures, filled with calcite, pyrite 20% gray-brown phase; soft 10% vein calcite

910	<u>Unit as above</u>	50% dark gray basalt, as above. Sparse yellow-green alteration on fractures. 20% gray-brown phase; soft 10% multicolored soft ash/clay 10% light gray to gray-green phase; medium hard to hard. 10% calcite
914	<u>Unit as above</u>	60% light gray to gray-green phase; medium hard to hard. Some yellow-green alteration on fracture surfaces; common pyrite 30% gray-brown phase; soft 10% calcite
925	<u>Lacustrine deposits(?)</u>	50% gray-brown phase; soft 20% light gray to gray-green phase; medium hard to hard. 20% soft multicolored ash/clay 10% calcite
930	<u>Unit as above</u>	70% gray-brown phase; soft 30% light gray to gray-green phase; medium hard to hard.

APPENDIX D

Results of Pump Test of Susan 1,
December 4-5, 1980.

Appendix D

Results of pump test of Susan 1, December 4-5, 1980.

Note: Water level referred to depth below porthole in casing, which is 4.42 feet below ground level. Flowing temperature of water stabilized at 174°F during entire test. Pump was set at 250 feet below ground level.

Water Level Below Ground Level, Feet	Water Level Below Porthole in Casing, Feet	Time of Observation	Minutes Elapsed Since Pump Turned On or Off
-----Start pump at 1550 hours, December 4. Pump Rate 250 gpm-----			
19' 11"	15.50	1620	30
20' 8"	16.25	1645	55
20' 4"	15.91	1700	70
20' 9"	16.33	1715	85
20' 9"	16.33	1730	100
21' 4"	16.91	1745	115
21' 6"	17.08	1800	130
21' 7"	17.16	1815	145
21' 7"	17.16	1830	160
21' 10"	17.41	1845	175
21' 8"	17.25	1900	190
21' 8"	17.25	1915	205
21' 10"	17.41	1930	220
21' 9"	17.33	1945	235
21' 9"	17.33	2000	250

Appendix D (continued)

Water Level Below Ground Level, Feet	Water Level Below Porthole in Casing, Feet	Time of Observation	Minutes Elapsed Since Pump Turned On or Off
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-----Shut off pump at 2000 hours-----

9' 8"	5.25	2001	1
9' 8"	5.25	2002	2
8' 6"	4.08	2003	3
7' 9"	3.33	2004	4
7' 7"	3.16	2005	5
7' 4"	2.91	2006	6
7' 2"	2.75	2007	7
7' 0"	2.58	2008	8
6' 10"	2.41	2009	9
6' 8"	2.25	2010	10
6' 4"	1.91	2001	11
5' 4"	0.91 ¹	2030	30

-----Start pump at 2100 hours, December 4, Pump Rate 350 gpm-----

29' 9"	25.33	2115	15
30' 4"	25.91	2130	30
32' 3"	27.83	2145	45
33' 5"	29.00	2200	60
33' 7"	29.16	2215	75
33' 9"	29.33	2230	90

Appendix D (continued)

Water Level Below Ground Level, Feet	Water Level Below Porthole in Casing, Feet	Time of Observation	Minutes Elapsed Since Pump Turned On or Off
34' 2"	29.75	2245	105
34' 2"	29.75	2300	120
34' 5"	30.00	2315	135
34' 8"	30.25	2330	150
34' 9"	30.33	2345	165
34' 10"	30.41	0015	195
34' 11"	30.50	0045	225
35' 1"	30.66	0115	255
35' 3"	30.83	0130	270
35' 3"	30.83	0200	300
35' 3"	30.83	0230	330
35' 2"	30.75	0300	360
-----Shut off pump at 0300 hours, December 5-----			
20' 4"	15.91	0301	1
18' 5"	14.00	0302	2
15' 9"	11.33	0303	3
12' 3"	7.83	0304	4
10' 11"	6.50	0305	5
8' 8"	4.25	0310	10
7' 10"	3.41	0315	15

Appendix D (continued)

Water Level Below Ground Level, Feet	Water Level Below Porthole in Casing, Feet	Time of Observation	Minutes Elapsed Since Pump Turned On or Off
7' 3"	2.83	0320	20
6' 8"	2.25	0325	25
6' 2"	1.75	0330	30
6' 0"	1.58	0335	35
5' 8"	1.25	0350	50
5' 6"	1.08	0405	65
5' 4"	0.91	0420	80
5' 3"	0.83	0450	110
5' 1"	0.66	0520	140
4' 11"	0.50	0550	170
4' 8"	0.25	0620	200
4' 5"	0.0	0650 ²	230

-----Start pump at 0655 hours, December 5. Pump Rate 150 gpm-----

5' 10"	1.41	0655	1
16' 4"	11.91	0700	5
18' 1"	13.66	0715	20
19' 0"	14.58	0730	35
19' 3"	14.83	0745	50
19' 0"	14.58	0800 ³	65

-----No detailed data available for 650 gpm pump rate--see note 4.-----

Appendix D (continued)

Footnotes:

¹Water level reported to attain rest level 1 hour after pump was turned off.

²Progress report by P. A. Edwardes indicates that rest level was attained 1 hour 20 minutes after pump was turned off. However, detailed report of test indicates that reaching rest level required 3 hours 50 minutes.

³Progress report by P. A. Edwardes states that rest level was attained for 150 gpm pump rate at 1 hour 15 minutes after pump was turned off.

⁴Progress report by P. A. Edwardes states that stable drawdown at 650 gpm was 83 feet below ground level, and that rest level was attained 1 hour 20 minutes after pump was turned off.

PLATE I. Lithology, drilling rate, and mud return temperatures of Susan I.

PLATE 2. Temperature logs of Susan I and Suzy 9A.