

G600505

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SALTON SEA SCIENTIFIC DRILLING PROGRAM
FLOW TEST ON WELL "STATE" 2-14,
28-30 DECEMBER 1985

for

Phase 1

BECHTEL NATIONAL, INC.
SAN FRANCISCO, CALIFORNIA

by

GeothermEx, Inc.

February 1986

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CONCLUSIONS

The following conclusions are based on direct observations and analysis of data collected during the flow test of well "State" 2-14 conducted during 28-30 December 1985:

1. The well encountered a permeable zone at 6,100 to 6,227 feet in depth, with a resource temperature of 581°F measured downhole.
2. The produced fluid had a calculated pre-flash total dissolved solids (TDS) content of approximately 27 weight-% and an estimated enthalpy of 400 BTU/lb. At atmospheric pressure, this resulted in a steam fraction of 26.5 weight-% and a 37 weight-% TDS content in the separated brine.
3. Pre-flash TDS content calculated by GeothermEx (27.2 weight-%) and by D. Michels (24.5 weight-%), are in reasonable agreement. Michels also estimated the pre-flash gas content to be 0.17 weight-%, consisting of about 99.6% carbon dioxide. Chemical analyses based on samples collected by Kennecott are suspect, as the TDS of samples collected at 460 and 195 psig are not in agreement. The sample collected at 460 psig appears to be diluted by excess steam.
4. Under throttled conditions, the flow rate stabilized at approximately 140,000 lbs/hr at a wellhead pressure of 450 psig. No stabilized data were obtained with the well flowing fully open, because of the short discharge time. Data collected during this time showed a decrease in wellhead pressure from 245 to 190 psig, with a corresponding decrease in flow rate from 490,000 to 360,000 lbs/hr. Because of the steep rate of pressure and mass flow decline, no estimate of stabilized conditions has been made.

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5. The producing zone has a productivity index of 300 lbs/hr/psi, based on a pressure survey conducted with the well flowing at 140,000 lbs/hr.
6. Pressure-buildup data were analyzed using both constant-pressure outer-boundary and infinite outer-boundary models. The formation flow capacity was estimated to be 6,500 and 11,700 millidarcy feet (md·ft) respectively from the two models; with skin factors of +6 and +10 respectively. The positive skin factors suggest that the well is damaged.
7. Temperature and pressure data from surface and downhole measurements were adequate to define the boiling-point curve for the brine. Some of the data, however, follow the pure-water boiling-point curve, and this is believed to indicate that separation of brine and steam occurred in the flowline between the wellhead and the sampling loop. It is suggested that pressure and temperature gauges be installed on the bottom of the pipeline prior to the next flow test to confirm this interpretation.
8. During the flow test, problems were encountered with the operation of the James tube, muffler and weirbox due to mineral deposition. It is believed that the majority of these problems can be overcome by simple modifications to the system before the next flow test. The following modifications have already been discussed with Bechtel:
 - a. The James tubes should be extended in length, to ensure that they discharge directly into the muffler and not into the baffle pipe.

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- b. An 8-inch line should be installed from the muffler to the brine pit, to allow the muffler to be drained.
 - c. The baffles in the weirbox and the weir plate should be removable so that sludge can quickly be cleaned out of the weirbox on a routine basis during the flow test.
 - d. A nitrogen bottle should be connected to the lip pressure tap line so that it can be blown down on a routine basis to prevent scaling.
9. In addition to the above, the following changes are recommended to improve the quality of the collected data:
 - a. The sight glass on the weirbox should be relocated at least two feet upstream of the weir to ensure that the maximum head is being measured.
 - b. The weir crest length should be reduced from the present 15 inches to 10 inches.
 - c. The pressure taps at the measuring orifice should be changed from flange taps to pipe taps, and gauges should be used to measure the pressure drop across the orifice.
10. Because of the slow reservoir response noted when the well was fully opened, it is recommended that the well be flowed at only two rates during the final flow test to ensure that stabilized conditions are achieved.

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1. INTRODUCTION

As part of the Salton Sea Scientific Drilling Program, the well "State" 2-14 was flowed from 28 to 30 December 1985, after encountering partial losses of circulation between 6,100 and 6,227 feet in depth, when drilling out below the 9-5/8-inch casing shoe at 6,000 feet. During the flow test, the well was discharged to an atmospheric muffler and the well's output was determined by use of the James lip-pressure method combined with water-flow measurements across a weir. This method is not normally used for testing of high-salinity brine wells because of the problems with mineral deposition. Recognizing this problem, GeothermEx, Inc. recommended the use of a high-pressure separator, with continuous metering of the separated steam and brine phases for calculating total mass-flow rate and enthalpy. However, because of the cost of such an installation, it was decided to proceed with the atmospheric muffler and weirbox.

GeothermEx personnel were on-site during the period of preparation for the flow tests and during the actual testing and sampling of 28 to 30 December. However, no GeothermEx personnel were present during the attempted downhole sampling of 31 December 1985.

GeothermEx, Inc. is responsible for the interpretation of physical and other data collected during the test. In addition, GeothermEx has provided advice to Bechtel on various aspects of testing, logging and sampling the well.

The purpose of this report is to present the physical data collected during the flow test and an interpretation of that data.

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Flow-Test Facility

The facility used for testing well "State" 2-14 is shown schematically in figure 1. Using this facility it was possible to discharge the well to either:

- a) the mud pit used during drilling;
- b) directly to the brine pit through the bypass blooie line; or
- c) to the atmospheric muffler/separator, with the water being discharged to a weirbox and then to the brine pit.

The pipeline in the facility was constructed of 10-inch schedule 40 pipe, instrumented at various points with temperature and pressure gauges. The locations of these measuring points are shown in figure 1. In the fluid-sampling loop, 4 orifice plates were installed at the locations shown in figure 1 (FO-1 to 4) to provide 4 fluid-sampling environments at different temperatures and pressures. A bypass around the sampling loop was also provided, so that the discharged fluid only flowed through the sampling loop during periods of sampling.

The mass flow rate to the muffler was monitored by recording the lip pressure at the end of the James tube and by measuring the water flow rate over a weir. Initially a 90° V-notch weir was installed, but this was later replaced with a 15-inch rectangular-notch weir. An orifice plate was also installed upstream of the James tube to provide a further method of calculating the mass flow rate. A Foxboro recorder was used to continuously monitor (a) the pressure upstream of the orifice plate, (b) the orifice plate differential pressure and (c) the lip pressure. The fluid level in the weir box was measured with both a dipstick and a sight glass.

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2. DESCRIPTION OF THE FLOW TEST

Well "State" 2-14 was flowed as part of the Salton Sea Scientific Drilling Program from 28 to 30 December 1985. The discharge history is summarized in figure 2 and in the following section. This section is based mainly on records and data collected by the U.S. Geological Survey on-site Science Manager and his staff.

The decision to flow the well was made on 24 December 1985 after partial losses of circulation were encountered between 6,100 and 6,227 feet in depth. After this decision was made, the drilling mud was displaced from the hole with fresh water, and the rig was put on standby. A suite of logs, including static temperature and pressure surveys, was then run in the well, and these were completed by 28 December 1985. By this time the wellhead pressure had risen to 165 psig, because of heating and subsequent expansion of the fresh water; and it was felt that the well could possibly discharge without the need for nitrogen injection.

The well was opened to the mudpit at 1324 hours on 28 December 1985, and the initial flow was estimated to be approximately 35 gallons per minute (gpm), at a wellhead pressure of 6 psig. The flow continued at this rate, with discharge temperature increasing from 165°F to 196°F. However, the temperature stabilized at 196°F, and it was noted that the fluid was becoming more muddy and the flow rate was decreasing. Therefore, at 1530 hours the decision was made to inject nitrogen in order to initiate a full discharge. Tubing was run into the well to 1,500 feet, and nitrogen was pumped at a constant rate of 250 cubic feet per minute (cfm). By 1800 hours the well was discharging to the mudpit.

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At 1830 hours the flow was bypassed to the brine-pit blooie line, which was equipped with a lip-pressure tap (figure 1), to give an initial indication of the flow rate. At 1858 hours the flow was bypassed to the atmospheric muffler, with the separated water flowing across a 90° V-notch weir into the brine pit.

At 1938 hours it was noted that water was backflowing out of the baffle pipe surrounding the James tube. It was believed that this was caused by flooding of the muffler, because of limited capacity in the weir-box, and the flow was diverted back to the blooie line at 1944 hours. To increase the capacity of the weirbox, it was decided to replace the 90° V-notch weir with a rectangular-notch weir having a crest length of 15 inches. It was also decided that the first baffle in the weirbox should be reduced in height.

While waiting for the welder to make the modifications, the flow was throttled back and rediverted to the muffler at 2151 hours. This was necessary because spray from the blooie line was being carried beyond the brine pit.

Modifications to the weirbox were completed at 0327 hours on 29 December 1985. While the modifications were being carried out, the flow was diverted to the blooie line, and the inside of the muffler was inspected to see if scale buildup was restricting the two 12-inch outlet lines. A coating of salt scale of approximately 1/4- to 1/2-inch thickness was found on the sides of the muffler; scale buildup also had occurred in the center of the muffler base. However, the two outlet pipes were found to be clear.

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It was also decided to replace the 7-inch James tube with a 5-inch James tube. After the James tube was removed, a buildup of scale was noted inside the baffle pipe, starting where the fluid would have discharged from the end of the James tube. This was cleaned out and the 5-inch tube was installed. A vacuum truck was also utilized to clean out the weirbox, which was found to be full of sludge.

The flow was diverted back to the muffler after the modifications were completed. However, at 0413 hours the flow was again diverted to the blooie line because of excessive fluid backflow past the James tube. The James tube was removed and the baffle pipe was found to be badly scaled. The scale was removed and a 10-inch James tube was installed. The flow was rediverted to the muffler at 0522 hours. However, the same problem was encountered, and the flow again was diverted to the blooie line at 0654 hours. After a few minutes it was realised that spray from the blooie line was still being carried beyond the brine pit, and that it would be necessary to modify the end of the line to direct the flow down into the brine pit. The flow was therefore rediverted to the muffler.

At 0753 hours the flow was diverted through the sampling loop so that fluid sampling could be started. However, it was found that the temperature drop between each of the sampling spools was inadequate and that it was thus necessary to replace the pressure-reducing orifice plates. The flow was therefore diverted back to the bypass line at 0915 hours. The orifice plates were replaced, and flow restarted through the sampling spools at 1234 hours. As before, the temperature drops were found to be inadequate, and the flow was bypassed at 1244 hours. After further changes were made in orifice diameter, the flow was diverted back to the sampling loop successfully at 1416 hours. Sampling continued until 2005 hours.

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While the orifice plates in the sampling loop were being replaced, the end of the blooie line was modified, to direct the flow down into the brine pit. Flow was bypassed from the muffler at 1227 hours. With the flow going to the blooie line, it was possible to remove the 10-inch James tube and to clean out the baffle pipe. The 10-inch James tube was also extended in length so that fluid would discharge directly into the muffler rather than into the baffle pipe, to overcome the problem of backflow from the baffle pipe. At the same time, preparations were underway to conduct temperature and pressure surveys with the well on discharge, using the "dewared" Kuster temperature and pressure tools.

However, prior to conducting the surveys, it was found that the flange above the master valve was leaking. It was decided to abort the surveys and shut in the well. The well was shut at 2115 hours, whereupon the bottom flange on the master valve also began to leak. Both flanges were retightened and a kill line was installed.

The well was reopened to the brine-pit blooie line at 0113 hours, 30 December 1985. At 0328 hours the flow was diverted to the muffler and the flow rate slowly was increased. The well was fully opened by 0435 hours. No problems were encountered with backflow at the baffle pipe, and there was no sign of excessive water carryover in the steam. It was found, however, that the weirbox quickly filled with salt sludge, and by 0515 hours the level was close to the bottom of the weir notch. The sludge was shovelled out manually, with the well continuing to flow to the muffler. However, the rate of scale buildup was sufficiently great to make this method of cleanout impractical. In addition, it appeared that the lip-pressure tap on the James tube also had scaled up by 0548 hours.

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With the well fully open, Kennecott then began to take fluid samples at sampling point PI-SP-2 (figure 1). It was noted, however, that the well output was falling off, possibly because of scaling in the well. Hence, it was decided that the well should be throttled back as soon as possible. Kennecott completed their sampling by 0613 hours, and the well was throttled back.

Flow was diverted through the sampling loop at 0743 hours to allow the second round of fluid sampling. Sampling was completed by 1520 hours.

During the morning of 30 December 1985, rigging was completed for the flowing temperature and pressure surveys; running in-hole began at 1350 hours. After completing the surveys, the tools were left in the hole at 5,950 feet (measured depth) to record pressure and temperature buildup after the well was shut-in.

After sampling was completed, the well continued to flow through the sampling loop until 1700 hours, at which time a thermowell (TI-6) in the low-pressure spool of the sampling loop washed out. The flow was then bypassed, and the well was shut-in at 1730 hours. The wellhead pressure had declined to zero by 2008 hours, and the temperature and pressure tools were recovered at 0100 hours on 31 December 1985.

Following recovery of the temperature and pressure tools, the downhole sampler from Los Alamos National Laboratory was rigged up and run into the well at 0400 hours. The tool was recovered, but it was found that the sampling valve had not opened, perhaps because of high cable resistance caused by leaks in the cable head. The cable head was serviced and a

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second attempt was made to recover a fluid sample. This was also unsuccessful, and it was concluded that leaks between the conductors in the cable were preventing the valve from opening when a surface power source and conductor cable were used.

Hence it was decided to use a battery pack, supplied by Sandia National Laboratory, to actuate the valve from downhole. During this run it was found that the valve did open, but because of the flashing which occurred when fluid entered the evacuated sampling vessel, the entry point scaled up. The motor was unable to close the valve because of the scale; and when the tool was recovered it was found that the battery pack had burnt out. After unsuccessful attempts were made to close the valve on the surface using a spare battery pack, it was concluded that the motor used to operate the valve also had burnt out.

Downhole sampling was therefore aborted at 2200 hours, and injection of the discharged brine back into the well was started at 2300 hours on 31 December 1985, at an approximate flow rate of 600 gpm.

During the downhole surveying and sampling, no evidence of scaling was found in the wellbore, indicating that the decrease noted in the flowrate when the well was fully open was a reservoir response and was not due to choking in the wellbore.

After completion of the flowtest, the pipelines and muffler were inspected for scale deposition. Pipelines were found to be relatively deposit-free, but deposits up to 18-inches thick were found in the muffler. The most severe deposition occurred opposite the tangential inlet, with a decreasing thickness away from that point. When the manhole cover was removed, a deposit 6 to 7 inches in thickness was found on the inside surface.

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3. ANALYSIS OF THE DATA

Data collected from the wellhead, sample spool and muffler during the flow tests are tabulated in Appendix A and plotted in figures 3, 4 and 5. These surface data, along with data collected from downhole surveys, are analyzed in the following sections.

Estimation of Fluid Enthalpy and Pre-Flash TDS

The discharge enthalpy has been estimated from the temperature (581°F) measured at the bottom of the casing with the well on discharge (figure 6), modified for TDS, using the following formula:

$$h_t = 0.36T^{1.16} \cdot 10^{-0.6x}, \quad (1)$$

where: h_t = total fluid enthalpy (BTU/lb),
T = temperature (°F), and
x = TDS (weight fraction)

TDS could not be measured directly, because of steam separation. However, by use of the chemical concentration measured in the weirbox (370,000 ppm), combined with percentage-steam-flash calculations and equation (1) in an iterative process, the fluid enthalpy and pre-flash TDS were estimated respectively to be 400 BTU/lb and 272,000 ppm or 27.2 weight-%. Using this value for enthalpy, the steam fraction at atmospheric pressure is calculated to be 26.5 weight-%.

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The calculated pre-flash TDS of 27.2 weight-% is close to the value of 24.5 weight-% estimated by Michels. Michels also estimated the pre-flash gas content to be about 0.17 weight-%, consisting of 99.6% weight-% carbon dioxide. Michels gives no estimate of the fluid enthalpy but indicates that the solution of mixed salts appears to have a smaller heat capacity than its weight-equivalent of sodium chloride brine. This would suggest that the value of enthalpy calculated using equation (1) may be slightly high. However, for calculations of flow rate, it is believed that the estimated enthalpy of 400 BTU/lb is reasonable.

Chemical samples were also collected by Kennecott using an LLL probe to sample at various points across the pipe. If the sampling was representative, the measured TDS should be the same as the pre-flash TDS. However, samples collected at 460 psig and 195 psig had TDS values of 102,430 ppm and 292,735 ppm respectively. The sample collected at 460 psig appears to be diluted with respect to the sample collected at 195 psig, probably due to entrainment of a higher percentage of steam. The sample collected at 195 psig is believed to be more representative of the true pre-flash TDS. However, unless the enthalpy of the sample is equal to the enthalpy of the steam and brine mixture in the pipe, the sample TDS will not be the same as the pre-flash TDS.

Flow Rate Calculations

The separated water flow rates were calculated from water levels measured in the weirbox (figure 5) using equations (2) and (3):

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$$w_f = 8953.2 \rho H^{2.481} \text{ (90° V-notch weir)} \quad (2)$$

$$w_f = 11988 \rho (1.25 - 0.2H) H^{1.5} \text{ (15-inch rectangular weir)} \quad (3)$$

$$w_f = 11988 \rho (1.25 - 0.2H)(H + H_V)^{1.5} - 3600 H_V^{1.5} \quad (4)$$

where: w_f = water flow rate (lbs/hr)

ρ = water density (lbs/ft³)

H = water level above weir (ft)

H_V = velocity head = $\frac{\text{velocity}^2}{2g}$ (ft)

The density of water in the weirbox was measured and found to be 72 lbs/ft³. In the calculations of water flow rate, it is assumed that density remained constant at this value throughout the flow test.

The calculated values of water flow rate, based on both the dipstick and sight-glass measurements, are plotted in figure 5.

Equations (2) and (3) assume zero approach-velocity upstream of the weir. With the buildup of salt sludge in the weirbox, this assumption may not always be valid. Equation (4) is used for a rectangular weir when the upstream velocity is not negligible; it indicates that the actual flow rate will be greater than in the zero-velocity case. Therefore, equations (2) and (3) yield a minimum water flow rate. For an upstream velocity of 2 ft/s, the actual flow rate could be underestimated by approximately 20%.

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The total mass flow rates shown on figures 3, 4 and 5 have been calculated from the estimated enthalpy of 400 BTU/lb and the measured water flow rate using flash calculations. Where possible, the flow rate also has been estimated from the lip-pressure measurements, using a James formula corrected for TDS. The correction to the James formula was made following the method outlined by Karamarakar and Cheng (1980)* using the Fauske model for 2-phase flow. The total mass flow rates calculated by this method are included in figures 3, 4 and 5; the results match closely with flow rates calculated from the water flow rates and the estimated enthalpy of 400 BTU/lb.

Data were available from the orifice plate upstream of the James tube for only a short period on the night of the 28 December 1985. Therefore, these data are not analyzed in this report.

From the above calculations, the well was found to produce a stable total flow rate of approximately 140,000 lbs/hr throttled to a wellhead pressure of 450 psig. The well also was discharged with the throttling valve fully open; however, flow rate and wellhead pressure did not begin to stabilise during the period of observation: wellhead pressure declined from 245 to 190 psig, with a corresponding decline in flow rate from approximately 490,000 to 360,000 lbs/hr. Because of the continued high rates of decline in pressure and mass flow, it has not been possible to estimate a final stabilized flow rate.

*Karamarakar, M. and Cheng, P.: A theoretical assessment of James method for the determination of geothermal wellbore discharge characteristics, Report No. LBL 11498, GREMP-12, UC-66a, November (1980).

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Temperature and Pressure Data

Temperature and pressure data were collected from a number of points in the surface pipework (figure 1) during the discharge test, and from downhole surveys conducted while the well was flowing (figure 6). Data measured at the surface and the 2-phase data from the downhole surveys are plotted in figure 7. The data for pure water have been included in figure 7 for comparison purposes.

Measurements taken at the sampling spools and the downhole data lie close to a single curve, which is believed to define the boiling-point curve for this brine. Data from TI-8/PI-8, located upstream of the sampling loop (see figure 1), follow the pure-water curve, whereas data from TI-1/PI-1 follow the brine curve at low pressures and the pure water curve at high pressures. The data are replotted to a larger scale in figure 8 to show these trends more clearly.

These data and trends indicate that water and steam have separated in the pipeline, and that water is flowing along the bottom of the pipe with steam at the top. Hence, the measurements at TI-8/PI-8 were made in steam which is essentially pure, and the measured temperatures and pressures thus reflect pure-water saturation conditions. Similarly, at TI-1/PI-1 there are indications that separation is occurring at low flow rates (high pressures), where the measured temperatures and pressures follow the pure-water curve; but that at high flow rates (low pressure), turbulence has reduced the amount of steam separation, and the measurements follow the brine curve.

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To test this hypothesis, it is suggested that temperature and pressure gauges be installed on the bottom of the pipe near TI-8/PI-8 for the next flow test.

The chemical samples collected by Kennecott also support the above hypothesis, as the high-pressure sample has only 35% of the TDS measured in the low-pressure sample. This suggests that the LLL probe was preferentially sampling steam.

Reservoir Deliverability

From the downhole static- and flowing-pressure surveys (figure 6), the drawdown during flow at 140,000 lbs/hr was calculated to be approximately 470 psi. This indicates that the well has a productivity index of 300 lbs/hr/psi, based on this single point.

The measured pressure buildup after shut-in is plotted on semi-log and log-log coordinates in figures 9 and 10 respectively. The last 4 data points are at the same pressure, suggesting that a model which includes a constant-pressure outer boundary should possibly be used to fit the data. Using this model and fluid properties for a 27.2 weight-% brine, the formation flow capacity and skin factor are calculated to be 6,500 millidarcy feet (md-ft) and +6, respectively. The positive value of skin factor indicates that the well is damaged and that the measured productivity index is affected by this damage.

Using the more common infinite outer-boundary solution (see figure 10), the formation flow capacity is calculated to be 11,700 md-ft, with a skin factor of +10.

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FIGURES

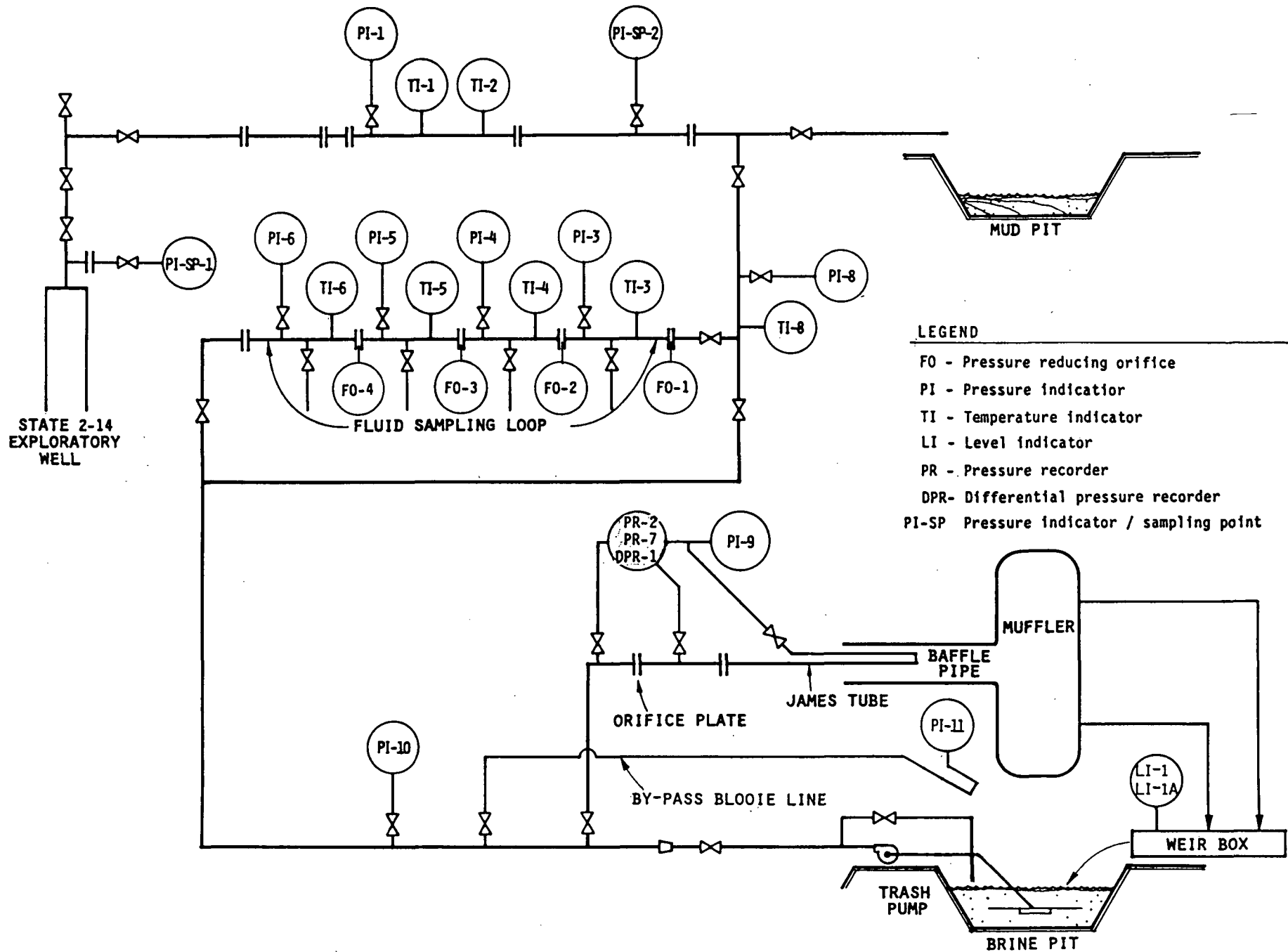
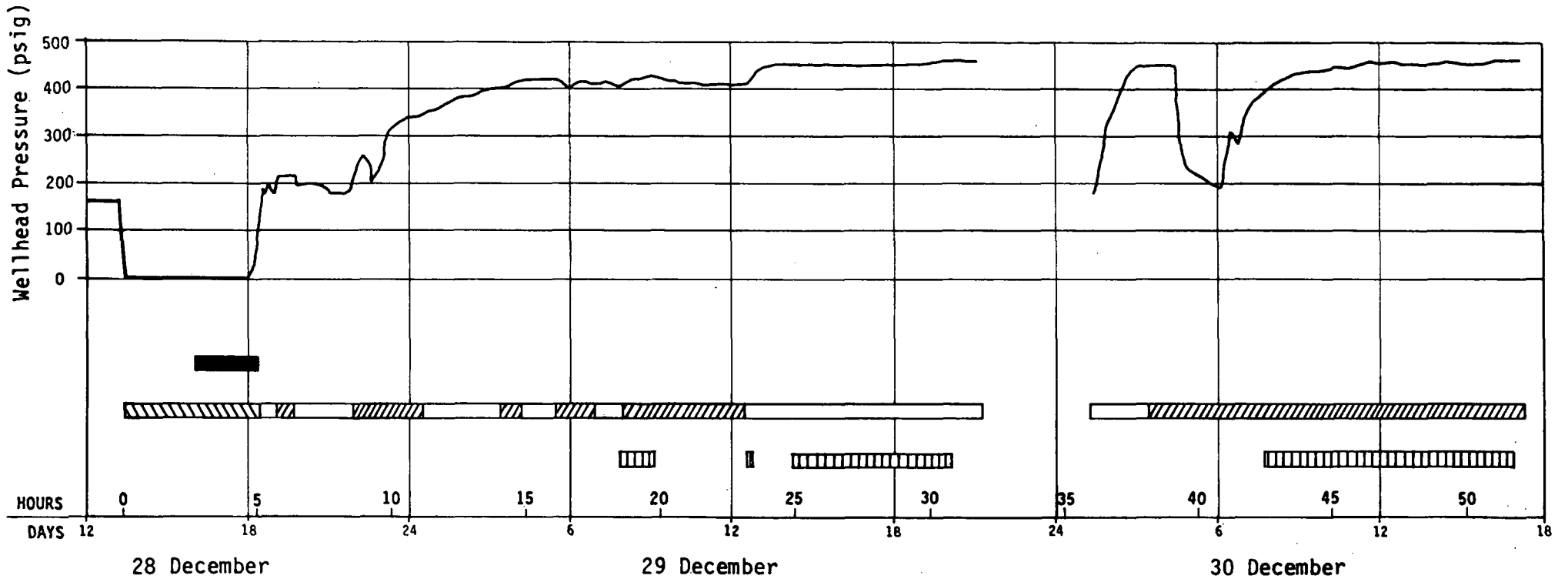


Figure 1. Schematic of flow test facility

SALTON SEA SCIENTIFIC DRILLING PROGRAM

WELL STATE 2-14

FLOW TEST 12/28/85 - 12/30/85



LEGEND

■ Nitrogen Stimulation

▨ Discharge to Mud Pit

□ Discharge to Brine Pit

▨ Discharge to Muffler/Weirbox

▤ Operating Sampling Spools

Figure 2. Summary of discharge history

FIGURE 3: DATA FROM WELLHEAD AREA, WELL STATE 2-14 FLOWTEST

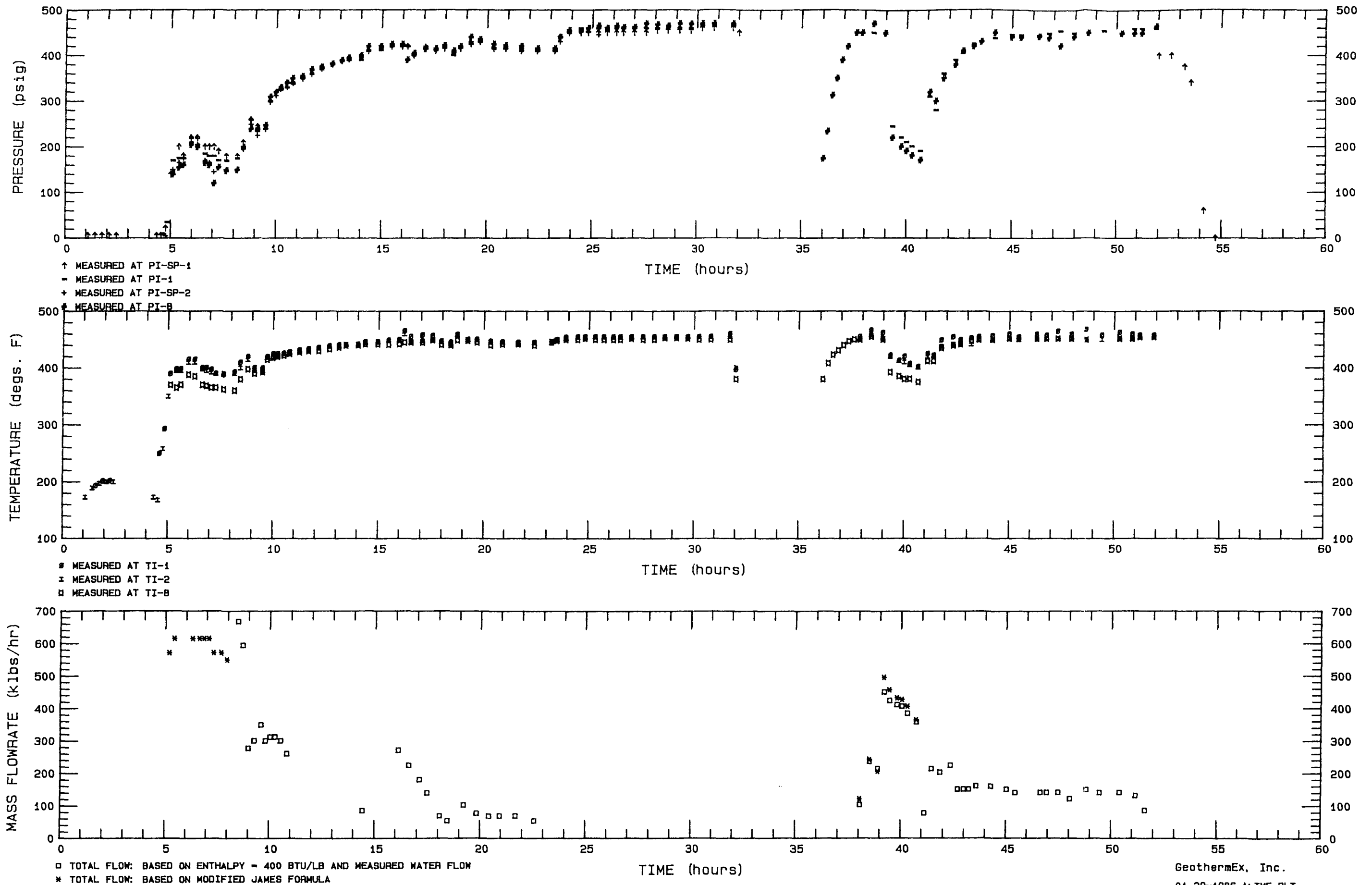


FIGURE 4: DATA FROM SAMPLE SPOOLS, WELL STATE 2-14 FLOWTEST

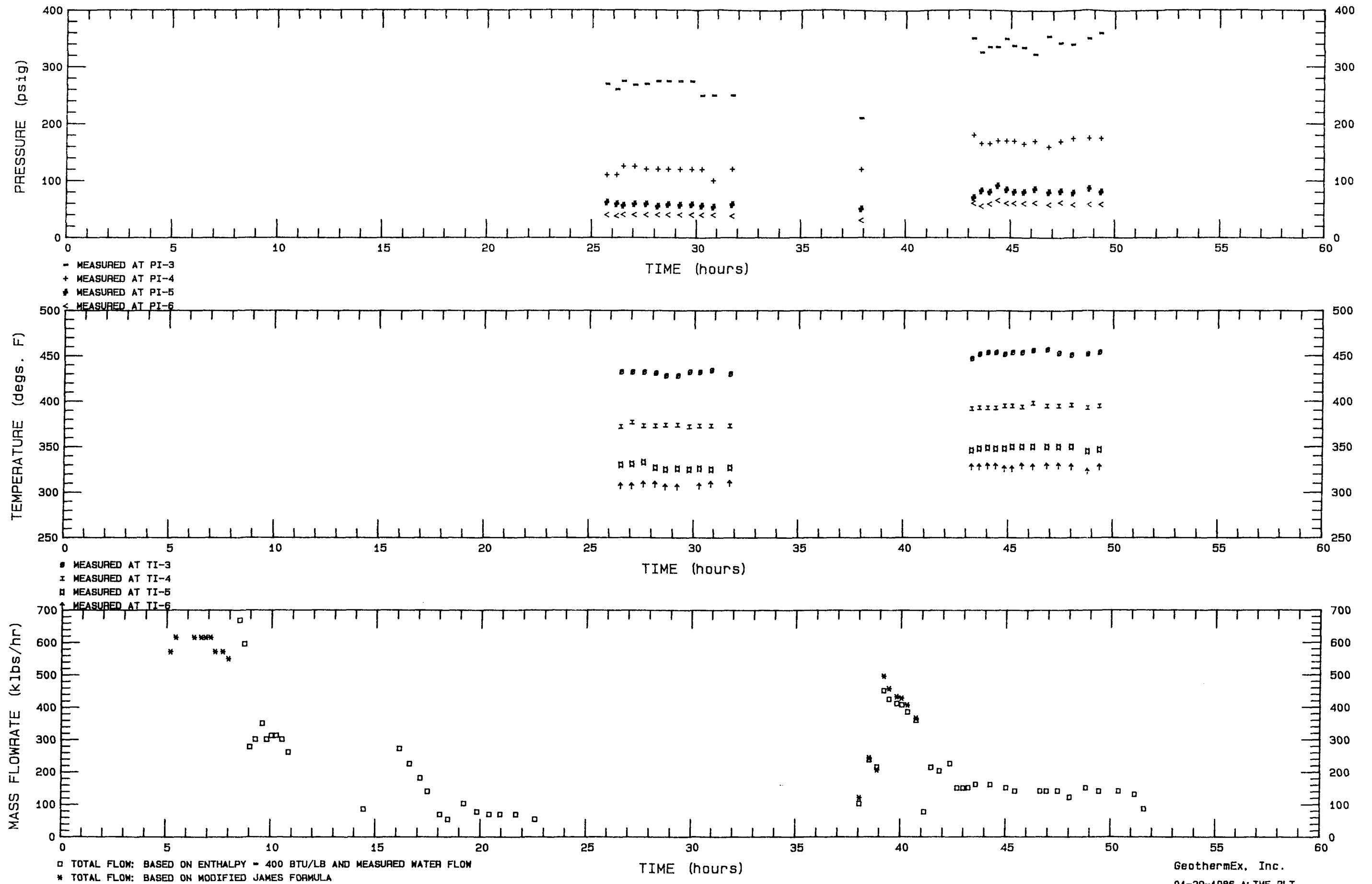


FIGURE 5: DATA FROM MUFFLER AREA, WELL STATE 2-14 FLOWTEST

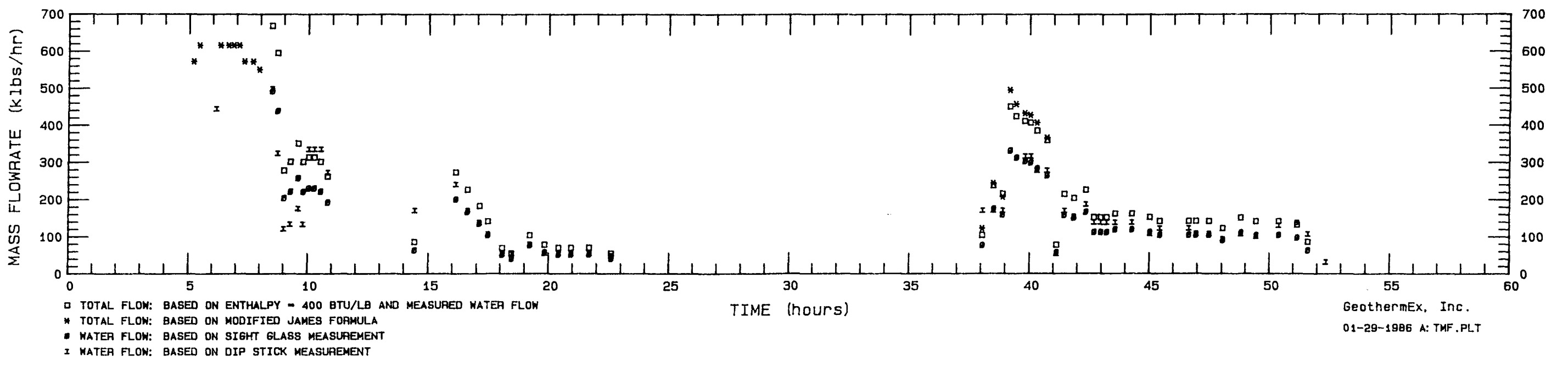
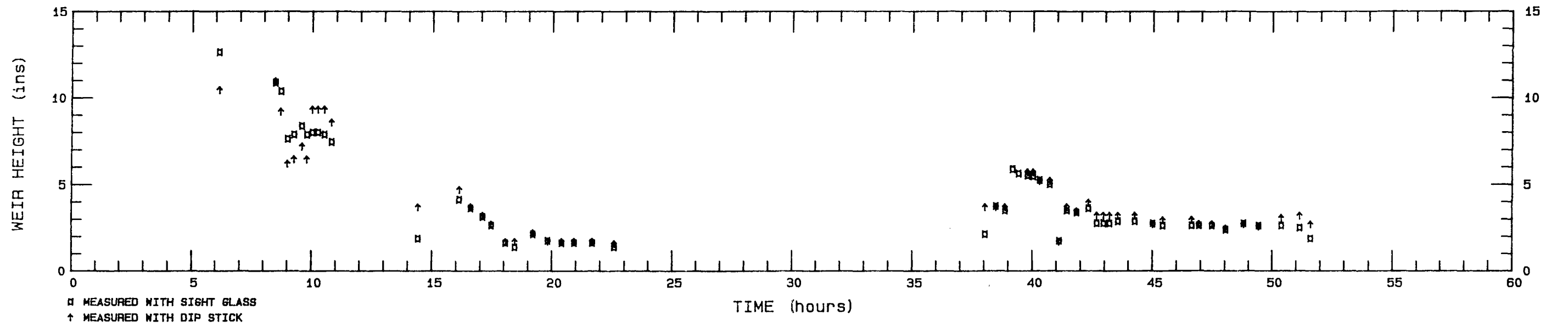
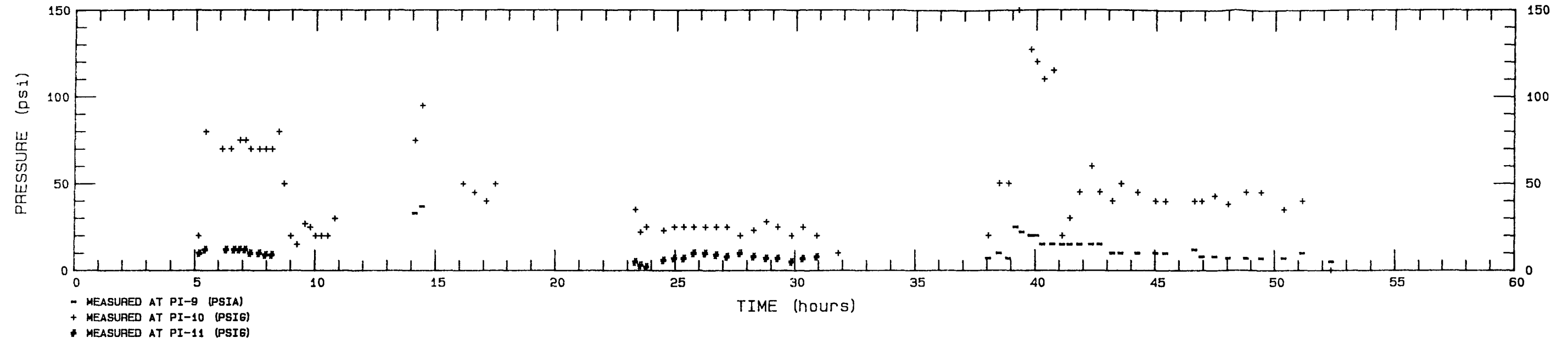
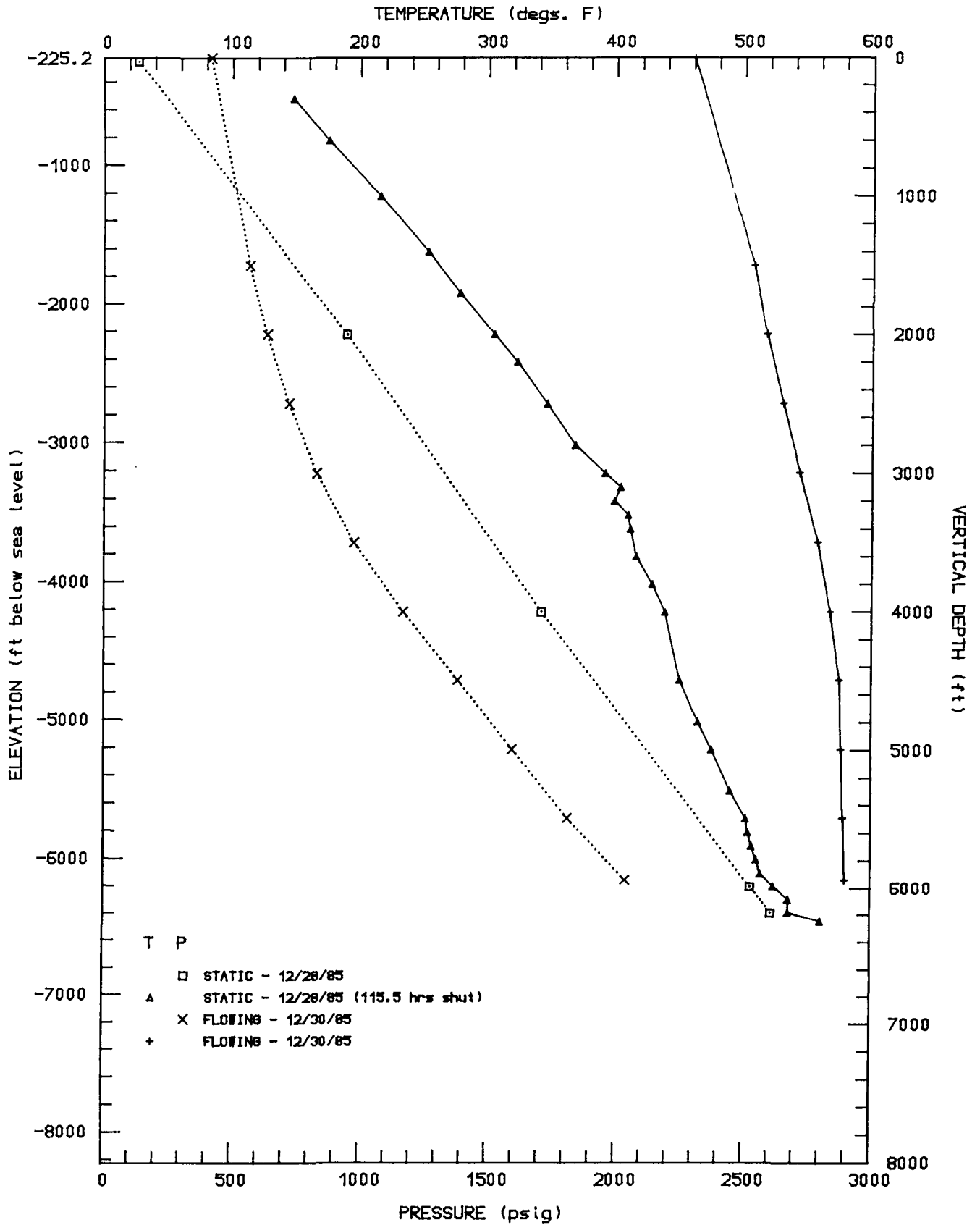


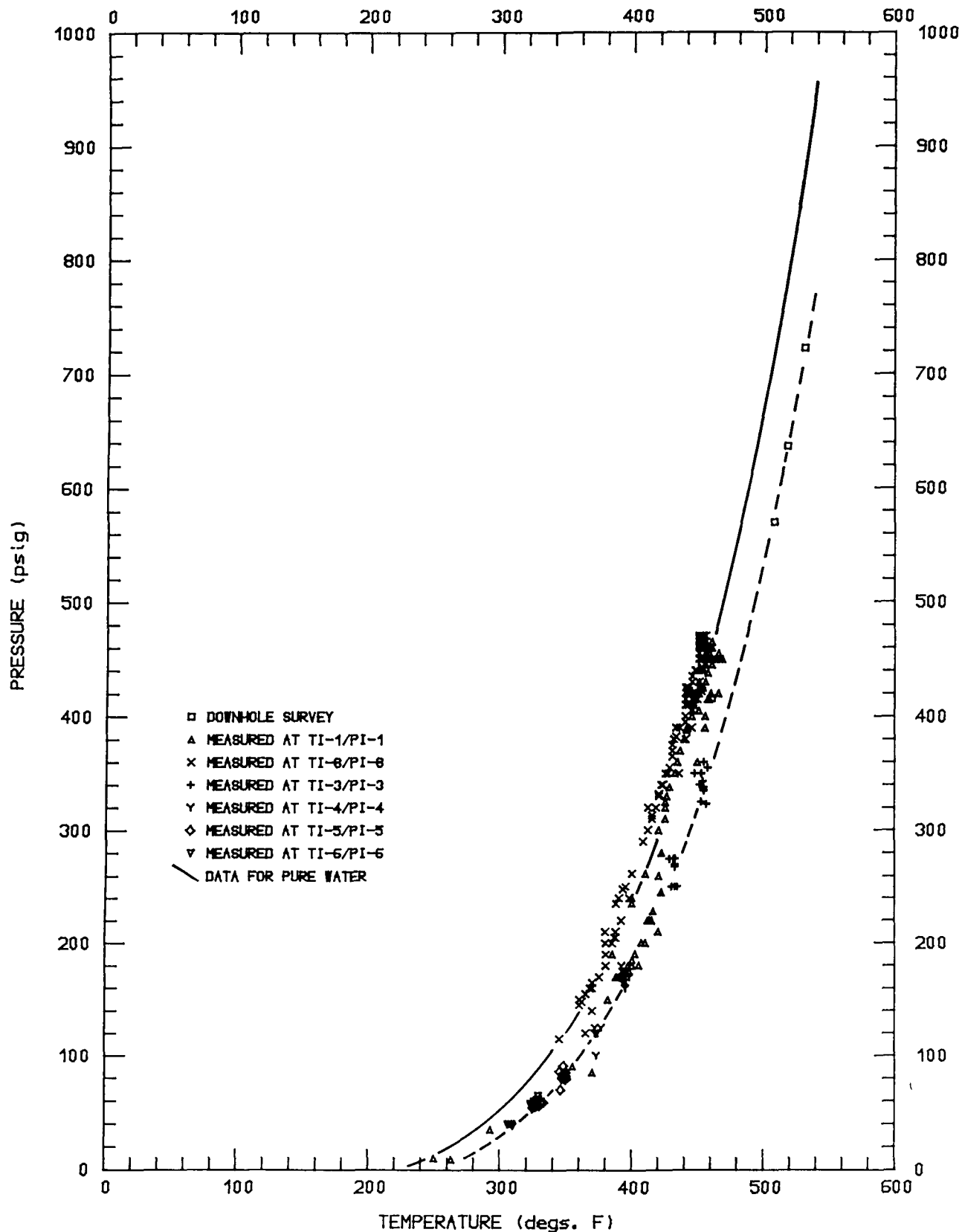
FIGURE 6: TEMPERATURE/PRESSURE SURVEYS, WELL STATE 2-14



GeothermEx, Inc.

01-28-1985 A:66SDPP2.PLT

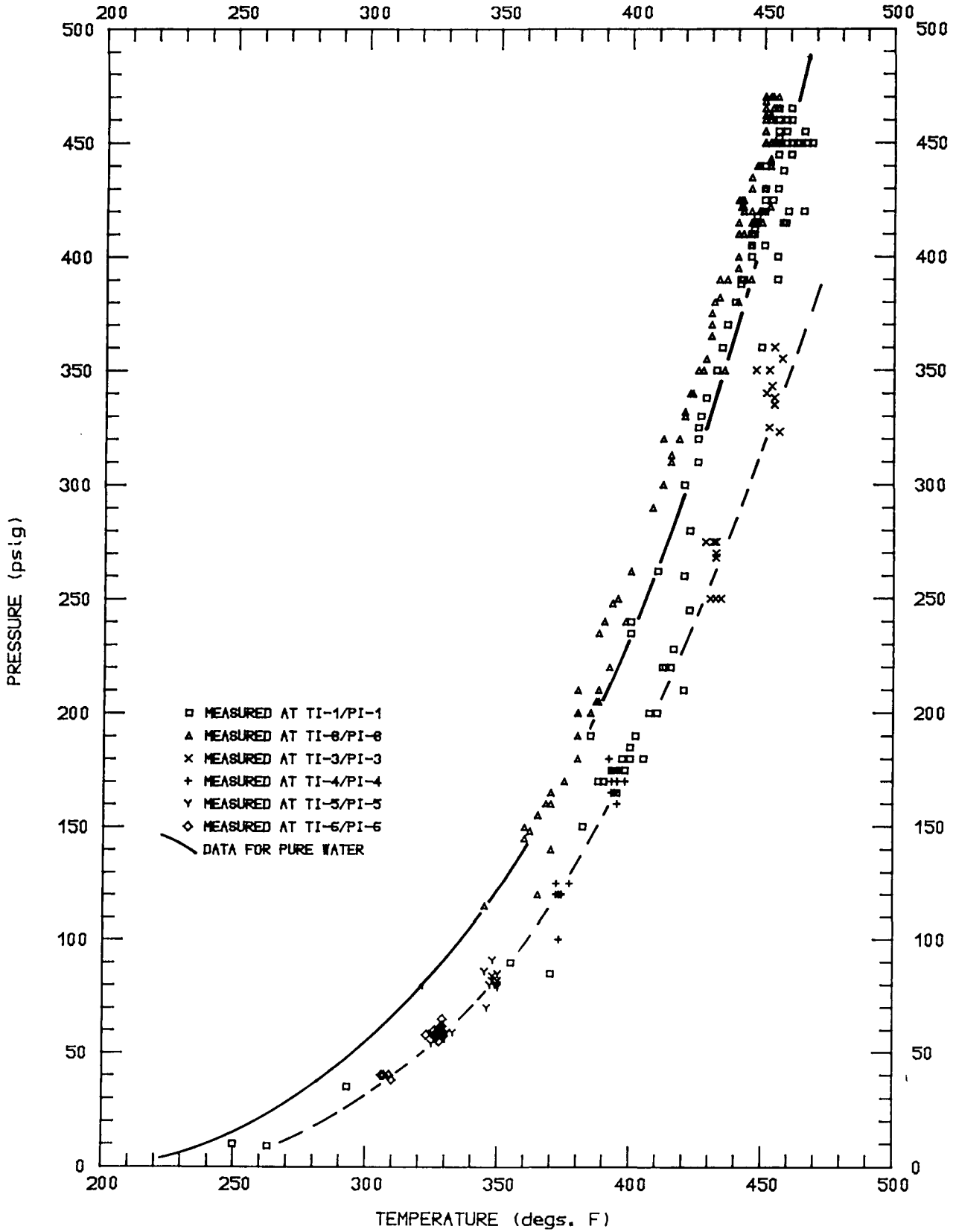
FIGURE 7: BOILING POINT CURVE, WELL STATE 2-14



GeothermEx, Inc.

02-14-1985 A:DHTP.PLT

FIGURE 8: BOILING POINT CURVE, WELL STATE 2-14



GeothermEx, Inc.

02-14-1986 A:WHTP.PLT

FIGURE 9: PRESSURE BUILDUP TEST (SEMI-LOG PLOT), WELL STATE 2-14

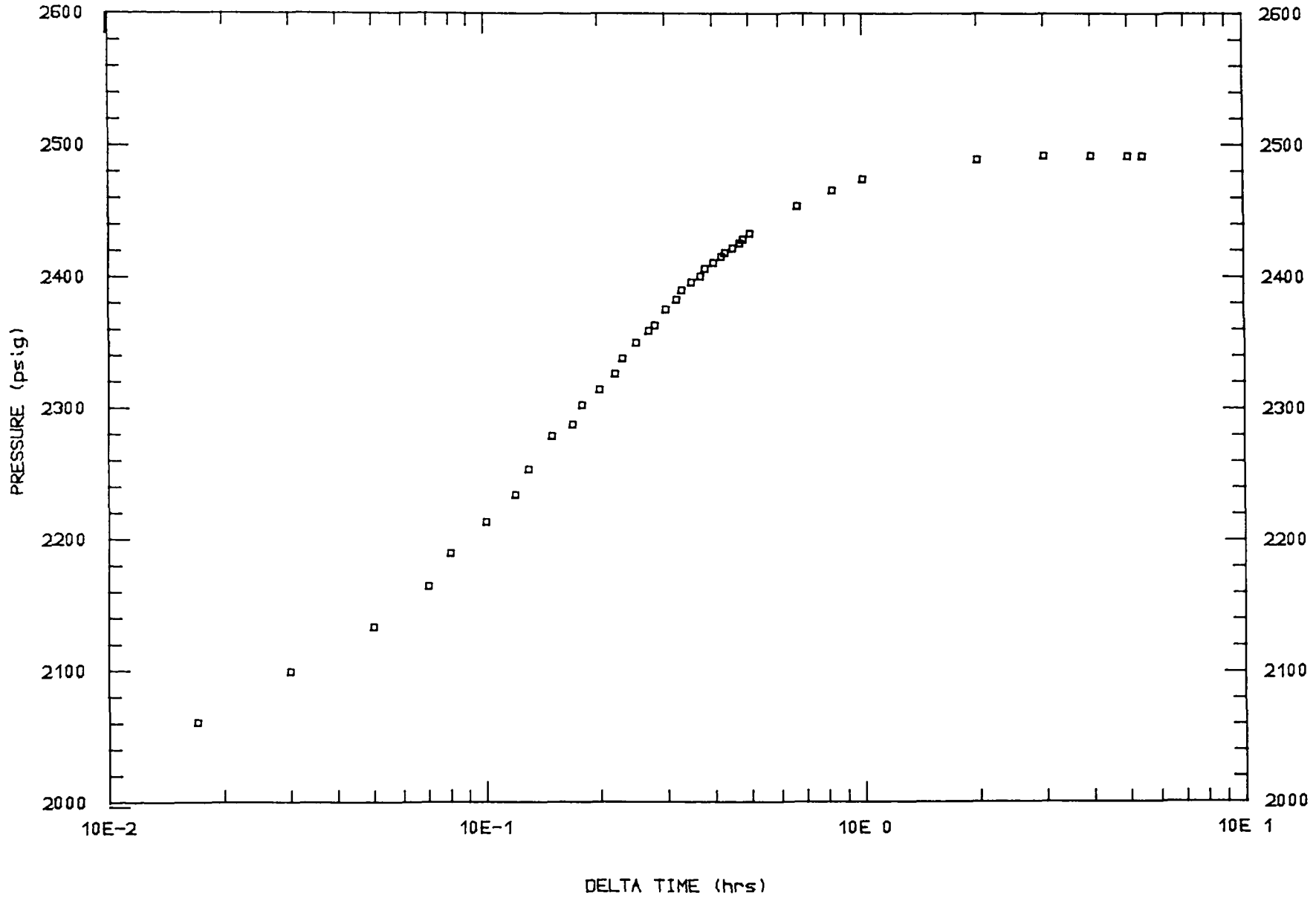
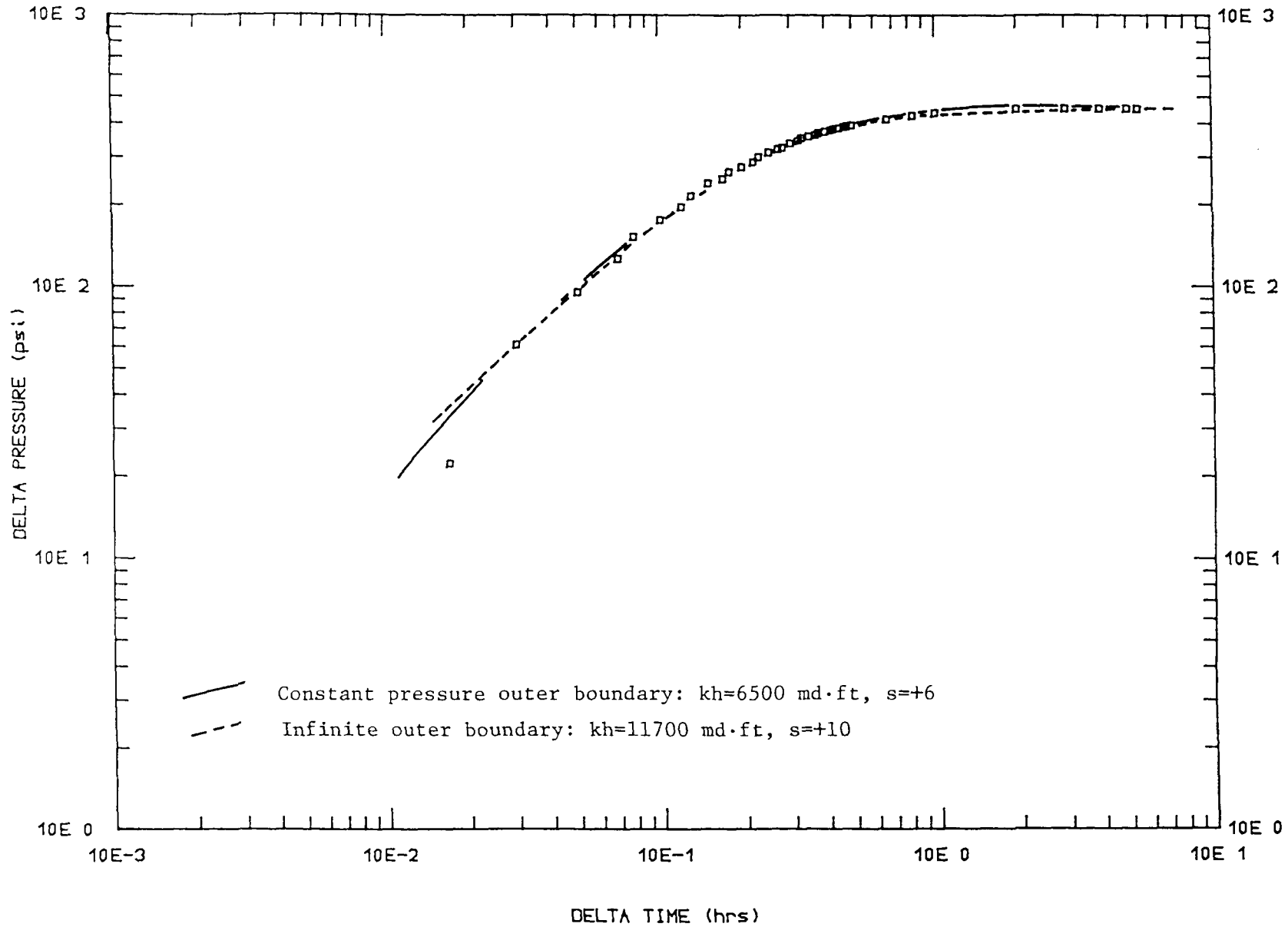


FIGURE 10: PRESSURE BUILDUP TEST (LOG-LOG PLOT), WELL STATE 2-14



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APPENDIX A

Data Collected During Flowtest

A.1: DATA FROM WELLHEAD AREA

DELTIME	PISP1	PI1	TI1	TI2	PISP2	PI8	TI8
1.100	6	-1.	-1.	173	-1.	-1.	-1.
1.267	6	-1.	-1.	181	-1.	-1.	-1.
1.433	6	-1.	-1.	189	-1.	-1.	-1.
1.600	6	-1.	193	193	-1.	-1.	-1.
1.767	6	-1.	197	197	-1.	-1.	-1.
1.933	6	-1.	201	200	-1.	-1.	-1.
2.100	6	-1.	202	200	-1.	-1.	-1.
2.267	6	-1.	202	200	-1.	-1.	-1.
2.450	6	-1.	202	200	-1.	-1.	-1.
4.350	6	-1.	-1.	173	-1.	-1.	-1.
4.450	6	-1.	-1.	168	-1.	-1.	-1.
4.550	6	-1.	-1.	168	-1.	-1.	-1.
4.617	30	10	250	250	-1.	-1.	-1.
4.684	15	-1.	240	240	-1.	-1.	-1.
4.767	22	9	263	258	5	-1.	-1.
4.850	50	35	293	290	8	-1.	-1.
4.933	-1.	85	370	340	8	-1.	-1.
5.017	140	90	355	350	-1.	-1.	-1.
5.100	190	170	390	383	150	140	370
5.217	180	150	382	378	120	115	345
5.384	200	175	398	395	165	155	365
5.600	180	175	398	395	175	160	370
5.717	220	220	412	408	220	205	387
5.967	220	220	415	410	210	205	388
6.267	220	220	415	410	205	200	385
6.400	200	180	405	400	170	165	370
6.634	200	185	400	398	170	165	370
6.834	200	180	400	395	165	160	368
7.067	200	180	397	392	145	120	365
7.284	190	170	390	390	155	155	365
7.650	180	170	388	390	150	148	362
7.767	180	165	395	390	150	145	360
8.167	180	175	393	390	150	150	360
8.450	210	200	410	400	195	200	380
8.800	260	260	420	415	250	240	398
8.900	260	262	410	400	255	250	395
9.117	245	235	400	395	225	240	390
9.217	210	190	385	380	200	200	380
9.500	240	240	400	395	240	248	393
9.717	300	300	420	419	300	310	415
9.983	320	320	425	420	312	320	418
10.200	330	325	425	422	325	330	420
10.483	340	330	426	425	330	340	422
10.750	340	338	428	426	340	350	425
11.217	350	350	432	430	350	355	428
11.650	360	360	434	432	367	370	430
12.133	375	370	436	435	370	375	430
12.650	380	380	439	438	380	382	433
13.100	388	388	441	439	388	390	436
13.433	395	390	441	439	390	395	440

DELTIME	PISP1	PI1	TI1	TI2	PISP2	PI8	TI8
14.017	400	390	442	440	395	400	440
14.350	410	410	446	445	412	420	442
14.950	420	412	446	447	415	420	442
15.467	420	420	449	449	420	425	441
15.967	420	420	450	448	420	425	442
16.217	420	420	465	460	390	390	445
16.517	400	400	455	445	400	405	445
17.050	415	415	458	448	420	415	445
17.534	410	415	457	449	410	415	449
17.950	415	418	447	446	415	422	441
18.400	405	400	445	442	405	410	440
18.500	405	405	445	442	405	410	442
18.717	415	420	459	459	415	420	449
19.217	425	425	450	449	430	440	448
19.650	430	430	450	449	430	435	445
20.300	415	415	447	445	418	425	440
20.867	415	415	446	446	415	422	442
21.617	410	410	445	442	415	420	442
22.383	410	410	445	445	410	415	440
23.200	410	410	445	444	410	415	446
23.450	440	440	450	450	430	440	448
23.883	450	450	454	452	450	455	450
24.450	450	460	455	455	455	455	450
24.800	450	452	455	453	453	460	452
25.283	450	460	455	455	445	465	450
25.700	450	455	455	455	460	460	450
26.150	450	460	455	455	465	465	450
26.483	450	460	455	455	460	462	450
27.017	450	460	455	455	460	462	452
27.567	450	460	455	455	460	470	450
28.100	455	460	455	455	460	468	450
28.600	455	465	455	455	460	465	453
29.150	455	460	455	455	-1.	470	453
29.683	455	460	455	455	-1.	470	452
30.233	460	465	455	455	-1.	470	450
30.800	460	465	455	455	-1.	470	450
31.717	460	465	460	455	-1.	470	450
32.017	450	-1.	397	400	-1.	-1.	380
36.033	-1.	-1.	-1.	-1.	-1.	175	-1.
36.133	-1.	-1.	-1.	-1.	-1.	210	380
36.233	-1.	-1.	-1.	-1.	-1.	235	388
36.317	-1.	-1.	-1.	-1.	-1.	262	400
36.383	-1.	-1.	-1.	-1.	-1.	290	408
36.466	-1.	-1.	-1.	-1.	-1.	313	415
36.533	-1.	-1.	-1.	-1.	-1.	332	420
36.600	-1.	-1.	-1.	-1.	-1.	340	423
36.683	-1.	-1.	-1.	-1.	-1.	350	427
36.767	-1.	-1.	-1.	-1.	-1.	365	430
36.850	-1.	-1.	-1.	-1.	-1.	380	431
36.933	-1.	-1.	-1.	-1.	-1.	390	433

DELTIME	PISP1	PI1	TI1	TI2	PISP2	PI8	TI8
37.033	-1.	-1.	-1.	-1.	-1.	410	440
37.100	-1.	-1.	-1.	-1.	-1.	410	440
37.183	-1.	-1.	-1.	-1.	-1.	420	445
37.266	-1.	-1.	-1.	-1.	-1.	430	445
37.350	-1.	-1.	-1.	-1.	-1.	440	447
37.600	-1.	-1.	-1.	-1.	-1.	450	450
37.876	-1.	450	455	450	-1.	450	450
38.417	-1.	450	466	458	-1.	470	455
38.967	-1.	450	462	452	-1.	450	450
39.333	-1.	245	422	420	-1.	220	392
39.450	-1.	-1.	-1.	-1.	-1.	205	-1.
39.517	-1.	228	416	416	-1.	210	388
39.750	-1.	220	413	412	-1.	200	385
40.000	-1.	210	420	410	-1.	190	380
40.267	-1.	200	407	405	-1.	180	380
40.667	-1.	190	402	401	-1.	170	375
41.100	-1.	310	425	420	-1.	320	412
41.383	-1.	280	422	422	-1.	300	412
41.750	-1.	360	449	438	-1.	350	435
42.300	-1.	390	455	442	-1.	380	440
42.650	-1.	405	450	442	-1.	410	442
43.167	-1.	425	453	442	-1.	420	448
43.533	-1.	430	455	450	-1.	430	450
44.183	-1.	438	457	450	-1.	450	450
44.983	-1.	445	460	452	-1.	440	452
45.433	-1.	445	455	450	-1.	440	452
46.300	-1.	445	460	452	-1.	443	452
46.767	-1.	450	458	452	-1.	440	452
47.300	-1.	455	465	452	-1.	422	452
47.937	-1.	450	460	452	-1.	442	452
48.650	-1.	450	468	450	-1.	450	450
49.400	-1.	455	458	450	-1.	-1.	-1.
50.250	-1.	450	463	452	-1.	450	452
50.850	-1.	460	460	452	-1.	450	452
51.217	-1.	460	458	455	-1.	450	455
51.883	-1.	460	458	455	-1.	465	455
52.033	400	-1.	-1.	-1.	-1.	-1.	-1.
52.633	400	-1.	-1.	-1.	-1.	-1.	-1.
53.267	375	-1.	-1.	-1.	-1.	-1.	-1.
53.567	340	-1.	-1.	-1.	-1.	-1.	-1.
54.183	60	-1.	-1.	-1.	-1.	-1.	-1.
54.733	0	-1.	-1.	-1.	-1.	-1.	-1.

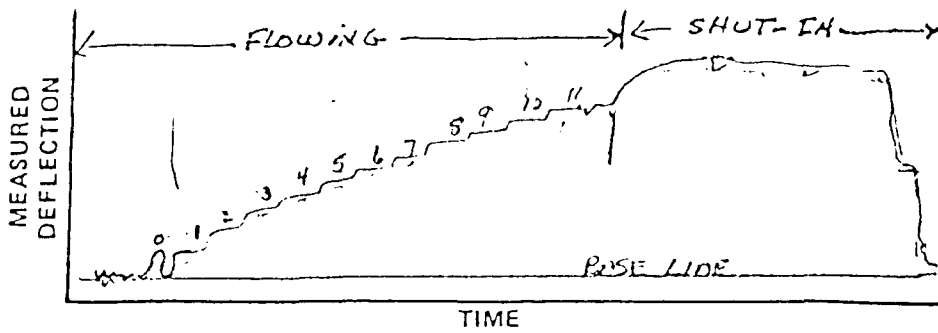
A.2: DATA FROM SAMPLING SPOOLS

DELTIME	PI3	TI3	PI4	TI4	PI5	TI5	PI6	TI6
25.733	270	-1.	110	-1.	62	-1.	40	-1.
26.200	260	-1.	110	-1.	59	-1.	38	-1.
26.517	275	432	125	372	56	330	40	307
27.050	268	432	125	377	59	331	40	307
27.600	270	432	120	373	59	333	40	309
28.150	275	431	120	373	55	327	40	309
28.633	275	428	120	374	58	325	40	306
29.200	275	428	120	374	57	326	40	306
29.767	275	432	120	372	58	325	40	-1.
30.267	250	432	120	373	56	326	40	307
30.833	250	434	100	373	54	325	40	309
31.733	250	430	120	373	58	327	38	310
37.883	210	-1.	120	-1.	50	-1.	30	-1.
43.233	350	447	180	392	70	346	60	328
43.600	325	452	165	393	82	348	55	328
44.000	335	454	165	393	80	349	59	329
44.383	335	454	170	393	91	348	65	329
44.800	350	452	170	395	84	348	60	326
45.167	338	454	170	395	80	350	60	326
45.633	335	454	165	394	80	350	60	329
46.150	323	456	170	398	85	350	61	328
46.817	355	457	160	395	80	350	58	329
47.367	343	453	170	395	82	350	62	329
47.967	340	451	175	396	79	350	58	328
48.750	350	452	175	393	86	345	58	323
49.337	360	454	175	395	80	347	58	328

A.3: DATA FROM MUFFLER AREA

DELTIME	PI10	PI9	LI1	LI1A	PI11	WF1	WF2	TMF
5.150	20.0	-1.0	-1.000	-1.000	-1.0	-1.00	-1.00	-1.00
5.183	75.0	-1.0	-1.000	-1.000	10.0	-1.00	-1.00	-1.00
5.267	60.0	-1.0	-1.000	-1.000	5.0	-1.00	-1.00	-1.00
5.350	80.0	-1.0	-1.000	-1.000	13.0	-1.00	-1.00	-1.00
5.433	80.0	-1.0	-1.000	-1.000	12.0	-1.00	-1.00	-1.00
5.517	75.0	-1.0	-1.000	-1.000	12.0	-1.00	-1.00	-1.00
5.633	82.0	-1.0	-1.000	-1.000	12.0	-1.00	-1.00	-1.00
6.133	70.0	-1.0	12.625	10.438	-1.0	710.86	443.37	968.19
6.317	80.0	-1.0	-1.000	-1.000	12.0	-1.00	-1.00	-1.00
6.500	70.0	-1.0	-1.000	-1.000	12.0	-1.00	-1.00	-1.00
6.650	85.0	-1.0	-1.000	-1.000	12.0	-1.00	-1.00	-1.00
6.867	75.0	-1.0	-1.000	-1.000	12.0	-1.00	-1.00	-1.00
7.100	75.0	-1.0	-1.000	-1.000	12.0	-1.00	-1.00	-1.00
7.317	70.0	-1.0	-1.000	-1.000	10.0	-1.00	-1.00	-1.00
7.683	70.0	-1.0	-1.000	-1.000	10.0	-1.00	-1.00	-1.00
7.950	70.0	-1.0	-1.000	-1.000	9.0	-1.00	-1.00	-1.00
8.217	70.0	-1.0	-1.000	-1.000	9.0	-1.00	-1.00	-1.00
8.483	80.0	-1.0	10.875	10.938	-1.0	490.92	497.95	668.63
8.717	50.0	-1.0	10.375	9.188	-1.0	436.81	323.09	594.94
9.000	20.0	-1.0	7.625	6.188	-1.0	203.45	121.16	277.10
9.267	15.0	-1.0	7.875	6.438	-1.0	220.41	133.68	300.20
9.583	27.0	-1.0	8.375	7.188	-1.0	256.78	175.71	349.73
9.800	25.0	-1.0	7.875	6.438	-1.0	220.41	133.68	300.20
9.867	20.0	-1.0	8.000	6.688	-1.0	229.19	146.93	312.16
10.017	20.0	-1.0	8.000	9.313	-1.0	229.19	334.10	312.16
10.250	20.0	-1.0	8.000	9.313	-1.0	229.19	334.10	312.16
10.517	20.0	-1.0	7.875	9.313	-1.0	220.41	334.10	300.20
10.817	30.0	-1.0	7.440	8.563	-1.0	191.43	271.27	260.72
14.133	75.0	33.0	-1.000	-1.000	-1.0	-1.00	-1.00	-1.00
14.433	95.0	37.0	1.875	3.688	-1.0	63.17	169.90	86.03
16.117	50.0	-1.0	4.125	4.688	-1.0	199.78	240.09	272.10
16.283	110.0	-1.0	5.125	5.188	-1.0	272.76	277.52	371.50
16.600	45.0	-1.0	3.625	3.688	-1.0	165.74	169.90	225.74
17.100	40.0	-1.0	3.125	3.188	-1.0	133.59	137.50	181.95
17.467	50.0	-1.0	2.625	2.688	-1.0	103.56	107.19	141.05
18.067	-1.0	-1.0	1.625	1.688	-1.0	51.14	54.07	69.65
18.450	-1.0	-1.0	1.375	1.688	-1.0	39.94	54.07	54.40
19.217	-1.0	-1.0	2.125	2.188	-1.0	75.95	79.26	103.45
19.833	-1.0	-1.0	1.750	1.688	-1.0	57.05	54.07	77.71
20.417	-1.0	-1.0	1.625	1.688	-1.0	51.14	54.07	69.65
20.933	-1.0	-1.0	1.625	1.688	-1.0	51.14	54.07	69.65
21.683	-1.0	-1.0	1.625	1.688	-1.0	51.14	54.07	69.65
22.583	-1.0	-1.0	1.375	1.563	-1.0	39.94	48.26	54.40
23.317	35.0	-1.0	-1.000	-1.000	5.0	-1.00	-1.00	-1.00
23.350	25.0	-1.0	-1.000	-1.000	-1.0	-1.00	-1.00	-1.00
23.533	22.0	-1.0	-1.000	-1.000	3.0	-1.00	-1.00	-1.00
23.783	25.0	-1.0	-1.000	-1.000	2.0	-1.00	-1.00	-1.00
24.500	23.0	-1.0	-1.000	-1.000	6.0	-1.00	-1.00	-1.00
24.950	25.0	-1.0	-1.000	-1.000	7.0	-1.00	-1.00	-1.00
25.350	25.0	-1.0	-1.000	-1.000	7.0	-1.00	-1.00	-1.00

DELTIME	PI10	PI9	L11	L11A	PI11	WF1	WF2	TMF
25.767	25.0	-1.0	-1.000	-1.000	10.0	-1.00	-1.00	-1.00
26.250	25.0	-1.0	-1.000	-1.000	10.0	-1.00	-1.00	-1.00
26.717	25.0	-1.0	-1.000	-1.000	9.0	-1.00	-1.00	-1.00
27.167	25.0	-1.0	-1.000	-1.000	8.0	-1.00	-1.00	-1.00
27.700	20.0	-1.0	-1.000	-1.000	10.0	-1.00	-1.00	-1.00
28.267	23.0	-1.0	-1.000	-1.000	8.0	-1.00	-1.00	-1.00
28.783	28.0	-1.0	-1.000	-1.000	7.0	-1.00	-1.00	-1.00
29.267	25.0	-1.0	-1.000	-1.000	7.0	-1.00	-1.00	-1.00
29.850	20.0	-1.0	-1.000	-1.000	5.0	-1.00	-1.00	-1.00
30.333	25.0	-1.0	-1.000	-1.000	7.0	-1.00	-1.00	-1.00
30.917	20.0	-1.0	-1.000	-1.000	8.0	-1.00	-1.00	-1.00
31.817	10.0	-1.0	-1.000	-1.000	-1.0	-1.00	-1.00	-1.00
38.050	20.0	7.0	2.125	3.688	-1.0	75.95	169.90	103.45
38.500	50.0	10.0	3.750	3.688	-1.0	174.08	169.90	237.10
38.883	50.0	7.0	3.500	3.688	-1.0	157.52	169.90	214.54
39.183	155.0	25.0	5.875	-1.000	-1.0	331.18	-1.00	451.07
39.267	150.0	24.0	6.250	-1.000	-1.0	361.42	-1.00	492.26
39.283	150.0	24.0	6.250	-1.000	-1.0	361.42	-1.00	492.26
39.350	135.0	22.0	6.000	-1.000	-1.0	341.19	-1.00	464.70
39.433	130.0	22.0	5.625	-1.000	-1.0	311.39	-1.00	424.12
39.800	127.0	20.0	5.500	5.688	-1.0	301.61	316.31	410.80
40.033	120.0	20.0	5.458	5.688	-1.0	298.35	316.31	406.35
40.300	-1.0	15.0	5.250	5.188	-1.0	282.30	277.52	384.49
40.333	110.0	17.0	-1.000	-1.000	-1.0	-1.00	-1.00	-1.00
40.717	115.0	15.0	5.000	5.188	-1.0	263.31	277.52	358.64
41.117	20.0	15.0	1.750	1.688	-1.0	57.05	54.07	77.71
41.433	30.0	15.0	3.500	3.688	-1.0	157.52	169.90	214.54
41.833	45.0	15.0	3.375	3.438	-1.0	149.42	153.45	203.51
42.333	60.0	15.0	3.625	3.938	-1.0	165.74	186.81	225.74
42.683	45.0	15.0	2.750	3.188	-1.0	110.86	137.50	150.99
42.967	-1.0	-1.0	2.750	3.188	-1.0	110.86	137.50	150.99
43.217	40.0	10.0	2.750	3.188	-1.0	110.86	137.50	150.99
43.567	50.0	10.0	2.875	3.188	-1.0	118.29	137.50	161.12
44.267	45.0	10.0	2.875	3.188	-1.0	118.29	137.50	161.12
45.017	40.0	10.0	2.750	2.688	-1.0	110.86	107.19	150.99
45.433	40.0	10.0	2.625	2.938	-1.0	103.56	122.07	141.05
46.637	40.0	12.0	2.625	2.938	-1.0	103.56	122.07	141.05
46.933	40.0	8.0	2.625	2.688	-1.0	103.56	107.19	141.05
47.467	43.0	8.0	2.625	2.688	-1.0	103.56	107.19	141.05
48.033	38.0	7.0	2.375	2.438	-1.0	89.43	92.91	121.81
48.800	45.0	7.0	2.750	2.688	-1.0	110.86	107.19	150.99
49.437	45.0	7.0	2.625	2.563	-1.0	103.56	99.97	141.05
50.383	35.0	7.0	2.625	3.063	-1.0	103.56	129.72	141.05
51.150	40.0	10.0	2.500	3.188	-1.0	96.42	137.50	131.33
51.600	-1.0	-1.0	1.875	2.688	-1.0	63.17	107.19	86.03
52.367	0.0	5.0	-1.000	-1.000	-1.0	-1.00	32.14	-1.00



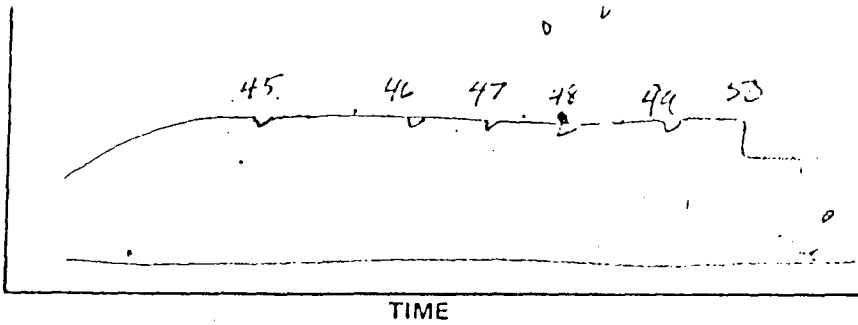
TEST DESCRIPTION A.4: FLOWING SURVEYS AND PRESSURE BUILDUP

850468 (5900 ft)

ELEM. NO.		DATE	ELAPSE TIME		REAL TIME	TIME DEPL INCH	PSI DEPL INCH	PSI @ 30°C	ADJUSTMENTS FACTORS		ADJUSTED		DEPTHS MEASURE	REMARKS
READ NO.	TEST NO.		1985	MIN.					HR.	OF	DEPL	DEPL		
0	2	12-30				0	0		-	-	-	-	SURFACE	ZERO IN
1	2				1415	0	.1425	416.0					275 FT GAGE	
2	2				1451	.3305	.1925	570.0					1500	20 min 510
3	2				1510	.4340	.2150	636.6					2000	
4	2				1522	.5320	.2440	722.5					2500	
5	2				1535	.638	.2710	820.1					3000	
6	2				1550	.7415	.330	977.2					3500	
7	2				1617	.913	.3955	1170.3					4000	20 min 510
8	2				1631	1.012	.4280	1385.0					4500	4497
9	2				1645	1.1165	.540	1598.2					5000	4995
10	2				1659	1.220	.6130	1814.3					5500	5493
11	2				1726	1.410	.6880	2032.6					5950'	5939
					Build-up									and time
12	2	12-30	0	0		1.451	.6890	2038.6					5950'	1.272-1.41
13	2		1	.17		1.458	.6955	2060.8					5950'	20"/127
14	2		2	.03		1.465	.7035	2099.3					5950'	1"/100.095
15	2		3	.05		1.472	.720	2133.4					5950'	
16	2		4	.07		1.479	.7305	2164.6					5950'	
17	2		5	.08		1.486	.739	2189.8					5950'	
18	2		6	.10		1.493	.747	2213.5					5950'	
19	2		7	.12		1.500	.754	2234.2					5950'	
20	2		8	.13		1.507	.7605	2253.5					5950'	
21	2		9	.15		1.514	.767	2278.2					5950'	
22	2		10	.17		1.520	.772	2287.6					5950'	
23	2		11	.18		1.527	.777	2302.4					5950'	
24	2		12	.20		1.534	.781	2314.3					5950'	
25	2		13	.22		1.541	.785	2326.2					5950'	
26	2		14	.23		1.548	.789	2338.0					5950'	

SSSDP 16937
 LASKY Sandia/DeWald
 Supplier
 Carrier
 Received By C. A. Haysler
 Date 1/11/86

MEASURED DEFLECTION



TEST DESCRIPTION (CONTINUED) BUILDUP - ELEMENT 850468 STATE CORN 7-14

ELEM. NO.		DATE	ELAPSE TIME		REAL TIME	TIME DEPL INCH	PSI DEPL INCH	PSI @ 80°C	ADJUSTMENTS FACTORS		ADJUSTED		DEPTHS MEASURE	REMARKS
READ NO.	TEST NO.		MIN.	HR.					OF	DEPL	DEPL	PSI		
27	2	19.5.1	15	.25		1.555	.793	2349.9					5750'	-Buildup-
28	2		16	.27		1.562	.796	2352.8					5950'	
29	2		17	.28		1.569	.7985	2363.2					5950'	
30	2		18	.30		1.576	.8015	2375.1					5950'	
31	2		19	.32		1.583	.804	2382.5					5950'	
32	2		20	.33		1.590	.8065	2389.9					5950'	
33	2		21	.35		1.597	.8095	2395.9					"	
34	2		22	.37		1.604	.810	2400.3					"	
35	2		23	.38		1.611	.812	2406.2					"	
36	2		24	.40		1.618	.8135	2410.2					"	
37	2		25	.42		1.625	.8150	2415.1					"	
38	2		26	.43		1.632	.8160	2418.1					"	
39	2		27	.45		1.639	.8175	2421.5					"	
40	2		28	.47		1.646	.8185	2425.5					"	
41	2		29	.48		1.652	.8195	2428.5					"	
42	2		30	.50		1.660	.821	2432.9					"	Time Unit
43	2		40	.67		1.729	.828	2453.2					"	10 ³ = .0675
44	2		50	.83		1.799	.8320	2465.5					"	
45	2		60	1.0		1.868	.8350	2474.4					"	
46	2		120	2.0		2.307	.840	2489.3					"	
47	2		180	3.0		2.742	.841	2492.2					"	
48	2		240	4.0		3.176	.841	2492.2					"	
49	2		300	5.0		3.602	.841	2492.2					"	
50	2		327	5.45		3.932	.841	2492.2					5950'	Pull out 174
51	2		343	5.72		4.120	.555	1642.6					4000'	Ascending

LEF WIDEN

U.T. DATA

Bechtel National, Inc.

Engineers — Constructors



Fifty Beale Street
San Francisco, California

Mail Address: P. O. Box 3965, San Francisco, CA 94119

5th May, 1986

Letter No. 16937-400-269

Mr. Harold J. Lechtenberg
U.S. Department of Energy
1333 Broadway
Oakland, California 94612

Subject: March letter re: GeothermEx Flow Test
Salton Sea Scientific Drilling Project
Bechtel Job No. 16937-400

Dear Harold:

On March 14, 1986, you were sent a draft copy of the GeothermEx Flow Test Report (December, 1985). In order that we may finalize the report, please provide your comments no later than May 13, 1986.

If you have questions, please contact C. A. Harper (415) 768-9918 or me at (415) 768-9232.

Very truly yours,

D. T. Rabb
Site Manager
Research and Development

DTR/jak

Dave Rabb.

Comments on Flow Test Report

If there are other methods available to interpret the build up test an explanation of why the constant pressure outer boundary and an infinite outer boundary models were chosen would appear to be appropriate. Details of the methods and assumptions used to determine skin factor and md-ft would be helpful. Is there any significance in the fact that md-ft and skin factor differ when calculated by the two different methods?

Without additional data to support, is the statement on page 17 para 4 "..... constant - pressure outer boundary should possibly be used to fit the data." somewhat speculative?

Has all raw data that was collected during the test been incorporated in the report.

H. J. Lechtenberg

Bechtel National, Inc.

Engineers—Constructors



Fifty Beale Street
San Francisco, California

Mail Address: P O Box 3965, San Francisco, CA 94119

March 14, 1986
16937-300-258

John Sass
U. S. Geological Survey
2255 North Gemini Drive
Flagstaff, Arizona 86001

Wilfred Elders
University of California
Riverside, California 92521

Gentlemen;

Enclosed for your review is a draft of the GeothermEx report on the first flow test. We would appreciate your comments back by the end of April

Sincerely,



C. A. Harper

cc: H. J. Lechtenberg (w/o)

DON MICHELS ASSOCIATES

P.O. BOX 895

WHITTIER, CALIFORNIA 90608

213/699-8678
~~699-8678~~
698-5728

March 2, 1985

Dr. W. A. Elders
IGPP
University of California
Riverside, California 92521

Subject: SSSDP Brine Composition, First Flow Test

Dear Wilf:

After too long a time, the results are available. The precision of the flash fraction determination is about two orders of magnitude more precise than is common in the industry. Part of the reason for taking so long was my amazement about that outcome and a suspicion that it wasn't really so. I've looked very closely at the factors affecting precision, and they seem to be in good order. It looks like we do know the composition of the brine to better than one part per several thousand.

The report accompanying this letter is labeled Part III. The first two parts are description of the surface facility and of the sampling methods, respectively. A draft of those was sent to Sue Goff for her inclusion in the archives description. A copy is enclosed here also, for your information, but without figures. The full set needs some additions and editing before it is ready for final distribution.

Regarding your dissemination of the brine composition to the rest of the scientists, most will be interested in nothing more than Table 4, which will require little to no explanation. For those interested in gases, Table 2 would be important. As far as I'm concerned, you may send out the whole Part III if you wish, but you may divide it any way you wish for brevity or economy.

This has been another episode in a marvelous exercise. These results far exceeded my expectation about sample quality in the sense of internal consistency of the data. Part of that is due to the good gas samples which were obtained through the portable separator borrowed from Al Truesdell at the last moment and appended to the in-line separator. It is an adjunct we need to incorporate next time, too.

Sincerely



Donald E. Michels

encl: Part III, original and one copy
Parts I and II draft

SSSDP

FLUID SAMPLING DURING FLOW TESTS

I. EQUIPMENT AND PROCEDURES

- A. Sampling Hardware
- B. Sample Collection
 - 1. Gases
 - 2. Brines

II. SAMPLES

- A. Brine
 - 1. Analysis of Chloride On-site
 - 2. Basic Composition
 - 3. Collection of Archival Samples
- B. Gases
 - 1. Field Analysis
 - 2. Lab Analysis
 - 3. Carbon Dioxide as a Tracer

I. EQUIPMENT AND PROCEDURES

A. Sampling Hardware

Geothermal well State 2-14 was fitted with a flowline system made mainly from 10-inch pipe, schedule 60. The complete system, approximately in sequence from the wellhead, included:

- multiple control valves,
- supports for accomodating growth of the wellhead due to thermal expansion of the casing,
- diversion line to the mud pit,
- test line of flanged spools that comprised the sampling section,
- by-pass for the sampling section,
- an expansion loop to accomodate thermal expansion of the surface piping,
- second diversion line (blooie line) to the main brine pit,
- metering orifice on the main line,
- James tube assembly
- cylindrical shroud entry to a silencer,
- vertical cylindrical silencer,
- twin discharge lines from the silencer to a stilling tank,
- metering weir at the end of the stilling tank (Figure 1).

The following description concerns the taking of steam and brine samples from the sampling section made of flanged spools.

The axis of the sampling section was colinear with the main flow line beyond the diversion point for the bypass. All the sampling section and the nearby piping were at the same elevation. Fluid could be throttled by a valve located at the head of the sample section (below the bypass connection). That valve constituted the major flow control point when the sampling section was operational.

All spools were constructed in the same way. Each was approximately ten feet long and all ends were flanged. Taps for pressure and temperature indicators were located about 4 feet upflow from the downstream ends, at the 9- and 12-o'clock positions.

The first spool of the test section was located about 15 feet down the flow direction from the throttle valve and was numbered S-3. The three subsequent spools were numbered sequentially through S-6. Those four spools and their accoutrements comprised the sampling section.

Three orifice plates were located, respectively, between S-3 and S-4, S-4 and S-5, and S-5 and S-6. Their purpose was to establish a 4-step cascade of temperature-pressure conditions in the sampling section. Each step would be characterized by pressure and temperature indicators. The sampling environments in the spools would be different also, reflecting sequential increases in the steam/brine ratios. Having a series of steam/brine ratios was a principal objective in the design of the sample section.

B. Sample Collection

1. Gas Samples

Each spool was equipped with an in-line separator (Figure 2). Essentially, this is a short pipe mounted radially inside a small chamber appended to the spool at the 12-o'clock position, beneath and connected to an access valve. As two-phase fluid moves through the short pipe toward the valve, brine droplets tend to deposit to the walls so that enriched steam exits the valve.

In some situations, steam from the access valve is brine-free and can be sampled directly. Otherwise, an additional separation effort is needed. In the case of good quality steam, a pressure reduction apparatus (Figure 3) was used to lead steam from the in-line separator to a low-pressure discharge tubing connected to a condensing coil. Condensate could be collected into sample containers open to the atmosphere. Non-condensable gases, with condensate, could then be collected by sampling trains, evacuated bulbs, syringes, etc.

Alternatively, a portable centrifugal separator was connected to the in-line separator. The steam discharge from the portable separator could be directed through any of various cooling coil assemblies to condense the steam fraction. Collection of condensate could be made into containers open to the atmosphere. Non-condensable gases, with accompanying steam condensate, were collected in pre-evacuated bulbs or in syringes.

2. Brine Samples

The objectives in brine sampling relate to obtaining a parcel of liquid that can be characterized in regard to its status in the flow line at the point of sampling, then preserving it for transport and analysis. Major factors to consider are the pressure in the flow line, two-phase conditions in the flowline, and chemical instabilities of the sample due to cooling. The cooling instabilities arise from the in-flowline cooling by steam release prior to sampling and from the in-sampler cooling.

Techniques of sample collection are aimed mainly at avoiding two kinds of problems. The first is incorporation of vapor into the sampling stream which, in the cooling coil, condenses, diluting the sample by an unknown amount. The second is to avoid plugging in the sample tubing that occurs due to particulates carried in the brine, deposition of silica scale in the mid-temperature areas, or deposition of sodium chloride in the cooler zones.

Each flowline spool was equipped with a 4-inch diameter downcomer about 16 inches long, mounted at 6 o'clock positions about three feet up from the downstream flanges. These served as liquid traps so that a probe inserted into them would be below a liquid level, thereby avoiding the collection of steam or a two-phase mixture.

Two valves were on these downcomers. One permitted insertion of a hollow steel probe into the space of the downcomer, the other allowed blowdown so that fresh fluid could be assured in the sampling zone.

The steel probe was inserted through a fitting equipped with an elastomer gland to control blowout of brine. It served as the leading part of an external assembly that included a cooling coil followed by a flow control valve (Figure 4).

Cooled brine exits the flow control valve as a stream that can be directed into sample containers. For many components collections are made into containers pre-loaded with dilutant water or a dilutant-preservative, such as acid. Exact dilutions can be determined by weighings made before and after the sample collections.

II. SAMPLES

A. Brine

1. Analysis of Chloride On-site

Samples of chilled brine from the 6-o'clock downcomers were collected into weighed amounts of distilled water, diluted into the sea water range of chloride concentrations as determined by weighing, and the chloride was titrated by oceanographic methods. The analyses were later verified in the laboratory. The increasing concentrations of chloride in the set of samples can be used to compute the incremental steam releases between the orifice plates.

2. Basic Composition

Chilled brine from the cooling coil out of the 6-o'clock downcomers was collected into about 2.5 volumes of

0.1N nitric acid to make the field samples. These samples served as stock from which analytical aliquots were prepared later, in the laboratory.

Composition of the lab aliquots was scanned for 37 elements by the method of ICP (inductively coupled plasma) and 15 components were typically above limits of detection. Additionally, analyses were made for chloride and ammonia.

The set of samples from the sequence of flowline spools also provides a redundant check on the steam releases identified in part 1.

3. Collection of Archival Samples

Because the purposes of archival samples are not clearly defined, different preservative methods were employed. All collections were into polyethylene bottles with polypropylene caps. Bottles and caps had been pre-rinsed with nitric acid, flushed with distilled water, and air dried.

The brine samples will undergo several changes during storage. Some are due to uncompensated reactivity of the brine. Others are due to in-diffusion of oxygen through the container walls and seals.

Three methods of sample preservation were used, none are perfect, but collectively, they will permit a variety of analytical investigations aimed at either brine or precipitates. Methods a and b yield abundant precipitates. Method c yields a true solution, although it is supersaturated in silica.

- a. No preservative -- Brine was collected directly into polyethylene bottles, which were filled to the top, and the caps seated after squeezing the bottle slightly to expel air. Sixteen 1/4-liter bottles were used.
- b. Distilled water -- Bottles were pre-loaded with distilled water and fillings were made to marks so as to yield a dilution of about 6:1. Exact dilutions were determined later by weighing. Air remained inside the bottles while the caps were being seated. Two 1-liter and four 1/4-liter bottles were used.
- c. Dilute nitric acid -- Bottles were preloaded with the 0.1 N nitric acid and fillings were made to marks so as to yield dilutions of about 3.5 to 1. Remaining treatment was as in part b. Two 1-liter and four 1/4-liter bottles were used.

B. Gases

The suite of non-condensable gases is dominated by carbon dioxide with the other prominent gases being methane, nitrogen, and hydrogen sulfide. Several other gases can be found in trace amounts. Gases were sampled from the in-line separators and from the portable centrifugal separator attached, in series, to the in-line separator. Different investigators had their own methods of trapping and preserving selected gas species. There was no attempt to collect gas for archive samples.

The basic characterization seeks only the carbon dioxide, hydrogen sulfide and the collective amount of other gases without regard to their identity. The following description applies to the samples taken for basic characterization of the gas contents.

1. Field Analysis

The sampling method used is a field assay based on pressure-volume-temperature relationships and the solubility of gases in water (condensate). A closed syringe (50 ml) is attached to the discharging cooling coil after flow through it is stabilized. The discharge pressure extends the syringe plunger while the mixture of condensate and gases fill the syringe body. A clamp limits the plunger motion, after which the syringe body continues to fill at constant volume as the syringe approaches system pressure. Care is taken to assure that the collection continues at ice temperature. When flow into the syringe ceases, readings are taken of the system pressure, liquid volume and total volume in the syringe. The condensates were subsequently collected into tared bottles for later weighing to obtain more accurate results.

Because the geothermal gases are a mixture, each assay involves two collections, one beginning with an empty syringe, as described. The other collection is similar, except for beginning with a syringe pre-loaded with a hydroxide solution. In the second collection, carbon dioxide and hydrogen sulfide are totally solubilized into the liquid. Temperature, volumes and pressure are treated as before, although considerably more condensate enters the syringe upon pressurization.

The two sets of PVT data permit computation of (i) weight percent of carbon dioxide in the steam and (ii) mole fraction of carbon dioxide in the non-condensable suite.

2. Lab Analysis

The hydroxide-condensate mixtures were saved into bottles and preserved with a solution of zinc acetate.

Analysis for sulfide was made later in a laboratory by standard methods.

3. Carbon Dioxide as a Steam Tracer

The results of the above methods are all based on the steam (condensate) as a carrier and concentrations refer to the steam available at the specific sampling point. By collecting samples at all four of the sampling spools, the increments in apparent gas contents are measures of the incremental steam yields.

Because the gases are essentially all exsolved at the first sampling point, algebraic manipulations can be made, yielding computations of the total steam fraction. Thereupon, the gas contents can be referenced to a basis of total fluid flow. The brine components are then similarly reported on a basis of total flow.

SSSDP

SALTON SEA SCIENTIFIC
DRILLING PROJECT

FLUID SAMPLING DURING FLOW TESTS

PART III. RESULTS OF FIRST FLOW TEST

DECEMBER 29-30, 1985

by

Donald E. Michels

February 28, 1986

SSSDP

FLUID SAMPLING DURING FLOW TESTS

PART III. RESULTS

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SSSDP

FLUID SAMPLING DURING FLOW TESTS

Donald E. Michels

PART III. RESULTS

Samples of brine were taken during the first flow test of State 2-14, on December 29 and 30, 1985. Steam samples were taken on December 30. Sampling was done through sets of ports that gave access to four different T-P and flash conditions inside the flowline.

Results from these samples are used to compute the steam fractions at the various sampling ports as well as the basic compositions there of the brine and steam phases. The pre-flash brine composition is derived from these measurements of steam fraction and flash temperature.

Enthalpy of the geothermal brine is computed from equations for enthalpy of pure NaCl brines and steam calibrated through the steam fractions measured in the sequence of sampling ports.

A. Field Concentrations

1. Brines

Brine samples considered in this section were taken from four sampling ports on two successive days. Brine issued from the sampling/cooling coils (ID = 2 mm) as a continuous jet into the atmosphere. Samples for basic characterization were collected into dilute nitric acid, without filtering. Field dilution factors were nominally 2.5. The field samples were further diluted in the laboratory by an additional factor near 23, again without filtering. The second dilution was with about 20 percent nitric acid solution, density 1.145 g/ml.

Analyses for 33 elements were made by a commercial laboratory, using inductively coupled plasma (ICP). Additional aliquots were analyzed for chloride by titrimetry and for ammonium by specific ion electrode.

Additional samples were taken in the field, for chloride analyses by an oceanographic method. Results are listed separately in Table 1. These highly accurate analyses of chloride were provided to the SSSDP

SSSDP FIRST FLOW TEST

TABLE 1:

UNADJUSTED FIELD CONCENTRATIONS IN BRINE SAMPLES

DAY	DECEMBER 29, 1985			DECEMBER 30, 1985							DL
	1750	1755	1755	1215	1215	1341	1341	1430	1255	1255	
PORT	3	4	5	3	3	4	4	5	6	6	
DEGREES F	431	373	327	455	455	395	395	346	328	328	
SAMPLE CODE	B 150	I 161	J 171	G 164	H 164	C 162	D 162	A 165	E 163	F 163	
FIELD DILUTION	2.2959	3.3117	2.2716	2.7514	2.7514	3.2193	3.2193	2.692	2.7055	2.7055	
LAB DILUTION	22.76	22.44	21.92	22.61	22.35	23.91	22.96	21.3	22.34	22.6	
SODIUM	57959	61658	64057	57754	57627	61444	61133	62848	63925	64081	30
CALCIUM	29892	31413	33312	29393	29324	30924	30922	32551	32886	32949	60
POTASSIUM	18301	19796	20396	18310	18314	19428	19366	20031	20217	20292	12
IRON	1682	1834	1906	1698	1694	1776	1771	1656	1893	1900	1
MANGANESE	1588	1713	1766	1586	1584	1734	1685	1748	1758	1768	12
ZINC	570	604	626	560	559	605	600	616	623	625	6
SILICA SiO2	511	470	342	530	530	464	469	434	380	380	25
STRONTIUM	453	482	499	451	449	481	478	496	497	498	.5
AMMONIUM	388	363	383	391	371	437	387	361	422	406	
BORON	282	304	314	281	261	301	299	309	311	312	6
BARIUM	220	236	251	216	219	223	225	237	241	245	30
LITHIUM	212	226	237	211	211	223	222	232	235	235	2.5
LEAD	108	114	119	106	104	108	107	115	123	121	12
MAGNESIUM	41	45	43	38	43	40	39	45	48	48	25
ANTHRAXUM	9	13	9	11	11	7	6	0	0	11	6
COPPER	5	6	9	5	5	6	6	5	5	5	3
CADMIUM	0	0	3	0	0	0	0	0	3	0	3
TUNGSTEN	0	6	4	0	0	0	0	0	0	0	6
CHLORIDE (1)	173192	173747	185954	168264	170142	174115	172555	186291	184068	185302	1
SUM	285324	293030	310229	279807	281466	292316	290270	308177	307633	309178	
OCEAN CL (2)	171000	179200	186900		171700		181800	186900		188600	
CALC CL (3)	166096	176304	184203	164900	164547	174834	174112	180490	183124	183540	
OCL/CCL (4)	1.0295	1.0164	1.0146	0	1.0435	0	1.0442	1.0355	0	1.0276	

FOR PORT 6, DEC 29: OCEAN CL = 188600, DEG F = 309

- (1) BY COMMERCIAL LAB WITH ORDINARY PRECISION
- (2) BY OCEANOGRAPHIC METHOD (MIT) ACCURACY +/- 400 PPM
- (3) COMPUTED FROM EQUIVALENTS OF CATIONS
- (4) (2)/(3)

DET. LIMITS FOR UNDETECTED ANALYTES ARE:

TI 6	AL 30	BE 0.03	CO 1	SH 6
U 300	AG 2.5	BI 120	CR 2.5	SB 35
V 60	AS 30	CD 3	MO 60	TE 60
ZR 6	AU 5	CE 12	NI 6	TH 120

Project by A. Campbell and S. Teach of MIT. The standardizations and weighed dilutions used in their procedure yield an accuracy/precision near ± 400 ppm for single analyses in the concentration range of the field samples, near 180,000 ppm chloride.

Analytical results and other factors are shown in Table 1, "Unadjusted Field Concentrations in Brine Samples". Values in Table 1 appear to be accurate generally to better than $\pm 3.5\%$ relative error. Precisions are better. The values in Table 1 are refined by procedures described in following sections.

Detection limits (DL) of the ICP method for each of its analytes were provided by the analyst in reference to the material as analyzed. Those values were multiplied by the average net dilution factor to obtain the detection limits listed in Table 1.

2. Steam

The gases in steam were sampled only on December 30. Results are given in Table 2, based on those determinations that appeared sound after review of the data. Two determinations for Port 4 were defective. A third result for Port 6 (9573 ppm at 1209hrs) was rejected for averaging.

CO₂ comprises about 98.5 mole percent of the total gases. Separate analysis were made for CO₂ and H₂S.

In the analysis procedure, other gases were determined as an undifferentiated molar sum, but they are reported in Table 2 in units of weight. An average molecular weight of 24, based on other wells, was used to provide entries in Table 2. For data on these gases in State 2-14, see other SSSDP specialist reports.

3. Concentration Adjustments and Analytical Precision

Chloride analyses provide special tools for evaluating brine data. Mainly this is because analysis for chloride can be made highly accurate. Also, chloride constitutes almost the sole anion in these brines. Results for the commercial lab analysis of chloride are given in Table 1 to show that overall analyses are essentially complete and conformable with the results from the oceanographic method. The commercial lab results for chloride are not used further in this discussion.

The oceanographic method for chloride analysis has a high accuracy and precision, in the range of ± 400 ppm per analysis. Replicate analyses were made of the samples so that results shown in Table 1 have smaller, but variable uncertainties, some as little as $\pm 0.06\%$ (110ppm). Because chloride constitutes almost all the anion material in the brine, its high accuracy can be partly transferred to the cation results by a charge balance procedure.

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**TABLE 2: FIELD CONCENTRATIONS OF GASES IN STEAM
ppm by weight**

Carbon Dioxide

Time\Port	3	4	5	6
1115		10650		
1230				9052
1246				8986
1321	15860			
1340	15580			
1345	15500			
1421			9629	
1426			9415	
1432			9704	
Average	15642	10650	9582	9019

Hydrogen Sulfide

1126	46.2	
1507		38.3

Other Non-Condensable Gases (1)

1126	57	
1507		50
1507		50

**GAS CONCENTRATIONS ON A TOTAL FLOW BASIS
ppm by weight**

	0.1094	0.1588	0.1818	0.1891	Avg
Flash Fraction					
Carbon Dioxide	1711	1691	1742	1705	1712
Hydrogen Sulfide		7.34	6.96		7.15
Other Gases (1)		9.05	9.09		9.07

(1) Presumed mixture of Nitrogen and Methane;
molar ratio 2:1; avg. mol. wt = 24

In Table 1, the line "COMP CL" is the electric charge equivalent of the non-chloride ions. The ratio "OCL/CCL" (oceanographic chloride/computed chloride) is taken to indicate the relative accuracy of the summed ICP results, about ± 1 to $\pm 3.5\%$. Table 3 is derived from Table 1 by multiplying the analytical values in columns by the corresponding values of OCL/CCL. This causes the overall cation assembly to be as highly accurate as the chloride results. The accuracy of the individual cation concentrations must also be improved, although specific improvements cannot be quantified.

Three pairs of brine samples were replicates prepared from field samples. The right side of Table 3 shows the commercial lab's precision in terms of the deviations (D) given by the differences between sample pairs (E,F; G,H; J,K) divided by their sums. The fourth column in Table 3, "Rootsum squares" (RSS) shows the square roots of the average square deviations. These are approximately the standard error/1.414.

Eight elements have RSS values smaller than 0.003, indicating a generally excellent reproducibility within the ICP system. The exceptions are minor components for which the ratios of concentration/detection limit are smaller than 100, and for ammonium.

Table 4 is the best composite presentation of brine and steam data. Column entries reflect charge balancing and include averages where available. Additional information shown, flash fractions, port temperatures, and preflash brine concentrations, are described below. Also provided is a computed composition for brine at Port 6 on December 29, for which there was no physical sample in this series.

B. Pre-Flash Composition of Brine

The pre-flash composition of the brine ranges nominally from 10 to 20 percent less than the field concentrations. It is useful to determine the precise flash fractions to convert from one basis to another. Additionally, the steam compositions of Table 2 are transposed to a whole-brine basis, shown in Table 4, by the flash fractions determined in this section.

The surface equipment did not include a steam separator, nor any independent (mechanical) measurements of separated steam and brine. Thus, the flash fractions are not available in the usual commercial form. Neither is it possible to compute the steam releases from temperature-enthalpy relationships. Enthalpy losses were not quantified between the flash point (about 4500 ft depth in the well) and the sample points, nor are the enthalpy-temperature equations defined for this heavy mixed-salt brine.

However, the flash fractions can be determined from the changes in concentrations of natural tracers in brine and steam. Several tracers are available, particularly the chloride determined by the oceanographic method and the several cations, identified as being analyzed with good precision. Also, the carbon dioxide in the steam

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TABLE 3: CONCENTRATIONS IN BRINE; ADJUSTED FOR CHARGE BALANCE (1)

DAY HOUR PORT CODE	DECEMBER 29			DECEMBER 30, 1965				DEC 30	DEC 30	DEC 30	APPARENT PRECISION (2)		
	1750 J B 150	1755 4 I 161	1755 5 J 171	1215 3 G 164	1215 3 H 164	1341 4 C 162	1341 4 D 162	1430 5 A 165	1255 6 E 163	1255 6 F 163			ROOTSUM E,F G,H J,K SQUARES
SODIUM	59320	62292	64616	59795	59791	63520	63462	64702	65458	65469	.00004	.00046	-9.E-5 .00027
CALCIUM	30594	31736	33602	30432	30425	31968	32099	33511	33675	33662	.00012	-.00020	.00019 .00119
POTASSIUM	18730	19999	20574	18957	19001	20085	20104	20622	20702	20732	-.0012	-.0005	-.0007 .00065
IRON	1722	1852	1923	1758	1758	1836	1838	1911	1938	1941	-6.E-5	-.0006	-.0007 .00053
MANGANESE	1625	1731	1781	1643	1644	1793	1749	1799	1800	1806	-.0004	.01241	-.0016 .00723
ZINC	584	610	632	579	580	625	623	634	638	638	-.0001	.00180	-.0004 .00106
SILICA SiO2	523	475	345	548	549	480	487	446	389	388	-.0009	-.0072	.00024 .00421
STRONTIUM	463	487	503	467	466	498	496	511	509	509	.00172	.00171	-.0004 .00142
AMMONIUM	397	367	386	405	384	452	402	371	432	415	.02599	.05815	.02099 .03872
BORON	289	307	317	291	292	311	310	319	318	319	-.0010	.00173	-.0004 .00119
BARIUM	225	238	253	226	227	230	233	244	246	250	-.0027	-.0068	-.0079 .00625
LITHIUM	217	228	240	218	218	230	231	239	241	240	-.0004	-.0011	.00100 .00088
LEAD	111	115	120	110	108	112	111	119	126	124	.00987	.00290	.00839 .00767
MAGNESIUM	42	46	44	39	45	42	40	46	49	49	-.0620	.01819	-.0046 .03738
OCEAN CL	170980	179160	186890	171720	171720	181800	181800	186900	188600	188600			
SUM	285822	299643	312225	287188	287207	303981	303985	312376	315120	315142			

(1) TO CONFORM WITH THE OCEANOGRAPHIC CHLORIDE RESULTS

(2) FOR REPLICATE PAIRS, DIFFERENCE/SUM

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TABLE 4: ELEMENT CONCENTRATIONS IN BRINE
CHARGE BALANCED AND AVERAGED
PPM BY WEIGHT

DAY	FIELD CONDITIONS				FIELD CONDITIONS				PRE-FLASH CONDITIONS		
	DECEMBER 29, 1985				DECEMBER 30, 1985				DEC 29	DEC 30	REL DIF
	1750	1755	1755		1215	1341	1430	1255			
PORT	3	4	5	6	3	4	5	6			
SAMPLE CODE #	B 150	I 161	J 171	CALC	G,H	C,D	A 165	E,F			
PORT TEMP DEG F	431	373	327	309	455	395	346	328			
FLASH FRACTION	.1057	.1461	.1813	.1891	.10942	.1588	.18176	.18913	0	0	
SODIUM	59320	62292	64616	65408	59793	63491	64702	65463	53037	53168	-.0012
CALCIUM	30594	31736	33602	33690	30428	32034	33511	33668	27318	27190	.00235
POTASSIUM	18730	19999	20574	20826	18979	20094	20622	20717	16887	16869	.00055
IRON	1722	1852	1923	1930	1758	1837	1911	1940	1565	1562	.00098
MANGANESE	1625	1731	1781	1804	1643	1771	1799	1803	1463	1472	-.0030
ZINC	584	610	632	641	579	624	634	638	520	519	.00054
SILICA	523	475	345	(475)	549	483	446	389	385	394	-.0112
STRONTIUM	463	487	503	510	467	497	511	509	414	416	-.0026
AMMONIUM	397	367	386	405	395	427	371	424	328	339	-.0169
BORON	289	307	317	321	292	311	319	318	260	260	.00001
BARIUM	225	238	253	251	226	232	244	248	204	199	.01113
LITHIUM	217	228	240	240	218	230	239	240	195	195	.00053
LEAD	111	115	120	122	109	112	119	125	99	97	.00723
MAGNESIUM	42	46	44	46	42	41	46	49	38	37	.00274
CHLORIDE (1)	170980	179160	186890	188609	171720	181800	186900	188600	152938	152930	.00005
SUM	285822	299643	312225	315279	287198	303983	312376	315131	255650	255639	.00002
RESIDUAL SILICA PREFLASH BASIS	468	405	282		489	406	365	315			
CARBON DIOXIDE											1712
HYDROGEN SULFIDE											7.15
OTHER GASES											9.07

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samples constitutes a tracer which is essential for the computation method used below. Since this approach for determining steam fractions has not been reported before, its description will be given in detail.

1. Computational Pathway

The inverse (I) of a concentration represents the amount of solution that accompanies a unit amount of a tracer. Selected inverse concentrations for brine components are shown in Table 5A, based on Tables 2 and 4. Successive decreases in the inverses for the series of brine samples represent the relative weights of water lost as steam between the sample points. Concomitantly, the inverses of gas concentrations in steam increase through the series of sample points, due to identically the same steam that affected the brine samples.

Converting inverse concentrations to flash fractions on a basis of pre-flash brine is a five-step process. First, the flash fractions of steam generated between sampling ports are computed for the brine tracers based on an intermediate brine. Let subscripts i, j represent sampling ports, with i being upstream (hotter). Then, the flash fraction $(F_{i,j})_i$ is the weight fraction of steam released between ports i and j on the basis of i -Port brine, Equation 1.

$$(F_{i,j})_i = (I_i - I_j) / I_i \quad (1)$$

Letting subscript o represent the pre-flash condition, the flash fraction at the i th sampling port, based on i -port brine, $(F_{o,i})_i$, is proportional to other increments of steam as determined by the gas tracers. Letting $IC_{i,j}$ represent the concentration inverses for carbon dioxide at the successive sampling ports, Equation 2 applies.

$$(F_{o,i})_i = (F_{i,j})_i [IC_i / (IC_j - IC_i)] \quad (2)$$

The flash fraction at Port i , given by (2) is converted to a basis of pre-flash brine by Equation 3.

$$(F_{o,i})_o = (F_{o,i})_i / [1 + (F_{o,i})_i] \quad (3)$$

The flash fractions for intermediate steps, computed from (1), are converted to a basis of pre-flash brine by Equation (4).

$$(F_{i,j})_o = (F_{i,j})_i [(F_{o,i})_o / (F_{o,i})_i] \quad (4)$$

The cumulative flash fractions through the series of sampling ports, on a basis of pre-flash brine, are given by addition, as in Equation (5).

$$(F_{o,j})_o = (F_{o,i})_o + (F_{i,j})_o \quad (5)$$

In principle, each brine tracer provides a quasi-independent estimate of the flash fraction. All share the only suitable gas tracer, carbon dioxide. Those estimates can be averaged. Alternatively, if several brine tracers are available, values for $(F_{i,j})_i$, computed in the first step above, can be averaged for the

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TABLE 5A: CONCENTRATION INVERSES

DAY	DEC 29	DEC 29	DEC 29	DEC 30	DEC 30	DEC 30	DEC 30
HR	1750	1755	1755	1215	1341	1430	1255
PORT	3	4	5	3	4	5	6
CODE	B 150	I 161	J 171	G,H	C,D	A 165	E,F
CALCIUM	32.686	31.510	29.760	32.864	31.217	29.841	29.702
LITHIUM	4614.1	4382.4	4175.1	4579.9	4342.5	4180.3	4161.6
POTASSIUM	53.390	50.003	48.606	52.690	49.766	48.491	48.270
IRON	580.83	539.85	520.10	568.84	544.33	523.24	515.53
SODIUM	16.858	16.053	15.476	16.724	15.750	15.455	15.276
BORON	3458.7	3258.7	3153.0	3428.4	3217.4	3138.6	3139.8
ZINC	1712.7	1639.9	1583.1	1725.8	1601.7	1577.0	1567.2
O-CHLORIDE	5.8486	5.5816	5.3507	5.8234	5.5006	5.3505	5.3022
CO2 IN STEAM				63.93	93.897	104.36	110.88

TABLE 5B: FLASH FRACTION ESTIMATES
BASED ON PORT 3 BRINE

CALCIUM	.03598	.08952	.05012	.09200	.09624
LITHIUM	.05021	.09514	.05183	.08726	.09134
POTASSIUM	.06344	.08961	.05550	.07968	.08389
IRON	.07055	.10455	.04310	.08017	.09372
SODIUM	.04771	.08197	.05824	.07588	.08662
BORON	.05782	.08839	.06153	.08452	.08417
ZINC	.04255	.07572	.07191	.08623	.09187
O-CHLORIDE	.04566	.08513	.05545	.08122	.08950
GEOM AVG	.05065	.08839	.05540	.08323	.08957
△ INVERSES FOR FOR CO2 IN STEAM FROM PORT 3			29.967	40.432	46.947

several tracers. A geometric average is appropriate. Carrying those averages through the rest of the computation (Eqs. 2-5) provides for a balanced estimate of flash fractions.

2. Computation of Flash Fractions

Beginning with data of December 30, values for flash fractions (Eq. 1) are given in Table 5B. The individual brine tracers yield slightly different results because their accuracies are less than the accuracy of their collective sum or of the chloride. The geometric average for the eight most precisely determined brine components constitutes a tracer. Chloride determinations by the oceanographic method (O-CL) were aimed especially at this computation because of their high accuracy. Chloride results are treated separately as well as being included with the group for averaging.

Making parallel computations from equations 2-5, based separately on the O-CL and geometric average tracer values of Table 5B, provides a range of values which tends to quantify the degree of uncertainty that may accompany this method of determining flash fraction. Each basis yields three estimates of $(F_{03})_3$ from Eq. (2). They are given in Table 6.

Table 6: Estimates of Flash Fraction at Port 3

Port	Tracer	
	O-CL	Geom. Ave.
4	.11830	.11819
5	.12842	.13160
6	.12188	.12197
avg	.12287	.12392

The flash fraction at Port 3 on a basis of pre-flash brine can be computed by Eq. (3). Results based on Table 6 averages are $(F_{03})_0 = 0.11026$ and 0.10942 , for the Geom. Avg and O-CL tracers, respectively.

The flash increments between Port 3 and the other ports, on a basis of preflash brine, are given by applying Eqs. (3) and (4) to values in Tables 5B and 6. Results are shown in Table 7.

Table 7: Increments of Flash Fraction at Successive Sampling Ports

	Tracer	
	Geom. Avg	O-CL
$(F_{34})_0$	0.04929	0.04938
$(F_{35})_0$	0.07405	0.07233
$(F_{36})_0$	0.07969	0.07971

The cumulative flash fractions at successive sampling ports can be computed for a pre-flash basis, by Eq. (5). Results are in Table 8.

Table 8: Cumulative Flash Fractions
Tracer

	Port	Geom. Avg	O-CL
(F ₀₃) _o	3	0.11026	0.10942
(F ₀₄) _o	4	0.15955	0.15880
(F ₀₅) _o	5	0.18431	0.18176
(F ₀₆) _o	6	0.18995	0.18913

3. Pre-Flash Brine Composition on December 30

The pre-flash brine composition can be estimated by applying the flash fractions determined above to the field brine compositions listed in the left sides of Tables 3 or 4. Data for each sampling port yields independent estimates of pre-flash concentrations. Example estimates are given in Table 9 for chloride and TDS. They are based on the O-CL tracer.

Table 9: Estimates of Preflash Concentrations in Brine

Port	(1-F)	CHLORIDE		TDS	
		Measured	Preflash	Table 4	Preflash
3	.89058	171720	152930	287198	255772
4	.84120	181800	152930	303983	255710
5	.81824	186900	152929	312376	255598
6	.81087	188600	152930	315131	255530

Although the four estimates for preflash chloride concentrations are identical, their uncertainties range from about 160 to 300 ppm, estimated from propagation of errors stemming jointly from the chlorinity measurement and the measurement of pressure inside the sampling syringe used for the CO₂ measurement. Counterpart uncertainties in the preflash TDS values are about 260 to 500 ppm.

Counterpart values for individual brine components are given in the right side of Table 4 [PREFLASH] as the averages of estimates based on the O-CL tracer. Four values were averaged for each entry; one per sampling port.

4. Brine Compositions on December 29

There were no steam samples taken on December 29 to correspond with the brine samples of that date. Consequently, it is not possible to derive the flash fractions with the procedure above. Flowline temperatures at the respective sampling ports were substantially cooler on December 29. This is reasonable because wellbore heat losses would be larger on the earlier day of flow. But, as a consequence, it is not feasible to use temperature as a correlate of flash fractions between the two days.

However, brine samples were taken for ICP analysis and for chloride by the oceanographic method. These results can be compared

with the December 30 data to provide an indirect method for estimating the flash on December 29, and consequently, the preflash brine concentrations.

The December 30 results for flash fractions were plotted versus measured chloride to establish a curve (not shown). Then the measured chloride values for December 29 are used to enter the graph and read flash fractions from the curve. This approach succeeds when the preflash brines have the same chloride content. Results are shown in Table 10.

Table 10: Estimates of Preflash Chloride Concentration on December 29

Port	3	4	5	6
Measured Chloride	170980	179160	186890	188590
Flash Fraction (graph)	0.1057	0.1461	0.1818	0.1891
Preflash Chloride	152907	152985	152913	152928

The computed preflash chloride values of December 29 are uniform among themselves and indistinguishable from those of December 30 -- the variations are less than the uncertainties. This outcome appears to validate the presumption that preflash chloride contents were the same on both sampling days.

Results for other elements were computed similarly and averaged to provide values in Table 4 for [Dec 29 PREFLASH]. The extreme right hand column in Table 4 shows the relative differences between the individual element concentrations for the two sampling days (difference/sum). Most differ by significantly less than one percent.

This outcome is significant for its indication that well production was compositionally stable, and thus accurately represents the brine that was in chemical equilibrium with the rocks.

5. Silica Content

The precision of lab analyses for silica is among the best of those indicated by replicates (Table 3). However, the silica results for successive sampling ports show prominent decreases, on the order of 170 ppm from a base near, or exceeding, 500 ppm (Table 4). These are stunning losses in terms of both chemical reaction rate and the implied rate of buildup of silica scale.

For example, residence time of the fluid through the set of four sampling spools is less than 1.5 seconds, based on mass flow rates, specific volumes, and flash fractions. Residence time in Spool 6 is only about 0.13 seconds.

Internal surface area of the four spools is about 11 square meters. If the missing silica were to deposit as $\text{SiO}_2 \cdot 2\text{H}_2\text{O}$ with a density of 2.2 g/ml, then a flow rate of 200,000 pounds per hour would

yield a silica deposition rate of about 1 mm/hr. Observed deposition rates are less than 1/10 that amount. Thus, the fate of silica is not clear. Silica losses in the sampling equipment have not been estimated.

C. Enthalpy-Temperature Relationships

The heat content of brine and steam comprise an essential feature of the resource. The data developed so far can be used to compute some other important quantities, such as the effective preflash temperature during the tests and the preflash enthalpy at other places in the wellbore.

The computational approach described next uses equations relating temperature and salt content to enthalpy of brine and enthalpy of steam-over-brine. The equations are based on solutions of pure NaCl. It is asserted here that the mixed-salt geothermal brine properties follow essentially similar equations, except for the values of coefficients for terms involving salt concentration. That is, any mixed-salt brine of a given gross concentration (based on TDS or chlorinity) has the enthalpy relationships of a specific NaCl brine, but with a somewhat different numerical concentration. For practical engineering purposes, the two concentrations are related by a simple multiplier. Part of the task in the subsequent section is to deduce a numerical value for the multiplier that applies to the geothermal brine.

1. Salt Effect on Steam and Brine Enthalpy

Equations for brine enthalpy, HB, and for heat of vaporization, HV, are given by Equations 6 and 7. Temperature is Fahrenheit, N represents weight percent NaCl in a simple brine, n is the multiplier that relates a mixed brine of N weight percent TDS and a simple brine with the same N-value. Units are Btu/lb. These equations are based on tables presented by Haas (1976).

$$HB = 0.36(T)^{1.16}[\exp_{10}(-.006Nn)] \quad (6)$$

$$HV = 1134 - (.7969)(T) + 2.482(Nn) \quad (7)$$

The enthalpy of total fluid, HF, at the sample ports is given by Equation (8), where (f) represents steam fractions determined in the previous section.

$$HF = HB + (f)HV \quad (8)$$

2. Brine Equivalent NaCl Content

The steam fractions have been determined independently of temperature, and the temperatures at the sampling ports have been determined by direct measurements. Equations 6-8 can be used to estimate values of HF for each sampling port. The objective is to

* find a value for (n) which yields the minimum variance among the four estimates of total fluid enthalpy. The appropriate value of (n) can be determined by iterating with equations (6) and (7). Results are:

Table 11: Enthalpies of Total Fluid on December 30, 1985

Port	3	4	5	6
Temp °F	455	395	346	328
HF	353.8	359.3	356.4	353.3

average HF = 355.5 Btu/lb n = 1.335

The enthalpy of total fluid was less during the December 29 sampling session. The value on that day can be estimated from equations 6-8, using the measured temperatures, flash fractions from the previous section, and the n-value derived above. Results are 339.8 Btu/lb.

3. Effective Pre-Flash Temperature

The true flash temperature was measured directly in the wellbore by Kuster tools, but there are real losses of enthalpy from the wellbore between flash level and wellhead. The steam fractions at the sampling ports derive from an effective temperature corresponding to the measured flash temperature diminished by the effect of enthalpy losses from the wellbore and surface equipment.

The preflash enthalpy of the previous section, which is determined concomitantly with the n-value, can be used in Eq. (6) to compute the flash temperature.

Results are 572.5 and 550.9 F (300.3 and 288.3 C) for December 30 and 29 respectively. The difference represents diminishing effects of wellbore heat losses as the period of flow is extended.

The flash temperature in the wellbore was measured late on December 30, at a depth near 4500 feet while the well was still flowing. The result was 301.5 C, only 1.2 degrees hotter than the temperature calculated above.

One would expect the computed and measured temperatures to differ by much more -- tens of degrees -- depending on the nature of heat losses in the wellbore and the flow rate of the geothermal fluid. This apparently small contrast represents some combination of discrepancies in Equations 6 and 7 and in the wellbore measurement. Resolution requires data beyond the scope of this report.

REFERENCES:

Haas, J.L., 1976, Thermodynamic properties of the coexisting phases and thermochemical properties of the NaCl component in boiling NaCl solutions: U.S. Geol. Surv. Bul. 1421-B Revised, 71 pp.