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RESERVOIR ASSESSMENT OF THE PUNA GEOTHERMAL FIELD, ISLAND OF HAWAII

for

ORMAT ENERGY SYSTEMS, INC.
Sparks, Nevada

by

GeothermEx, Inc.
Richmond, California

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CONTENTS

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ILLUSTRATIONS

Tables

Figures

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EXECUTIVE SUMMARY

The existence of a commercial geothermal reservoir underlying the Puna lease of Ormat has been proven by six deep wells drilled by Thermal Power Company and others. Hot water and steam at temperatures as high as 680°F exist in a reservoir lying between the depths of 4,000 to 7,000 feet. The Puna reservoir is one of the hottest in the United States; in fact, only three other geothermal fields in the U.S. (The Geysers, Salton Sea and Coso Hot Springs, all in California) have displayed such high fluid temperatures. These three reservoirs produce more than 90% of the commercial geothermal power in the United States. The total generating capacities already installed or being installed in the above-mentioned fields are as follows: The Geysers - 2,000 MW; Salton Sea - 216 MW; and Coso Hot Springs - 258 MW.

The Puna discovery well (HGP-A) was drilled in 1976 and has been supplying a 3 MW demonstration plant since 1982. Three Thermal Power Company wells (Kapoho State 1, 1A and 2) were drilled and flow-tested between 1981 and 1985. Of the three wells, the newest (Kapoho State 1A) is potentially available as a production well with a power capacity of about 3 MW (gross). The two older wells (Kapoho State 1 and 2) are no longer usable because of mechanical well damage; however, these two wells were originally capable of producing about 3 MW (gross) and 2 MW (gross), respectively. Two other wells (Lanipuna 1 and Lanipuna 6) were drilled just outside of the subject lease area by Barnwell Industries between 1981 and 1984. These two wells proved to be outside the main reservoir and therefore unproductive; however, they provide valuable subsurface temperature and geologic information, and one of them (Lanipuna 6) is usable as an injection well.

The subsurface temperature increases to the NW and there is a strong horizontal temperature gradient (1°F/16 feet) within the drilled area of the lease; this indicates that thermal fluid is being channeled along steeply dipping structures paralleling the NE-trending 1955 eruption fissure. Assuming that temperatures are developed symmetrically on both sides of the fissure, the resulting temperature pattern suggests that a horizontal component of flow is directed from SW to NE parallel to the trend of the East Rift. A strong horizontal pressure gradient of 0.3 psi/ft parallels the temperature gradient, indicating relatively poor horizontal permeability in the NW-SE direction, and further supports the above conclusion that flow is dominated by steep NE-trending structures.

Based on the structure of older rift zones exposed elsewhere in the Hawaiian Islands, it is probable that the zones of good permeability are related to fracturing during dike emplacement. The dikes which form rift zones are individually only a few feet wide, dip from 90° to 70° and, in densely intruded areas, are spaced only a few feet apart.

Hydrological studies and chemical analyses of fluids produced from the deep Puna wells indicate that the thermal fluid is a mixture of fresh water and sea water, with the sea water component apparently increasing to the SE, away from the fissure zone. This suggests that recharge to the system may be mainly meteoric in origin. Although various warm springs occur along the coast SE of the drilled area, the absence of large hot springs indicates that the system discharges in the

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subsurface. The basal ground water level is just above sea level, and an early exploration well found near-boiling temperatures at sea level just NE of the drilled area. The thin high temperature zone penetrated by the early exploration well suggests that there is a lateral discharge of thermal fluid on top of the local cold water table.

Based on the hydrogeological model developed in this report, three different reservoir areas can be defined within the Puna lease with varying degrees of certainty concerning their potential reserves. The three areas are referred to in this report as proven, probable and possible in a decreasing order of certainty. The proven area, defined by successful production wells drilled to date, is estimated to be about 0.2 square miles. The probable area, defined by conservative geological extrapolation of the drilling results to date, is estimated to be 0.5 square miles. The possible area, defined by less conservative geological extrapolation, is estimated at 3.6 square miles and is located mainly on the Ormat lease. The maximum development capacity of the lease, therefore, is about 200 MW. At this stage of development of the lease, there is a cumulative probability of about 92% that the capacity will exceed 28.2 MW (gross).

Based on the production test results of the HGP-A and Kapoho State wells, it is reasonable to assume that future wells producing from the same reservoir will have an average capacity of 3 MW. Ten production wells plus one or two standby wells, therefore, should be required for a 28.2 MW plant. If KS-1A is available for production, an additional nine production wells are needed for the 28.2 MW plant. This requirement could be reduced to eight new wells if well HGP-A can also be used to supply the 28.2 MW plant.

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It is anticipated that only one injection well and one stand-by injector will be required because of the high enthalpy of the fluid produced from existing wells. Because of its high permeability and location outside, but adjacent to, the high temperature reservoir, well Lanipuna 6 is a likely candidate for injection.

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1. INTRODUCTION

1.1 Purpose

The first step in assessing a geothermal resource is to develop a hydrogeologic model which defines the three-dimensional distributions of temperature and pressure and relates these distributions to the geologic structures that control the flow of thermal fluid. An assessment of the available energy beneath the lease will be based on the temperature distribution, and the drilling plan will be based on the permeability distribution inferred from the hydrogeologic model.

Surface geology, interpreted from aerial photographs, and subsurface geology, inferred from geophysical data, are described in Section 2 of this report. Subsurface temperature and pressure distributions are described in Sections 3.1 through 3.3 and section 3.4 summarizes the hydrogeological model developed from interpreting the temperature and pressure distribution patterns in relation to the geology described in Section 2. Section 4 summarizes the results of well tests, including the chemistry of the thermal fluid. Section 5 describes the volumetric estimate of reserves.

1.2 Background Information

The Puna geothermal reservoir has been proven by six deep wells drilled by Thermal Power Company and others. Hot water and steam at temperatures of up to 680°F exist in a reservoir lying between the

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depths of 4,000 to 7,000 feet. The Puna reservoir is one of the hottest in the U.S. In fact, only 3 other geothermal fields in the U.S. (The Geysers, Salton Sea and Coso Hot Springs, all in California) have displayed such high fluid temperatures; all three of these now produce commercial power. The power capacities already installed or being installed in the above-mentioned fields are as follows: The Geysers - 2,000 MW; Salton Sea - 216 MW; and Coso Hot Springs - 258 MW.

The field discovery well HGP-A was drilled in 1976 and has been supplying a 3 MW demonstration plant since 1982. Three Thermal Power Company wells (Kapoho State 1, 1A and 2) were drilled and flow-tested between 1981 and 1985. Of the three wells, the newest (Kapoho State 1A) is currently available as a production well with a power capacity of about 3 MW (gross). The two older wells (Kapoho State 1 and 2) are no longer usable because of mechanical well damage; however, originally these two wells were capable of producing about 3 MW (gross) and 2 MW (gross), respectively. Two other wells (Lanipuna 1 and Lanipuna 6) were drilled just outside of the Puna lease area by Barnwell Industries between 1981 and 1984. These two wells proved to be outside the main reservoir and therefore unproductive; but they provide valuable subsurface temperature and geologic information, and one of them (Lanipuna 6) is usable as an injection well.

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2. GEOLOGIC FRAMEWORK

The Puna geothermal field is located on the "East Rift Zone" of Kilauea volcano (figure 2.1). The East Rift extends from Kilauea's central caldera in a 25-mile linear course to the NE coast of the island with a further 43-mile submarine extension. In the vicinity of the Puna lease, the rift is about 1.5 miles wide, as indicated by both surface morphology and aeromagnetic anomalies.

At the surface the rift zone is marked by open fissures and lines of cinder and spatter cones. From knowledge of older rifts in the Hawaiian Islands, now exposed by erosion, rift zones in the subsurface consist of swarms of closely spaced, nearly vertical, and nearly parallel dikes. In the central part of a main fissure zone, the number of dikes, which average 3 to 5 feet in width, ranges between 100 and 200 per mile of zone width, with a maximum of about 1,000 per mile. Along the length of the East Rift, including the Puna area, the most recently active fissures are located on the southern boundary of the dike complex which forms the rift.

Specific geologic information for the Puna field comes from these sources:

a) surface geologic mapping and interpretation of air photographs

b) geophysical surveys; and

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c) lithologic logs and "mud logs" available from exploration drilling.

2.1 Surface Geologic Features

The most important, and obvious, geologic features within the Puna lease are the surface traces of fissures through which lava was erupted in 1955, marked by linear trends of small craters and by small scarps marking recent fault offsets. The fissure and scarps strike N 60° E in an en echelon pattern. The locations of these features, as mapped from large-scale air photographs, are shown in figure 2.2.

As shown on figure 2.2, wells KS-1 and KS-2 are drilled very close to the fissure zone, which extends in an en echelon pattern 3.5 miles to the NE of the wells. The fissure zone terminates at the small unnamed crater from which the extensive lava flow of 1960 was erupted. This vent is located 0.8 miles NW of Kapaho crater. Just to the SW of wells KS-1 and HGP-A, the fissure zone is offset 0.8 miles to the SE. It has been postulated by a number of geologists and geophysicists that this offset is an important "transverse fault" to which the Puna field is in some way genetically related. There are no NW-trending fractures on the surface to indicate the presence of this postulated fault, however, and as discussed in the following section, the main evidence of its existence is a discontinuity in the trend of the magnetic pattern related to the rift dikes.

From the NW-trending offset the main eruptive fissure extends another 6 miles to the SW, but no recent eruptions have occurred along the 2-mile length nearest the offset. The Puulena craters (figure 2.2),

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which parallel the fissure just to the SW of the offset, are old features with no record of historic eruptions.

2.2 Results of Geophysical and Geochemical Surveys

A number of government-funded geophysical surveys were carried out over the East Rift during the 1970s. These included gravity, magnetic, seismic, and a variety of electrical surveys, including DC (bipole-dipole and pole-dipole), EM (time domain, variable frequency inductive sounding and transient sounds), mise-a-la-masse and self-potential (S.P.).

Of the many geophysical anomalies defined by these surveys, S.P. anomalies appear to be most closely associated with geothermal features, both in the Kilauea crater area, and the East Rift. Indeed, the discovery well of the Puna field, HGP-A, was sited, in part, on the basis of a large SP anomaly located N of Puulea crater (figure 2.2 and 2.3). The hole was not sited directly on the anomaly (figure 2.3) because a lease for an appropriate site could not be obtained.

A consultant for Thermal Power Company reviewed all the geophysical data available for the Puna area in 1982, and concluded that because most of the data were too broad-scale to be useful for either detailed evaluation of the lease, or for locating exploration targets. Consequently, the consultant recommended:

a) a detailed aeromagnetic survey to better delineate the NW-trending offset of the fissure zone near well HGP-A; and

b) modeling results that might be expected from a controlled source audiomagnetotelluric survey (CSAMT) to determine if such a survey would be effective.

Subsequently, an aeromagnetic survey of the Kilauea Rift was published by the U.S.G.S. in 1986 (MAP MF-1845-A). The survey shows a major discontinuity in magnetic anomalies corresponding to the location of the proposed offset fault. Assuming that the area of offset is prospective, however, the resolution of the magnetic survey is insufficient for selecting specific drilling targets.

The consultant's second recommendation was also implemented and a modeling study was commissioned by Thermal Power. The results indicated, that a CSAMT survey would be able to delineate the reservoir. Thermal Power commissioned the survey with a geophysical contractor, but because electrode contact resistance was much higher than the contractor anticipated, it was not possible to complete the first phase of the survey according to specifications. In addition, based on the limited data that the contractor was able to gather, it appeared that the CSAMT method would not be able to delineate closely, and unequivocally, the limits of the reservoir. In view of these problems, the survey was abandoned.

The anomaly most closely associated with the surface trace of the main eruptive fissure zone shown in figure 2.2 is the chemical anomaly caused by the concentration of mercury in near-surface soil samples. Again, as with the aeromagnetic anomaly, this anomaly shows the NW-trending discontinuity near HGP-A presumed to be caused by a fault offsetting the rift trend. The highest concentrations of soil

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mercury, however, are not in the area of offset but over the NE-trending fissure just to the NE of the presently drilled area.

In summary, the geophysical and geochemical surveys completed in the Puna lease area located several anomalies. The anomalies, however, do not coincide with each other in area and therefore cannot be used with confidence to delineate the reservoir; nor do they have sufficient resolution to be useful for well siting. Additional geophysical surveys are not recommended, but geochemical surveys may be useful.

2.3 Subsurface Geology

The lithologic logs of the exploration wells drilled in the Puna area record, as would be expected, a monotonous sequence of basalt from surface to their total depth. The only variations consist of the irregular occurrence of alteration zones, and a gradual decrease in the ratio of vesicular to non-vesicular lava with depth, indicating an increase in submarine lavas, in contrast to subaerial lavas.

The penetration rate logs of the Kapoho State wells were reviewed from the point of view of well correlation, but it is clear from these logs that penetration rate is more a function of the type of drilling fluid than variation in rock type. Drilling with water is about 1.5 times faster than drilling with mud.

The main parameter of interest contained on the logs is the location of zones of loss of circulation. This information is included on the summary plots of the logs, which are discussed in detail in the following section of this report.

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3. HYDROGEOLOGIC MODEL

The hydrogeologic model was developed by: a) plotting the three-dimensional distribution of temperature and pressure; b) using these data to define flow paths in the system; and c) relating these flow paths to permeable geologic structures.

The three-dimensional temperature distribution in the Puna field was determined by :

a) plotting all the downhole temperature surveys available for the Lanipuna, Kapoho State and HGP-A wells;

b) interpreting the survey data to determine the most likely true rock temperature profile in each well;

c) plotting the interpreted data on subsurface level maps, at vertical intervals of 1,000 feet, to show the horizontal distribution of temperature though the drilled depth of the field; and

d) constructing cross-sections through the level maps to show the vertical distribution of temperature.

3.1 Interpretation of Temperature Logs

The temperature logs from the Puna wells are shown on downhole summary plots (figures 3.1 through 3.11). The summary plots include: depth data reduced to elevation; information on well completions; locations of lost circulation zones; and spinner data for wells HGP-A and KS-1A. The rock temperatures interpreted from these surveys are listed in table 3.1.

Lanipuna 1

Although the maximum undisturbed heat-up time prior to logging temperature was only 56 hours, the general trend and slope of the gradient is the same in six of the logs (excluding the log taken one day after air lift). Because of this relative uniformity of slope, true rock temperatures were interpreted to fall on a line drawn through the highest measured temperatures at 3,000 feet and 5,600 feet, and parallel to the slope defined by all the curves. The temperatures between -1,000 and -7,000 feet msl resulting from this interpretation are given in table 3.1.

Lanipuna 1-ST

The temperature gradient measured between 4,400 and 5,100 feet depth on 7/18/83 was projected upward to 3,000 feet depth to estimate true rock temperatures at -3,000 and -4,000 ft msl. The temperature reversal below 6,000 feet depth was assumed to be real because it persisted for 28 days of heating time in a zone where no loss of

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circulation was noted. A temperature of 330°F was projected to -6,000 feet msl.

Lanipuna 6

Between -1,000 and -3,000 feet msl, true rock temperatures were interpreted to fall on a line drawn between the temperature measured 16 hours after pumping (8/7/84) at -1,000 feet and the maximum temperature measured at -3,100 feet after 53 days of heating. The temperature reversal below -3,800 feet msl is considered to be real because it persists 600 feet below the lost circulation zone at -3,800 feet msl.

HGP-A

The temperature profile measured on 3/8/77 (well undisturbed for 25 days) was interpreted to represent true rock temperature most closely. This profile is in good agreement with the profiles measured on 12/4/76 and 1/3/77 which also were measured after relatively long undisturbed periods. The high temperatures measured between 4,000 and 5,500 feet depth in logs of 7/22, 7/29 and 8/4/76 are considered to be influenced by recent production, and therefore, not true rock temperature.

internal circulati

KS-1

Only the temperature measured at 1,600 feet depth, after setting a plug at 1,750 feet depth, was used from the profiles measured in this well. The temperatures measured between 1,800 and 3,600 feet

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depth are consistently lower than that measured 100 feet away in well KS-1A, and therefore, are considered to be unstable.

leak in casing convective flow through the well not in

KS-1A

In spite of the relatively large number of temperature logs (14) measured in this well, the temperature data are the most difficult to interpret. The logs run after 11/8/85 all show temperatures in excess of 550°F at 2,000 feet depth, which is considered to be unrealistically high for this depth and probably caused by convection of two-phase fluid (the profiles are on a boiling-point-for-depth curve). The log run on 11/6/85 (6 days of heating after production) agrees with the temperatures measured above the plug at 1,750 feet in KS-1 (almost 200°F) but still appears to be influenced by recent production below this point. On the other hand, the profile run on 9/11/85 (heating 5 days after injection) appears to be cooler than true rock temperature. In view of the lack of stabilized profiles, a smooth curve was drawn between 174°F at -1,000 feet msl and 580°F at -4,000 feet msl to approximate temperatures between these elevations. The later point corresponds to an inflow zone on the 9/11/85 profile. True rock temperatures appear to correspond to a boiling-point-for-depth curve between 5,500 feet depth and T.D. and this curve was used to estimate temperatures at -5,000 and -6,000 feet msl.

KS-2

Temperatures measured in this well are also affected by two-phase convection of fluids within the well, and consequently, profiles measured on 4/14, 4/17, 4/24 and 4/29/82 probably do not

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reflect true rock temperatures. Profile 6/14/83 was run 5 months after setting a plug at 3,175 feet depth and temperatures measured on that log at -1,000 and -2,000 msl are considered to be correct because it is unlikely that convection would occur above the plug. Between 3,700 and 5,000 feet depth temperatures measured on the combination of profiles 4/1, 4/14 and 4/17 were considered to be closest to true rock temperature. Temperatures at -5,000, -6,000 and -7,000 feet msl were assumed to fall on a slightly curved line connecting the 520°F temperature measured at -4,000 msl, and a projected bottom hole temperature of 690°F. The bottom hole temperature was projected from a boiling-point-for-depth curve drawn through profile 4/24/82.

3.2 Temperature Distribution

Temperature contour maps have been prepared for each 1,000 foot elevation interval between -1,000 and -6,000 feet msl based on the interpretation of the temperature logs described in section 3.1 above. Table 3.1 lists the temperatures chosen for contouring for each well at each elevation interval. As the kick-off-point for well L-1ST is at 3,570 feet depth, the points of measurement of temperatures at the -1,000, -2,000 and -3,000 foot levels are the same for both the original hole and the side track. Nevertheless, because of disequilibrium conditions, temperatures are not in agreement between the two series of logs taken over this interval, as can be seen in figures 3.1 and 3.2 and table 3.1. The temperatures interpreted to be the nearest to true rock temperature above -3,000 ft·msl in well L-1 and L-1ST are underlined in table 3.1. The temperatures given in table 3.1 at -5,000 feet msl for well L-6, and at -6,000 feet msl for wells HGP-A and KS-1/KS-1A are projected downward from shallower measurements.

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Figures 3.12 through 3.17 show the interpreted temperature distribution for levels -1,000 through -6,000 feet msl, respectively. At -1,000 feet msl (figure 3.12) Well HGP-A is in the highest temperature area, with temperatures decreasing to the N, S and E. There are insufficient data to close the contours to the W. This pattern remains the same at -2,000 feet msl (figure 3.13), with well HGP-A still in the highest temperature area. At -3,000 feet msl, although HGP-A is still the hottest well, temperatures in the Kapoho wells are significantly hotter compared to higher levels. At -4,000 feet msl (figure 3.15) well KS-1A is the hottest and temperatures decrease uniformly to the SE. This pattern is repeated on the -5,000 and -6,000 feet levels, with the addition of a relatively low temperature zone developing around well L-1ST (figure 3.16 and 3.17) developed on the -5,000 and -6,000 foot levels.

On the -1,000 and -2,000 foot levels the axis of symmetry of the temperature anomaly trends N70°E, which is within 10° of the direction of the rift fractures (N 60°E). The axis of symmetry of the anomaly however, is displaced 1,000 to 1,500 feet to the SE of the main fissure zone. The spatial relationship of surface geology with the temperature anomalies developed on the -1,000 and -2,000 foot levels, therefore, suggests that the anomalies are caused by thermal fluid moving on fractures parallel, but to the SE of, the main rift fracture.

On the -3,000 foot level and below, the well data define only a gradient with temperatures decreasing to the SE, rather than an anomaly with a center of symmetry, as on the -1,000 and -2,000 foot levels. Because of the similarity in trend of the isotherms between the lower

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levels, and the -1,000 and -2,000 levels, it is probable that the anomaly below -2,000 feet is also due to fluid movement along rift fissures, and although not proven by well data, it is also probable that the patterns developed on the -3,000 to -6,000 feet levels are due to fluid movement from SW to NE in the main fissure zone. If so, a mirror image of the temperature pattern developed from well data on the SE side of the main fissure would exist on the NW side. This interpretation is illustrated in figures 3.14 through 3.17 by contouring with solid lines the temperature pattern defined by well data on the SE side of the main rift fissure, and with dashed lines the inferred, mirror image pattern on the NW side of the fissure.

Projection of a mirror image temperature pattern to the NW side of the fissure implies that geology, and therefore permeability patterns, are the same on each side of the fissure. This may not be true, however, because as noted in section 2, the active fissures of the East Rift are located on the southern boundary of the dike complex which forms the rift. The permeability pattern N of the fissure, therefore, may be more influenced by the presence of steeply-dipping dikes than the permeability pattern on the south side of the fissure. Clearly, sub-surface temperature data from the north side of the fissure is needed to confirm the temperature patterns proposed in figures 3.12 to 3.17, which have been drawn on the assumption that the geology on the NE side of the fissure is similar to that found on the SE side.

The 400°F isothermal surface, resulting from the temperature distribution described above, is contoured in figure 3.18. This figure shows that the top of the anomaly is relatively flat between -2,000 and -3,000 feet msl; its sides are quite steep between the -3,000 and -5,000 foot levels; below -5,000 feet msl, the anomaly contracts, producing temperature reversals.

Vertical sections perpendicular to the NE trend of the anomaly are shown along section lines A - A′ and B - B′ in figures 3.19 and 3.20, respectively. The margins of the rift zone and lease boundaries are shown on the sections as are the projected traces of the nearby wells. The sections have no vertical exaggeration, and consequently illustrate the relative flatness of the anomaly above -3,000 feet msl, and the steepness of the sides of the anomaly below this elevation. As stated above, this steepness indicates the control of flow paths by steeply-dipping fissure zones. At higher levels (above -3,000 feet msl) flow paths appear to be modified by stratigraphic permeability. This would account for the temperature reversal found in well L-6, as seen on the S side of section A - A′ (figure 3.19). The relatively cold zone found in well L-1ST, as shown on the S side of section B - B′ (figure 3.20) appears to be an artifact of another, steeply-dipping hot zone developed along the main fissure zone which is offset to the SE of the drilled area.

3.3 Pressure Distribution

Information on pressure gradients is available for 4 wells: L-1ST; HGP-A; KS-1A; and KS-2. These data are plotted on the downhole summary plots. Pressures recorded (or projected) to the common datum of -5,000 feet msl are given in the second column of table 3.2, and the pressure gradients recorded between -4,000 and -5,000 feet msl are given in the third column. These elevations were chosen because they are in

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the open hole intervals of the wells and, being in the zone of loss of circulation, are believed to reflect true reservoir conditions.

The four pressure values at the -5,000 foot level are contoured on figure 3.21, which shows that the orientation of the isobars is similar to the orientation of the isotherms at this same level, that is, pressure increases uniformly to the SE as temperature decreases uniformly in the same direction. The horizontal pressure gradient is 600 psi over a distance of 2,000 feet (0.3 psi/feet). This gradient indicates there is a horizontal component of flow from SE to NW on the -5,000 foot level. The location and orientation of the isobars suggests that this flow is feeding upward convection on the main fissure, which is compatible with the interpretation in Section 3.2 that flow within the fissure is responsible for the temperature pattern seen on levels -3,000 through -6,000 feet. The relatively low vertical pressure gradients measured in the Kapoho State wells, as compared to the gradients measured in HGP-A and Lanipuna 1, also support the interpretation that upward convection is taking place on the main fissure zone because the Kapoho wells are located adjacent to the fissure. Indeed, the logs of the lower parts of these wells indicate that temperatures are on the boiling-point-for-depth curve.

3.4 Summary of Hydrogeologic Model

The characteristics of the hydrogeologic model can be summarized as follows:

1. The increase of temperature to the NW within the drilled areas and a strong horizontal temperature gradient (1°F/16 feet),

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indicate that thermal fluid is being channeled along steeply dipping structures paralleling the NE-trending, 1955 eruptive fissure.

2. By assuming that temperatures are developed symmetrically on both sides of the fissure, then the resulting temperature pattern suggests that a horizontal component of flow is directed from SW to NE parallel to the trend of the East Rift.

3. A strong horizontal pressure gradient of 0.3 psi/ft parallels the temperature gradient, indicating relatively poor horizontal permeability in the NW-SE direction, and supports the above conclusion that flow is dominated by steep, NE-trending structures.

The presence of temperature profiles on the boiling point-for-depth curve in the deeper parts of the Kapoho State wells indicates that steam-water counter flow is also occurring close to the fissure.

Bull

. Based on the structure of older rift zones exposed elsewhere in the Hawaiian Islands, it is probable that the zones of steep permeability are related to fracturing during dike implacement. The dikes which form rift zones are individually only a few feet wide, dip from 90° to 70° and, in densely intruded areas, are spaced only a few feet apart.

6. As discussed below (section 4.5), the thermal fluid is a mixture of fresh water and sea water, with the sea water

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component apparently increasing to the SE, away from the fissure zone. This suggests that recharge to the system may be mainly meteoric in origin.

7. Although various warm springs occur along the coast SE of the drilled area, the absence of large hot springs indicates that the system discharges in the subsurface. The basal ground water level is just above sea level, and an early exploration well found near-boiling temperatures at sea level just NE of the drilled area. The thin (100 foot thick), high temperature zone indicates the presence of lateral discharge on top of the local cold water table.

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4. ANALYSIS OF WELL TEST DATA

Six deep geothermal wells have been drilled within or near the boundary of the Puna lease (figure 2.2). Four of these wells have been commercially successful: HGP-A, Kapoho State 1 (KS-1), Kapoho State 2 (KS-2) and Kapoho State 1A (KS-1A). All but the first were drilled by Thermal Power Company. Well HGP-A has been supplying a 3 MW demonstration plant since 1982. Wells Lanipuna 1, Lanipuna 1 ST and Lanipuna 6, drilled by Barnwell, were unsuccessful and appear to be located outside the productive geothermal reservoir although Lanipuna 1 and Lanipuna 1 ST were drilled into zones of high (>500°F) temperatures.

Of the 3 wells drilled by Thermal Power Company, only KS-1A is currently available as a production well. The two older wells (KS-1 and KS-2) were originally productive but are not usable because of mechanical well damage. The histories of the wells are discussed in Chapter 6.

The well test data from the three Thermal Power Company wells and HGP-A, including their power capacities based on a separator pressure of 165 psia and steam consumption of 19,200 pounds per hour (lbs/hr) per megawatt electrical (MW), are discussed in the following sections. The steam consumption is based on the original plant design provided by Ormat; however, Ormat's latest plant design requires 17,000 lbs/hour per MW.

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4.1 Well Kapoho State 1

Well KS-1 was completed on November 10, 1981 to a total depth of 7,920 feet. Figure 3.7 is a downhole summary plot for the well, and includes well completion details and available temperature and pressure surveys. Although the temperature surveys probably do not reflect true rock temperatures at the indicated depths, they indicate reservoir temperatures in the range of 625°F to 650°F. The permeable zones of the well occur at a number of intervals between 5,000 and 7,200 feet depth.

The initial flow test was conducted for 45 minutes on December 16, 1981, using a James tube discharging into a twin tower silencer. Following this test, a leak was found in the 9-5/8-inch production casing. A 7-inch liner was therefore cemented from surface to 1898 feet in May 1982, and the well was re-tested, first using a James tube for 30 hours and then a pressure separator for 293 hours during August 1982.

During the separator test in August 1982, the well was found to produce dry steam. The discharge data are summarized in table 4.1 and plotted in figures 4.1 and 4.2. It can be seen from figure 4.2 that the well was capable of producing 3.1 to 3.6 MW.

On February 18, 1983 a temperature survey was conducted in the well while injecting cold water because it was believed that a second leak had developed in the cased section of the well. The survey (figure 3.6) shows a very rapid increase in temperature from 134°F to 557°F at 660 to 680 feet, suggesting that the injected water was leaving the well through a casing leak at this depth.

compare Tem
profile w/ KS 1A

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4.2 Well Kapoho State 2

Well KS-2 was completed on March 28, 1982 to a total depth of 8,005 feet. Figure 3.11 is a downhole summary plot, which includes the well completion details and a number of temperature and pressure surveys. The temperature surveys indicate the well encountered somewhat higher temperatures than well KS-1; temperatures range from 600°F to 680°F in the open interval. Below the production shoe, permeable zones occur from 5,000 feet to 7,200 feet depth.

The well was flow tested several times from April to August, 1982. The most reliable data was collected when the well flow was directed to a pressure separator from July 28 to August 2, 1982. During that test, the well produced essentially dry steam at high wellhead pressures and wetter steam at wellhead pressures below 160 psia. It was believed that the variation in steam wetness with wellhead pressure was due to a casing leak located using temperature surveys at approximately 1,000 to 1,100 feet. These surveys are not shown on figure 3.10, but a later survey conducted on January 25, 1983 also indicates a possible casing leak at that depth.

The well discharge data are included in table 4.1 and plotted in figures 4.1 and 4.2. It can be seen from figure 4.2 that the well was capable of producing approximately 2.0 MW. This is approximately half the capacity of well KS-1; however, it is thought that downhole constrictions in the wellbore may have significantly lowered the true potential of the well.

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4.3 Well Kapoho State 1A

Well KS-1A is located approximately 100 feet south of well KS-1 and was completed on September 3, 1985 to a total depth of 6,505 feet. Figures 3.8 through 3.10 are downhole summary plots, which include well completion details and temperature and pressure surveys. Temperatures in the well have reached approximately 670°F at bottomhole.

Well KS-1A was tested to a pressure separator from October 7, 1985 to October 31, 1985. The raw data from the test have been analyzed and the calculated flow rate and enthalpy data are plotted as a function of time in figure 4.3. The variation in measured wellhead pressure with time is also shown. Using the calculated production data, the variations in flow rate, enthalpy and power output with wellhead pressure are plotted in figures 4.4, 4.5 and to 4.6, respectively. The data are also summarized in table 4.1.

The flow data from well KS-1A show that the well can produce approximately 3.4 MW. Unlike wells KS-1 and KS-2, well KS-1A produces a two-phase mixture of approximately 82% steam and 18% water. The constant discharge enthalpy measured while flowing at low wellhead pressures suggests that the well encountered higher permeability, resulting in less reservoir drawdown, than that found in wells KS-1 and KS-2. It is thought that the production of dry steam in the other two wells is due to excessive drawdown caused by limited permeability rather than the presence of naturally occurring steam zones in the reservoir.

At high wellhead pressures, the discharge enthalpy decreased figure 4.5) which is interpreted to indicate that flow from an upper

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two phase zone in the well is being restricted. However, the high wellhead pressure data were, only collected over a two day period; therefore, the measured enthalpies are not considered to be stable. The true stable enthalpies are probably lower than the measured values.

During the flow test, a downhole spinner was run and the data are included in figures 3.~~6~~9 + 3.10 ~~through 3.8~~. The spinner log suggests that about 50% of the volumetric flow is derived from zones deeper than 6,300 feet and the other 50% is derived from between 4,500 and 5,500 feet. A temperature survey conducted 7 hours after well shut-in also shows significant cooling between 5,400 and 6,300 feet; this condition is thought to be related to the flashing flow of steam and water from the reservoir into the well.

Attempts were made to measure the reservoir flow capacity (transmissivity or "kh") in the vicinity of the well by conducting an injection test followed by a pressure falloff test and a pressure buildup test after the flow test was completed. The injection test indicated an injectivity index of 1,100 lbs/hr/psi, which is average for a geothermal system of this type. The pressure falloff data could not be analyzed due to non-isothermal effects and associated density changes in the well. The pressure buildup data appear to be affected by internal flows within the well. Internal flows also may have caused the cycling in wellhead pressure that occurred after shut-in.

In an attempt to measure possible interference with surrounding wells, water level measurements were taken at the Malama Ki and Airport wells before, during and after the flow test. These wells are located approximately 1.5 miles south southeast and about 2.5 miles northwest of

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well KS-1A, respectively. No change in water level was measured. The large distances between the wells and the large differences in completion depths make these results predictable. The discharge parameters at well HGP-A were also closely monitored for any changes due to the discharge of well KS-1A, but no measurable effect was detected.

4.4 Fluid Chemistry

Background

Water sample data from wells HGP-A, KS-1A, KS-2, Lanipuna 1 and Lanipuna 6 are listed in table 4.2. The background of these data is as follows:

HGP-A is represented by selected samples which illustrate the well's chemistry since it was first tested in 1976, through the beginning of regular production in 1981, until 1984. More recent data has been published only in graphical and narrative formats. Examples of the non-condensible gases also are available.

KS-1A was sampled during a flow test in October, 1985. All analyses are listed. Gas data also are available.

KS-1 was sampled during testing in April and June 1982. Tabulations of the analyses were not found, except for some measurements of Cl. We did find narrative discussions of the results, but these are very incomplete and not well-documented. The only cation data appear in table 4.5.1. Limited gas data are available.

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KS-2 testing produced steam with very little water. No analyses of the liquid phase were found. There is one report on analyses of the steam and gases, but the results were incomplete and plagued by technical problems.

Lanipuna 1 and Lanipuna 6 were sampled during brief pumping by air lift. All analyses are listed.

Excess steam effects

Table 4.4.2 lists all samples as collected. Samples from wells HGP-A, KS-2 and KS-1A were affected by boiling and separation of steam prior to sample collection. Therefore, to compare reservoir conditions at these wells it is necessary to correct the sample analyses to reservoir liquid concentrations, by removing the boiling and steam separation effects. This is easily done, using the steam fraction at separation pressure, when a well produces only water into the wellbore and boiling does not begin until the fluid begins ascending the well.

However, these wells produce a high steam fraction, which includes "excess" steam produced directly from the reservoir. At HGP-A, there is about 43 wt% steam at a production separator pressure of 170 psia. At KS-1A, there was about 83 wt% steam at 170 psia. From downhole measurements of pressure and temperature we know that the reservoir contains only liquid water in its natural state. The "excess" steam does not exist in the reservoir before it is tapped by the well, but forms when boiling occurs in the formation when the well is produced. Because of the excess steam, it is meaningless to use the

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observed steam fraction at separation pressure as a basis for correcting analytical concentrations to reservoir concentrations before boiling. Instead, it is necessary to know first what fraction of the steam formed from boiling of the liquid mass produced, and what fraction is excess.

These fractions can be estimated using either measured production zone temperature(s) or chemical geothermometers to calculate the reservoir liquid temperature and enthalpy prior to production. This enthalpy value is used to calculate the steam fraction at sample separation pressure, and that value, instead of measured total steam fraction, is used to correct sample analyses to pre-flash reservoir liquid concentrations. Reasonable results often can be obtained using the quartz, adiabatic geothermometer. There are numerous uncertainties introduced by analytical errors, sampling errors, mixing of fluids from different production zones, and loss of SiO_2 during scale formation before sampling. The uncertainty is largest for well KS-1A, where the very high steam fraction could have caused some excess evaporation of the liquid phase. However, the results still allow gross comparisons between wells, and within one well over time.

Table 4.3 shows the analyses from wells HGP-A and KS-1A corrected to average reservoir liquid composition, using enthalpy and steam fraction determined from the quartz, adiabatic geothermometer. The method requires an analysis of SiO_2 and documentation of separation pressure, so samples lacking this information, including the one sample from well KS-2, are omitted. We also have omitted four samples (numbers 20, 21, 24 and 28) from well KS-1A which contained higher levels of SiO_2 than can possibly have been reached at the recorded separation pressure, unless there was extreme excess evaporation. Three of these four

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samples also contain anomalously high levels of all other ions, so we suspect that they were not collected at the high pressures which were recorded, but rather at a lower pressure, perhaps from a weir box. (Interpretation of the data from Thermal Power wells was constantly hampered by incomplete, inconsistent and inadequate documentation.) Separation pressures appear in table 4.4.2.

As discussed below, the quartz temperatures obtained from well KS-1A average about 50°F lower (575°F) than the probable main reservoir temperature (625°F). If the reservoir liquid enthalpy (based on quartz temperatures) has been underestimated, then the steam fraction to correct surface samples to reservoir conditions (table 4.3) also has been underestimated. The quartz temperatures yielded steam fractions at sampling pressure of 25 wt% to 30 wt%. In contrast, a reservoir liquid temperature, before boiling, of 625°F yields steam fractions of about 35 wt%, lowers the reservoir concentrations about 10% to 15% below the values in table 4.3.

Reservoir liquid compositions

Dissolved solids in the Puna reservoir liquids are dominantly sodium (Na) and chloride (Cl). The overall composition commonly is characteristic of seawater hydrothermally altered during reactions with basaltic rocks, and diluted with about 25% to 50% meteoric water. An exception is the first production from well HGP-A, which was much more dilute and resembled meteoric water altered in basalts with or without a small altered seawater component. During its history, the fluid from well HGP-A has slowly shifted to the altered seawater signature. Like

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the current production, the early production was an Na - Cl fluid, but with distinct ion ratios and much lower total dissolved solids.

The sequence of seawater hydrothermal reaction and dilution is not easily established; i.e. we cannot tell for sure whether seawater becomes diluted and then reacts with hot rocks, or whether dilution follows the principal hydrothermal reactions. Reaction followed by dilution probably is the dominant process. Some dilution undoubtedly occurs during mixing of wellbore fluids of different salinities.

There are strong chemical gradients in the reservoir. At well HGP-A the earliest production had average pre-flash reservoir liquid Cl
about 1,700 ppm, whereas the Cl level by 1984 was over 7,000 ppm.
increase in Cl occurred between 1981 (first steady production) and
5, and the well has been stable since that time. The increasing Cl
accompanied by the above-mentioned changes in other ions, showing a
ft from meteoric-hydrothermal to seawater-hydrothermal character. It
s appears that the well tapped a small, lower salinity hydrothermal
tem which contained mostly meteoric water altered by heating in
alts, and that depletion of this system has caused altered seawater
to be drawn in, either from the side or below.

Horizontal gradients also exist. The present 7,000+ ppm Cl at well HGP-A compares with 12,000 - 14,000 ppm at KS-1A, about 17,000 ppm at Lanipuna 1, and 15,500 ppm at Lanipuna 6. These compare with 19,000 ppm Cl in seawater. From well KS-2 there are reports of over 40,000 ppm Cl in brine flashed to the atmosphere. The brine flow rate was apparently very small, and the steam flow rate high, so the brine may have suffered extreme excess evaporation. We think that this is the

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most likely explanation for the very high Cl at that well. However, the data show that a concentrated brine might be present in the reservoir. There is also a report that fluid containing 1,500 ppm Cl entered well KS-2 through a casing leak at 1,050 feet, when the well was flowed at low WHP.

what T are we referring to for HGP-A

Average chemical temperatures of the reservoir waters are as follows:

Average Temperature, °F

Well	Silica	Na-K-Ca	Na-K	Measured
HGP-A	555	480	500	c.560F
KS-1A	575	560	600	c.625F
KS-2 (1 sample)	n.a.	545	585	
Lanipuna 1	320	440	440	c.320F
Lanipuna 6	265	345	330	

The silica temperatures represent the quartz, adiabatic geothermometer at wells HGP-A and KS-1A, and the chalcedony, conductive geothermometer at Lanipuna 1 and Lanipuna 6. Measured temperatures are the probable temperature of the main production zone at HGP-A and KS-1A, determined from temperature and spinner logs, and the temperature at a fracture which is believed to be the source of production in Lanipuna 1.

As mentioned above, the quartz, adiabatic temperatures of samples from well KS-1A are about 575°F compared to a probable reservoir temperature of about 625°F. The low quartz temperatures suggest that either the liquid portion of production comes from a cooler zone in the well, above the 625°F production zone, or that silica was lost prior to

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sample collection. Either cause is possible. We note that the reservoir temperature near the top of the slotted liner in well KS-1A is about 580°F. This suggests that the silica temperature is correct, that the 625°F reservoir zone mostly produces steam, and that the water produced by the well mostly comes from near the top of the liner.

Figure 4.7 shows Na and K in all of the water samples (table 4.2), which illustrates their relative Na/K temperatures because Na/K decreases as temperature increases. At well KS-1A both cation temperatures Na/K and Na-K-Ca agree fairly well with the quartz and measured temperatures. At HGP-A the cation temperatures are distinctly low. This suggests that the more saline water which has been drawn into the well (above) comes from a lower temperature regime and has not completely equilibrated to conditions near the well.

During the production of well HGP-A since 1981 its silica concentrations and silica temperatures have remained constant. It has been reported that Na-K-Ca temperatures have declined from an initial value of about 570°F in 1981 to 480°F today. However, this is not apparent from the samples in table 4.3, which have a constant Na-K-Ca temperature always close to 480°F.

Regardless of the accuracies of the chemical temperatures, the relative temperatures at each well are consistent with measured temperature gradients across the reservoir. The temperature is highest at KS-1A, grading outward and down to KS-2, HGP-A, Lanipuna 1, then Lanipuna 6.

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Non-condensible gases

At well HGP-A, non-condensible gases (NCG) in steam have changed only slightly during production since 1981. Concentrations are as follows, showing the concentration in steam at initial production (1981) followed by the concentration 3-1/2 years later: CO_2 1,250ppmw/1,150ppmw; H_2S 950ppmw/850ppmw; N_2 130ppmw/120ppmw; H_2 12ppmw/12ppmw; CH_4 1ppmw/no data; total NCG 2,340ppmw/2,130ppmw. These concentrations were determined in steam separated at a typical pressure of about 155psig.

At well KS-1A the gases in steam are: CO_2 230-320ppmw; H_2S 1,200ppmw; total NCG 2,000-2,200ppmw, also determined at about 155psig.

Reliable data on gases at KS-1 and KS-2 have not been found.

The CO_2/H_2S ratio in these gases is quite low compared to typical values in geothermal systems world-wide, and H_2S/steam is much higher than found in typical water-dominated systems. The unusual CO_2/H_2S ratio and high H_2S are probably related to the recent magmatic activity in the Puna area, and/or to reactions between seawater and reduced iron in hot basalt, which could reduce seawater sulfate to sulfide.

Risks of development associated with fluid chemistry

The fluid chemistry at the Puna wells will impact geothermal development, requiring special consideration to avoid undue risks to safety and to project economics. The principal risks associated with

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fluid chemistry are silica scaling and the effects of the high H_2S in steam.

The potential for silica scaling is illustrated on figure 4.8, which shows that the typical reservoir liquid at well KS-1A will become oversaturated with 400 ppmw SiO_2 at a steam separation pressure of 150 psig. This is Ormat's current design pressure. The reservoir liquid is considered to carry 780 ppm SiO_2 at 625°F, based on the solubility of quartz in a 2.84 wt% NaCl solution. This is a probable upper limit on reservoir SiO_2, because the actual reservoir salinity is probably closer to 2.0 wt%, and measured SiO_2 data suggest that the reservoir liquid production comes from a zone between 575°F and 625°F (see discussion of silica temperatures above).

Silica scaling is known to be occurring in the production separator and flow lines at well HGP-A, where the normal separation pressure is 155 psig. Well KS-1A is slightly hotter and theoretically will present a slightly greater scaling problem. Scaling also could increase if the wells begin to produce brine combined with greatly superheated steam, generated during reservoir boiling. This would increase the concentration of the brine during boiling, but the increase may well be offset by a decrease in the brine flowrate. Reservoir boiling also will cause reservoir silica scaling which will reduce reservoir permeability. The loss probably will not be significant.

The amount of scaling in the production system at well HGP-A has not been prohibitive, and the amount in the proposed Ormat production system should be only slightly greater. At well HGP-A, the brine handling system was inspected in August, 1983, after about 22

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months of production. The 10-inch diameter pipeline between the wellhead and primary separator contained a layer of vitreous silica scale, about 0.5 mm thick. The primary brine separator (4′-7" diameter; 17′-10" high) was coated with a scale of silica plus <5% iron sulfides (corrosion products), a few mm to 2 cm thick. In the outlet pipe downstream of the separator there was 0.5 to 2 cm of scale. However, there was evidence that the scaling in the outlet pipe had been enhanced by flashing in the pipe immediately downstream of the separator. It also was found that small diameter nipples and connection points such as sample points had been bridged by scale, probably because of heat loss or turbulence.

does not compute
17% brin
83% ste
conden

At lower temperatures in the HGP-A production system there is a problem with silica, because abundant flocculated silica has sealed the percolation ponds and required that they be greatly enlarged. The lower temperature conditions in the proposed Ormat plant design will be different, because the brine will be mixed with steam condensate and injected back into the reservoir. As shown on figure 4.8, the mixing will shift the brine from c.400 ppmw oversaturation, in the production separator, down to about 120 ppmw oversaturation at the mixing point. (Note: in preparing figure 4.8 it was assumed that conductive heat losses are minimal.) This is a small level of oversaturation, which indicates that further scaling will probably be nearly insignificant, unless the fluid is allowed substantial cooling. If the injection well is much cooler than the fluid temperature at the mixing point (about 300°F), there will be some risk of scaling in the injection well and resulting loss of injectivity.

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5. RESERVE ESTIMATE

5.1 Reservoir Definition

As discussed section 3.4, surface geology combined with subsurface temperature data indicates that the geothermal reservoir consists of thermal fluid circulating in fractures located within about 2,000 feet of the eruptive fissure of 1955. The temperature contours further indicate that fluid is moving parallel to the rift zone from SW to NE. Based on this hydrogeologic model, 3 different reservoir areas can be defined with varying degrees of uncertainty concerning their potential reserves. These are discussed below in order of increasing uncertainty of reserve estimate.

Area of Proven Production

The Proven area is defined by drilling results. It is bounded on the NW by the eruptive fissure; on the NE by the 400°F isothermal surface (assuming that 400°F is the cut-off of economic production for a flash-cycle plant); and on the SE and SW by the Puna lease boundary. Because the 400°F temperature boundary expands downward from about the -2,800 foot level, the proven area also increases with depth from 0.163 square miles at -3,000 feet msl to 0.196 square miles at -6,000 feet msl. This gives an average area of 0.194 square miles. By using this measured area to calculate volumes enclosed by isothermal surfaces, and summing the volumes from level to level, a total volume of 0.128 cubic miles and average temperature of 505°F for the Proven area was calculated.

Area of Probable Production

By assuming that the 1955 eruptive fissure forms a plane of symmetry for temperature distribution as discussed in section 3.4, an area which is probably productive can be defined. This area is bounded on the SE by the eruptive fissure, on the NE and NW by the 400°F isothermal surface and on the SW by the Puna lease boundary. As in the Proven area, the area enclosed by the 400°F contours increase with depth. In this case, the area increases from 0.242 square miles at -3,000 feet msl to 0.382 square miles at -5,000 feet msl. At -6,000 feet msl it contracts to 0.283 square miles. The average area over the range from -3,000 to -6,000 feet msl is 0.502 square miles. A calculation of the volumes enclosed by isothermal surfaces, similar to that described for the Proven area, results in an average volume of 0.206 cubic miles and an average temperature of 498°F for the Probable area.

Area of Possible Production

Temperature contours are shown closed to the NE in figures 3.14 to 3.17 because temperature in well KS-2 have been interpreted to be about 50°F lower than temperatures in KS-1A at compatible elevations (except at -6,000 feet, where this temperature differential is only 20°F). Because of poor data, however, there is considerable uncertainty concerning the true rock temperatures in both wells. Geochemical temperatures in KS-2 appear to be only slightly lower than in KS-1A, but again poor data also makes this conclusion uncertain.

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In view of these uncertainties, it is possible that fluid temperatures in KS-1A and KS-2 are similar. In that case subsurface temperature contours would parallel the eruptive fissure zone, making the entire length of the zone within the lease prospective. The length of the fissure zone within the Puna lease is about 4.5 miles. In the drilled area, the average distance from the fissure to the 400°F contour is about 0.4 miles. Assuming a symmetrical development of temperature contour. Parallel to the entire length of the fissure zone within the lease, then the area of Possible production is 2 x 0.4 x 4.5 = 3.6 square miles.

The three areas of Proven, Probable, and Possible production, as defined above, will be used in the following section to estimate the probable production capacity of the Puna lease.

5.2 Probable Production Capacity

Because the Puna area is still in an early stage of development, the reserve estimation is based on a volumetric approach. We have used, with some important modifications, the volumetric reserve estimation introduced by the U.S. Geological Survey. We have further improved this approach, to account for uncertainties in some parameters, by using a probabilistic basis.

In our method, the maximum sustainable power plant capacity (E) is given by:

$$E = AhC_V(T-T_0)\cdot R/F/L, \qquad (1)$$

where A = areal extent of the reservoir,

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h = thickness of the reservoir,

C_v = volumetric specific heat of the reservoir,

T = average temperature of the reservoir,

T_o = base temperature

R = overall recovery efficiency (the fraction of thermal energy in-place within the reservoir volume at a temperature of To or more that is converted to electrical energy at the power plant),

F = power plant capacity factor (the fraction of time the plant produces power on an annual basis), and

L = power plant life.

The parameter R can be determined as follows:

$$R = r \cdot e, \tag{2}$$

where r = recovery factor (the fraction of thermal energy in-place within the reservoir volume at a temperature of To or more that is recoverable as thermal energy), and

e = thermal-to-electrical power conversion efficiency

The parameter C_v in (1) is given by:

$$C_v = \rho_r\, C_r\, (1-\phi) + \rho_f C_f\, \phi \tag{3}$$

where ρ_r = density of rock matrix,

C_r = specific heat of rock matrix,

ρ_f = density of reservoir fluid, and

ϕ = reservoir porosity.

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Ormat's modular power plant design indicates a steam requirement of 50,000 lbs per hour per module at 215 psia for a gross power capacity of 2.82 MW. This is equivalent to an 'e' value of about 16%. This is a very attractive value of 'e' for a small power plant module and compares favorably with conventional flash geothermal power plants.

The following parameters could be estimated for the PGV leaseholds without significant uncertainty:

$\rho_r C_r$ = 34.0 (based on representative rock types at Puna),
To = 350°F (minimum acceptable resource temperature),
F = 0.85 (typical for modern geothermal plants), and
L = 25 years (typical amortization period for a power plant).

The remaining parameters required for reserve estimation were considered to have some uncertainty. Therefore, it is prudent to estimate reserves in a probabilistic way, using the Monte Carlo simulation method, with the following estimates of the uncertain parameters:

area: a triangular probability distribution was used with the minimum value equal to the proven area (0.194 square miles); the maximum value equal to the possible area (3.6 square miles) and the most likely value equal to the ~~Proven plus~~ Probable area (0.502 square miles).

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thickness: a uniform probability distribution was used between the values of 3,000 and 3,800 ft., based on cross-section A-A′ and B-B′.

porosity: a range from 0.03 to 0.07, with uniform probability, is considered appropriate for fractured igneous rock (basalt).

temperature: a maximum of 505°F, which is the average temperature of the proven area, and a minimum of 450°F, which is our best estimate for the possible area, were used with equal probability.

recovery factor: a range from 0.25 to 0.50, with equal probability was used.

Estimates of C_f and ρ_f are determined by the probability distribution of T.

The values of the uncertain parameters were sampled randomly 1,000 times, and the reserves were calculated for each sampled set of parameters. Appendix A includes the computer printout of the Monte Carlo simulation study. Figure 5.1 presents the results of simulation as a probability distribution of the calculated MW capacity. The mean value of the calculated MW capacity of the Puna reservoir is 83 MW, with a standard deviation of 43 MW. This high standard deviation reflects the fact that a large part of the leasehold is yet to be explored fully. The maximum estimated potential of the leasehold is 200 MW.

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Figure 5.2 presents the same results in terms of the cumulative probability distribution. This figure shows that the probability is about 92% that the reserves will exceed 28.2 MW (gross).

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6. WELL COMPLETION CONSIDERATIONS

6.1 Completion of Wells KS-1 and KS-2

Wells Kapoho State 1 and 2 (KS-1 and KS-2) were completed in November 1981 and March 1982, respectively. The completion details for these wells are shown on table 6.1.

Both KS wells were designed with similar hole and casing diameters, depths, casing type and casing grade. Similar cementing techniques and equipment were used in both wells. The drilling conditions and the problems experienced during the drilling stages were also very similar. Both wells also developed similar problems during their first testing period. The evidence of some type of casing failure was noted initially during the first flow testing of the wells. Further evaluation, based on temperature and pressure surveys that were conducted while cold water was being injected into the wells, clearly revealed the existence of casing leaks at depths of 900 to 940 and 1,040 to 1,080 feet in well KS-1, and between 1,987 and 1,093 feet in well KS-2. In both wells, a remedial program was prepared to repair the casing damage.

In well KS-1, after several unsuccessful attempts to squeeze cement into the leaking zones, it was decided to run and cement a 7-inch casing patch to cover the interval from 0 to 1,898 feet. The patching was conducted with minor difficulties. During the same workover

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program, the existing ANSI Series 600 master valve was changed for a higher rated ANSI Series 900 valve. Also, an attempt was made to clean out the 7-inch perforated liner, but during this operation the 7-inch mill that was used for the job became stuck and a 237 feet portion of the cleaning assembly was eventually left in the hole, with the top of the fish at 4,570 feet. The well was plugged with cement at a depth of 1,750 ft.; further evaluation of the caliper logs revealed severe damage with possibly parted casing from 226 to 233 ft.; from 362 to 363 ft. and possible gaps at numerous collars.

In well KS-2, it was suspected that a four foot gap existed at the depth of the 9-5/8-inch casing tie-back after comparing the results from a casing collar locating log and the drillers casing tally logs. The problem was later confirmed by a caliper log that was run in the well. A remedial program was designed and followed to repair the damaged casing, including squeezing cement into the damaged sections and clearing the wellbore from wireline debris and logging tools that had been left in the hole during previous logging operations.

Several cement plugs were squeezed into the damaged zone without successfully plugging it. No further attempt was made to repair the damage in the casing and the wellbore cleanup operation had to be abandoned after experiencing severe difficulties running the milling tools below the depth of 4,396 feet. A cement plug was placed at 3,175 feet and the well was closed.

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6.2 Completion of Well KS-1A

Based on the experience gained from drilling, cementing and testing the KS-1 and KS-2 wells, well KS-1A was drilled and completed in September, 1985, using a new design. The 20-inch casing was set at a depth of 1,377 feet as compared to 71 and 68 ft. in KS-1 and KS-2, respectively, to provide increased protection to the intermediate and production casing strings. The 13-3/8-inch casing was also set deeper in this well, to a depth of 2,701 feet, compared to 900 feet in well KS-1 and 1,313 feet in well KS-2. The 9-5/8-inch casing was cemented at the top of the production zone, at 4,061 feet, and the 7-inch slotted liner was run from 3,874 to TD (6,505 feet). The completion details for this well are shown on table 6.1.

The intermediate string (13-3/8-inch), the production string (9-5/8-inch) and the production liner (7-inch) consisted of grade C-90 casing, which is made from a low carbon, high yield strength steel. This particular grade provides a considerable resistance to corrosion and hydrogen embrittlement. The 13-3/8- and 9-5/8-inch casings were ordered with premium VAM and Hydril threaded connections.

The casing strings were prepared with stage cementing collars to cement the first stage in order to anchor the casing, and then apply a pre-tensioning force to the casing before cementing the second stage. The wellhead equipment had to be specially designed to maintain the tension force in the casing during the cementing operation and to allow the casing to expand during the well warm-up. The two-stage cementing operation helped to reduce the weight of the cement column and the possibility of inducing losses of circulation during the cementing process. The pre-tensioning and the two-stage cementing operations were erformed with relatively minor problems.

Since its completion, well KS-1A has been tested extensively or production without any of the problems that were common for the KS-1 nd KS-2 wells.

.3 Completion of Well HGP-A

The HGP-A well was drilled by the University of Hawaii, from 22 November, 1975 to 8 June, 1976. Details of well completion are shown in Table 6.1. During the drilling stages, some losses of circulation occurred at shallow depths, and high mud return temperatures were measured. The casing strings used on this well consisted of standard grades K-55 and N-80, cemented with Class I cement. No cement returns were detected during the cementing operations of both the 20-inch and the 9-5/8-inch casings. A cement bond log, run after cementing the 9-5/8-inch casing, indicated the presence of void spaces in the annulus between the 9-5/8 and the 13-3/8-inch casings at depths between 40 to 220 ft. and 320 to 868 feet. The 9-5/8-inch casing was perforated and cement was squeezed to fill the voids; a significant improvement was noted when another CBL was run.

The well was flow-tested on July 19 and 20, 1976, and has been flowing without apparent complications during the 5-year operation of the power plant.

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6.4 Recommended Completion of Future Wells

The failure of the casing in wells KS-1 and KS-2 has been reported as a product of hydrogen embrittlement caused by the high content of H_2S in the fluids. After flow testing, the formation of an abnormally high pressure gas cap in the shut-in wells has been observed. The H_2S-enriched environment of this gas cap may have been a major cause of the casing failure.

The original mechanical properties of the carbon steel utilized in the fabrication of the K-55 casing are easily deteriorated by the embrittlement caused by the H_2S. During the early life of a geothermal well, the process of cooling and heating (especially during the testing periods) produces stress fractures that later develop as major casing leaks. This deterioration is further increased both internally and externally by erosion and cavitation that occur as a result of the turbulent flow and especially when external portions of the casing are poorly protected by a channeled, weakened or defective cement sheath.

The combination of a low carbon, high yield casing material, together with premium threads such as the Vallourec-VAM thread, has worked satisfactorily in well KS-1A. The VAM threads, originally used in this well to provide an extra strong connection, also offer an internal flush metal-to-metal seal that reduces flow turbulence and consequently helps control the erosion and cavitation problems that are common to the Buttress connections under similar conditions. The low carbon content of the steel also reduces the problem of hydrogen embrittlement.

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The extra cost of the grade C-90 or C-95 casing with respect to the K-55 grade, plus the extra cost of the premium threads such as the VAM thread with respect to the Buttress thread is about 15%.

The deeper surface and intermediate casing setting and the use of combined stage cementing collars and stab-in cementing collars in the casing, are recommended, in order to protect the integrity of the well and to ensure the best possible results during the cementing operation.

Casing tensioning is a technique that has proven to be helpful in the Cerro Prieto field in Mexico, where the production fluid temperatures are very high. It is a superior technique if the well is expected to have a minimum of thermal changes, which occur when occasional short-term flow test and long shut-in periods occur. If the tensioning technique is applied, the cost of the extra wellhead equipment that is required becomes an important part of the total cost of the well. Additionally, it becomes necessary to maintain the well on bleed in order to maintain a constant temperature regime in the casing. The bleed could prove detrimental and difficult to maintain, since the H_2S gas that boils out of the fluids will be dispersed in the atmosphere, creating potential environmental problems. Additionally, the constant boiling of the liquid level inside the casing could cause severe scaling problems. For these reasons, we do not recommend this technique for future Kapoho wells.

In conclusion, it appears that Thermal Power Company's choice of premium casing materials, deeper casing setting depths, and stage cementing has eliminated the problem of casing joint pull-apart found in

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KS-1 and KS-2. However, in view of the relatively trouble-free history of well HGP-A, which has a more conventional design, it is not clear whether all these measures adopted by Thermal are absolutely necessary.

Well HGP-A, which had been drilled within a short distance (1,600 ft) of the KS well pads, using standard K-55 and N-80 grades of casing, which were poorly cemented, produces fluids of similar nature to those from the KS wells, and with the addition of a tie-back string, has been able to maintain its integrity as a geothermal production well for 12 years.

Unfortunately, very few downhole logs and little chemical data are available from this well, making it difficult to define the reason why the behavior of this well is different from that of the KS wells. Further investigation of the physico-chemical conditions of this well, and its maintenance history, is necessary. This investigation could lead to some important conclusions regarding well completion materials and techniques to be used in the future wells.

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TABLES

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Table 3.1. Rock Temperatures Interpreted from Downhole Temperature Surveys

Elevation (feet, msl)	Temperature, °F, Estimated for Wells					
	L-1	L-1ST	L-6	HGP-A	KS-1/Ks-1A	KS-2
-1,000	100	118	150	215	175	110
-2,000	210	175	235	410	336	240
-3,000	295	280	320	510	483	415
-4,000	385	385	255	550	580	520
-5,000	450	415	~270	555	640	580
-6,000	520	330	-	~660	~660	640
-7,000	680	-	-	-	-	-

Note: ~ = value derived from downward projection of gradient

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Table 3.2. Pressures at -5,000 feet msl and Vertical Pressure Gradients Between -4,000 and -5,000 Feet msl

Well	Pressure, psig at -5,000 feet msl (Projected Where Necessary)	Vertical Pressure Gradient psi/foot -4000 to -5,000 ft msl
L-1ST	2,620	0.44
HGP-A	2,180	0.42
KS-1A	1,980	0.33
KS-2	2,200	0.33

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Table 4.1 : Summary of Discharge Parameters, Wells KS-1, KS-2 and KS-1A

Well	Wellhead Pressure (psia)	Enthalpy (BTU/lb)	Total flow rate (klbs/hr)	Power rating* (MWe)
KS-1 (August 11-28, 1982)				
	122	dry steam	71.0	-
	126	dry steam	78.9	-
	233	dry steam	59.7	3.1
	168	dry steam	69.6	3.6
	154	dry steam	69.5	-
	133	dry steam	68.0	-
	193	dry steam	66.4	3.5
	131	dry steam	73.0	-
	216	dry steam	59.7	3.1
	129	dry steam	72.5	-
KS-2 (July 28-August 2, 1982)				
	163	wet steam	37.8	2.0
	225	dry steam	19.0	1.0
	188	dry steam	35.2	1.8
KS-1A (October 7-31, 1985)				
	170	1038	74.9	3.2
	94	1049	70.9	-
	124	1038	77.5	-
	170	1034	79.1	3.3
	217	1021	78.1	3.2
	271	1009	76.6	3.1
	314	999	75.5	3.0
	364	976	74.7	2.8
	418	980	73.5	2.8
	486	960	68.4	2.5
	514	955	70.6	2.6
	679	906	63.9	2.2
	920	782	49.3	1.3
	168	1046	80.7	3.5

* based on separator pressure of 165 psia and steam consumption of 19.2 klbs/hr per MWe.

TABLE 4.2: PUNA, HAWAII GEOCHEMISTRY DATA BASE -- CONCENTRATIONS IN MG/KG

KEY TO COLUMN HEADINGS [Listed in approximate order, some may not be included in this printout]

PARTS I AND II : SAMPLE BACKGROUND DATA

NUM	=	sample number
NAME	=	full name of sample.
DATEHRS	=	date and time of collection in format yymmdd.hrs
DATASRC	=	source of analytical data -- laboratory name and date, or report title.
PORT	=	sample type or source: BRN = brine from weir or separator. BLOO = water sample from blooie line, airlift.
WHP	=	wellhead pressure, g=gauge, a=absolute, psi
SPG	=	pressure of steam-water separation, psi gauge
SPA	=	pressure of steam-water separation, psi abs.
HT	=	reported total flow enthalpy, btu/lb
VAPF	=	steam flow at SPG/SPA, klb/hr
WATF	=	water flow at SPG/SPA, klb/hr
TMF	=	total flow, klb/hr
XSTM	=	steam flow as percent of total
STATUSCOM	=	comment concerning sample collection and/or status of source at time of collection

PARTS III TO V : ANALYTICAL DATA AND COMMENTS

PHL	=	sample pH, measured in laboratory, 25degC
CA...MN	=	species concentrations in mg/l
HCO3,CO3	=	total alkalinity as bicarbonate and carbonate, mg/l
TDSS	=	total dissolved solids by summation of Ca,Mg,Na,K,Li,HCO3,CO3,SO4,Cl,SiO2 and B
COMMENT	=	additional comments
TRACEANIONS	=	other anions
TRACECATIONS	=	other cations

Note: -1 or blank signifies no data. 0.0 indicates below detection limit of analysis,

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NUM	NAME	DATEHRS	PORT	WHP	TMF	DATASRC	STATUSCOM
1	HGP-A	761202.0000	BRN	-1	-1.00	Thomas,USGSPP-1350	DOWNHOLE SAMPLE, -1300m
2	"	770209.0000	BRN	-1	-1.00	Thomas,USGSPP-1350	PROBABLY A WEIRBOX SAMPLE; HT FRM #8, XSTM FRM HT
3	"	770422.0000	BRN	-1	-1.00	Thomas,USGSPP-1350	PROBABLY A WEIRBOX SAMPLE; HT FROM #8, XSTM FRM HT
4	"	800110.1000	BRN	-1	-1.00	Thomas (1980)	Brine line frm separator; HT FRM #8, XSTM FRM HT
5	"	800111.1300	BRN	-1	-1.00	Thomas (1980)	Brine line frm separator; HT FRM #8, XSTM FRM HT
6	"	800116.0000	BRN	-1	38.39	Thomas,USGSPP-1350	HT FRM #8, XSTM FRM HT
7	"	810612.0000	BRN	-1	-1.00	Thomas,USGSPP-1350	PROBABLY A WEIRBOX SAMPLE; HT FRM #8, XSTM FRM HT
8	"	810904.0000	BRN	-1	-1.00	Thomas,USGSPP-1350	HT FRM THOMAS TYPICAL XSTM 43% @ 1,200kPa=174psia
9	"	811211.0000	BRN	-1	-1.00	Thomas,USGSPP-1350	PROBABLY A WEIRBOX SAMPLE; HT FRM #8, XSTM FRM HT
10	"	820607.0000	BRN	-1	-1.00	Thomas,USGSPP-1350	HT FRM #8, XSTM FRM HT
11	"	821116.0000	BRN	-1	-1.00	Thomas,USGSPP-1350	HT FRM #8, XSTM FRM HT
12	"	830504.0000	BRN	-1	-1.00	Thomas,USGSPP-1350	HT FRM #8, XSTM FRM HT
13	"	831205.0000	BRN	-1	-1.00	Thomas,USGSPP-1350	HT FRM #8, XSTM FRM HT
14	"	840112.0000	BRN	160g	-1.00	IOVANETTI MMO 871016	
15	"	840626.0000	BRN	-1	-1.00	Thomas,USGSPP-1350	HT FRM #8, XSTM FRM HT
16	"	841128.0000	BRN	-1	-1.00	Thomas,USGSPP-1350	HT FRM #8, XSTM FRM HT
17	KS-1A	851016.0930	BRN	155g	-1.00	TPnotesSmpl1002/Anatec	NOTES SAY C.17%BRINE; begin flow test; PRODUCTION SEPARATOR,362F
18	"	851019.1700	BRN	155g	-1.00	TPnotesSmpl1003/Anatec	NOTES SAY C.17%BRINE;PRODUCTION SEPARATOR, 357F
19	"	851019.1700	BRN	155g	-1.00	TPnotesSmpl1004/UURI	NOTES SAY C.17%BRINE; duplicate of smpl 1003
20	"	851024.2100	BRN	155g	-1.00	TPnotesSmpl1005/Anatec	NOTES SAY C.17%BRINE; PRODUCTION SEPARATOR, 365F
21	"	851024.2100	BRN	155g	-1.00	TPnotesSmpl1006/UURI	NOTES SAY C.17%BRINE; PRODUCTION SEPARATOR, 365F
22	"	851024.2100	BRN	155g	-1.00	Thermal Power/Brewer	PRODUCTION SEPARATOR, 365F
23	"	851024.2100	BRN	155g	-1.00	Thermal Power/Brewer	PRODUCTION SEPARATOR, 365F
24	"	851026.2100	BRN	80g	-1.00	TPnotesSmpl1007/Anatec	PRODUCTION SEPARATOR, 315F; XSTM ASSUMES HT 1050BTU/LB
25	"	851028.0400	BRN	155g	-1.00	TPnotesSmpl1009/Anatec	PRODUCTION SEPARATOR, 365F; DURING STEP RATE TEST
26	"	851028.2330	BRN	345	-1.00	TPnotesSmpl1010/Anatec	PRODUCTION SEPARATOR, 363F;XSTM ASSUMES HIGH WHP NO EFFECT ON HT
27	"	851029.1330	BRN	640	-1.00	TPnotesSmpl1011/Anatec	PRODUCTION SEPARATOR, 363F;XSTM ASSUMES HIGH WHP NO EFFECT ON HT
28	"	851031.1245	BRN	155g	-1.00	IOVANETTI MMO 871016	PRODUCTION SEPARATOR, 365F, WHT=368F
29	KS-2	820609.0000	BRN	175g	-1.00	IOVANETTI MMO 871016	
30	LANIPUN1	810422.0000	BLOO	-1	-1.00	GEx\Amtech0405-81	LAST OF 4 AIR LIFT SMPLS,INCR.SAL.;PERM.ZONE 4000FT 160C
31	"	810714.2200	BLOO		-1.00	GEX/Amtech 0813-81	
32	"	810715.0200	BLOO		-1.00	GEX/Amtech 0813-81	
33	"	810715.0300	BLOO		-1.00	GEX/Amtech 0813-81	
34	"	810799.9999	BLOO		-1.00	GEX/Amtech 0813-81	labeled sample from 4000ft+
35	LANIPUN6	840803.1320	BLOO	-1	-1.00	GEx	unloading well
36	"	840808.1600	BLOO	-1	-1.00	GEx	unloading well
37	"	840809.1600	BLOO	-1	-1.00	GEx	unloading well
37	IHP SPR	750107.0000		-1	-1.00	HGP INI.PH.II PROG. 2/76	ISAAC HALE PARK SPRING, 36C

NUM	NAME	DATEHRS	PORT	WHP	TMF	DATASRC	STATUSCOM
39	"	751027.0000		-1	-1.00	HGP INI.PH.II PROG. 2/76	ISAAC HALE PARK SPRING
40	MALAMA K.	750107.0000		-1	-1.00	HGP INI.PH.II PROG. 2/76	MALAMA KI WELL (WELL 9-9), 52.5C
41	"	750722.0000		-1	-1.00	HGP INI.PH.II PROG. 2/76	MALAMA KI WELL (WELL 9-9)
42	GEOTH #3	750107.0000		-1	-1.00	HGP INI.PH.II PROG. 2/76	WELL GEOTHERMAL #3, 93C
43	"	750721.0000		-1	-1.00	HGP INI.PH.II PROG. 2/76	WELL GEOTHERMAL #3
44	"	750721.0000		-1	-1.00	HGP INI.PH.II PROG. 2/76	WELL GEOTHERMAL #3, THIEF SMPL FRM 50-60FT BELOW WTR SURF, 74C
45	RAIN	750000.0000		-1	-1.00	HGP INI.PH.II PROG. 2/76	LOCAL RAIN FROM KALAPANA, AIRSTRIP, AND ISAAC HALE

NUM	NAME	DATEHRS	PORT	WHP	SPG	SPA	HT	VAPF	WATF	TMF	XSTM	STATUSCOM
1	HGP-A	761202.0000	BRN	-1	-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	DOWNHOLE SAMPLE, -1300m
2	"	770209.0000	BRN	-1	-1.000	14.930	710.00	-1.00	-1.00	-1.00	54.5924	PROBABLY A WEIRBOX SAMPLE; HT FRM #8, XSTM FRM HT
3	"	770422.0000	BRN	-1	-1.000	14.930	710.00	-1.00	-1.00	-1.00	54.5924	PROBABLY A WEIRBOX SAMPLE; HT FROM #8, XSTM FRM HT
4	"	800110.1000	BRN	-1	88.000	102.700	710.00	-1.00	-1.00	-1.00	46.1617	Brine line frm separator; HT FRM #8, XSTM FRM HT
5	"	800111.1300	BRN	-1	154.000	168.700	710.00	-1.00	-1.00	-1.00	43.1895	Brine line frm separator; HT FRM #8, XSTM FRM HT
6	"	800116.0000	BRN	-1	-1.000	132.000	710.00	-1.00	-1.00	38.39	44.7480	HT FRM #8, XSTM FRM HT
7	"	810612.0000	BRN	-1	-1.000	14.930	710.00	-1.00	-1.00	-1.00	54.5473	PROBABLY A WEIRBOX SAMPLE; HT FRM #8, XSTM FRM HT
8	"	810904.0000	BRN	-1	-1.000	174.000	710.00	-1.00	-1.00	-1.00	43.0000	HT FRM THOMAS TYPICAL XSTM 43% @ 1,200kPa=174psia
9	"	811211.0000	BRN	-1	-1.000	14.930	710.00	-1.00	-1.00	-1.00	54.5473	PROBABLY A WEIRBOX SAMPLE; HT FRM #8, XSTM FRM HT
10	"	820607.0000	BRN	-1	-1.000	169.700	710.00	-1.00	-1.00	-1.00	43.1512	HT FRM #8, XSTM FRM HT
11	"	821116.0000	BRN	-1	-1.000	169.700	710.00	-1.00	-1.00	-1.00	43.1512	HT FRM #8, XSTM FRM HT
12	"	830504.0000	BRN	-1	-1.000	169.700	710.00	-1.00	-1.00	-1.00	43.1512	HT FRM #8, XSTM FRM HT
13	"	831205.0000	BRN	-1	-1.000	159.500	710.00	-1.00	-1.00	-1.00	43.5471	HT FRM #8, XSTM FRM HT
14	"	840112.0000	BRN	160g	-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	
15	"	840626.0000	BRN	-1	-1.000	159.500	710.00	-1.00	-1.00	-1.00	43.5471	HT FRM #8, XSTM FRM HT
16	"	841128.0000	BRN	-1	-1.000	159.500	710.00	-1.00	-1.00	-1.00	43.5471	HT FRM #8, XSTM FRM HT
17	KS-1A	851016.0930	BRN	155g	160.000	174.700	-1.00	-1.00	-1.00	-1.00	83.0000	NOTES SAY C.17%BRINE; begin flow test; PRODUCTION SEPARATOR,362F
18	"	851019.1700	BRN	155g	156.000	170.700	-1.00	-1.00	-1.00	-1.00	83.0000	NOTES SAY C.17%BRINE;PRODUCTION SEPARATOR, 357F
19	"	851019.1700	BRN	155g	156.000	170.700	-1.00	-1.00	-1.00	-1.00	83.0000	NOTES SAY C.17%BRINE; duplicate of smpl 1003
20	"	851024.2100	BRN	155g	155.000	169.700	-1.00	-1.00	-1.00	-1.00	83.0000	NOTES SAY C.17%BRINE; PRODUCTION SEPARATOR, 365F
21	"	851024.2100	BRN	155g	155.000	169.700	-1.00	-1.00	-1.00	-1.00	83.0000	NOTES SAY C.17%BRINE; PRODUCTION SEPARATOR, 365F
22	"	851024.2100	BRN	155g	155.000	169.700	1054.00	-1.00	-1.00	-1.00	83.3899	PRODUCTION SEPARATOR, 365F
23	"	851024.2100	BRN	155g	155.000	169.700	1054.00	-1.00	-1.00	-1.00	83.3899	PRODUCTION SEPARATOR, 365F
24	"	851026.2100	BRN	80g	72.000	86.700	-1.00	-1.00	-1.00	-1.00	84.9972	PRODUCTION SEPARATOR, 315F; XSTM ASSUMES HT 1050BTU/LB
25	"	851028.0400	BRN	155g	154.000	168.700	-1.00	-1.00	-1.00	-1.00	83.0000	PRODUCTION SEPARATOR, 365F; DURING STEP RATE TEST
26	"	851028.2330	BRN	345	153.000	167.700	-1.00	-1.00	-1.00	-1.00	83.0000	PRODUCTION SEPARATOR, 363F;XSTM ASSUMES HIGH WHP NO EFFECT ON HT
27	"	851029.1330	BRN	640	153.000	167.700	-1.00	-1.00	-1.00	-1.00	83.0000	PRODUCTION SEPARATOR, 363F;XSTM ASSUMES HIGH WHP NO EFFECT ON HT
28	"	851031.1245	BRN	155g	153.000	167.700	1042.00	-1.00	-1.00	-1.00	82.0264	PRODUCTION SEPARATOR, 365F, WHT=368F
29	KS-2	820609.0000	BRN	175g	-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	
30	LANIPUN1	810422.0000	BLOO	-1	-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	LAST OF 4 AIR LIFT SMPLS,INCR.SAL.;PERM.ZONE 4000FT 160C
31	"	810714.2200	BLOO		-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	
32	"	810715.0200	BLOO		-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	
33	"	810715.0300	BLOO		-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	
34	"	810799.9999	BLOO		-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	labeled sample from 4000ft+
35	LANIPUN6	840803.1320	BLOO	-1	-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	unloading well
36	"	840808.1600	BLOO	-1	-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	unloading well
37	"	840809.1600	BLOO	-1	-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	unloading well
37	IHP SPR	750107.0000		-1	-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	ISAAC HALE PARK SPRING, 36C

NUM	NAME	DATEHRS	PORT	WHP	SPG	SPA	HT	VAPF	WATF	TMF	XSTM	STATUSCOM
39	"	751027.0000		-1	-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	ISAAC HALE PARK SPRING
40	MALAMA K.	750107.0000		-1	-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	MALAMA KI WELL (WELL 9-9), 52.5C
41	"	750722.0000		-1	-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	MALAMA KI WELL (WELL 9-9)
42	GEOTH #3	750107.0000		-1	-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	WELL GEOTHERMAL #3, 93C
43	"	750721.0000		-1	-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	WELL GEOTHERMAL #3
44	"	750721.0000		-1	-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	WELL GEOTHERMAL #3, THIEF SMPL FRM 50-60FT BELOW WTR SURF, 74C
45	RAIN	750000.0000		-1	-1.000	-1.000	-1.00	-1.00	-1.00	-1.00	-1.0000	LOCAL RAIN FROM KALAPANA, AIRSTRIP, AND ISAAC HALE

PUNA, HAWAII GEOCHEMISTRY DATA BASE -- MG/KG : PART III

NUM	NAME	DATEHRS	BASIS	PHL	CA	MG	NA	K	LI	HCO3	CO3	SO4	CL	F_	SIO2	B	TDSS
1	HGP-A	761202.0000	SAMPLE	-1.00	17.3	0.70	480.0	85.0	-1.00	-1.0	-1.0	-1.0	920.0	-1.00	740	-1.0	2243
2	"	770209.0000	SAMPLE	-1.00	30.1	0.10	720.0	135.0	-1.00	-1.0	-1.0	-1.0	1610.0	-1.00	-1	-1.0	2495
3	"	770422.0000	SAMPLE	-1.00	72.2	0.10	1480.0	277.0	-1.00	-1.0	-1.0	-1.0	3190.0	-1.00	-1	-1.0	5019
4	"	800110.1000	SAMPLE	-1.00	16.3	0.00	1430.0	200.0	-1.00	-1.0	-1.0	50.0	2390.0	-1.00	865	-1.0	4951
5	"	800111.1300	SAMPLE	-1.00	33.2	0.00	1463.0	211.0	-1.00	-1.0	-1.0	60.0	2450.0	-1.00	792	-1.0	5009
6	"	800116.0000	SAMPLE	-1.00	33.9	0.01	1520.0	224.0	-1.00	-1.0	-1.0	69.0	2593.0	-1.00	832	-1.0	5272
7	"	810612.0000	SAMPLE	-1.00	25.5	0.01	900.0	200.0	-1.00	-1.0	-1.0	69.0	2065.0	-1.00	1198	-1.0	4458
8	"	810904.0000	SAMPLE	-1.00	66.5	0.03	1890.0	295.0	-1.00	-1.0	-1.0	69.0	3622.0	-1.00	860	-1.0	6803
9	"	811211.0000	SAMPLE	-1.00	33.0	0.01	1590.0	300.0	-1.00	-1.0	-1.0	69.0	2763.0	-1.00	1004	-1.0	5759
10	"	820607.0000	SAMPLE	-1.00	122.5	0.05	3120.0	525.0	-1.00	-1.0	-1.0	69.0	5667.0	-1.00	803	-1.0	10307
11	"	821116.0000	SAMPLE	-1.00	217.0	0.10	3940.0	650.0	-1.00	-1.0	-1.0	69.0	7029.0	-1.00	829	-1.0	12734
12	"	830504.0000	SAMPLE	-1.00	270.0	0.15	4220.0	675.0	-1.00	-1.0	-1.0	69.0	7965.0	-1.00	805	-1.0	14004
13	"	831205.0000	SAMPLE	-1.00	319.0	0.21	4650.0	763.0	-1.00	-1.0	-1.0	24.0	8827.0	-1.00	825	-1.0	15408
14	"	840112.0000	SAMPLE	6.60	358.0	0.26	4927.0	756.0	1.10	18.5	0.0	24.0	8968.0	0.25	386 ←	4.3	15434
15	"	840626.0000	SAMPLE	-1.00	489.0	0.25	4840.0	773.0	-1.00	-1.0	-1.0	15.0	8900.0	-1.00	885	-1.0	15902
16	"	841128.0000	SAMPLE	-1.00	399.0	0.20	5420.0	733.0	-1.00	-1.0	-1.0	4.5	9514.0	-1.00	913	-1.0	16984
17	KS-1A	851016.0930	SAMPLE	5.80	950.0	1.20	9750.0	2500.0	8.40	15.0	0.0	25.0	19000.0	1.10	850	11.0	33103
18	"	851019.1700	SAMPLE	4.80	900.0	1.70	10000.0	2500.0	8.20	0.0	0.0	11.0	19500.0	1.00	1000	10.0	33931
19	"	851019.1700	SAMPLE	4.80	800.0	0.00	9428.0	2308.0	7.33	1.2	0.0	15.0	18800.0	0.93	870	8.8	32238
20	"	851024.2100	SAMPLE	4.60	860.0	1.70	10000.0	2500.0	8.60	0.0	0.0	20.0	21000.0	0.91	1500	7.0	35897
21	"	851024.2100	SAMPLE	4.60	838.0	0.00	9805.0	2400.0	7.68	1.2	0.0	14.0	19465.0	-1.00	1390	8.4	33929
22	"	851024.2100	SAMPLE	8.32	903.0	2.15	10720.0	2940.0	-1.00	3.5	0.0	25.0	19645.0	0.75	900	5.5	35142
23	"	851024.2100	SAMPLE	5.42	853.0	2.19	11030.0	-1.0	-1.00	3.3	0.0	-1.0	19620.0	0.76	-1	-1.0	31507
24	"	851026.2100	SAMPLE	4.70	1100.0	2.40	12500.0	2400.0	10.00	0.0	0.0	7.2	24000.0	1.10	1700	14.0	41734
25	"	851028.0400	SAMPLE	-1.00	870.0	1.80	9500.0	2500.0	8.40	-1.0	-1.0	-1.0	-1.0	-1.00	-1	-1.0	12880
26	"	851			[illegible]	[illegible]	[illegible]	[illegible]	6.90	0.0	0.0	7.2	17000.0	0.76	1000	8.7	28934
27	"	851											0.0	0.69	950	7.2	23058
28	"	851											0.0	0.86	2000	11.0	36642
29	KS-2	82											-1.0	0.80	1100	25.0	22157
30	LANIPUN1	81											00.0	0.27	53	5.4	26033
31	"	81											00.0	0.28	201	3.5	17961
32	"	81											00.0	0.38	150	5.3	22439
33	"	81											00.0	0.27	284	16.4	28673
34	"	81											00.0	0.14	0	7.3	26475
35	LANIPUN6	84											00.0	-1.00	137	3.5	24549
36	"	84											00.0	-1.00	133	3.4	26118
37	"	84											00.0	-1.00	135	3.4	26497
37	IHP SPR	7											534.0	-1.00	82	-1.0	6489

KSIA $\Delta SiO_2 \approx \Delta Na$ on decreasing press.
of flash suggesting that ?
isenthalpic flash makes no sense
at all 17% steam sep @ 170psia should
drop to ~9.1% @ 87 psi and to
0.5% @ 14.7 psi none of the ion
ratios approach these variations

NUM	NAME	DATEHRS	BASIS	PHL	CA	MG	NA	K	LI	HCO3	CO3	SO4	CL	F_	SIO2	B	TDSS
39	"	751027.0000	BASIS	-1.00	98.0	239.00	2140.0	87.5	-1.00	61.0	0.0	552.0	3660.0	-1.00	-1	-1.0	6807
40	MALAMA K.	750107.0000	BASIS	7.02	66.8	210.00	2105.0	109.0	-1.00	144.0	0.0	471.0	3811.0	-1.00	101	-1.0	6945
41	"	750722.0000	BASIS	7.45	117.0	293.00	2890.0	149.0	-1.00	128.0	0.0	598.0	5120.0	-1.00	-1	-1.0	9230
42	GEOTH #3	750107.0000	BASIS	6.85	76.8	52.00	2050.0	190.0	-1.00	30.0	0.0	314.0	3274.0	-1.00	97	-1.0	6068
43	"	750721.0000	BASIS	-1.00	81.0	59.00	2000.0	195.0	-1.00	-1.0	-1.0	335.0	3410.0	-1.00	-1	-1.0	6080
44	"	750721.0000	BASIS	1.40	71.0	62.50	1740.0	158.0	-1.00	20.0	0.0	317.0	2980.0	-1.00	-1	-1.0	5338
45	RAIN	750000.0000	BASIS	-1.00	-1.0	-1.00	-1.0	-1.0	-1.00	-1.0	-1.0	-1.0	-1.0	-1.00	-1	-1.0	0

NUM	NAME	DATEHRS	H2S	NH4	FE	BR	AS_	MN	COMMENT
1	HGP-A	761202.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
2	"	770209.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
3	"	770422.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
4	"	800110.1000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
5	"	800111.1300	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
6	"	800116.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
7	"	810612.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
8	"	810904.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
9	"	811211.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
10	"	820607.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
11	"	821116.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
12	"	830504.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
13	"	831205.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
14	"	840112.0000	15.00	0.00	0.00	44.0	0.09	0.2	
15	"	840626.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
16	"	841128.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
17	KS-1A	851016.0930	6.00	0.17	0.30	20.0	0.40	4.0	ANALYSES IN MG/L; DENSITY 1.02; alternate copy has 9900mg/l Na
18	"	851019.1700	3.40	0.19	3.00	40.0	0.50	8.1	ANALYSES IN MG/L; DENSITY 1.02; Cl=ave 2 det. 19000 & 20000
19	"	851019.1700	3.20	15.00	-1.00	53.0	0.30	7.8	ANALYSES IN ppm; DENSITY 1.016; Cl=ave 2 det. 18500 & 19100
20	"	851024.2100	7.80	0.13	8.60	80.0	0.60	8.1	ANALYSES IN MG/L; DENSITY 1.03; Cl = also reptd 17000 & 20000
21	"	851024.2100	7.20	0.13	9.77	74.0	0.44	8.8	ANALYSES IN ppm; DENSITY 1.017; Cl = ave two det. 19230 & 19700
22	"	851024.2100	30.00	0.21	8.32	-1.0	0.06	13.8	SP.GR = 1.02345
23	"	851024.2100	26.00	-1.00	10.01	-1.0	0.06	13.3	
24	"	851026.2100	2.20	0.12	8.10	100.0	0.80	9.5	ANAL.IN MG/L; DEN. 1.03; Na=ave 12000&13000; K 2400? OR 2900?
25	"	851028.0400	4.30	0.11	5.40	-1.0	0.50	8.0	ANALYSES IN MG/L
26	"	851028.2330	8.30	-1.00	6.50	70.0	0.40	7.6	ANALYSES IN MG/L
27	"	851029.1330	7.80	0.10	3.40	50.0	0.40	5.8	ANALYSES IN MG/L
28	"	851031.1245	5.20	0.10	8.40	80.0	-1.00	8.5	ANALYSES IN MG/L; DENSITY 1.03
29	KS-2	820609.0000	-1.00	-1.00	1100.00	1.5	0.00	110.0	
30	LANIPUN1	810422.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	MG/L CONCENTRATIONS
31	"	810714.2200	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	lab reported difficulty obtaining reproducible SiO2 values
32	"	810715.0200	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	lab reported diff.obtaining reproducible SiO2 values
33	"	810715.0300	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	lab reported diff.obtaining reproducible SiO2 values
34	"	810799.9999	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
35	LANIPUN6	840803.1320	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
36	"	840808.1600	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
37	"	840809.1600	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	prob.seawater altd and diluted 25-30% w/cool component
37	IHP SPR	750107.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	TRITIUM = 8.5 +- 1.0 TU

NUM	NAME	DATEHRS	H2S	NH4	FE	BR	AS_	MN	COMMENT
39	"	751027.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	CA VALUE REPORTED SUSPECT.
40	MALAMA K.	750107.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	TRITIUM = 15.6 +- 1.6 TU
41	"	750722.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	TRITIUM = 8.6 +- 1.0 TU
42	GEOTH #3	750107.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	TRITIUM = 10.3 +- 0.8 TU
43	"	750721.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	TRITIUM = 7.3 +- 0.9 TU
44	"	750721.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	
45	RAIN	750000.0000	-1.00	-1.00	-1.00	-1.0	-1.00	-1.0	TRITIUM = 9.1+-1.2TU (1SMPL); DEL-180=-4.04 TO -6.21 (5SMPLS)

Table 4.3 :
SAMPLES FROM WELLS HGP-A AND KS-1A CORRECTED FOR STEAM LOSS FROM QUARTZ TEMPERATURE ENTHALPY

NAME	DATEHRS	PHL	CA	MG	NA	K	LI	HCO3	SO4	CL	F_	SIO2	B
HGP-A	761202.0000	-1.00	-1.0	-1.00	-1.0	-1.0	-1.00	-1.0	-1.0	-1.0	-1.00	-1	-1.0
"	770209.0000	-1.00	-1.0	-1.00	-1.0	-1.0	-1.00	-1.0	-1.0	-1.0	-1.00	-1	-1.0
"	770422.0000	-1.00	-1.0	-1.00	-1.0	-1.0	-1.00	-1.0	-1.0	-1.0	-1.00	-1	-1.0
"	800110.1000	-1.00	11.8	0.00	1032.6	144.4	-1.00	-1.0	36.1	1725.7	-1.00	625	-1.0
"	800111.1300	-1.00	25.5	0.00	1124.1	162.1	-1.00	-1.0	46.1	1882.5	-1.00	609	-1.0
"	800116.0000	-1.00	25.2	0.01	1129.8	166.5	-1.00	-1.0	51.3	1927.3	-1.00	618	-1.0
"	810612.0000	-1.00	14.8	0.00	521.7	115.9	-1.00	-1.0	40.0	1197.1	-1.00	694	-1.0
"	810904.0000	-1.00	49.8	0.02	1414.6	220.8	-1.00	-1.0	51.6	2710.8	-1.00	644	-1.0
"	811211.0000	-1.00	20.5	0.01	989.4	186.7	-1.00	-1.0	42.9	1719.3	-1.00	625	-1.0
"	820607.0000	-1.00	93.8	0.04	2387.8	401.8	-1.00	-1.0	52.8	4337.1	-1.00	615	-1.0
"	821116.0000	-1.00	164.3	0.08	2982.7	492.1	-1.00	-1.0	52.2	5321.2	-1.00	628	-1.0
"	830504.0000	-1.00	206.4	0.12	3226.5	516.1	-1.00	-1.0	52.8	6089.8	-1.00	615	-1.0
"	831205.0000	-1.00	240.9	0.16	3511.1	576.1	-1.00	-1.0	18.1	6665.1	-1.00	623	-1.0
"	840112.0000	6.60	-1.0	-1.00	-1.0	-1.0	-1.00	-1.0	-1.0	-1.0	0.25	-1	-1.0
"	840626.0000	-1.00	360.1	0.18	3563.8	569.2	-1.00	-1.0	11.0	6553.2	-1.00	652	-1.0
"	841128.0000	-1.00	290.4	0.15	3944.7	533.5	-1.00	-1.0	3.3	6924.4	-1.00	664	-1.0
KS-1A	851016.0930	5.80	714.2	0.90	7329.9	1879.5	6.31	11.3	18.8	14283.9	1.10	639	8.3
"	851019.1700	4.80	633.3	1.20	7036.6	1759.1	5.77	0.0	7.7	13721.3	1.00	704	7.0
"	851019.1700	4.80	595.5	0.00	7018.3	1718.1	5.46	0.9	11.2	13994.9	0.93	648	6.6
"	851024.2100	4.60	-1.0	-1.00	-1.0	-1.0	-1.00	-1.0	-1.0	-1.0	0.91	-1	-1.0
"	851024.2100	4.60	-1.0	-1.00	-1.0	-1.0	-1.00	-1.0	-1.0	-1.0	-1.00	-1	-1.0
"	851024.2100	8.32	663.4	1.58	7875.4	2159.9	-1.00	2.6	18.4	14432.2	0.75	661	4.0
"	851024.2100	5.42	-1.0	-1.00	-1.0	-1.0	-1.00	-1.0	-1.0	-1.0	0.76	-1	-1.0
"	851026.2100	4.70	-1.0	-1.00	-1.0	-1.0	-1.00	-1.0	-1.0	-1.0	1.10	-1	-1.0
"	851028.0400	-1.00	-1.0	-1.00	-1.0	-1.0	-1.00	-1.0	-1.0	-1.0	-1.00	-1	-1.0
"	851028.2330	3.80	499.0	1.05	5692.8	1475.9	4.85	0.0	5.1	11947.8	0.76	703	6.1
"	851029.1330	3.80	424.0	0.43	4814.9	1293.6	2.80	0.0	4.5	9342.3	0.69	683	5.2
"	851031.1245	4.50	-1.0	-1.00	-1.0	-1.0	-1.00	-1.0	-1.0	-1.0	0.86	-1	-1.0

GeothermEx, Inc.

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FIGURES

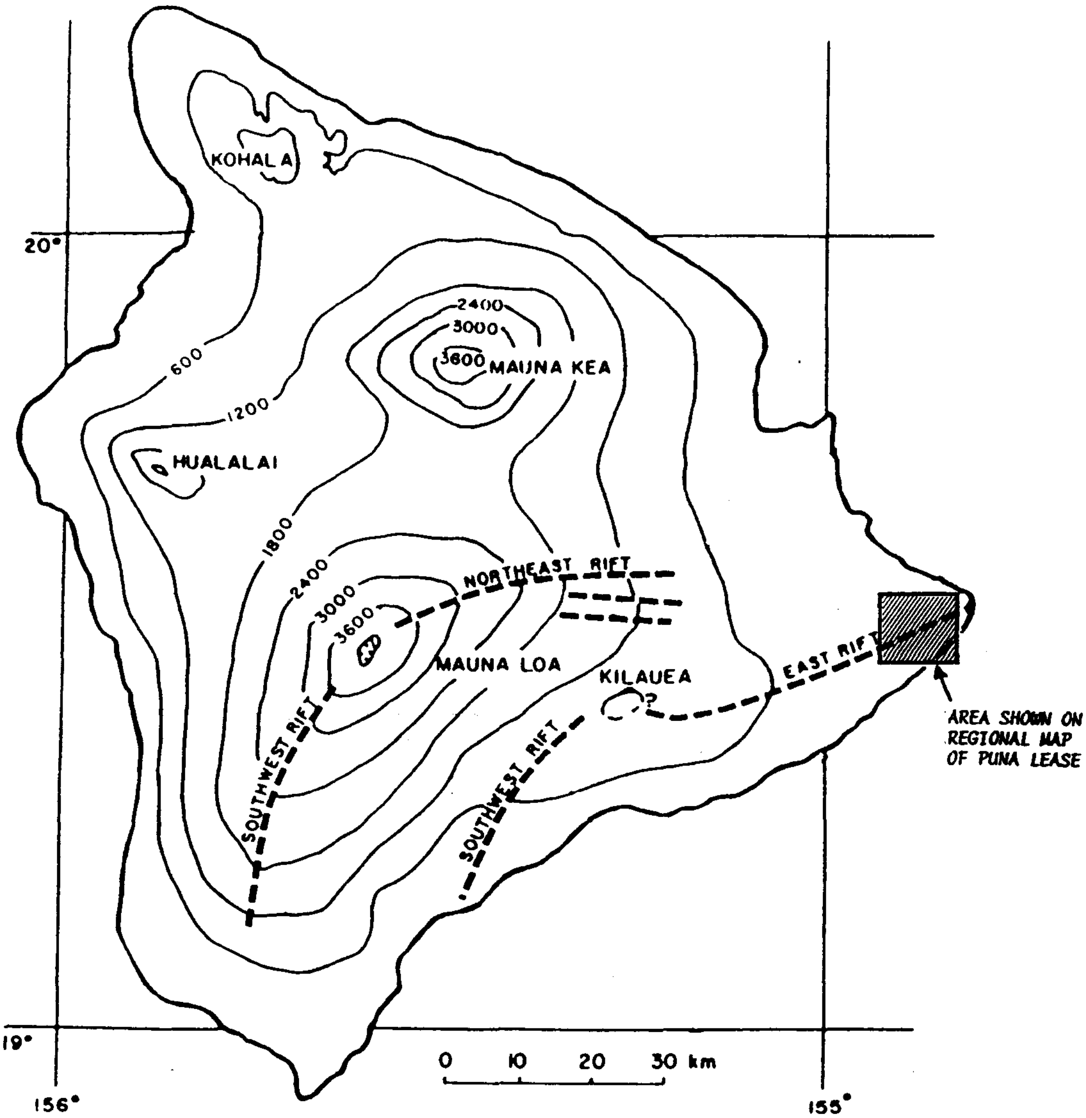
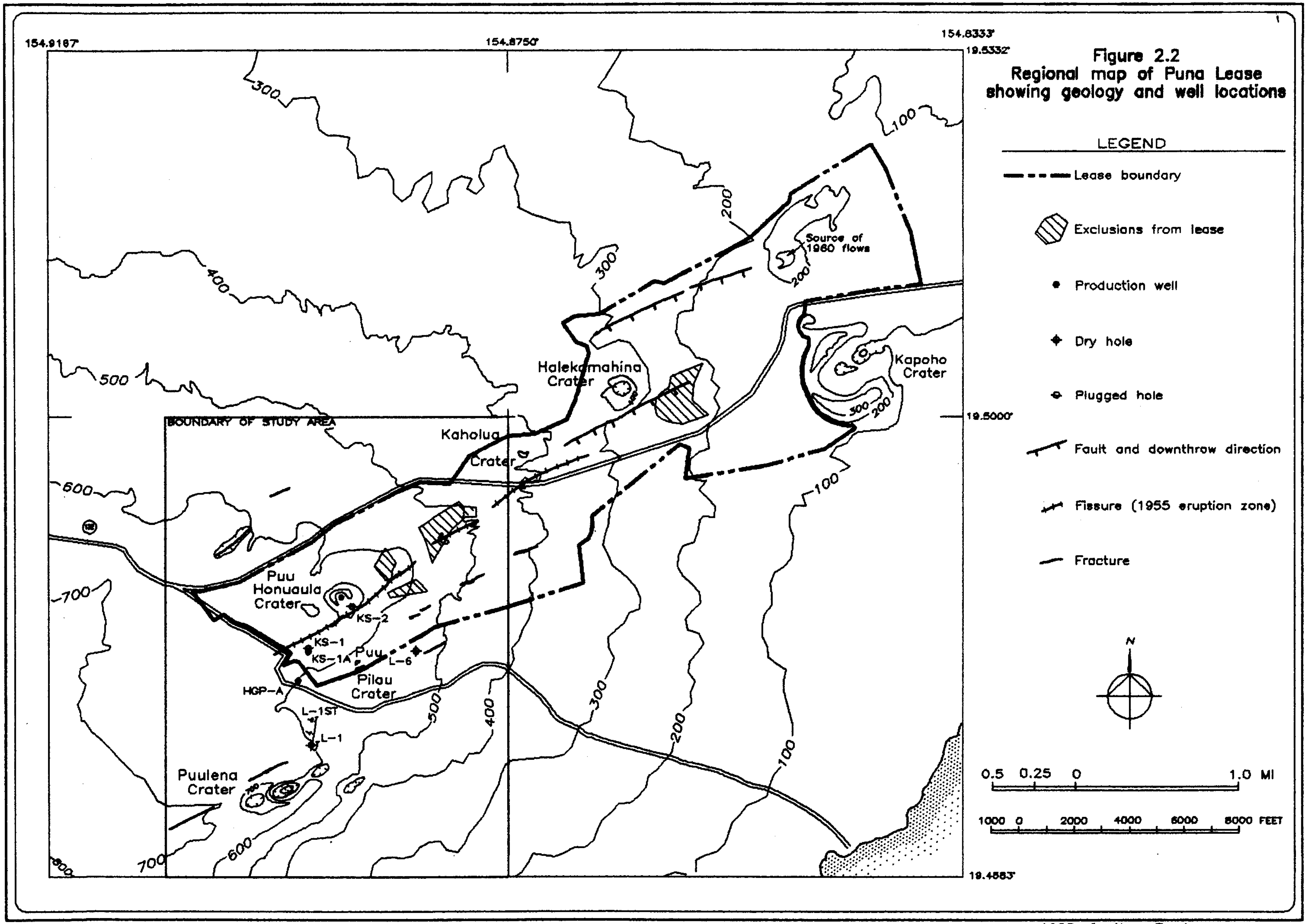
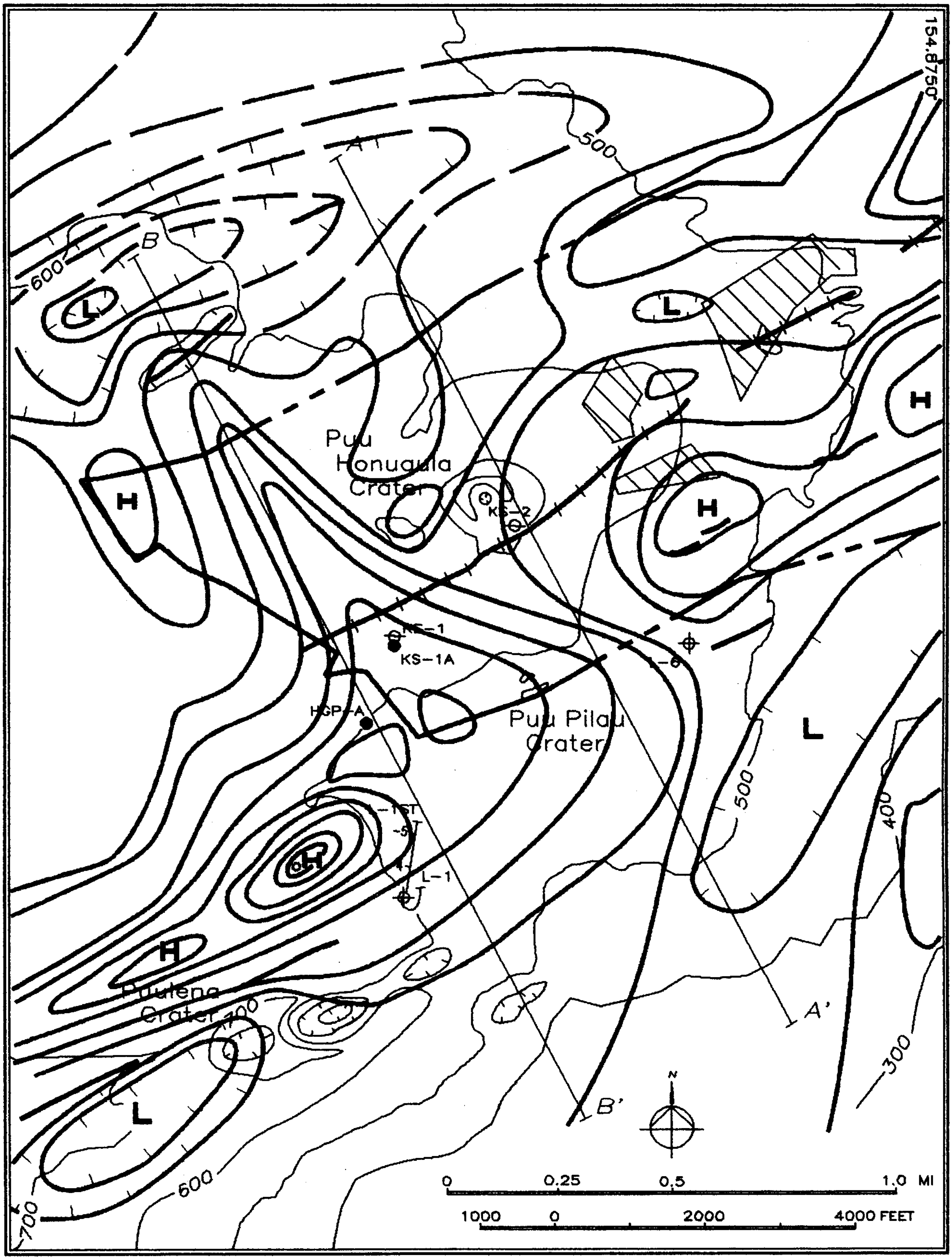


Figure 2.1 Map of the East Rift Zone of Kilauea Volcano



1988, GeothermEx, Inc.



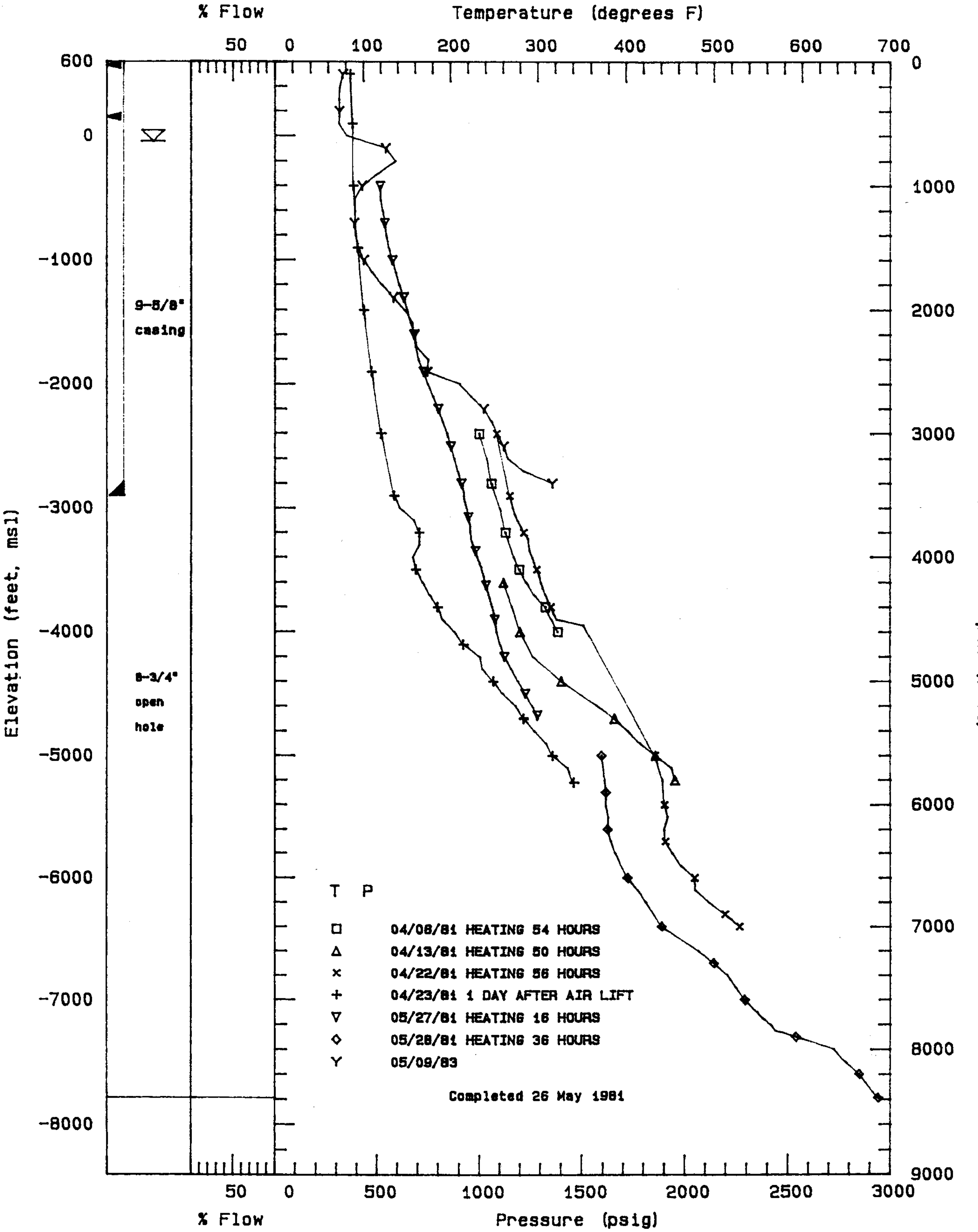
LEGEND

Self-potential contour showing 50 mV interval (H=high; L=low)	Production well	Fault and downthrow direction
Lease boundary	Dry hole	Fissure (1955 eruption zone)
Exclusions from lease	Plugged hole	Fracture

Figure 2.3 Local self-potential anomaly map

1988, GeothermEx, Inc. LSPA/101488/H1066

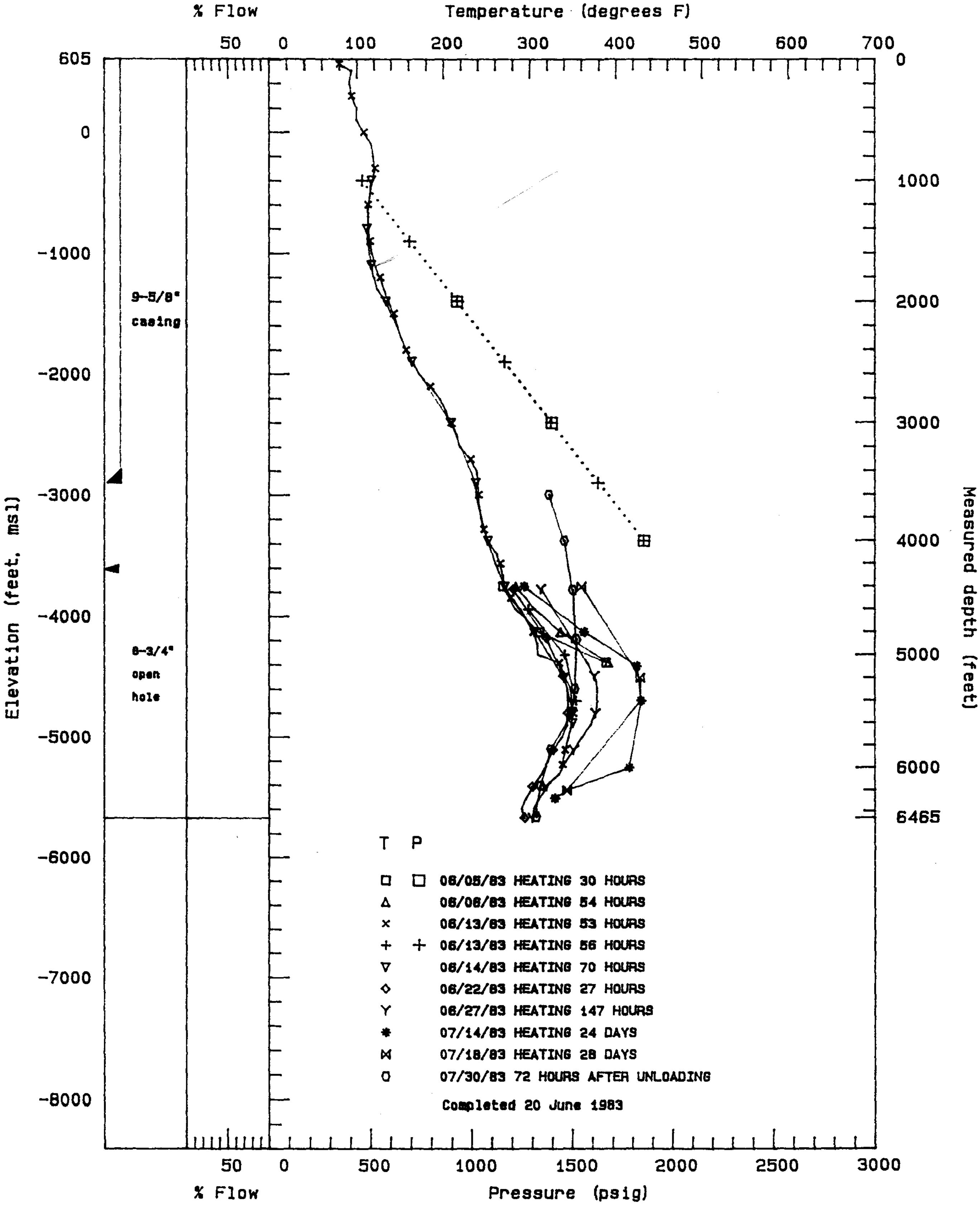
Figure 3.1 : DOWNHOLE SUMMARY PLOT, WELL LANIPUNA 1



GeothermEx, Inc.

09-12-1988 T1.PLT

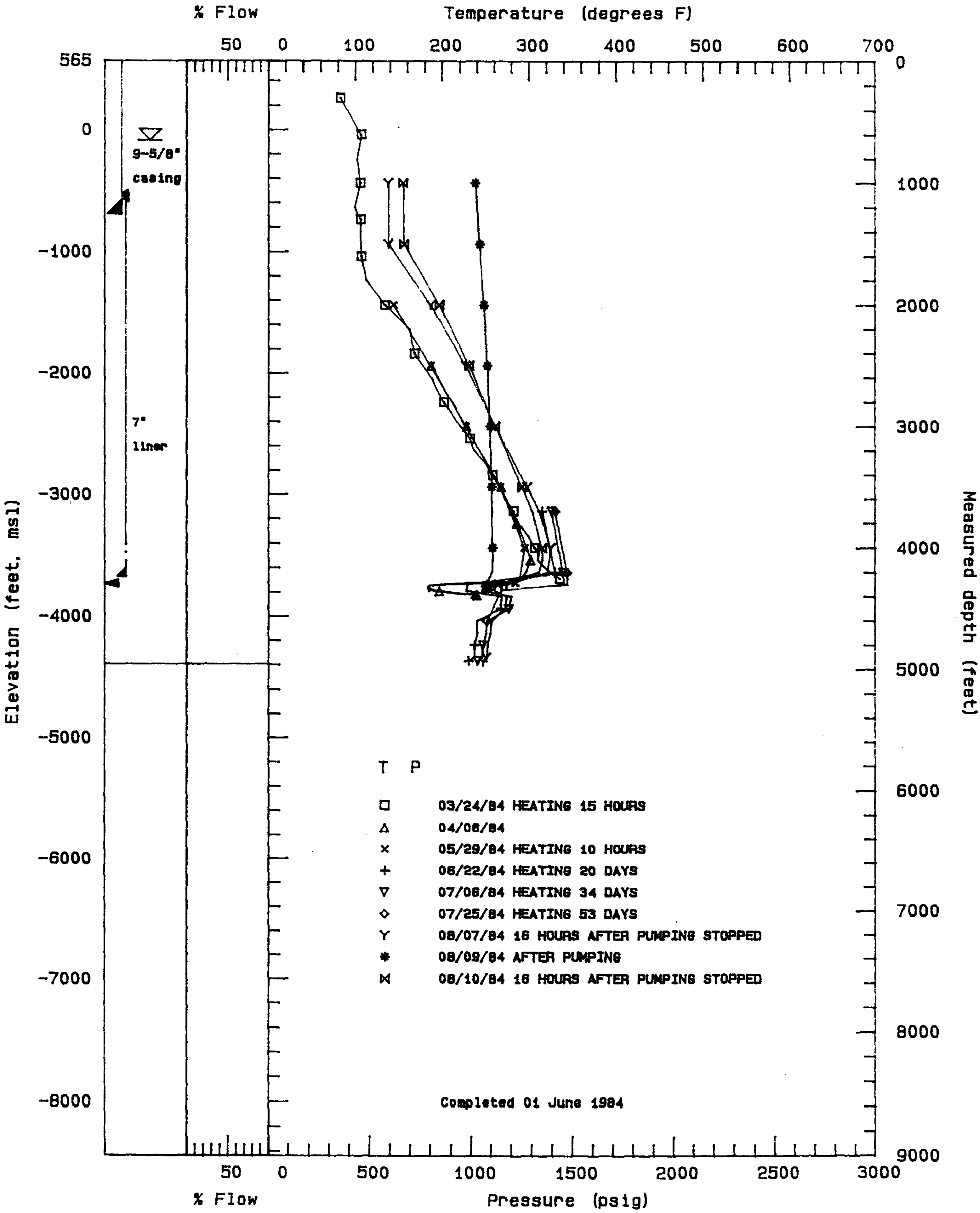
Figure 3.2: DOWNHOLE SUMMARY PLOT, WELL LANIPUNA 1 ST



GeothermEx, Inc.

09-12-1988 TP1.PLT

Figure 3.3: DOWNHOLE SUMMARY PLOT, WELL LANIPUNA 6



GeothermEx, Inc.

09-12-1988 T1.PLT

Figure 3.4 : DOWNHOLE SUMMARY PLOT, WELL HGP-A

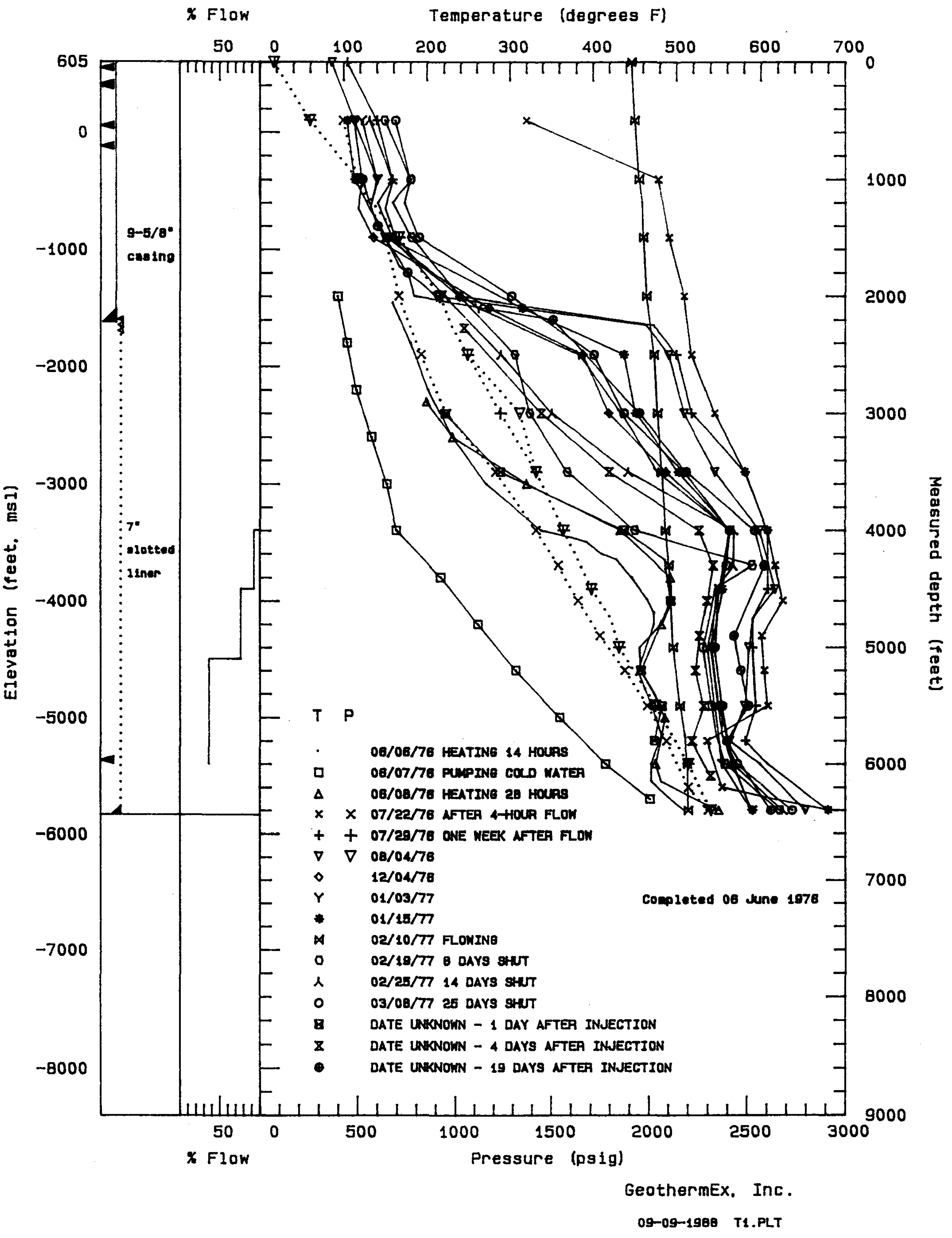
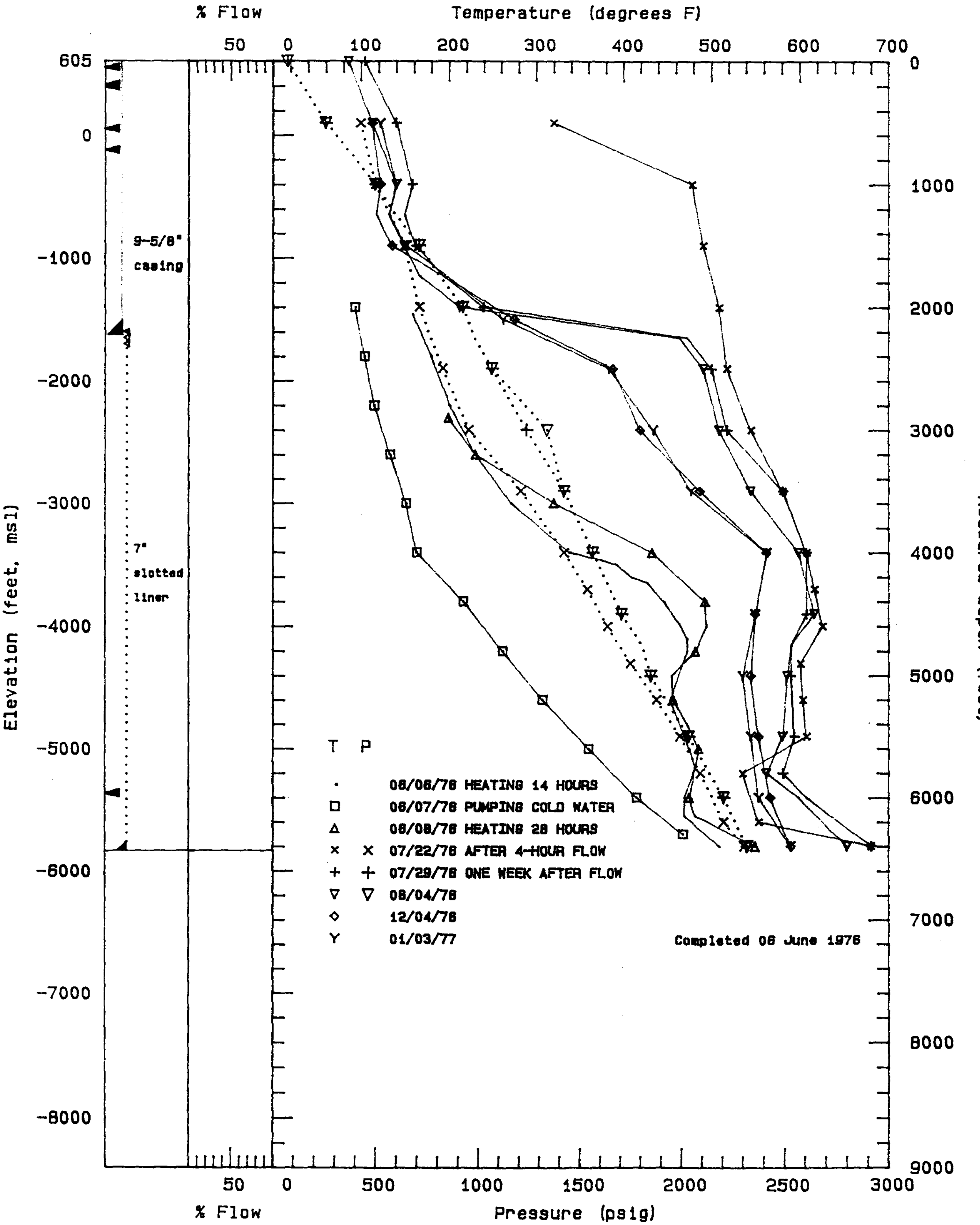


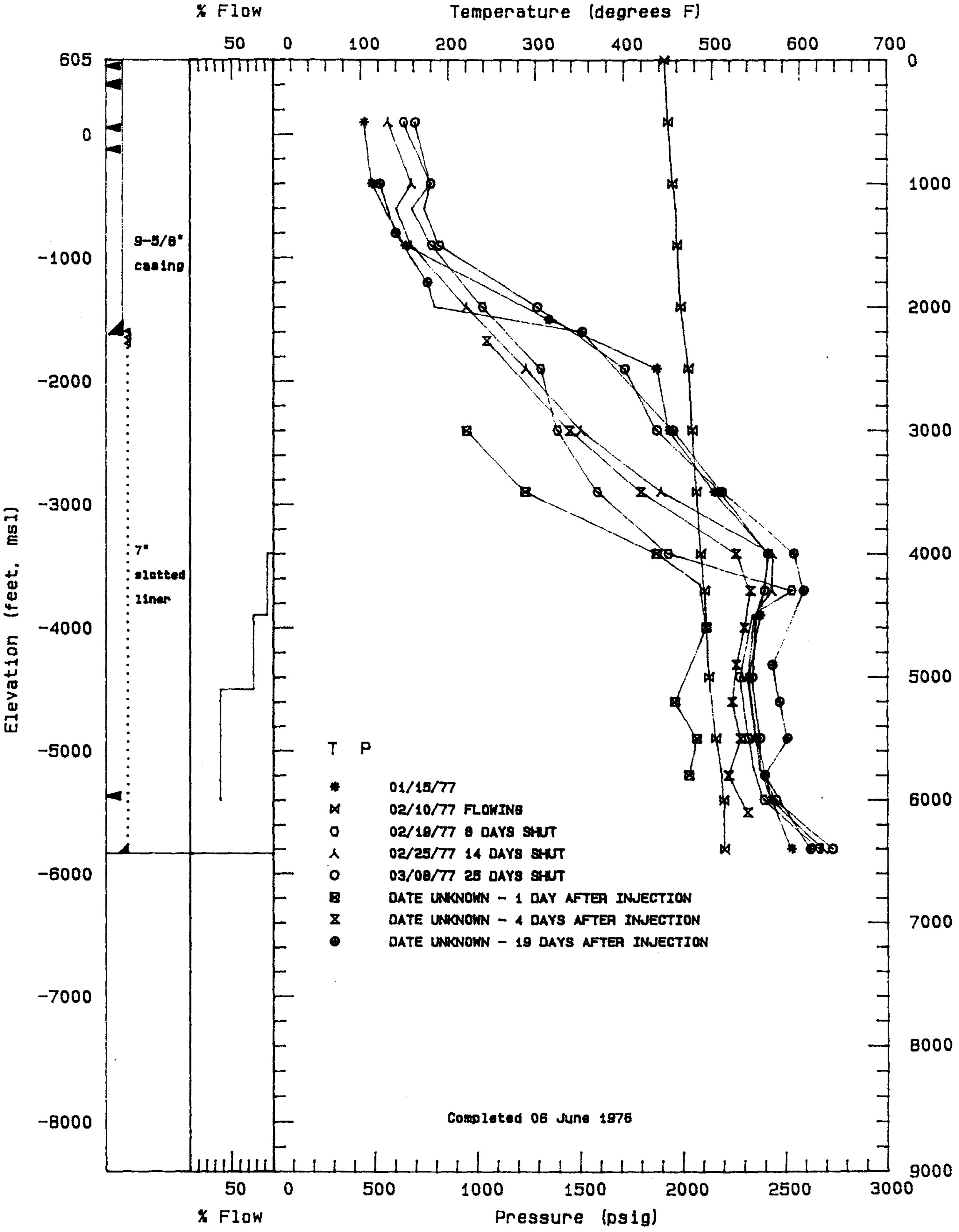
Figure 3.5 : DOWNHOLE SUMMARY PLOT, WELL HGP-A



GeothermEx, Inc.

09-14-1988 T1.PLT

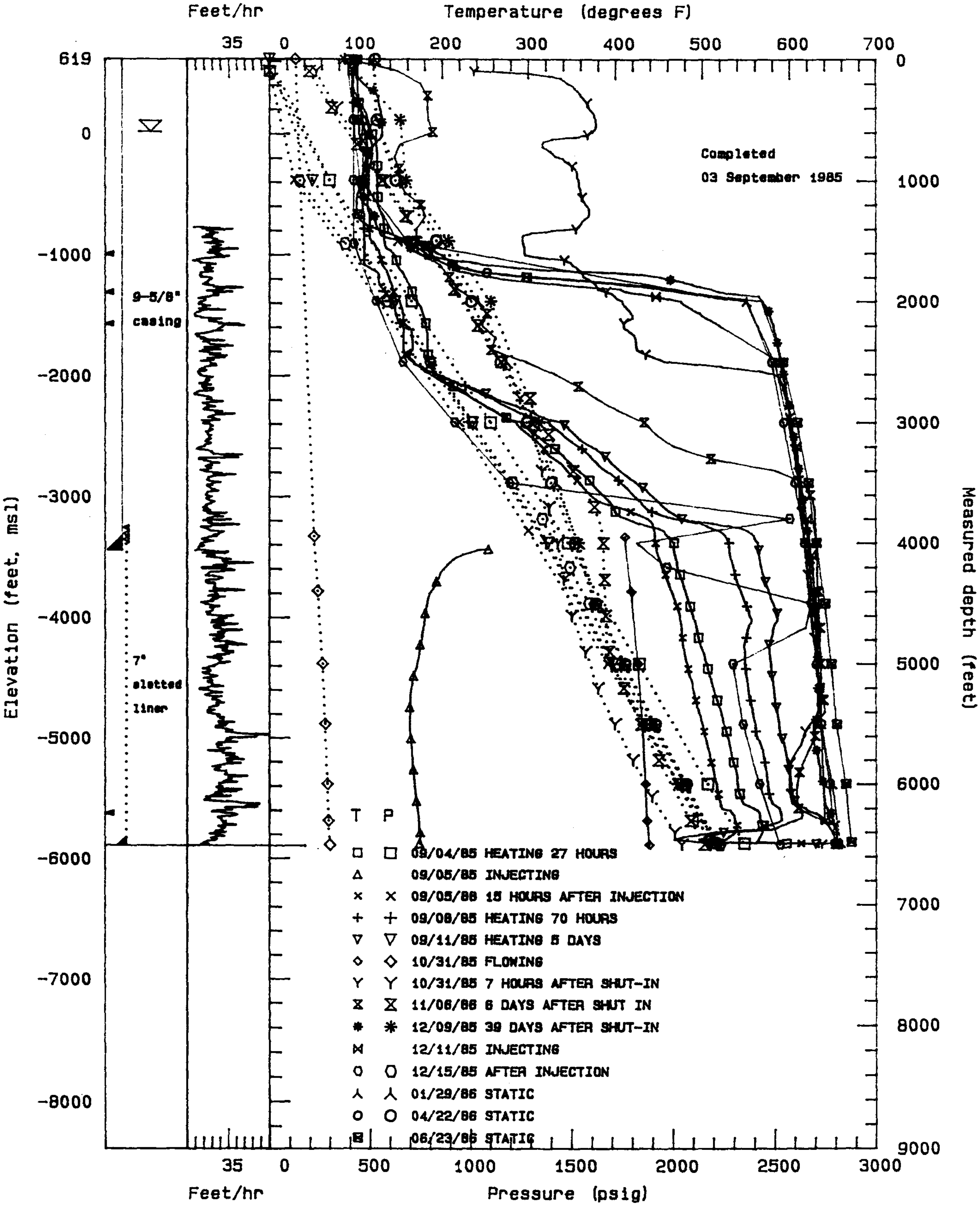
Figure 3.6: DOWNHOLE SUMMARY PLOT, WELL HGP-A



GeothermEx, Inc.

09-15-1988 T7.PLT

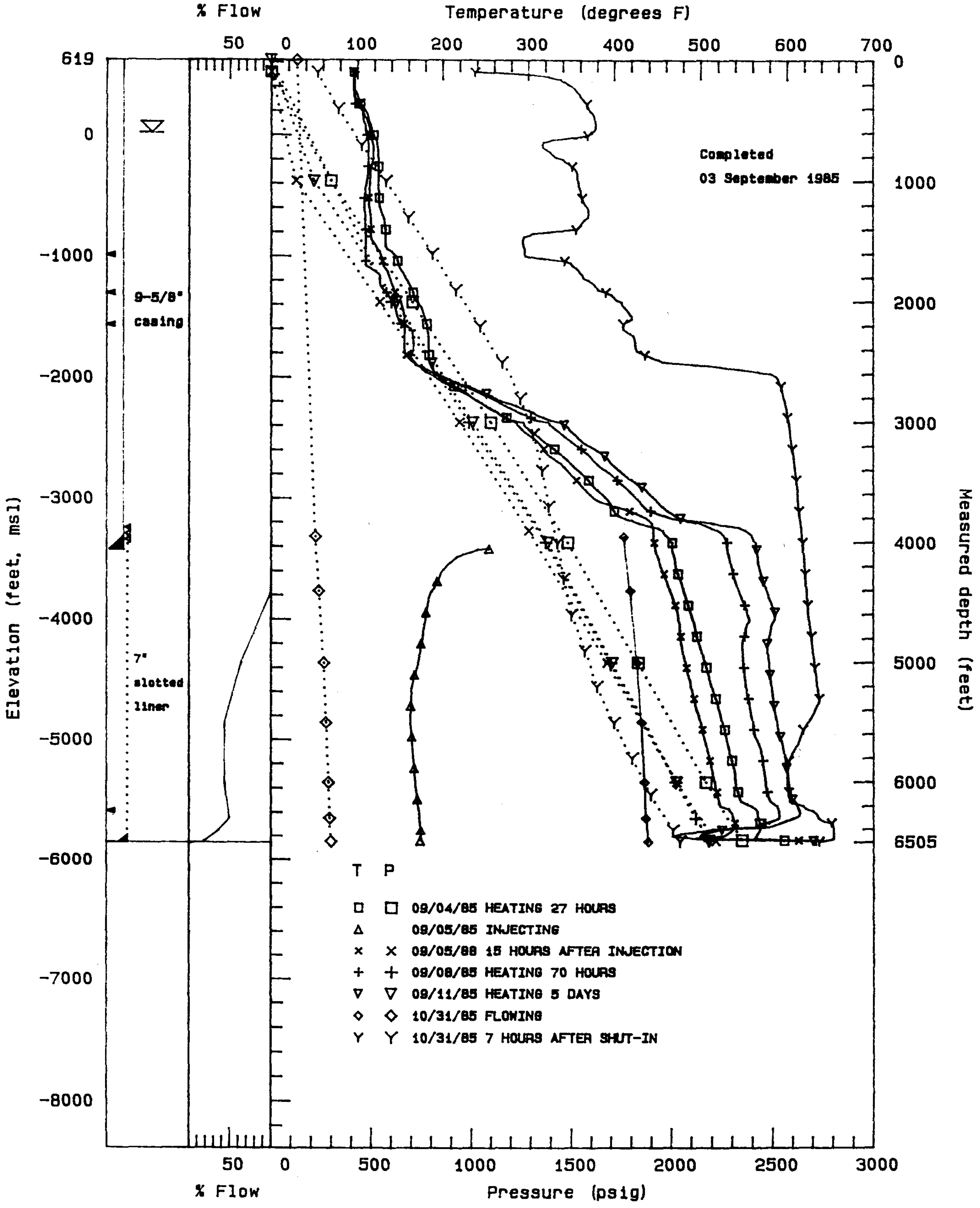
Figure 3.8 : DOWNHOLE SUMMARY PLOT, WELL KS-1A



GeothermEx, Inc.

10-13-1988 KS1A27T.PLT

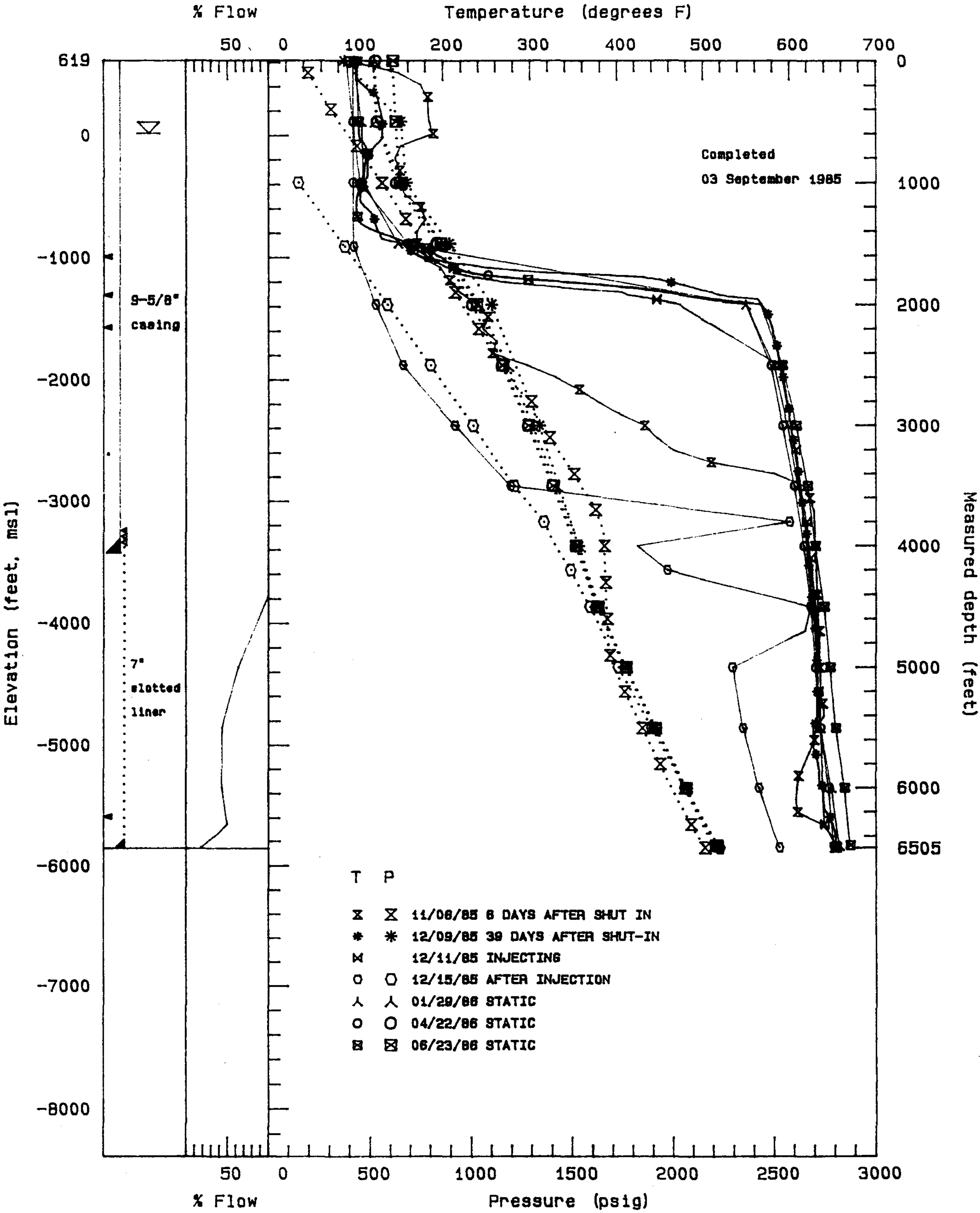
Figure 3.9 : DOWNHOLE SUMMARY PLOT, WELL KS-1A



GeothermEx, Inc.

09-15-1988 KS1A27T.PLT

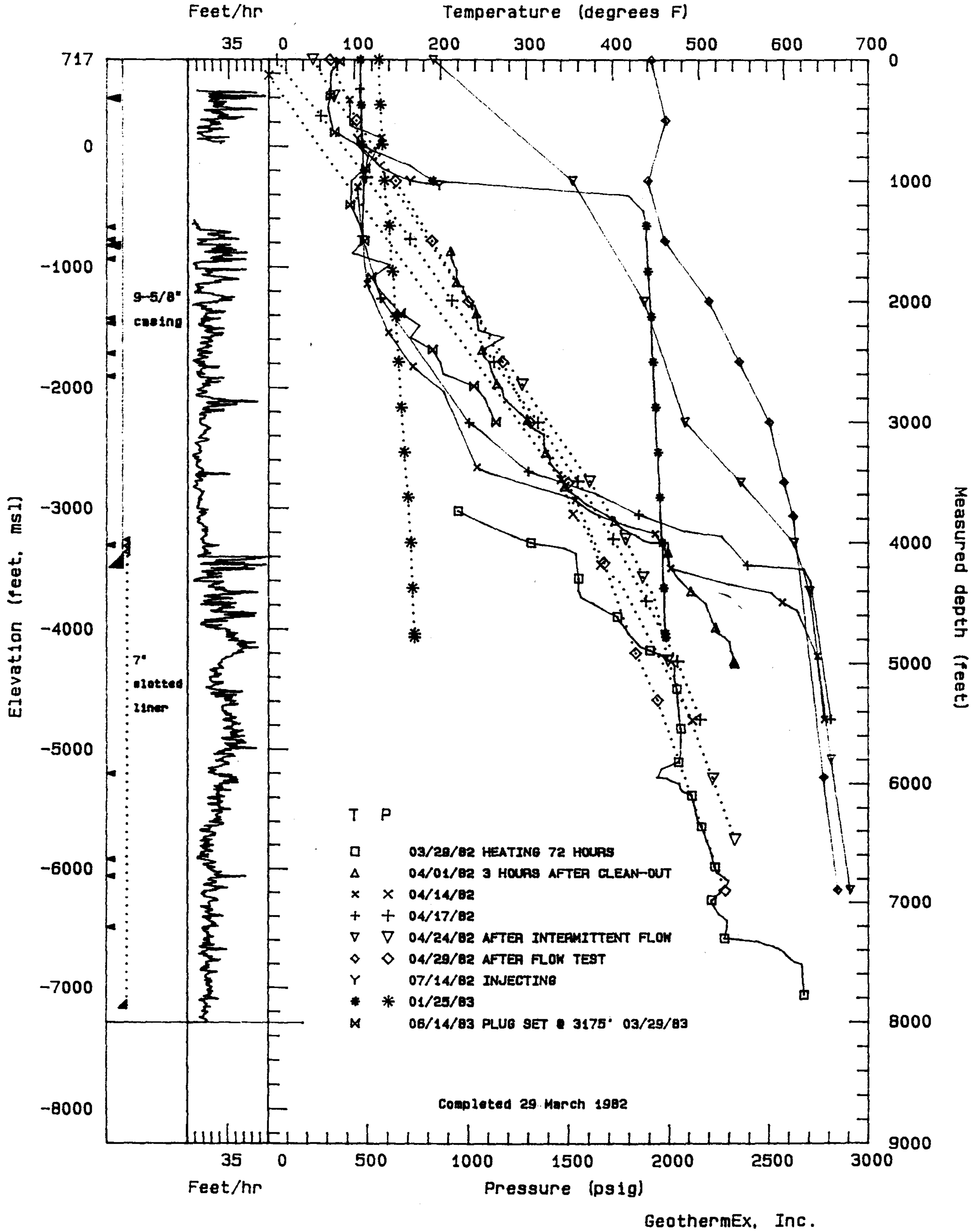
Figure 3.10: DOWNHOLE SUMMARY PLOT, WELL KS-1A



GeothermEx, Inc.

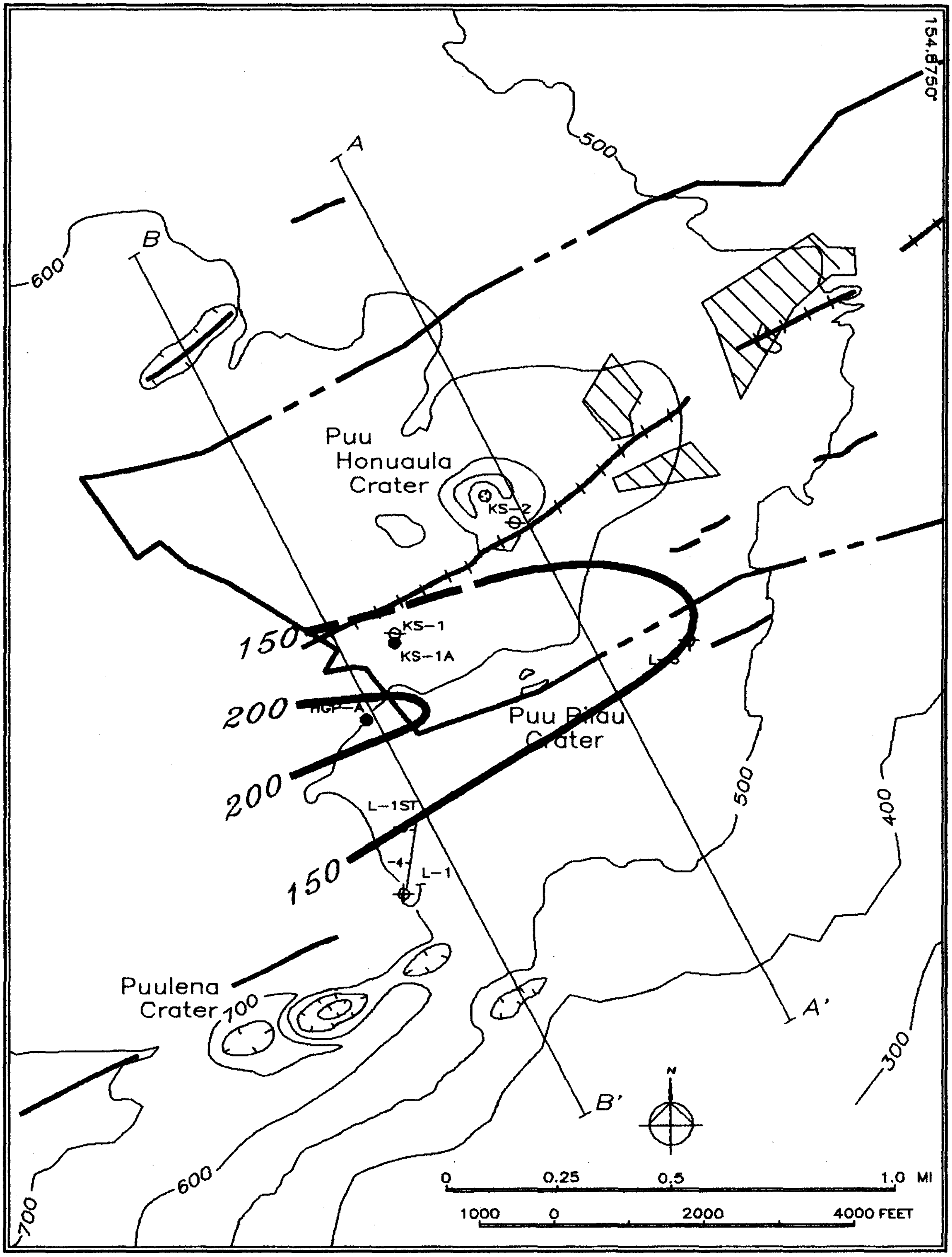
09-15-1988 T8.PLT

Figure 3.11: DOWNHOLE SUMMARY PLOT, WELL KS-2



GeothermEx, Inc.

10-13-1988 KS2TO.PLT

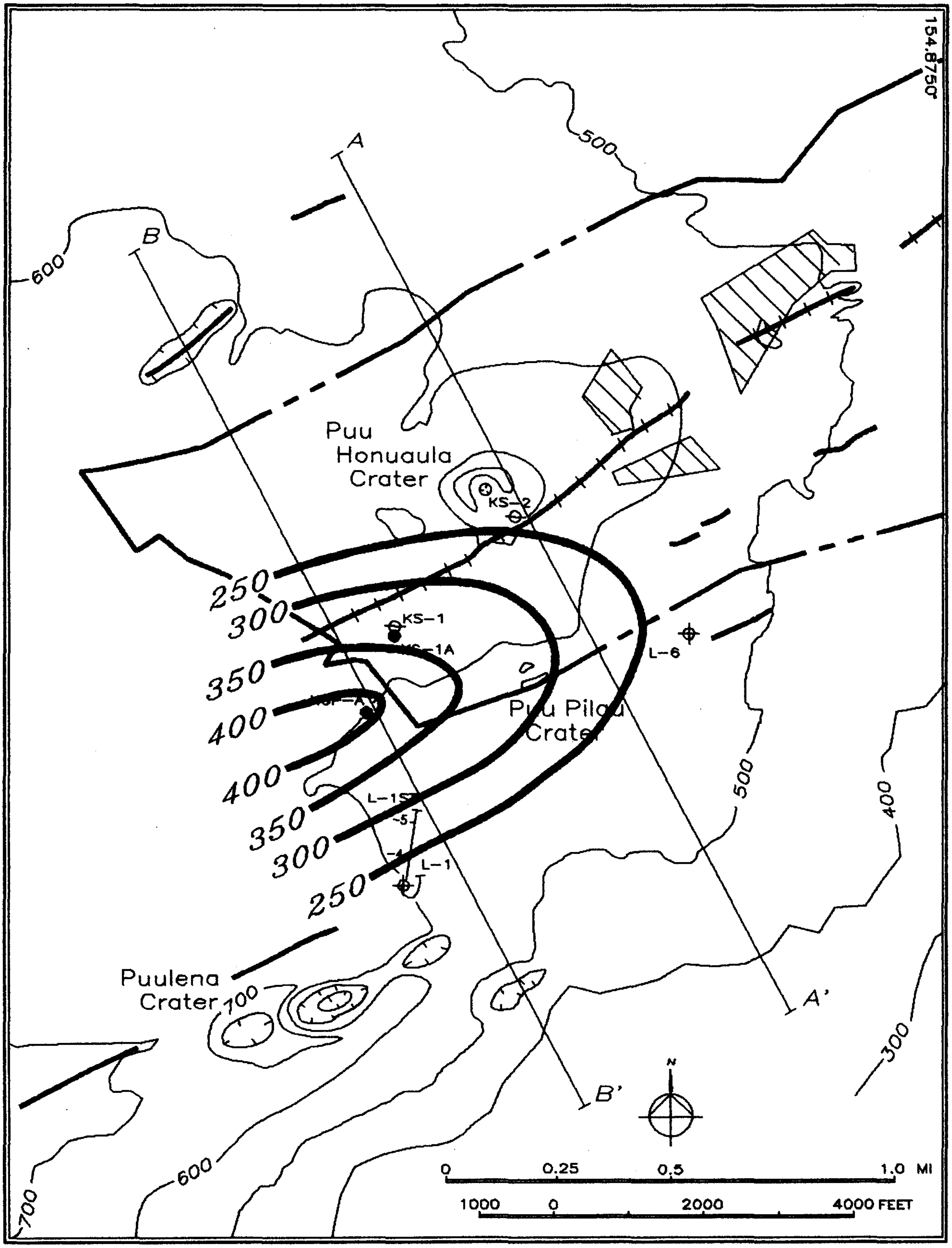


LEGEND

400 Temperature, °F	Production well	Fault and downthrow direction
Lease boundary	Dry hole	Fissure (1955 eruption zone)
Exclusions from lease	Plugged hole	Fracture

Figure 3.12 Temperature distribution at −1,000 feet, msl

1988, GeothermEx, Inc. LPT1000/101288/H1058

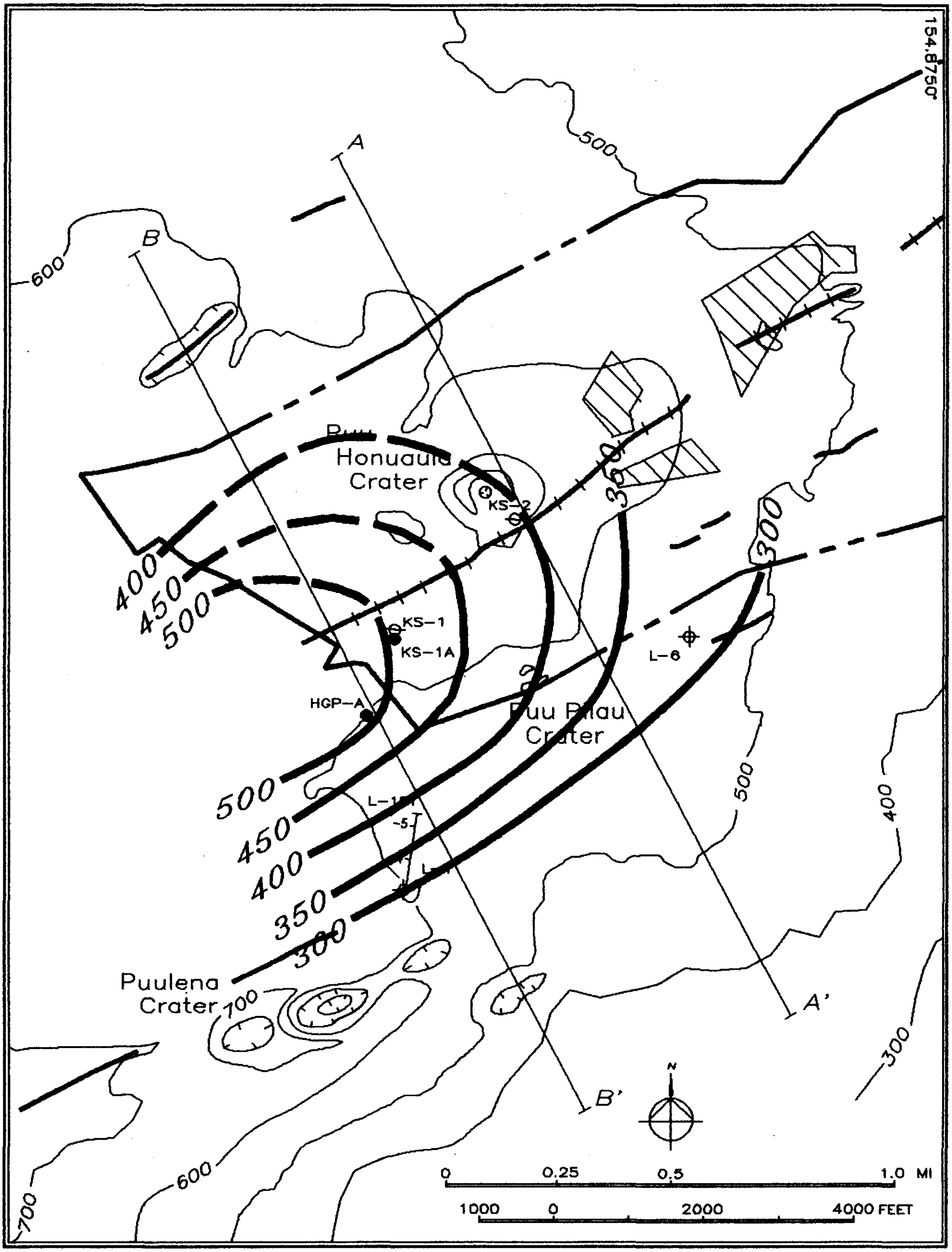


LEGEND

400 Temperature, °F	Production well	Fault and downthrow direction
Lease boundary	Dry hole	Fissure (1955 eruption zone)
Exclusions from lease	Plugged hole	Fracture

Figure 3.13 Temperature distribution at −2,000 feet, msl

1988, GeothermEx, Inc. LPT2000/101288/H1068



LEGEND

400 Temperature, °F	Production well	Fault and downthrow direction
Lease boundary	Dry hole	Fissure (1955 eruption zone)
Exclusions from lease	Plugged hole	Fracture

Figure 3.14 Temperature distribution at −3,000 feet, msl

1988, GeothermEx, Inc. LPT3000/101188/H1062

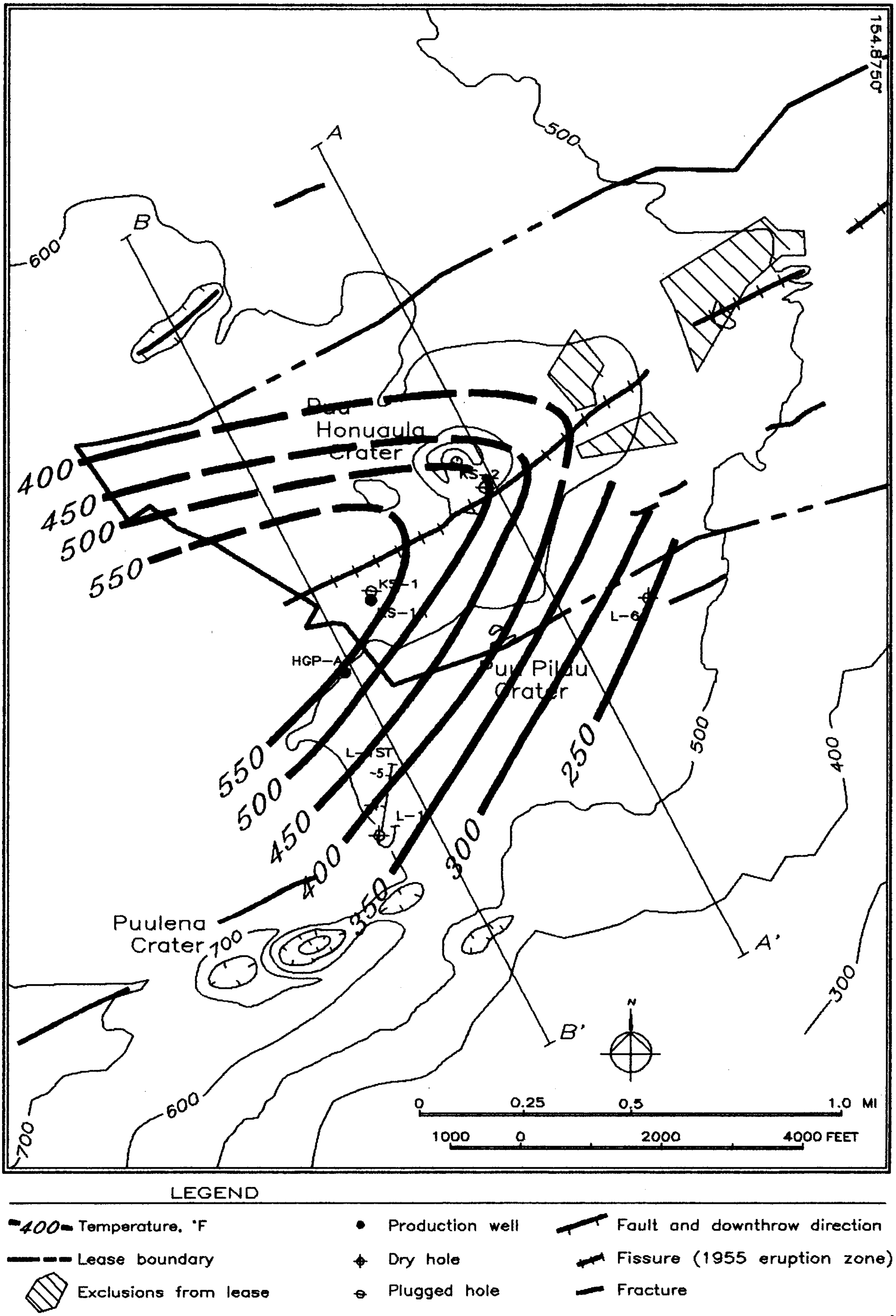
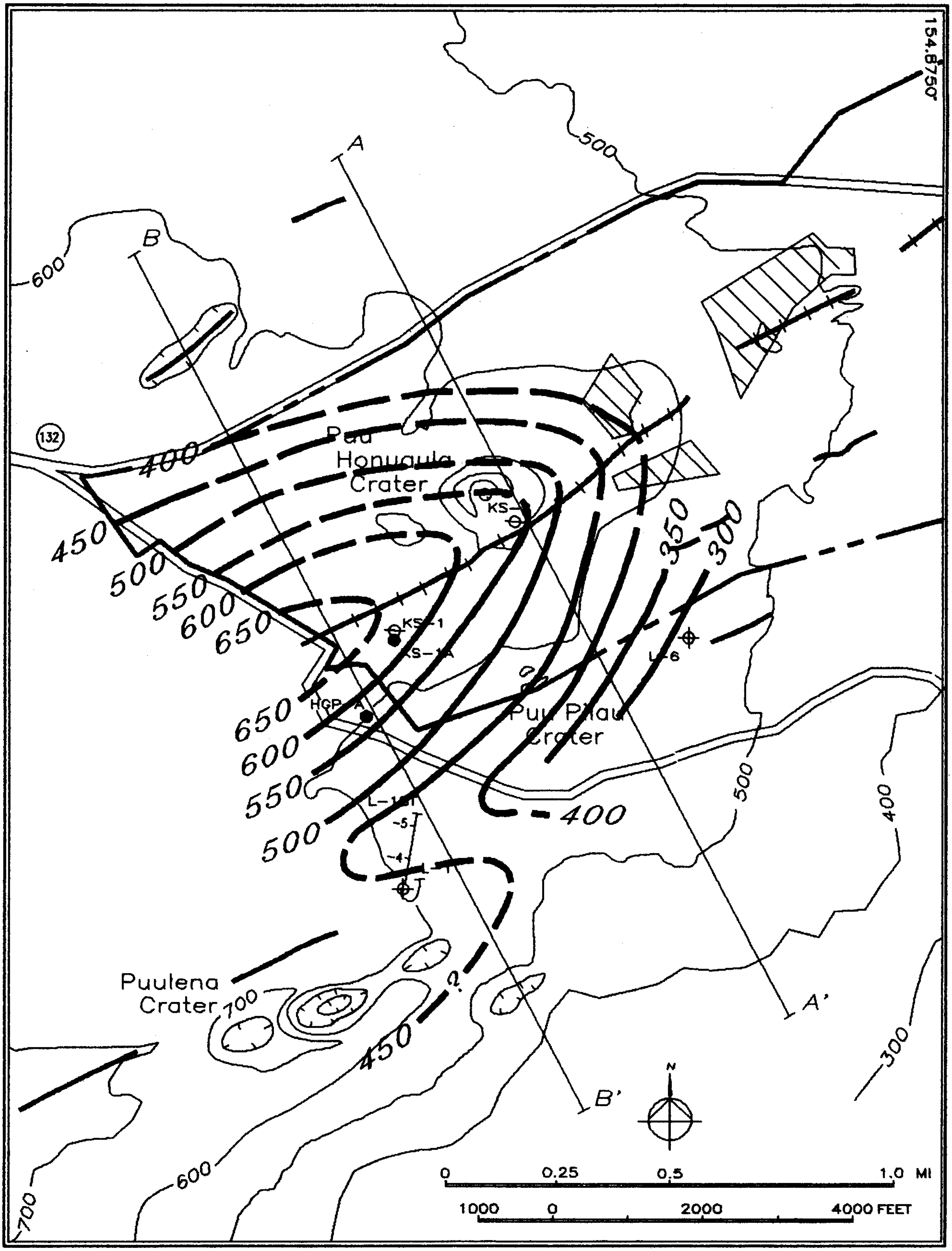


Figure 3.15 Temperature distribution at −4,000 feet, msl

1988, GeothermEx, Inc. LPT4000/101188/H1062



LEGEND

400 Temperature, °F	Production well	Fault and downthrow direction
Lease boundary	Dry hole	Fissure (1955 eruption zone)
Exclusions from lease	Plugged hole	Fracture

Figure 3.16 Temperature distribution at −5,000 feet, msl

1988, GeothermEx, Inc.

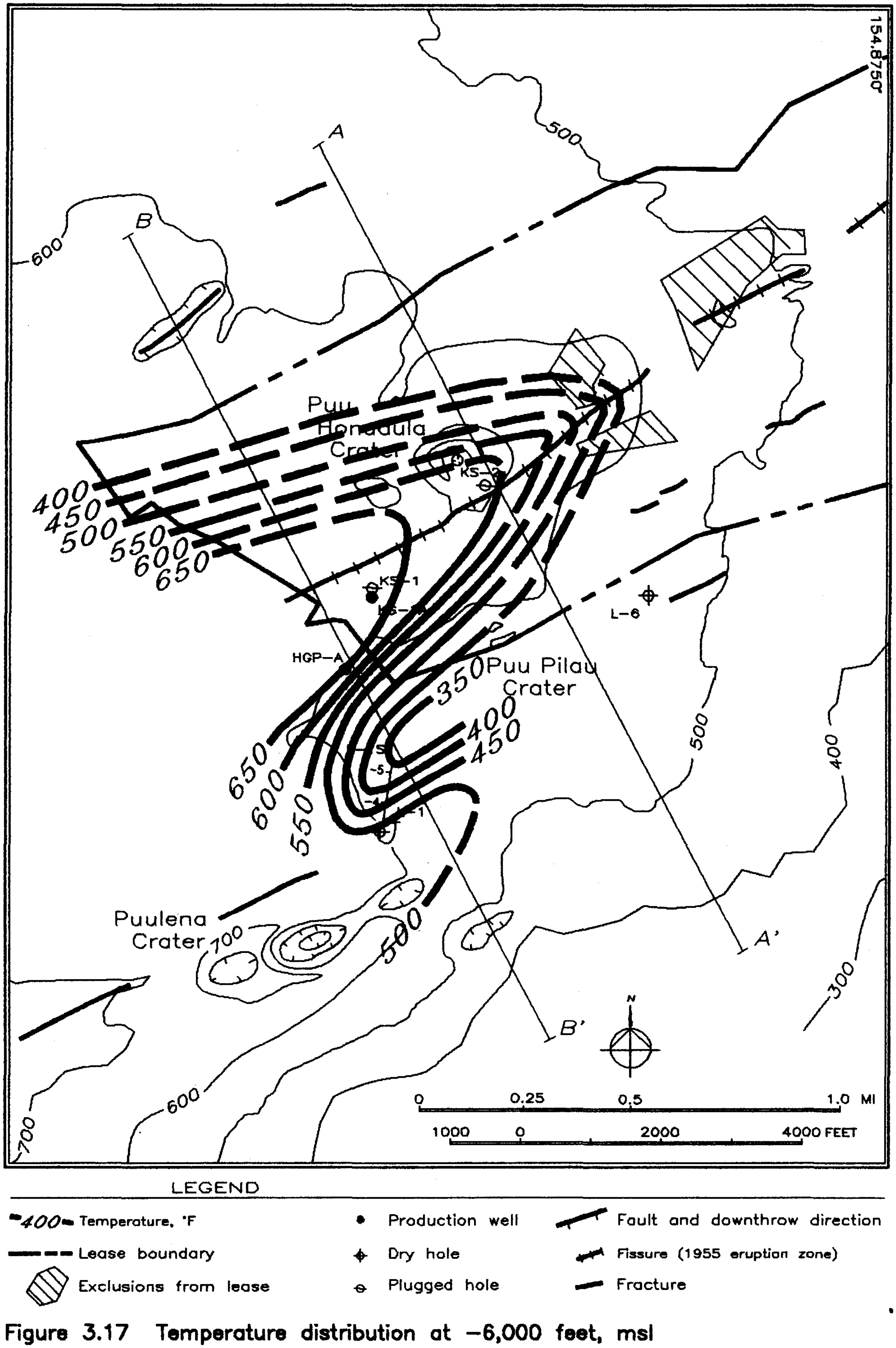


Figure 3.17 Temperature distribution at −6,000 feet, msl

1988, GeothermEx, Inc. LPT6000/101188/H1049

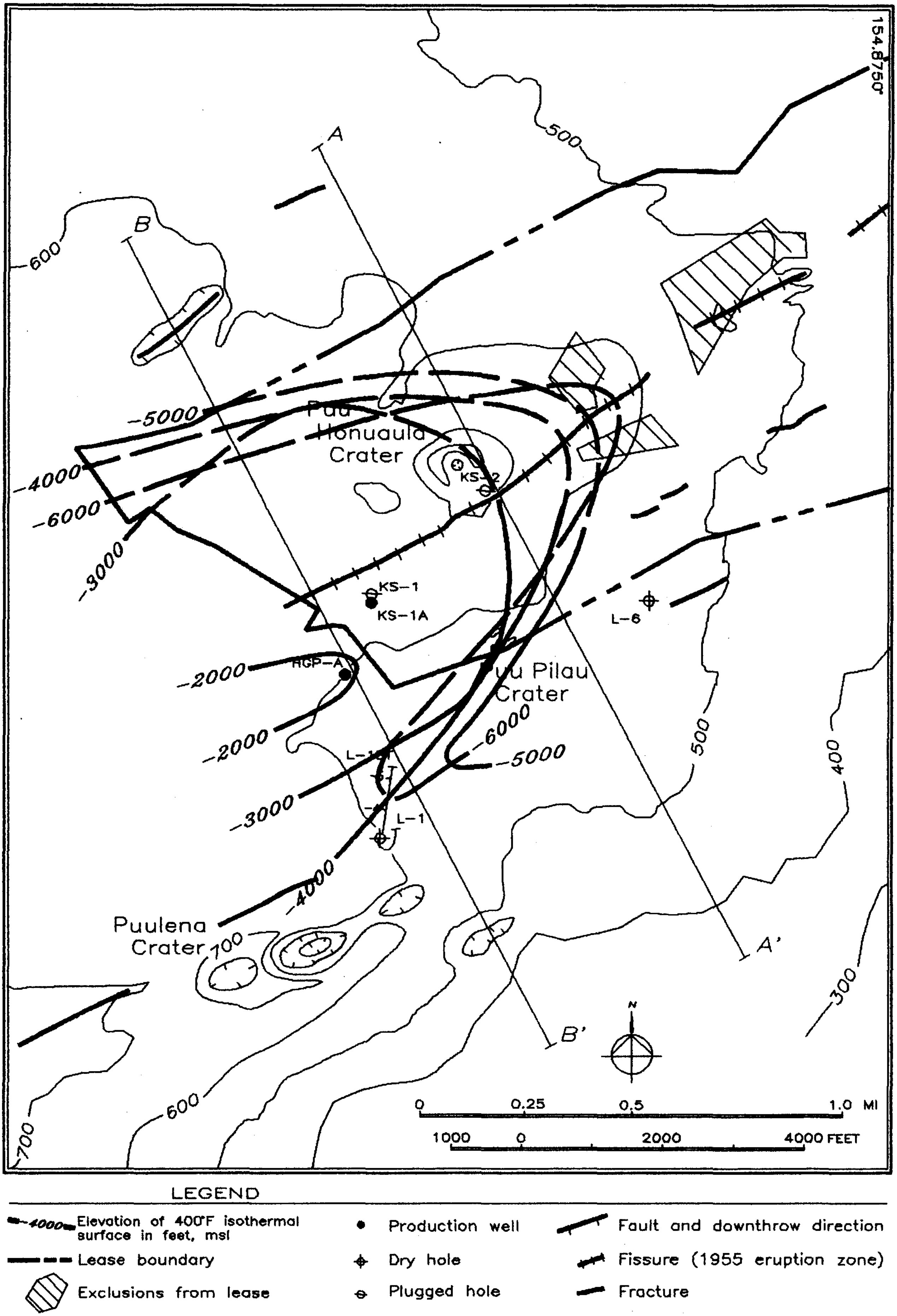


Figure 3.18 Contour map of the 400°F isothermal surface

1988, GeothermEx, Inc. IS400/101288/H1066

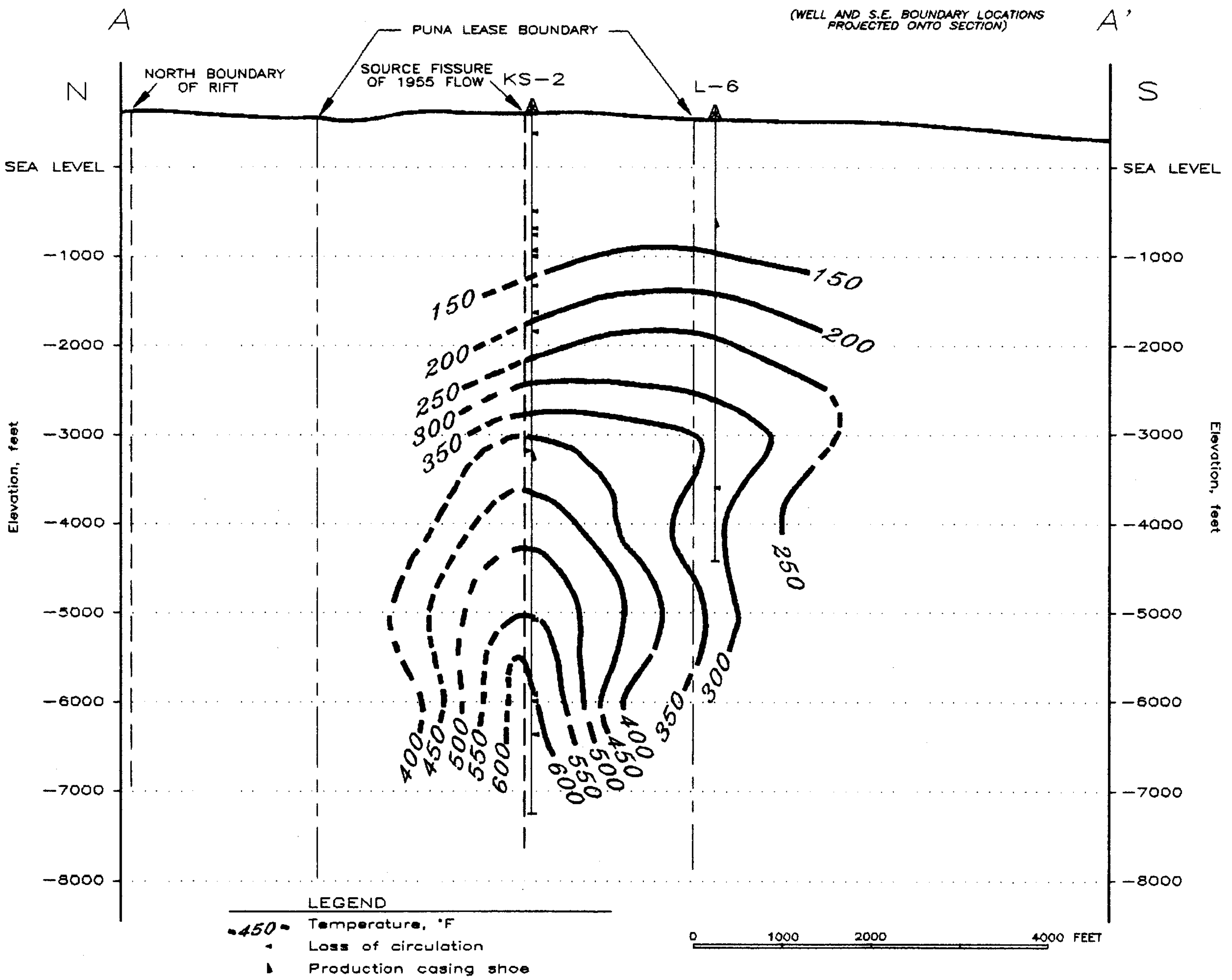


Figure 3.19 Temperature cross-section A-A'

1988, GeothermEx, Inc. XSAA/100688/H1006

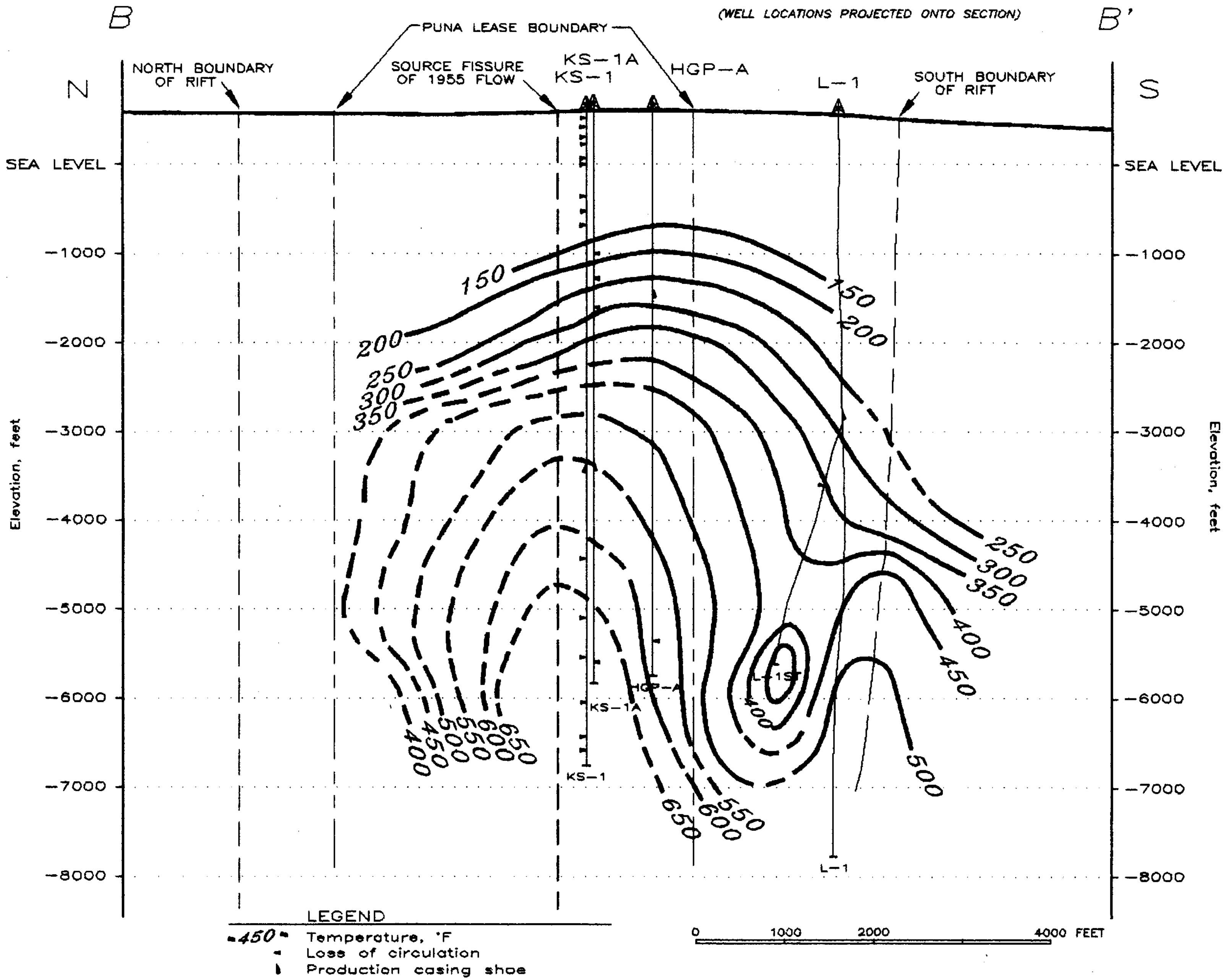
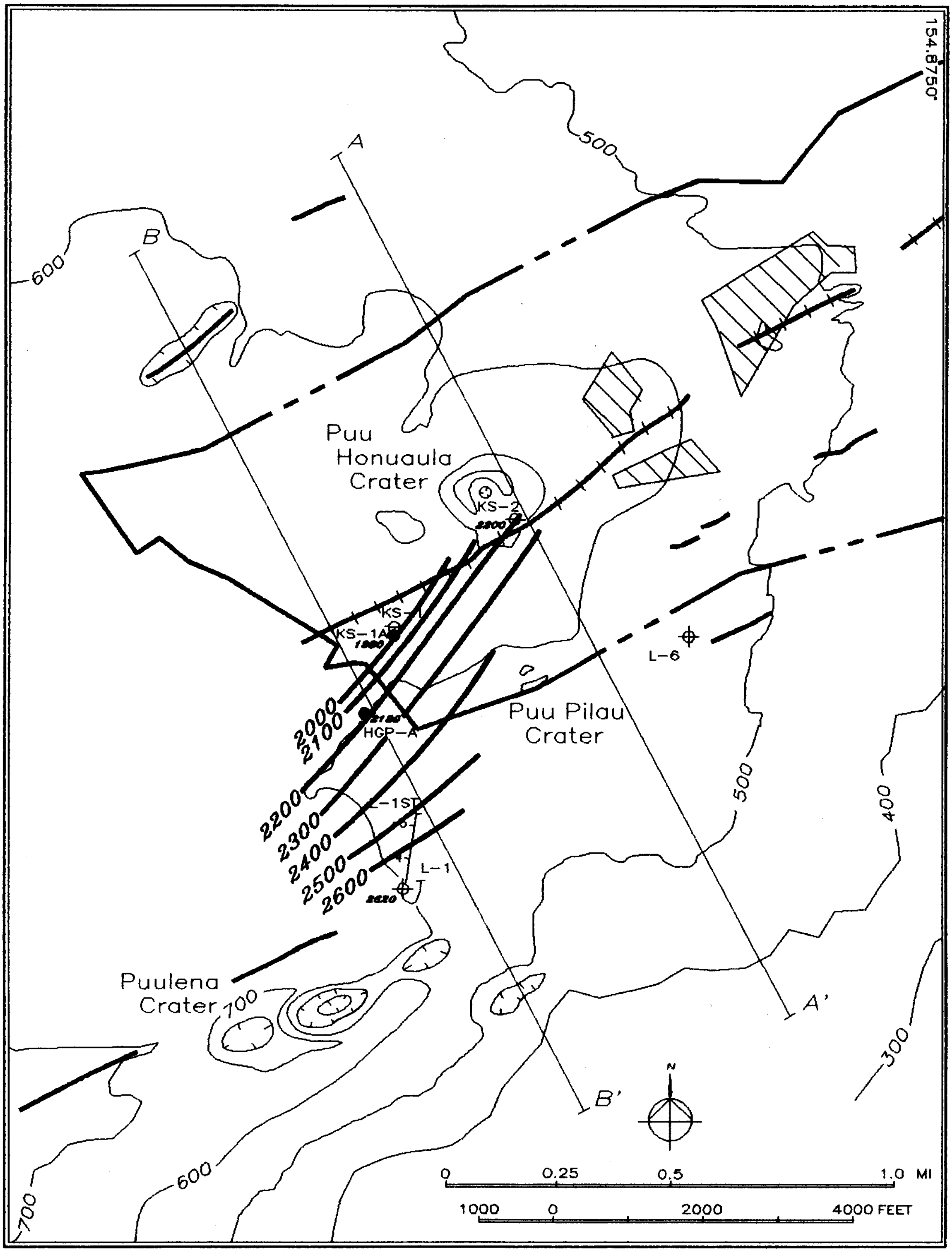


Figure 3.20 Temperature cross-section B-B'

1988, GeothermEx, Inc. X588/100588/H1006



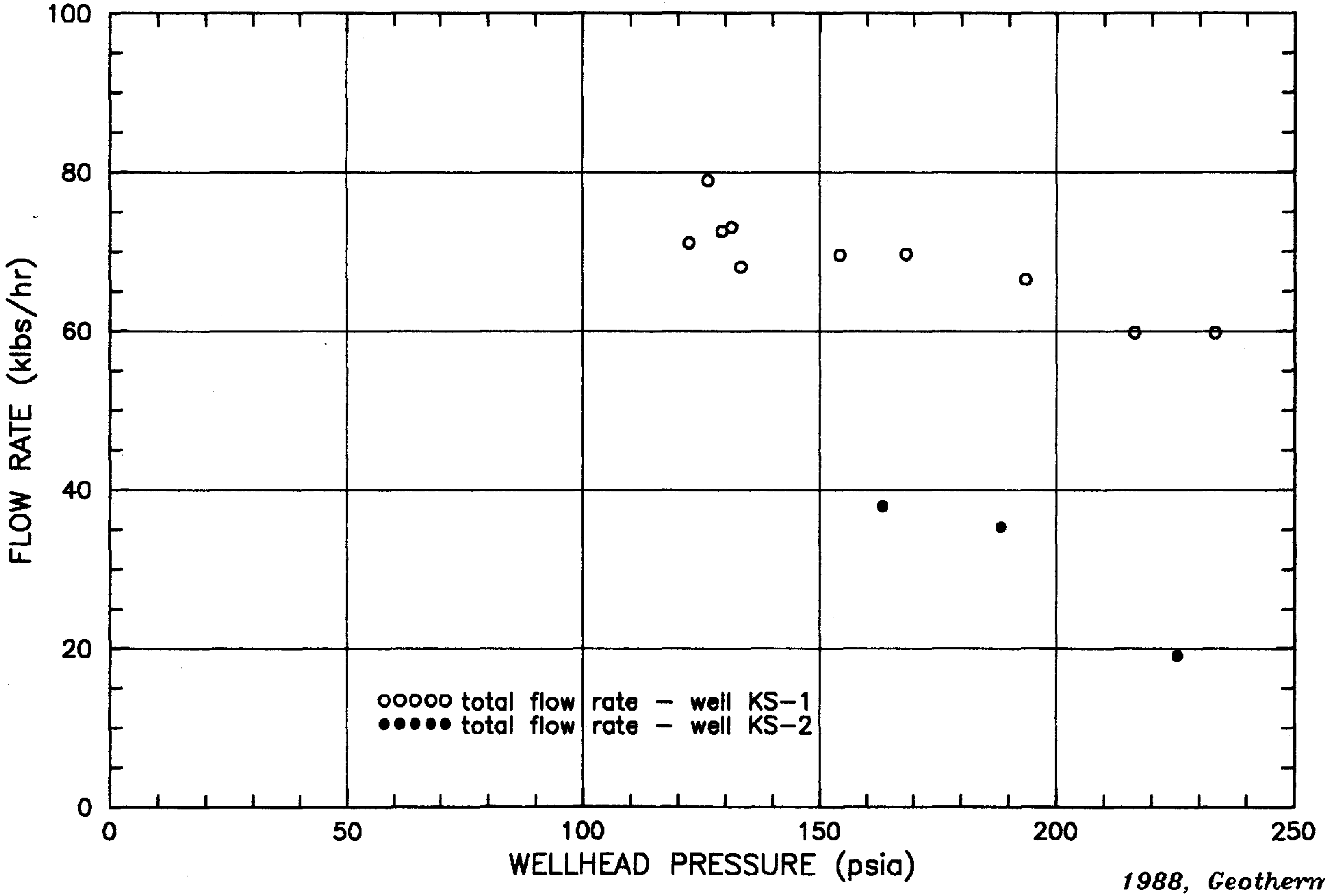
LEGEND

2500 Pressure at −5,000 feet (msl), psig	Production well	Fault and downthrow direction
Lease boundary	Dry hole	Fissure (1955 eruption zone)
Exclusions from lease	Plugged hole	Fracture

Figure 3.21 Contour map of pressure distribution at −5,000 feet, msl

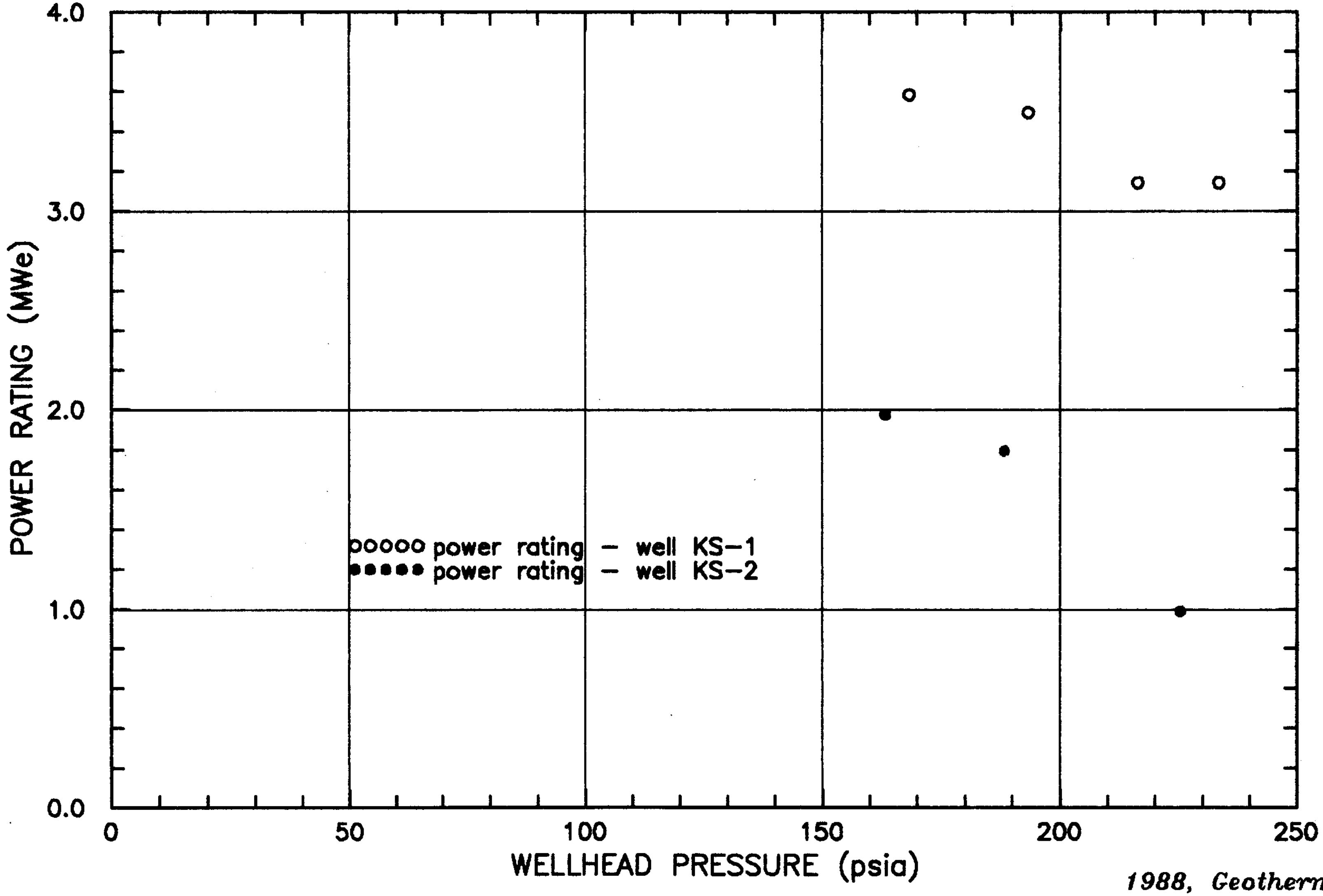
1988, GeothermEx, Inc. P5000/101488/H1066

FIGURE 4.1: FLOW RATE vs WELLHEAD PRESSURE, WELLS KS-1 and KS-2



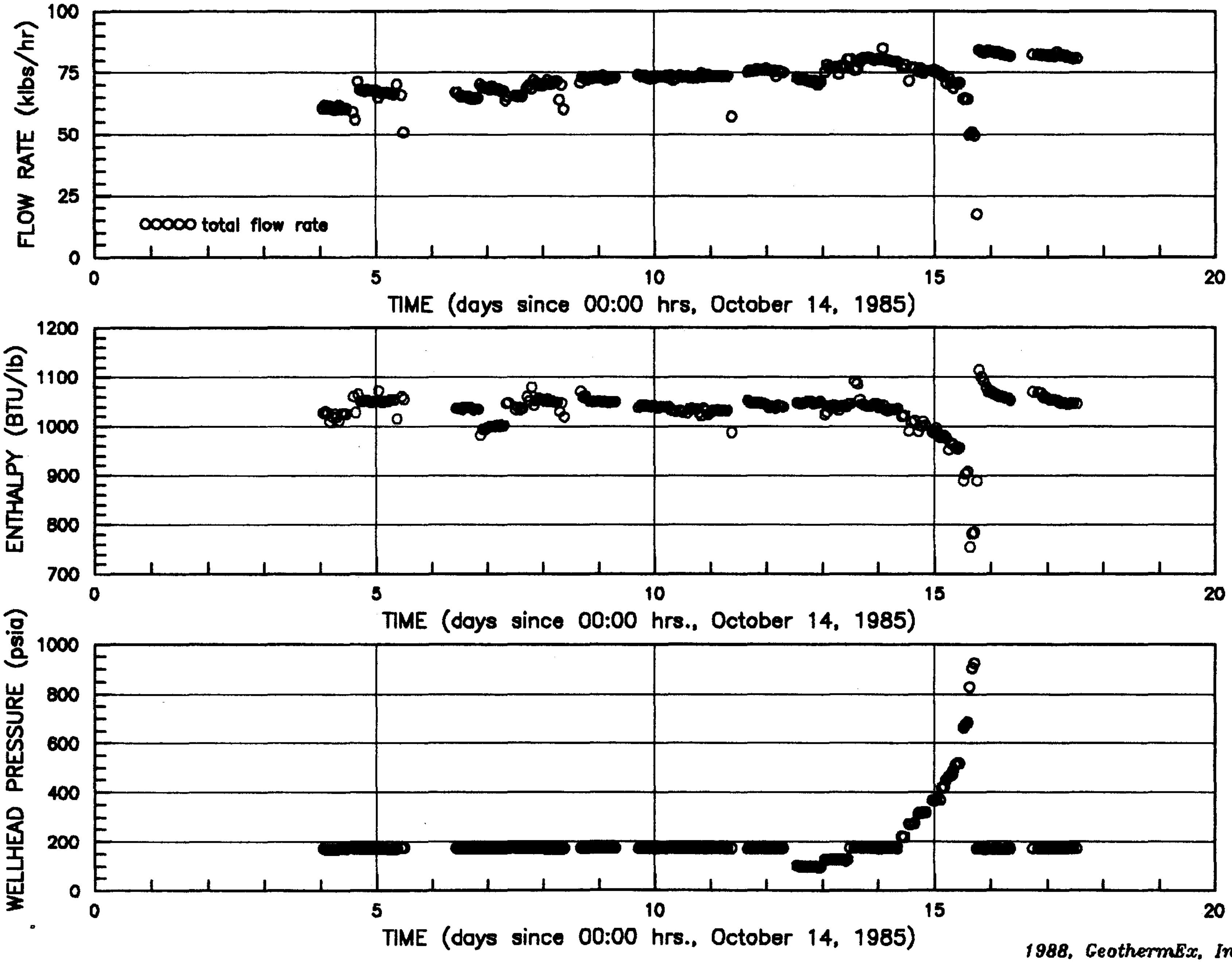
1988, GeothermEx, Inc.

FIGURE 4.2: POWER RATING vs WELLHEAD PRESSURE, WELLS KS-1 and KS-2



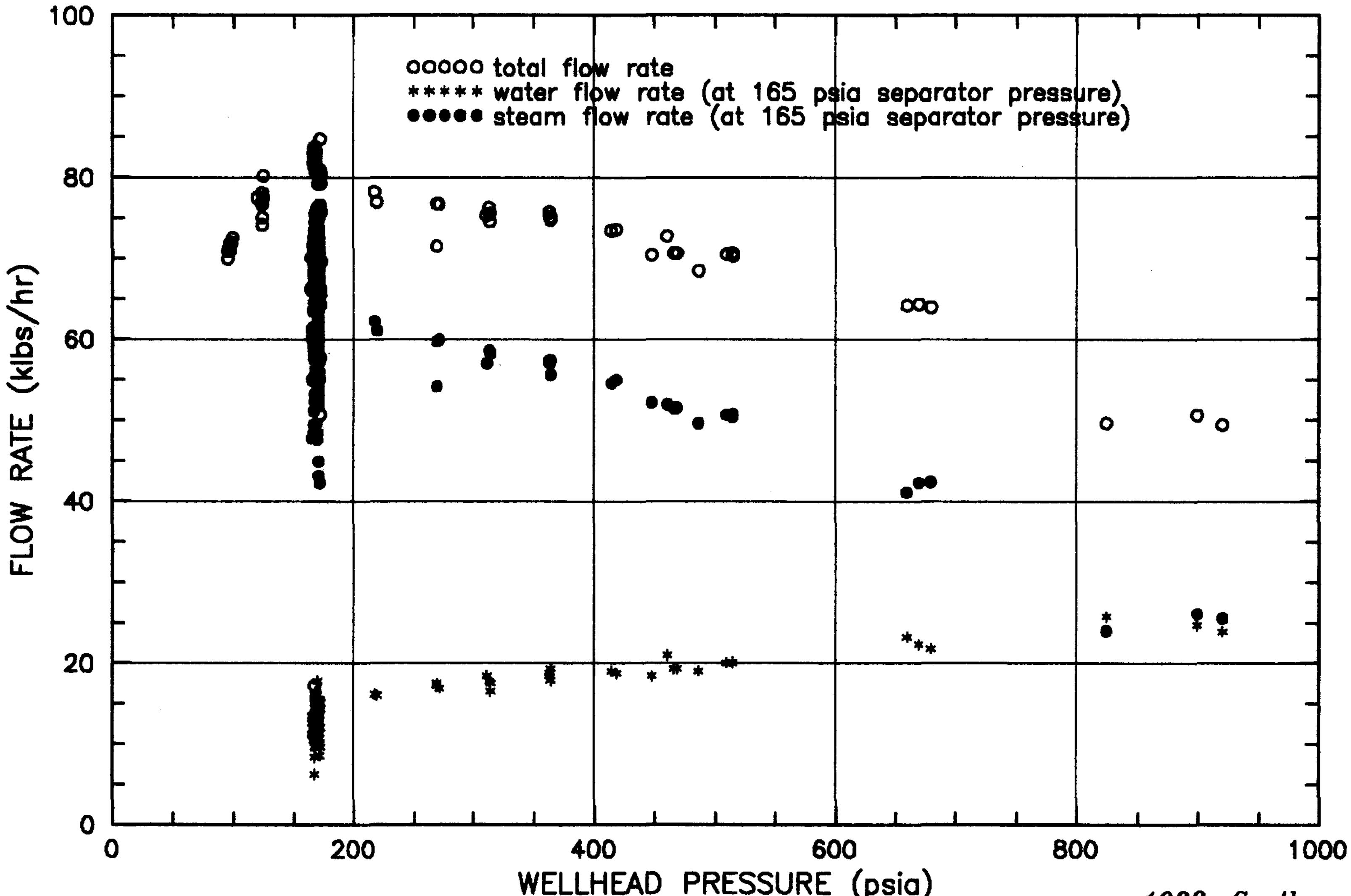
1988, GeothermEx, Inc.

FIGURE 4.3: TOTAL FLOW RATE, ENTHALPY and WELLHEAD PRESSURE vs TIME, WELL KS-1A



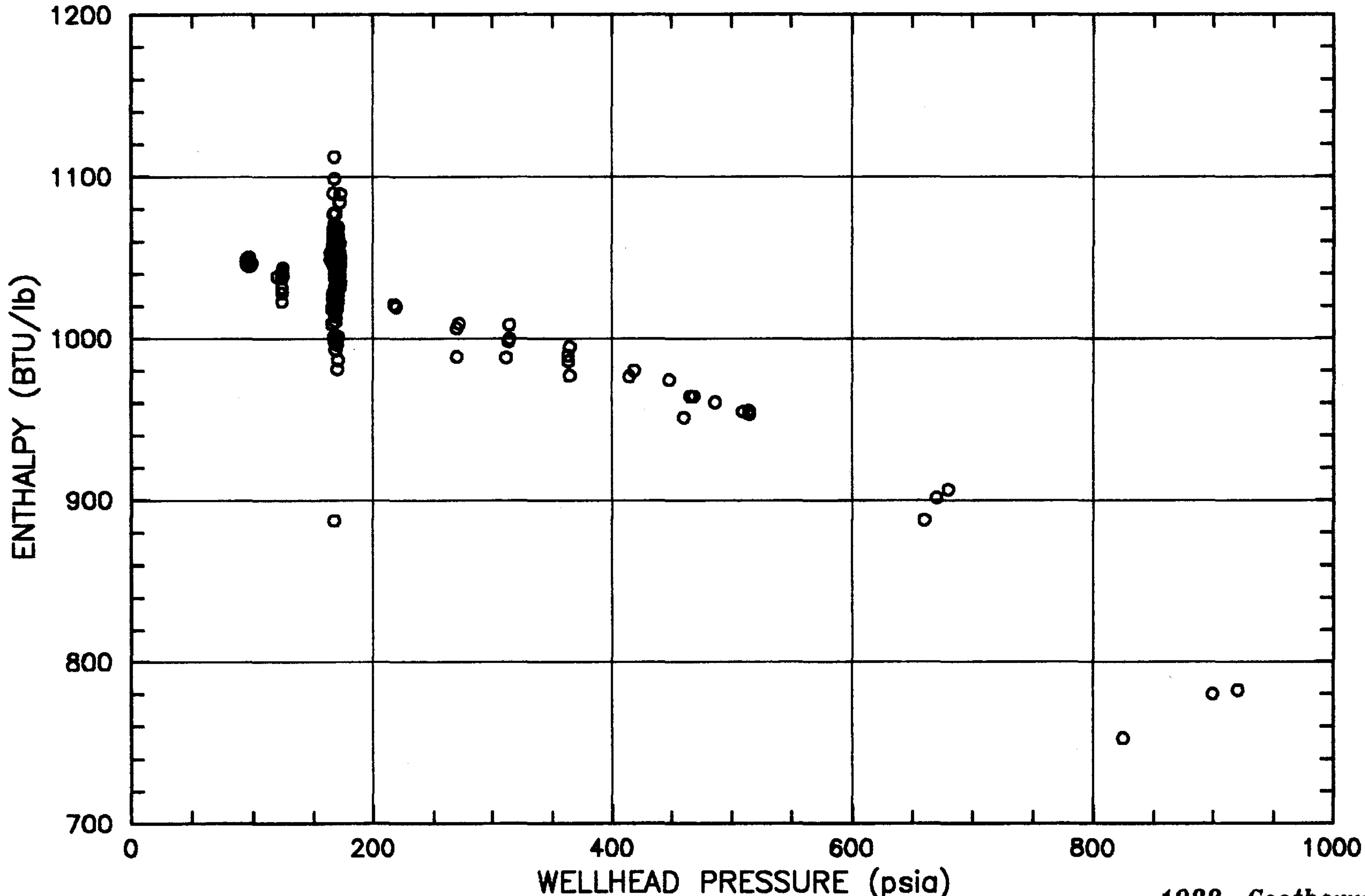
1988, GeothermEx, Inc.

FIGURE 4.4: FLOW RATE vs WELLHEAD PRESSURE, WELL KS-1A



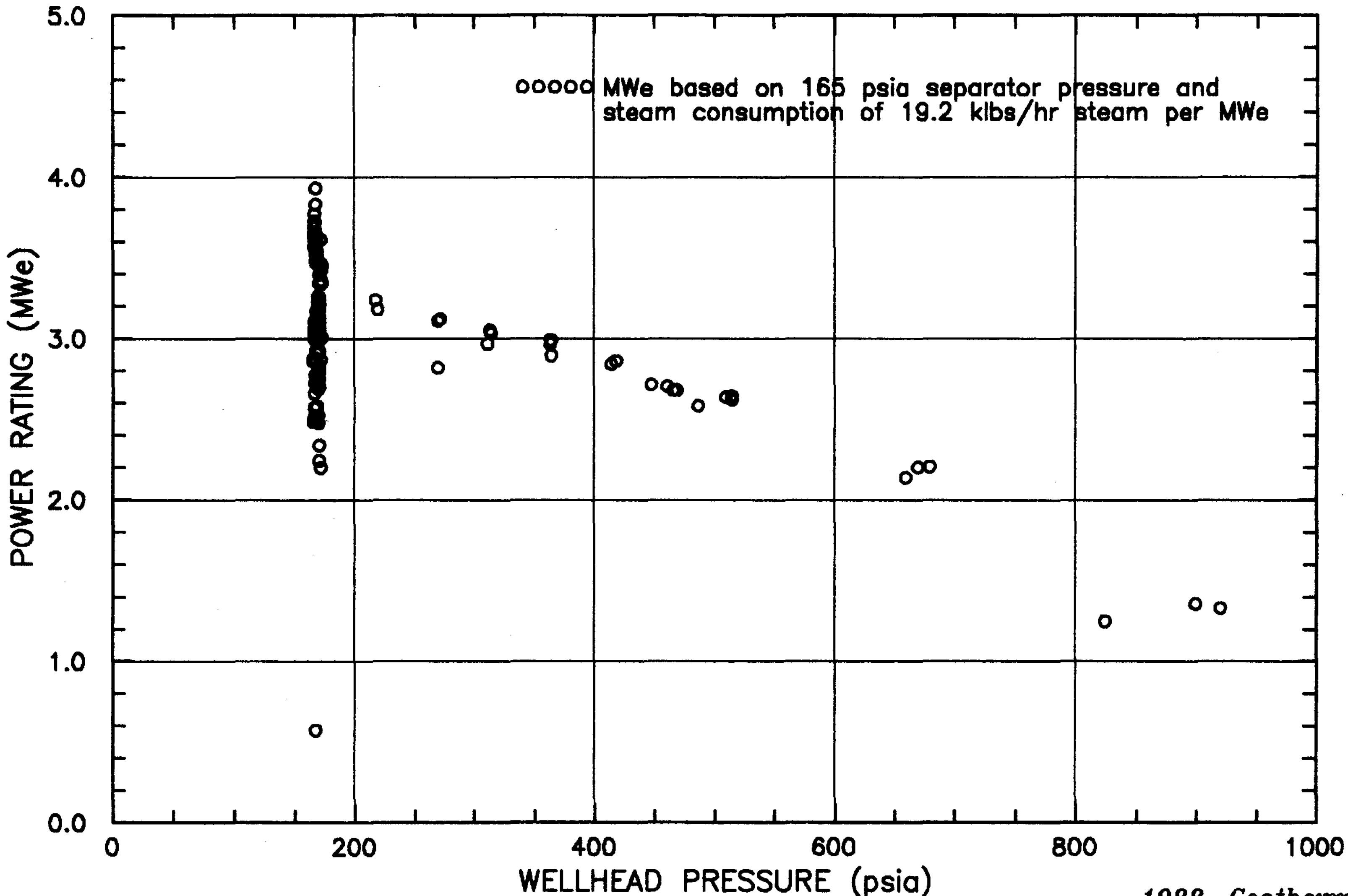
1988, GeothermEx, Inc.

FIGURE 4.5: ENTHALPY vs WELLHEAD PRESSURE, WELL KS-1A



1988, GeothermEx, Inc.

FIGURE 4.6: POWER RATING vs WELLHEAD PRESSURE, WELL KS-1A



1988, GeothermEx, Inc.

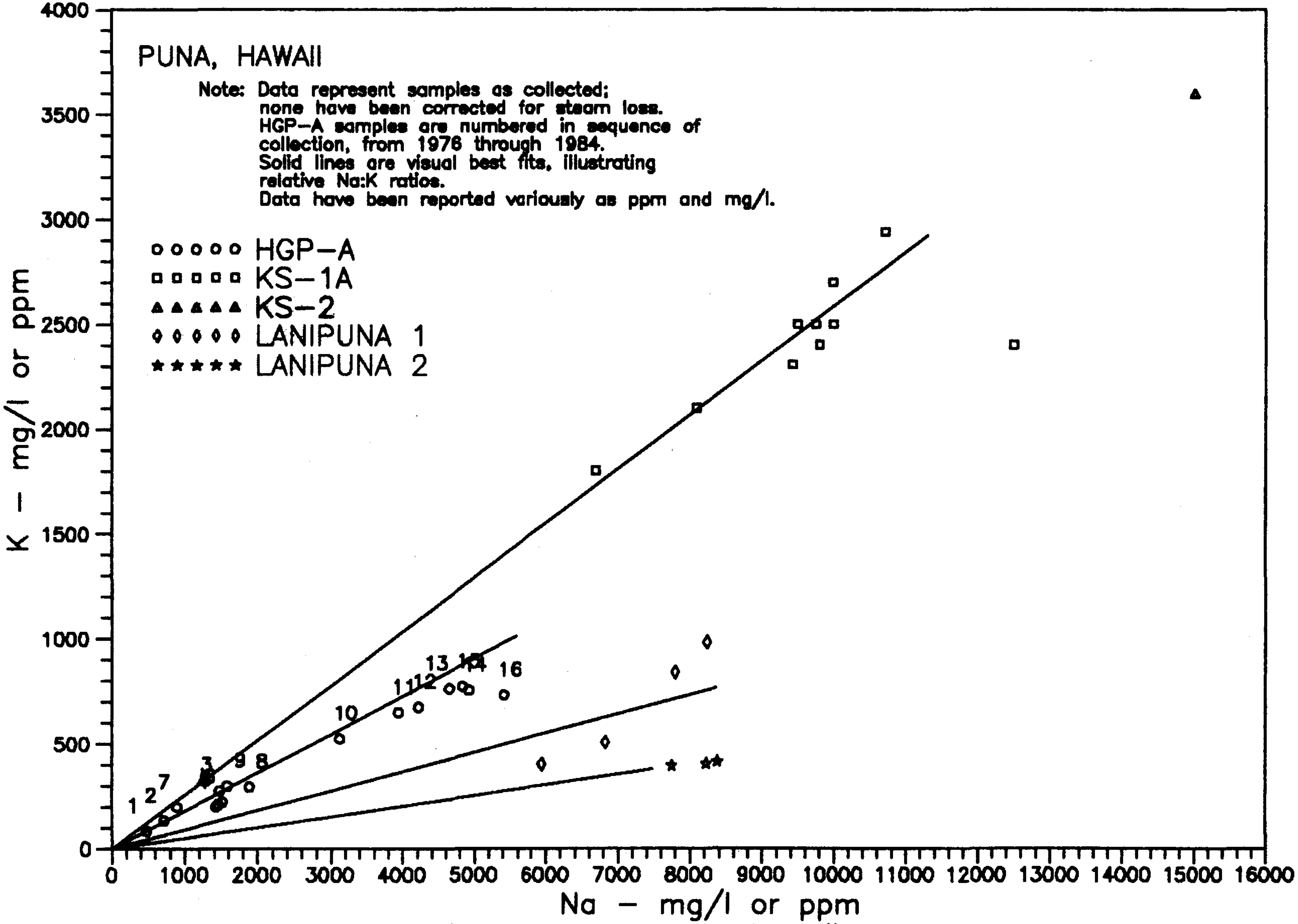
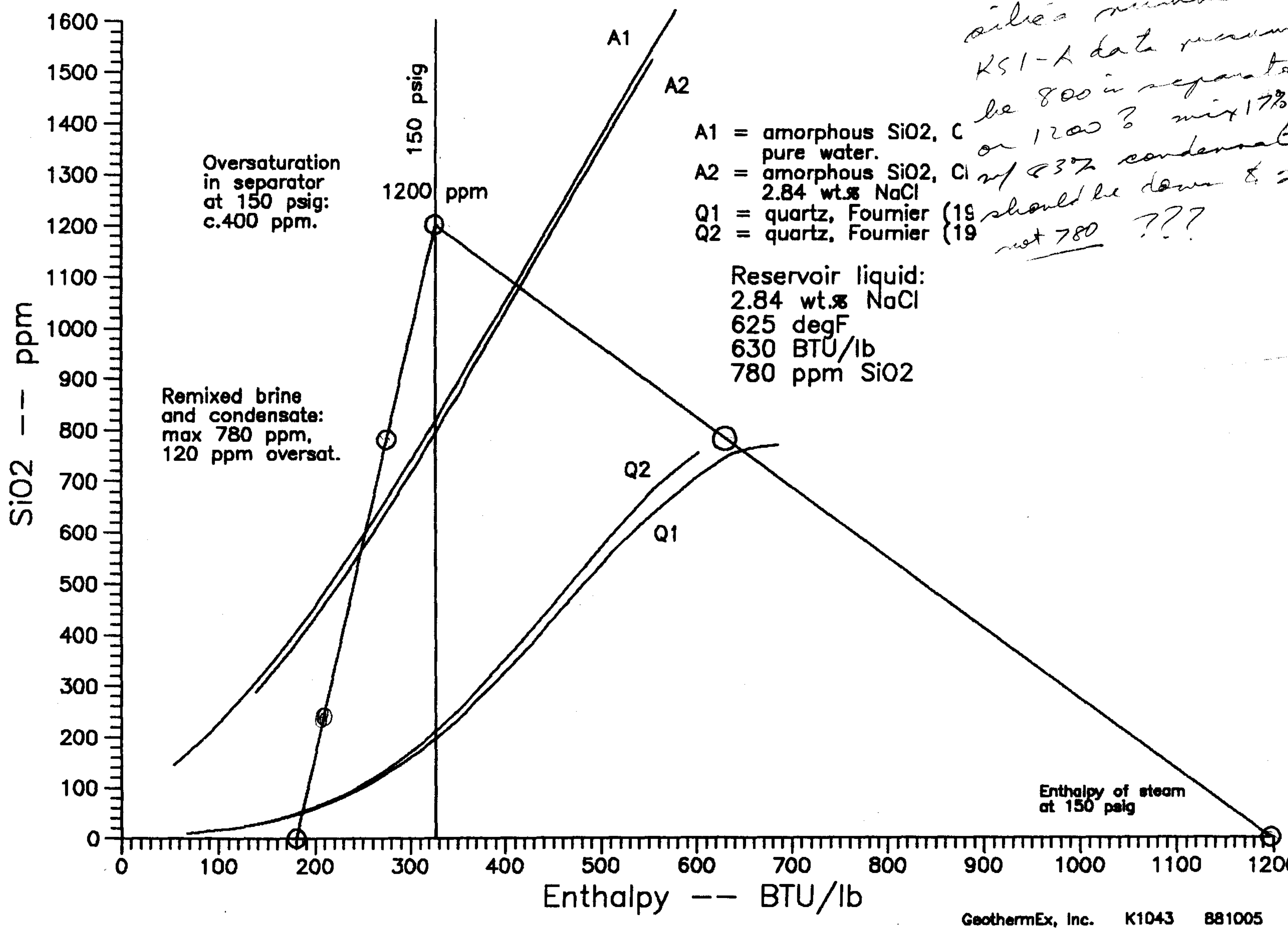


Figure 4.7: Na vs. K in waters of Puna, Hawaii thermal wells

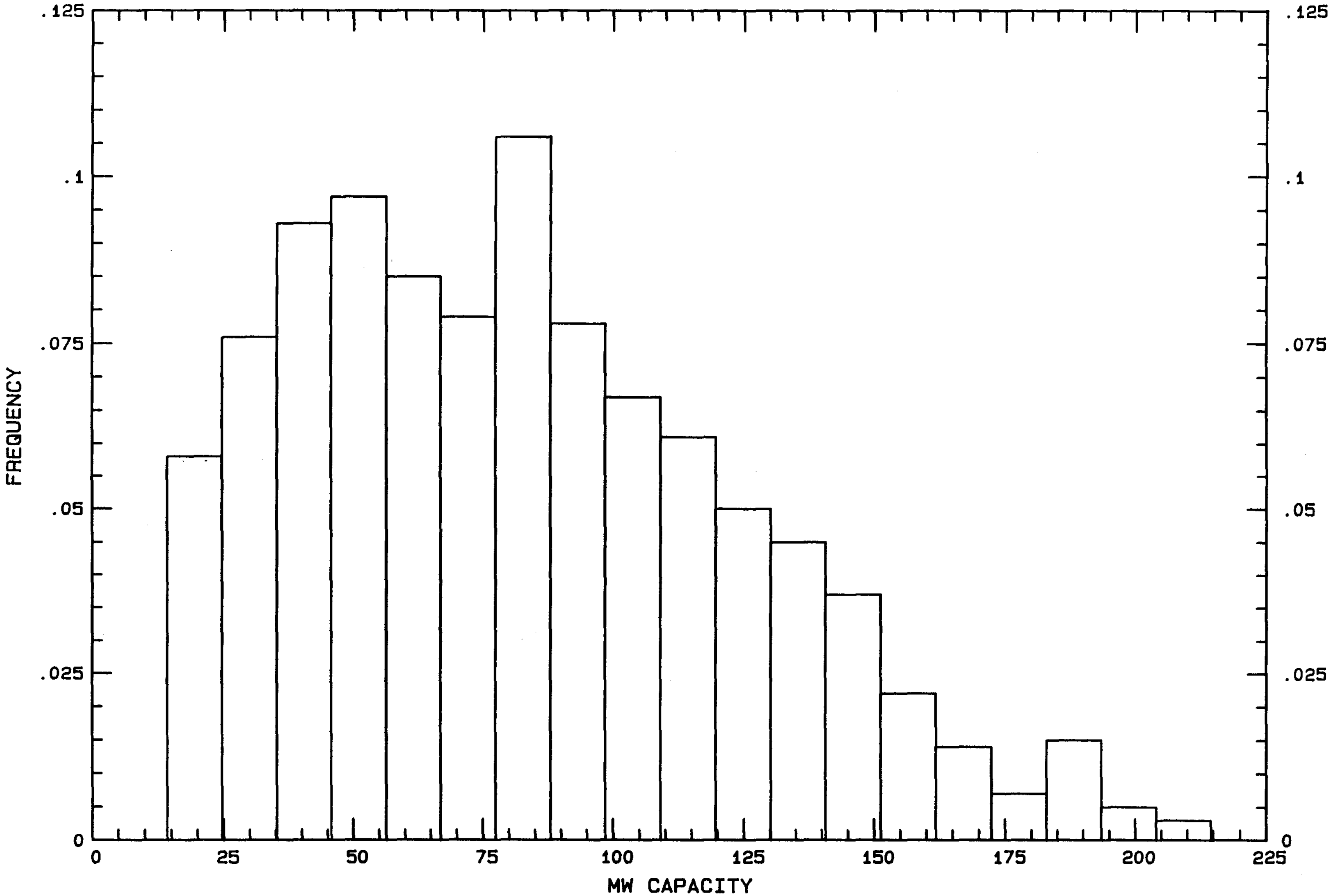
GeothermEx,Inc.- K1043 NA→K8511 - 881003

Figure 4.8: Graph showing process conditions and s...
saturation enthalpy — ORMAT PUNA, H



do not understand
silica number
KS1-A data measured to
be 800 in separator
or 1200? mix 17% brine
w/ 83% condensate
should be down to 204 ppm
not 780 ???

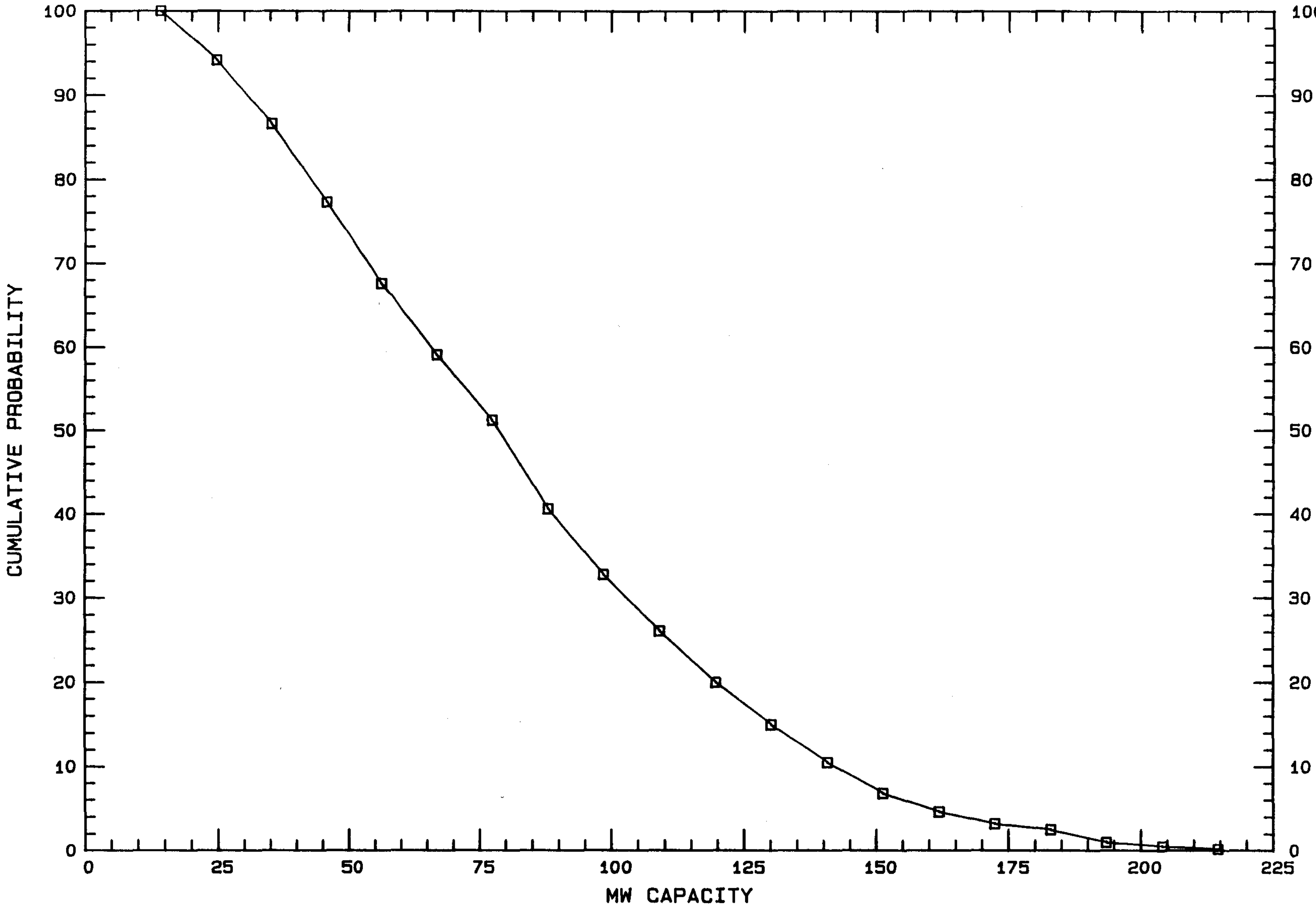
FIGURE 5.1: HISTOGRAM OF MW CAPACITY, PUNA GEOTHERMAL LEASEHOLD



GeothermEx, Inc.

07-19-1989 D: PUNA1HIS.PLT

FIGURE 5.2: CUM. PROBABILITY OF MW CAPACITY, PUNA GEOTHERMAL LEASEHOLD



GeothermEx, Inc.

07-19-1989 D: PUNA1CMP.PLT

analysis of mud loss data would be useful to determine magnitude of loss zones & ∴ permeability