PUNA GEOTHERMAL VENTURE
A Hawaii Partnership

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DIV. OF WATER &
LAND DEVELOPMENT

HAND DELIVER

October 24, 1991

Mr. William Paty
Director
State Department of Land and Natural Resources
P.O. Box 621
Honolulu, Hawaii 96809

Dear Mr. Paty:

Subject: Puna Geothermal Venture (PGV)
Proposed Amendment to Plan of Operations

Attached please find, for your review and approval, PGV's proposed amendment to the Plan of Operations regarding the following two aspects of the geothermal field development: 1) drilling sequence and schedule; and 2) geologic modeling of the PGV geothermal resource. This amendment is consistent with the recommendations presented in the Geothermal Management Plan, issued on October 4, 1991, by the joint State and County Task Force.

Puna Geothermal Venture is currently completing the noise analysis and will submit this document for your review upon completion. Subsequently, PGV will submit the following documents: 1) revised drilling application for KS-8; and 2) a revised casing and testing program for KS-3 for approval. Future submittals will be made as appropriate to the project.

If you have any questions regarding this submittal or any future applications, please feel free to contact me in the Hilo office at 961-2184.

Sincerely,

Maurice A. Richard
Vice President
Puna Geothermal Venture

Attachment

91151.011

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HDROGEOLOGIC MODEL OF THE
PUNA GEOTHERMAL VENTURE GEOTHERMAL RESOURCE
UPDATE OCTOBER 22, 1991

EXECUTIVE SUMMARY

1. The Puna Geothermal Venture (PGV) geothermal resource lies entirely within the Lower East Rift Zone (LERZ). The LERZ is a 1-2 mile wide, volcanically and tectonicaly active zone characterized by frequent basaltic eruptions and widespread tensional fracturing.

2. Puna Geothermal Venture (PGV) and other operators have drilled nine deep exploration into and adjacent to the PGV geothermal resource.

3. Drilling, testing, and long-term commercial production from the deep wells have confirmed the existence of a significant commercial geothermal resource.

4. The commercial resource is characterized by two distinct reservoir types: 1) a pervasive, low transmissivity, high temperature reservoir; and 2) high transmissivity zones contained within steeply dipping fractures.

5. The low transmissivity reservoir underlies much of the PGV project site at depths below 5000 feet. The reservoir is capable of sustaining commercial production in the range of 60 thousand pounds per hour (kph) steam per well which is equivalent to 3 megawatts of net electrical generation per well.

6. Wells drilled into the low transmissivity reservoir also exhibit good injection characteristics. Two to three wells drilled into the reservoir will provide injection capacity for the 25 MW power plant effluent stream.

7. The high transmissivity zone, as encountered by production well KS-8, appears to provide very high productivity, possibly in excess of 200 kph steam per well (10 MW electric per well).

8. Based on the current reservoir model, PGV production wells will be targeted to intersect the KS-8 fracture at depths below 3500 feet. Injection wells will be targeted to the low transmissivity reservoir as stepouts from the injection zone defined by KS-3.

9. Thermal breakthrough from injection zones to production zones is not expected to occur because of the diffuse nature and low transmissivity of the fracture system in the injection zone.

10. Non-condensable gas breakthrough is not expected because the gas will be highly undersaturated in the injection zone and will not be concentrated above natural reservoir dissolved gas levels by the power conversion cycle prior to injection.

PUNA GEOTHERMAL VENTURE
PROPOSED AMENDMENT TO PLAN OF OPERATIONS

I. DRILLING SEQUENCE AND SCHEDULE:

Upon the reinstatement of the drilling permits (suspended as a result of the June 12, 1991, uncontrolled flow event at KS-8), PGV proposes the following sequence of drilling and field development activities:

1. Complete and test production well KS-8 using Parker Rig #231.

2. Perform injection test and casing integrity program on KS-1A. Place in service as injection well.

3. Move Parker Rig #231 to KS-3 and complete well modification and testing required to covert well into an injection well.

4. Move Parker Rig #231 to KS-4 and drill an injection well.

5. Move Parker Rig #231 to KS-9 and drill a production well.

6. Move Parker Rig #231 to a development well location, to be determined by previous drilling data, and drill an injection or production well, as required by the project.

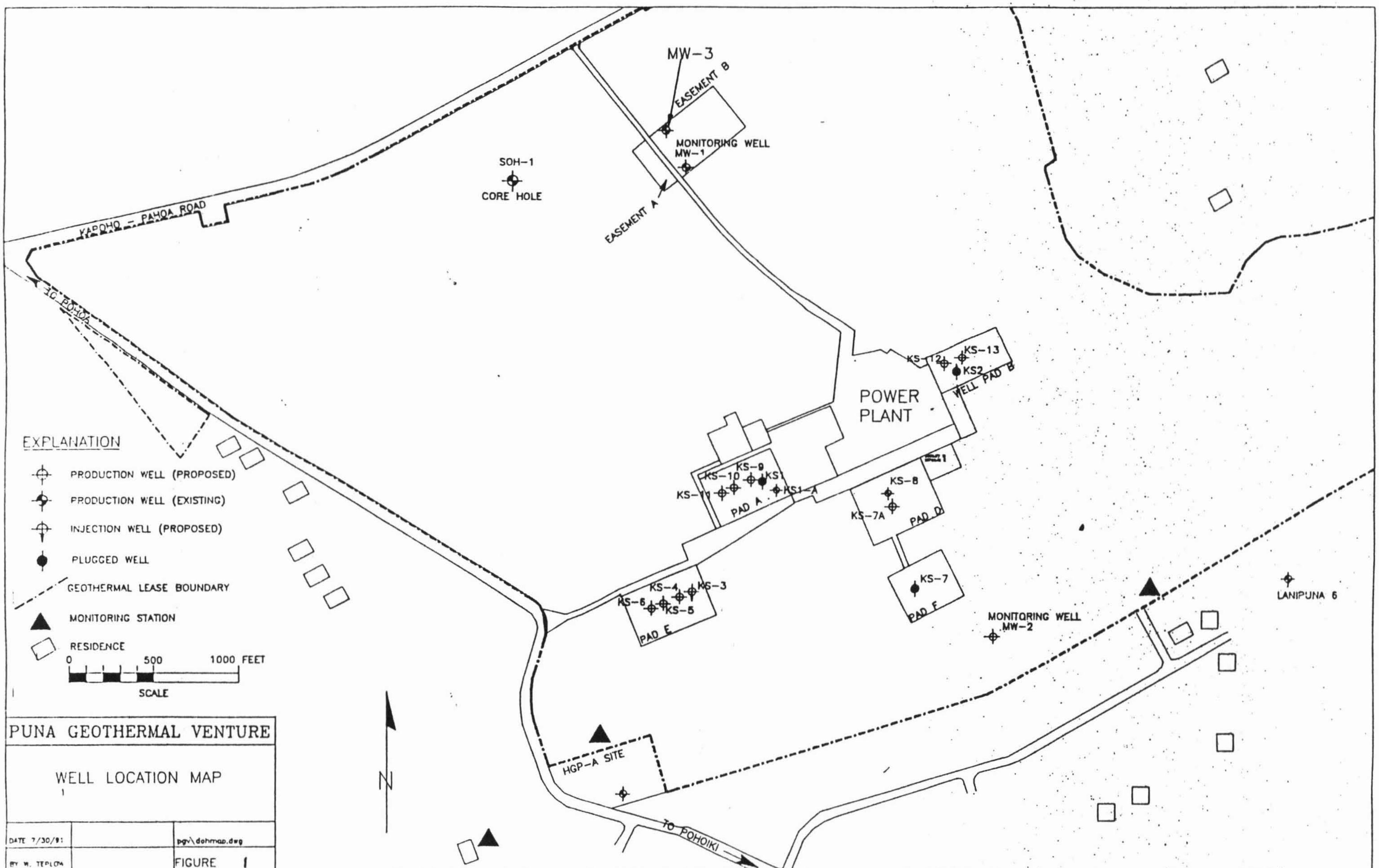
7. Move Parker Rig #231 to KS-7 and perform a well evaluation for possible plug and abandonment.

Well locations are shown on Figure 1. The sequence and schedule described above is shown in Figure 2 as they relate to the power plant startup. The power plant startup will commence upon the completion of the KS-3 conversion to an injection well. This is expected to take place approximately 35 days after reinstatement of the drilling permits.

The schedule and drilling sequence described above may be further modified in the event that two drill rigs are used simultaneously. The use of a second drill rig is dependent upon meeting environmental standards and operational safety requirements put forth by the Hawaii Department of Health (HDOH) and the Hawaii Department of Land and Natural Resources (DLNR). In the event that a second rig is allowed, an additional development well will be drilled at the KS-11 site immediately upon receipt of agency authorization. The well can be targeted either as an injection or production well, depending upon the previous drilling and testing data and the need to provide redundant injection capacity in a timely manner.

II. GEOLOGIC MODEL

The PGV geologic staff updates the geologic model of the PGV geothermal resource from time to time as significant new data is gathered from drilling and testing operations and ongoing geotechnical studies. This updated model is provided to DLNR as part of the revision to the Plan of Operations. This is done so that the DLNR staff has an current geologic basis for making regulatory decisions related to drilling and wellfield operations. Attachment A contains the updated geologic model for the PGV geothermal resource. The model incorporates all drilling data and geotechnical studies available to date to the PGV staff. This attachment contains data and analyses which PGV considers to be proprietary and strictly confidential. Puna Geothermal Venture is making this information available to DLNR with the understanding that the document will be maintained in strictest confidence for the internal use of the DLNR and HDOH staff only.



MW-3
EASEMENT B
MONITORING WELL
MW-1
SOH-1
CORE HOLE
EASEMENT A
KAPOHO - PAHOA ROAD
TO PAHOA
KS-12
KS-13
KS2
WELL PAD B
POWER
PLANT
KS-10
KS-9
KS1
KS-11
KS1-A
PAD A
KS-8
KS-7A
PAD D
KS-4
KS-3
KS-6
KS-5
PAD E
KS-7
PAD F
MONITORING WELL
MW-2
LANIPUNA 6
HGP-A SITE
TO POHOIKI
N
EXPLANATION
PRODUCTION WELL (PROPOSED)
PRODUCTION WELL (EXISTING)
INJECTION WELL (PROPOSED)
PLUGGED WELL
GEOTHERMAL LEASE BOUNDARY
MONITORING STATION
RESIDENCE
0
500
1000 FEET
SCALE
PUNA GEOTHERMAL VENTURE
WELL LOCATION MAP
DATE 7/30/91
pgv\dohmap.dwg
BY W. TEPLOW
FIGURE 1

Figure 2

GENERAL
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                                     PGV FIELD DEVELOPMENT SCHEDULE, ONE RIG
                                                      Months
                                            --+-------+--------+-------+-------+--------+-------+--------+--
        Task            Resource    Schd      |   1   |   2    |   3   |   4   |   5    |   6   |   7    |
  4 Days Per Column                 Dur       |       |        |       |       |        |       |        |
                                            --+-------+--------+-------+-------+--------+-------+--------+--
FIELD2.PJ                           232dy ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
 Field Development                  232dy ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
  Agency review                      31dy ++++++++                     |
  Reinstate permits                   0dy         M                    |
  Complete KS-8, test                21dy        ++++++                |
  Injection Test KS-1A                3dy        XX___*                |
  Test, complete KS-3                14dy         |     ++++           |
  Drill KS-4, Injection              52dy         |        ++++++++++++++
  Drill KS-9, Prod.                  52dy         |                    |   ++++++++++++++
  Drill devel. well                  52dy         |                    |                 ++++++++++++++
  P&A KS-7                           10dy         |                    |                              +++
 Power Plant                        232dy ++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
  Reinstate const. perm               0dy M____.  |                    |
  Complete construction              45dy XXXXXXXXXXXX____*            |
  Startup and online                166dy         |        ++++++++++++++++++++++++++++++++++++++++++++
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HYDROGEOLOGIC MODEL OF THE PUNA GEOTHERMAL VENTURE GEOTHERMAL RESOURCE UPDATE OCTOBER 22, 1991

1 INTRODUCTION

1.1 Background

To date, six geothermal development wells have been drilled on the Puna Geothermal Venture (PGV) 500 acre project site (Figure 1 and 2). Three wells, KS-1, KS-1A, and KS-2, were drilled by the previous operators in the period 1982 to 1985, and three (KS-3, KS-7, and KS-8) were drilled by PGV beginning in November 1990. A core hole (SOH-1) was also drilled on the PGV project site to a depth of 5500 feet by the University of Hawaii Natural Energy Institute. Core from this hole was made available to the PGV staff for examination. Three additional deep exploratory and production wells, Lanipuna 1, Lanipuna 6, and HGP-A were drilled by other operators to the south of the PGV project site. These exploratory and development wells range in depth from 1678 feet to 8400 feet. Seven of the nine deep wells have encountered commercial grade geothermal resources. The drilling, testing, and commercial production from these wells forms the basis for planning and execution of the additional geothermal field development required for completion of the PGV 25 MW power project.

Geologic data from the deep wells are augmented by numerous geologic, geophysical, and geochemical studies performed in the public sector. In addition, four shallow observations are located on or adjacent to the project site. These wells penetrate into the top of the unconfined aquifer and provide data relating to the nature of the shallow ground water system and the influence of the underlying geothermal resource on that system. The broad database for both the shallow and deep hydrologic systems forms the basis for synthesizing a hydrogeologic model of the PGV resource. Previous hydrogeologic models of the project site have been discussed in the PGV Plan of Operation (EMA, 1988) and by Iovenetti (1988).

Since November, 1990, PGV has drilled three development wells at the project site. The first development well drilled by PGV, KS-3, was flow tested for seven days. Much new information relating to the structure and reservoir conditions of the PGV geothermal resource has accrued from this drilling and testing activity. During this period, the PGV staff has also performed a review of all available literature both from the public and private sector relating to the geology, geochemistry, and reservoir characteristics of the Puna geothermal resource.

1.2 Purpose

The purpose of this document is to present an updated hydrogeologic model of the PGV geothermal resource. The model is a synthesis of the newly acquired geotechnical data from PGV drilling and testing activities together with previous geologic models and studies.

The updated model is the basis for making major field development decisions including the following:

* Production and injection well siting.
* Production and injection well spacing.
* Production and injection well design and casing configuration.

The model also serves as the basis for creating a numerical simulation of the reservoir. The numerical simulation is currently under development by PGV and will be used to predict reservoir pressure and temperature behavior during commercial production. The hydrogeologic model will be updated from time to time as new drilling, testing, production, and numerical simulation data are acquired.

1.3 Scope

This document covers various geologic and hydrologic characteristics of the PGV 500 acre project site as they relate to the commercial geothermal resource. Geologic data from areas outside the project site are incorporated only to the extent that they specifically add to an understanding of the Puna geothermal resource. The document also describes the PGV production and injection drilling strategies which are derived from the model.

2 REGIONAL GEOLOGY

The PGV project site is located within the Lower East Rift Zone (LERZ) of the Kilauea Volcano. The general structure and dynamics of magma movement within the Kilauea system is described by Decker (1987). The LERZ is the eastward extension of the East Rift Zone, one of two major rift features radiating from the eruptive center of the Kilauea massif. The East Rift Zone and LERZ extend over a distance of 50 miles of which the eastern most 20 miles lies beneath the sea. The rift zones are major conduits of basaltic magma draining from a central magma chamber located beneath the Kilauea caldera.

The LERZ in the vicinity of the PGV site is a highly linear feature, 1.5 to 2 miles wide, which is characterized by numerous surface fractures and vents (Figure 1). The fractures and vents have a strong N 63 E trend. The project site is located in one of the narrowest portions of the LERZ and effectively straddles the most active part of the zone over a width of 5000 feet in the NW-SE direction.

3 LITHOLOGY AND STRATIGRAPHY

All rocks types encountered in the Lower East Rift Zone are basalts that are essentially similar in origin. Differentiation based on macroscopic physical attributes are a function of the depositional environment during emplacement and minor variations in the chemical compositions of the basalt. Three types of basalts can be differentiated by chemical composition (Moore, 1983). These are mafic olivine tholeiites derived from the primary magma chamber beneath the summit of Kilauea caldera, differentiated basalts derived from secondary magma chambers in the rift zone, and basalts that are mixtures of the two basic magmas.

Surface lavas in the vicinity of the PGV site consist of differentiated basalts originating from a secondary magma chamber that exists beneath Puu Honuaula and primary olivine tholeiites which have flowed down-rift following topography (Moore, 1983; Slemmons et al, 1981). Moore believes that the Puu Honuaula secondary magma chamber has existed for over 1,500 years. The primary olivine tholeiites are recognized by the appearance of large percentages of olivine phenocrysts and lesser amounts of plagioclase laths. Differentiated basalts contain abundant plagioclase phenocrsyts, minor to common pyroxene phenocrysts and rare olivine crystals.

The depositional environment directly affects the physical appearance of all three basalt types. Subaerial basalts, aa and pahoehoe, occur as solid flows separated by rubblized interflow breccias or sometimes are totally fragmented and rubblized flows. Submarine basalt flows occur as dense conglomerates of pillows and pillow fragments infilled by ocean floor clays and silica. Dikes are typically coarser-grained tabular bodies that intruded pre-existing flow basalts. Hyaloclastites are deposits of grit- to sand-sized granular glass fragments formed when hot fluid basalt flows into the ocean creating phreatic explosions. The hyaloclastite material may be deposited off or near shore as black sand beaches or on shore as littoral cones and tuff rings depending on the prevailing winds and intensity of the lava-water reaction. Primary olivine tholeiites as well as differentiated basalts can be found as subaerial, submarine, hyaloclastite or intrusive dike deposits. However, because of the proximity of the Puu Honuaula secondary magma chamber, the identified dike units in the geothermal field are derived almost exclusively from differentiated magmas.

Review of all available mud logs and examination of available cuttings and core indicate that the downhole lithology can be divided into 4 major correlatable units: 1) subaerial basalt flows; 2) transitional near-shore assemblage dominated by hyaloclastites; 3) submarine pillow basalts; and 4) a dike complex in submarine basalt host rock. The following is a detailed description of each unit based on KS-3 lithology.

MEASURED DEPTH (K.B.)	LITHOLOGY
Surface to 1150 ft	<u>No sample</u>; Drilled with no returns
1150 to 3050 feet	<u>Subaerial Basalts</u>:Intercalated lava flows, cindery basalts, scoria zones and weathered interfaces. Two types of basalts occur as vesicular and non-vesicular flows: 1. Olivine-Tholeiitic basalt: rare to trace, locally common, phenocrysts of olivine and subordinate plagioclase in an aphanitic to glassy groundmass. 2. Differentiated Tholeiitic basalts: porphyritic with common to abundant phenocrysts of olivine, plagioclase and pyroxene in a fine-grained holocrystalline to hyalocrystalline

groundmass composed of microlites of plagioclase, pyroxene and magnetite. Includes a small percentage of intrusive dikes.

3050 to 4040 feet — Transitional Zone: Hyaloclastites (layered units composed of granular fragments of volcanic glass, locally conglomeritic, derived from basaltic ash eruptions, littoral deposits and black sand deposits) intercalated with differentiated basalts and less commonly tholeiitic basalts. Differentiated basalts represent intrusive dikes or surface flows. Tholeiitic basalts probably deposited as submarine pillow basalts or surface flows.

4040 to 6450 feet — Submarine Basalts: Tholeiitic pillow basalts, glassy, aphanitic basalt with rare to trace, locally common, phenocrysts of olivine and plagioclase, intercalated with minor units of hyaloclastite. Section is cross-cut by microporphyritic to porphyritic intrusive dikes composed of differentiated basalt, phenocrysts of plagioclase, olivine and pyroxene in a holocrystalline groundmass of plagioclase, pyroxene and magnetite. Coarse-grained diabasic unit of differentiated basalt encountered between 4700 and 4740 feet.

6450 to 7406 feet — Intrusive Dike Complex: Microporphyritic to porphyritic differentiated basalts as above with subordinate thin intervals of pillow basalts and hyaloclastite deposits.

A cross section showing the distribution of the four major lithologic units is shown in Figure 4. The lithologic units are not internally homogeneous. Evaluation of the core from SOH-1 (Figure 2) shows that the subaerial basalt unit grades from aa flows of differentiated basalts near the surface to pahoehoe flows of primary olivine tholeiite at the base. Below about 2,000 feet M.D., there is a noticeable decrease in the thickness of and a reduction in the porosity of the interflow rubblized breccias. This lithologic transition is due to the flow characteristics of the dominant pahoehoe lavas and is also induced by the effects of lithostatic compaction. The Hyaloclastite Unit grades from poorly consolidated granular deposits in the upper 200-300 feet of the unit to densely welded, compacted beds near the base. This too may be a function of changes in depositional environmental, i.e. from on shore to shallow marine, and to increased lithostatic load.

The frequency and thickness of dikes increases with depth. The shallowest dike encountered in SOH-1 was at 829 feet M.D. Within the subaerial basalt unit, the dikes are few in number and tend to be less that 18 inches thick or in swarms no more that 6 to 10 feet thick. In the Hyaloclastite unit dikes are more common, sometime occurring in localized swarms up to 80 feet thick but generally make up less than 30% of the total rock. Dikes become more common and locally are the dominant rock type in the submarine basalts below 4,000 feet in the Kapoho State wells and in also in SOH-1. Individual dikes and sills measure tens of feet thick and intense dike concentrations hundreds of feet thick are common. The frequency of dike intrusion increases with depth in Kapoho State 3, below 6450 feet dikes constitute about 80% of the total rock.

4 STRUCTURE AND TECTONICS

The structure of the LERZ within the project area is dominated by steeply dipping dikes and vertical to near vertical fractures. Rift zone dike swarms which are probably analogous to those found in project area below a depth of 6000 feet have been described in detail by Walker (1987). The dike swarms are characterized by dike density within the host rock of 60-80%. Individual dike thicknesses average from 2-6 feet with dips ranging from 70 degrees to vertical. The host rock separating each dike is typically brecciated. Dike density decreases rapidly upward and only rarely do dikes penetrate to the surface, resulting in subaerial discharge of lava. A possible configuration for the dike swarm is shown schematically in a highly simplified form in Figure 4.

Surface expression of fracturing is common within the project area (Figure 3). Surface fractures are typically 1-3 feet wide and trend parallel to the N 63 E trend of the LERZ. The surface fractures are generally near-vertical and penetrate at least to the top of the warm ground water aquifer as evidence by discharge of warm water vapor at the surface. It is not known whether the surface fractures extend to depths below the ground water. However, in the rock overlying shallow intrusive bodies and dike swarms it is common for vertical fracture systems to develop that extend from the surface to the top of the intrusive bodies. The rock mechanics involved in this process have been described by Rubin and Pollard (1988) and Mastin and Pollard (1988). This process is considered a key component of the formation of permeable fractures which constitute the commercial production targets in the PGV project area.

The cross section A-A' (Figure 4) shows a configuration for two possible steeply dipping permeable fractures in the PGV resource area. The hypothesized geometry of the KS-8 fracture is based on the apparent high transmissivity production zone encountered in the 3340-3488 foot depth interval in KS-8. The zone was observed to flow steam and brine with a bottom hole pressure of 2000 psi and temperature of 633 degrees F. Further evidence for a steeply dipping permeable fracture is given by the temperature and pressure data from KS-8 and surrounding wells as discussed in Section 6. If the assumption is made that high transmissivity persists to the observed depth within the fracture, then certain constraints are placed on the fracture geometry by the drilling results of nearby wells. None of the four wells drilled to the north of KS-8 encountered the same temperature and pressure regime associated with the KS-8 fracture. This limits the possible dip angle in the northward direction to a minimum of approximately 80 degrees. A possible dip of the fracture to the south is limited by the proximity of HGP-A. The KS-8 fracture is shown in Figure 4 with an 85 degree N dip. A structure contour map on the fracture surface based on the postulated dip angle in shown in Figure 3. The strike of the fracture is assumed to be parallel to the LERZ trend. The length of the KS-8 fracture along strike shown in Figure 3 is arbitrary. Additional drilling will be required to provide constraints on the actual strike length.

The possibility that the KS-8 production zone is a stratigraphically controlled horizon with a significant areal extent is precluded by data from surrounding wells. Wells in the vicinity of KS-8 with the exception of KS-7 do not show any evidence of a high temperature, high pressure production zone in the 3340-3488 foot depth interval. The anomalous temperature and pressure observed in KS-7 at a depth of 1678 feet, coupled with the extensive hydrothermal alteration, places the upper extension of the producing fracture in close proximity to KS-7.

The only other evidence for a high transmissivity fracture zone below a depth of 1500 feet is seen in Lanipuna 6. The well encountered a massive lost circulation zone at 4300 feet with an anomalously low temperature of approximately 340 oF. As in KS-8, a horizontally extensive aquifer is not probable because no evidence for lateral extension of this zone is seen in any nearby wells.

Ongoing tectonic activity within the LERZ is consistent with the existent of a deeply penetrating, near vertical fracture system. The LERZ has been exhibiting rapid subsidence since at least as early as 1958 when subsidence studies in the region were initiated. This subsidence mechanism is described by Delaney, et al (1990). The subsidence is attributed to dilation of overlying rock during the emplacement of dike complex below a depth of 6000 feet Fracturing may be enhanced in the particular case of the LERZ because of the ongoing slumping of the south flank along deeply penetrating listric faults. High permeability is expected in the resulting fractures because of the highly tensional regional stress environment. The direction of maximum tensional stress in the PGV area probably lies parallel to the plane of cross section A-A'. The subsidence pattern over a thirty-year period is shown superimposed on the geologic cross section in Figure 4. The position of maximum subsidence corresponds closely with the suspected location of the KS-8 and Lanipuna 6 fractures. This pattern is consistent with that of other rift zones such as those found in Iceland and Afar (Rubin and Pollard, 1988).

5 GROUND WATER HYDROLOGY

Ground water in Hawaii, as on all oceanic islands, exists as a lens-shaped body of fresh, meteoric-derived water, known as basal water, floating on denser saline ocean-derived ground water. This hydrologic condition is described by the Ghyben-Herzberg principle (Fetter,1980). The near surface hydrology in the East Rift Zone is characterized by high recharge rates and rapid subsurface flow (Thomas, 1987). The highly permeable subaerial basalt flows, composed of thin, highly fractured and often rubblized basalt flows, allow nearly 100% of the rainfall to infiltrate down to the basal aquifers. Ground water transmissivities were measured at 5 X 10^4 darcies and ground water residence times are only 10 - 20 years (Thomas, 1987, Iovenetti, 1990). Recharge from rainfall exceeds 120 inches per year in the Lower East Rift Zone and penetration of the meteoric water is essentially complete as evidenced by the absence of stream run-off and standing bodies of water.

Within the East Rift Zone, the ground water distribution is modified by the occurrence of near-vertical to steeply dipping dikes which act as localized semipermeable dams to ground water flow. These physical barriers create a sub-parallel series of permeable compartments that allows the dike-controlled and dike-confined ground water aquifers to rise significantly higher than mean sea level. Because these compartments are isolated from one another by semipermeable dikes, disparate water levels may be observed between compartments and associated water chemistries may display extreme ranges of compositions (Fetter, 1980; Thomas, 1987; Iovenitti, 1990).

Hydrology studies by Druecker and Fan, 1976, demonstrated that the dikes swarms in the East Rift Zone impacted the regional flow of ground water. Meteoric ground water originating north of the rift flows southerly along topographic gradients, until it is impeded by the dikes which divert the ground water flow northeast toward the ocean. Transverse flow across the rift, therefore, is limited. Within the rift zone, ground water flow is controlled by the en echelon dike swarms. Here, water moves down rift parallel to the dikes toward the ocean to the northeast. Ground water encountered south of the rift flows southerly to the ocean conforming to the local topography. Since the volume of fresh water south of the rift is relatively low, coastal waters have a saline chemistries due to salt water mixing and, to a lesser degree, contamination by geothermal waters.

The depth to ground water and flow characteristics of the three monitoring wells drilled on the PGV lease demonstrate the hydrologic characteristics described above. Each water/monitor well encountered the water table at different depths. In MW-1, water was initially encountered at a depth of 8 feet above sea level, MW-2 encountered water at a depth of 16 feet above sea level and MW-3, drilled only 250 feet northwest of MW-1, encountered water at a depth of 14 feet above sea level. The pump test of MW-3 showed no evidence of a gradual draw down with time and both MW-3 and MW-1 displayed almost instantaneous recoveries at the conclusion of their respective pump and flow tests. These parameters are indicative of aquifers with extremely high transmissivities and storativities.

Chemical analyses of waters from MW-1 and MW-2 exhibit disparate characters (see Table 1). MW-2, located at the southern boundary of the known geothermal field, has a chemistry which is higher in sodium and chloride and lower in sulfate and silica. Total dissolved solids typically range from 950 to 1150 mg/l. MW-1, located on the northern portion of the lease, has a chemistry which is higher in silica and sulfate but is very low in sodium and chloride. Total dissolved solid concentrations in MW-1 typically range from 450 to 550 mg/l. Temperatures also differ. MW-2 displays bottom hole temperatures that fluctuate about 10 °F per day, from the high 120's to the high 130's °F. These fluctuations are cyclical with a 24 hour period indicating they are caused by tidal effects. MW-1, however, shows no diurnal temperature fluctuations as fluid temperature measurements are steady at 106 °F.

Water samples from wells and springs throughout the East Rift Zone exhibit similar extreme ranges in temperature and chemistries (Cox and Thomas, 1979; Thomas, 1987; Iovenetti, 1990). The observed variations in chemistry and temperatures are indicative of the mixing of ground waters and geothermal waters within the rift zone. The mixing may be from four sources: cold meteoric, cold sea water, hydrothermal altered meteoric water and hydrothermally modified sea water. The observed characteristics of MW-1 and MW-2 are typical of geothermally modified ground waters (Thomas, 1981). When compared to the waters from GTW III or the Malama Ki well which have higher fluid temperatures and very high concentrations of sodium, chloride, and silica, it is evident that the degree of contamination of meteoric water by geothermal sources in MW-1 and MW-2 is relatively modest.

MW-2 possesses a greater geothermal component than MW-1 as evidenced by higher sodium, chloride, and silica levels and ratios that are similar to waters from GTW III and Malama Ki, wells that are clearly contaminated by upwelling geothermal fluids. This chemical signature, albeit more dilute, is analogous to the chemistries of the geothermal brines from KS-1A and KS-3. As evidenced by the observed temperature fluctuations, MW-2 is in communication with the ground water south of the rift zone which is in equilibrium with the ocean. These observations indicate that upwelling geothermal fluids are mixing with meteoric waters in the near surface unconfined aquifer beneath MW-2 and the geothermally contaminated ground water flows southerly toward the sea. Similar interpretations were suggested by Iovenitti, 1990, and Thomas, 1987.

MW-1, located north of Puu Honuaula, but more significantly, north of the graben fault that defines the northern boundary of the main geothermal reservoir, exhibits temperature and chemical characteristics that show the well is isolated from the producing reservoir. The higher than normative silica and sulfate concentrations and the elevated fluid temperatures are indicative that the ground water is modified by geothermal mixing but not by the leakage of the highly saline fluid typical of the producing reservoir. The absence of diurnal temperature fluctuations infers that the well is not in communication with the sea. It can be concluded from this evidence that the ground water in MW-1 (and MW-3) probably represents meteoric water sweeping down rift parallel to the PGV geothermal reservoir but isolated from it by intervening dikes.

6 THE GEOTHERMAL SYSTEM

6.1 Temperature

The temperature regime within the PGV project area is characterized by three types of temperature-for-depth profiles (Figure 5). The type represented by the Lanipuna 1 profile exhibits a purely conductive thermal gradient in rock of extremely low permeability from a depth 2000 feet to below 8000 feet. The KS-3 profile exhibits four distinct temperature zones reflecting variations in transmissivity with depth. The 600 to 2000 foot interval is nearly isothermal, confirming vigorous lateral flow of ground water through the area. Below 2000 feet temperature increases moderately to 2750 feet and increases extremely rapidly to a depth of 3000 feet. This zone of rapid temperature increase is a result of the extremely low transmissivity in the interval. From 3000 feet to 5000 feet temperature rises in a series of steps indicating alternating low and moderately permeable rock.

Below 5000 feet the temperature profile follows the boiling point for depth curve. The relatively uniform distribution of temperature within this interval indicates a pervasive, though relatively low transmissivity, which allows convection to take place throughout the interval. This interval defines the low transmissivity geothermal reservoir with production characteristics such as observed in wells KS-3 and KS-1A. The wide distribution and pervasive nature of this reservoir interval is confirmed by testing of KS-1, KS-1A, KS-2, KS-3, and seven years of commercial production from HGP-A. Defining the top of this interval from the static temperature surveys is made difficult by commonly observed interzonal flow in the wellbore under shut-in conditions.

In the KS-8 profile, high temperatures reservoir temperatures at the boiling point are found as much as 2000 feet shallower than in KS-3 and 4000 feet shallower than in Lanipuna 1. The KS-8 profile in Figure 5 is a composite profile made from combining the calculated KS-8 boiling point for depth curve below a depth of 3400 feet with an actual static temperature survey performed prior to drilling into the production zone. The boiling point for depth portion of the profile is based on measurements of down hole pressure and temperature during a period of interzonal flow within the well bore. The profile indicates that a permeable conduit is transmitting reservoir fluid from a depth of at least 7000 feet with no significant heat loss. In order to maintain this temperature, significant mass flow must be taking place vertically, probably along a permeable fracture.

Convergence of the three types of profiles at a depth of 7400 feet below mean sea level indicates that a relatively uniform temperature of approximately 680 degrees F exists over a widespread area within the LERZ.

When temperature profiles are plotted against the geologic section A-A', it becomes evident that the temperature distribution within the PGV resource is highly influenced by permeable vertical fracturing. Temperatures measured in KS-7 and KS-8 define a thermal plume which is constrained laterally by temperature profiles from adjacent wells. This narrow plume serves to confirm the existence of a high transmissivity, near-vertical fracture.

6.2 Pressure

Distinct pressure regimes are evident from the pressure profiles of wells in the project area (Figure 7). At the basal 7000 foot depth level, the horizontal pressure gradient declines from sea water through an intermediate pressure at Lanipuna 1 to a relatively low pressure at KS-3. This supports the geochemical data that sea water is moving into and forms the main recharge for the Puna hydrothermal system.

At depths shallower than 7000 feet, KS-8 pressures rapidly exceed all surrounding pressure regimes. This suggests that fluid moving up the KS-8 fracture is supplying hot fluid to the surrounding rock and supporting the temperature and pressure in the low transmissivity reservoir defined by KS-3 type wells. Only a small temperature drop is observed between the permeable fracture and surrounding low transmissivity reservoir. This is due to the temperature/steam saturation pressure relationship at temperatures above 650 degrees F. For water at the boiling point under the observed reservoir conditions, a large change in pressure result in relatively small temperature change.

The KS-7 pressure profile is a boiling point-for-depth profile calculated from bottom hole conditions measured during drilling. The KS-7 profile is the lowest pressured boiling point-for-depth profile observed in field. This indicates that KS-7 is seeing pressure and temperature support at a relatively shallow depth from the nearby KS-8 fracture, though highly attenuated by intervening low transmissivity rock.

6.3 Hydrothermal Alteration and Mineralization

Two types of hydrothermal mineralization and alteration are observed in the Kapoho State wells: fracture-fill mineral deposits and replacement mineralization. Replacement mineralization is defined as minerals which have been replaced by in situ crystallization of the original basaltic mineral phases and groundmass glass. These minerals include clays, chlorite and disseminated pyrite. Replacement processes reflect changes in thermal conditions with or without the presence of migrating fluids. Fracture-fill mineralization represents the precipitation of mineral phases from migrating geothermal fluids. Fracture-fill minerals occur as massive deposits of very fine-grained material or as euhedral crystals up to millimeter size that infill open voids, such as fractures, vugs, and vesicles in the host rock fabric. Euhedral crystals may grow isolated or as closely packed clusters of crystal aggregates. Fine-grained, massive deposits often infill spaces around drusy crystals, completely cementing shut the pre-existing open spaces in the rock. The dominant fracture-fill minerals observed in the PGV wells are anhydrite, quartz, pyrite, chlorite and epidote. Less common to rare minerals include zeolite, calcite and garnet.

In geothermal systems, distinctive mineral assemblages form in equilibrium with the particular conditions of temperature, pressure, fluid chemistry and volatile chemistry. Stereomicroscope examination of the cuttings by Tecton Geologic mudloggers and PGV staff geologists have identified most of the fracture fill minerals. Four distinctive mineral assemblages are recognized. The highest stratigraphic, lowest temperature assembly consists of amorphous silica (opaline silica and chalcedony) + anhydrite + pyrite $\pm$ clay/chlorite $\pm$ zeolite(s) $\pm$ calcite. A moderate to high temperature assemblage is composed of anhydrite + pyrite + quartz + chlorite $\pm$ garnet $\pm$ chalcopyrite. The highest temperature, deepest stratigraphic assemblage consists of quartz + epidote + chlorite $\pm$ actinolite $\pm$ anhydrite. Quantitative studies of the replacement clay minerals are unavailable because detailed petrographic and petrologic studies of the cuttings from the PGV wells have not yet been undertaken.

A quantitative relationship between reservoir temperatures and these mineral assemblages has not been established due to the

propensity of higher temperature fluids from deep in the reservoir to flow upwards within the well bore and mask the flow from the upper cooler entries. From mineralogical and fluid temperature correlations from other known geothermal fields, the low temperature mineral assembly probably represents reservoir temperatures of 300 - 400 °F, the moderate temperature assembly represents temperatures of 400 - 550 °F, and the high temperature group 550+ °F. Temperatures exceeding 680 °F have been measured in the PGV wells.
A fourth group of minerals and associated textural alteration, that forms only in the presence of subsurface boiling water (Sternfeld and Walters, 1989; Moore et al., 1989) has been encountered in KS-7 and KS-8 near the top of the producing intervals. This mineral assembly consists of calcite + quartz + pyrhhotite + pyrite + anhydrite in a bleached, cellular matrix. Evidence for hydro-brecciation is also observed. These textures and the presence of pyrhhotite is evidence for acid alteration and hydrofracing of the host rock in the presence of high concentrations of gases (especially hydrogen sulfide and carbon dioxide) produced by localized boiling of reservoir fluids. The bleached material was pervasive in cuttings from 1290 to 1678 feet in KS-7. A trace occurrence of this type of material was found in KS-8 between 3320 and 3340 feet M.D.

Joe Moore of UURI conducted a fluid inclusion microthermometry study of crystalline material from KS-7 and determined that the minerals formed at 520+ °F, temperatures that exceed hydrostatic boiling conditions at 1350 -1500 feet M.D. A significant number of vapor-filled fluid inclusions were identified in the crystals, indicating that boiling occurred as the minerals formed. Homogenization temperatures associated with the vapor-filled inclusions averaged 410 °F, indicative of boiling under the present hydrostatic conditions (i.e. water table at 575 feet). These measurements are evidence that superheated, overpressured fluids migrated to shallow depths. Superheating of the host rock under these low hydrostatic and lithostatic pressure conditions caused hydrofracing, boiling and subsequent deposition of the observed mineral suite.

The Puna geothermal resource is a highly fractured reservoir overlying a potent heat source, the secondary magma chamber beneath Puu Honuaula. All the wells drilled in this area, from HGP-A to the PGV wells exhibit a noticeable thermal alteration of the drilled cuttings characterized by replacement of basaltic groundmass glass and mafic minerals by clays minerals and incipient disseminated pyrite beginning at depths of 1,500 to 1,700 feet. Clay alteration of the basalts is pervasive and extensive in the pillow basalts below 4,000 feet.

Above 2,700 feet, there is minor, very sporadic evidence for fluid migration and deposition of low temperature fracture-fill minerals, with the exception of KS-7. Between 3,000 feet and 4,000 feet, corresponding to the Hyaloclastite unit, there are distinctive thin intervals of fracture-fill minerals that correlate with fluid bearing fractures in HGP-A, KS-1A, KS-3, and KS-8. These producing zones, with the exception of KS-8, are relatively low temperature (<450 °F). Within the submarine basalt interval, 4,000 feet to 7,000 feet, narrow zones of fracture-fill mineralization, with and without clear evidence for fluid entries, are encountered in HGP-A, KS-1A, KS-1, KS-2 and KS-3. These producing fractures are apparently restricted to fractured pillow basalts and pillow breccias as hydrothermal alteration of dike rocks is rare or absent in the cores from the 3 SOH holes. Mineralization of the pillow breccias range from anhydrite + quartz + chlorite to epidote + quartz + actinolite. In the deeper sections of the PGV wells, there is little or no evidence for secondary mineralization in the dike-dominated lithologies.

KS-7 is a unique case. Unlike adjacent wells, the cuttings originating at 1,000 feet were pervasively altered to clays and disseminated pyrite with minor occurrences of drusy anhydrite and quartz. Between 1390 feet 1640 feet, the host rock was intensely altered by acid leaching. At depths greater than 1450 feet, up to 20 % of the cuttings samples was composed of large euhedral crystals of anhydrite, quartz and pyrite. As described above, this alteration assemblage is indicative of very shallow high temperature fluids. It provided evidence that a major up flow zone exists beneath KS-7 and not beneath the 1955 eruption fissure as originally thought by Puna Geothermal geologists.

The capacity for rapid self sealing of fractures was evidenced during the KS-8 uncontrolled flow event. Rapid buildup of anhydrite-silica scale in the annulus between the well bore and drill collars resulted in partial sealing of cross flow from the bottom of the well to a permeable zone at the casing shoe. This scaling mechanism may be prevalent in the natural system in limiting and sealing breaches in the reservoir cap rock, thereby curtailing leakage of high pressure fluid in the KS-8 fracture into the shallow ground water. The sealing is not complete, however, as evidence by contamination of the ground by geothermal reservoir fluid (See Section 5).

6.4 Transmissivity

Two distinct transmissivity regimes have been identified to date in the PGV reservoir. The more widely distributed type is a low transmissivity reservoir which appears to be pervasive and volumetrically extensive below a depth of about 5000 feet. This type of transmissivity has been characterized by the flow testing of KS-1, KS-2, KS-1A, and KS-3 and by seven years of continuous production of HGP-A. In contrast, the production zone encountered by KS-8 represents a much higher transmissivity regime. The apparent high transmissivity in KS-8 has not been encountered in any other well within the high temperature resource area.

Pressure and temperature data gathered during flow testing of KS-1A, KS-3, and HGP-A indicate that reservoir fluid in the vicinity of the well bore throughout the production interval is two-phase during production. This reservoir production characteristic makes measurement of transmissivity by normal drawdown and buildup methods very difficult. However, sufficient buildup data was acquired after the KS-3 flow test to allow an estimate of transmissivity (Harrison, April 1991). The pressure buildup was measured at a depth of 5000 feet which helped to reduce temperature transient and well bore storage effects. The calculated transmissivity was approximately 1000 md-ft.

By normal geothermal standards a transmissivity of 1000 md-ft would yield a non-productive well. However, during production of the KS-3 type reservoir, the pressure in the well bore is controlled by a near vapor static pressure gradient due to the extremely high resource temperature. This results in a pressure drop of approximately 2000 psi between the reservoir and the well bore. This very large pressure gradient produces commercial quantities of two-phase flow in the range of 70 to 90 thousand pounds per hour (kph).

The estimated flow rate and down hole pressure and temperature measurements made during the KS-8 uncontrolled flow event indicate that KS-8 penetrated a much higher transmissivity zone than observed in the KS-3 type reservoir (Harrison, August 1991). The estimated flow rate potential of more than 400 kph and the observed low pressure drop during flow indicate that transmissivity in the KS-8 fracture is at least an order of magnitude higher than the KS-3 value. The high transmissivity zone, which has only been encountered in KS-8, appears to be associated with a single fracture with very limited lateral extent (See Section 6.1 and 6.2)

6.5 A Conceptual Hydrogeologic Model

The hydrogeologic model derived from the geologic data discussed above is shown schematically superimposed on the cross section A-A' in Figure 9. The main features of the conceptual model are as follows:

* The basal pressure within the hydrothermal system is controlled by cold sea water at a depths below 6400 feet MSL. Both sea water and cold meteoric water hydrostatic pressures exceed the pressure in the geothermal reservoir below that depth. Both types of water, therefore, tend to migrate laterally into the base of the reservoir thereby providing a mixed meteoric/sea water recharge.

* High temperatures in the range of 680 to 700 oF are generated in the center of the PGV resource area by an intense heat source associated with ongoing magmatic activity within the LERZ dike complex.

* Discrete high transmissivity fractures created by the tensional stress field overlying the dike complex allow heated fluid to migrate upward to relatively shallow depths.

* Leakage from the fractures takes place laterally into the surrounding low transmissivity reservoir and vertically into the shallow ground water system.

* Sufficient vertical mass flow is maintained in the fracture to allow high temperatures to propagate to depths as shallow as 1600 feet below the surface. High basal level pressures are propagated vertically within the fracture due to the very low density of the geothermal fluid at elevated temperatures. Temperature and pressure propagates vertically in the fracture along the boiling point for depth curve.

* Above the cap rock, pressure and temperature rapidly dissipate, laterally away from the fracture, due to the movement of massive volumes of cold ground water through the shallow aquifers.

* Pressures within the fracture exceed the cold water hydrostatic gradient at shallow depths, allowing geothermal fluid to flow into the shallow aquifer. Upward migration of hot fluids and subsequent contact with cold ground water effects the deposition of a self-sealing mineralized cap. Sudden and catastrophic breaching of the mineralized cap results in boiling within the fracture. Boiling causes rapid mineral deposition resulting in resealing of the fractures in the cap rock layer, thereby making the leakage a self limiting process.

* Below a depth of 4000 feet, pressures decrease significantly away from the fracture due to the relatively low transmissivity of the surrounding rock. However, pressures remain sufficiently high within the low transmissivity reservoir to exceed the normal hydrostatic gradient. Temperatures decline only slightly, moving laterally away from the fracture, into the low transmissivity host rock.

* A cap rock in the 2750-4000 foot depth interval prevents dissipation of pressure in the low transmissivity reservoir.

* High transmissivity fractures on the periphery of the system form a conduit for the downward migration of cold water into the low transmissivity reservoir. Depth of penetration of the permeable fractures allows for sufficient hydrostatic head to develop in the cold down flow to overcome the pressure in the low transmissivity reservoir. Once down flow is established, it will tend to be self sustaining. The same mechanism is observed during the cold water kill operations for wells drilled into the low transmissivity reservoir.

* Cold ground water sweeping from north to south across the LERZ is contaminated by leakage from the deep reservoir along fractures penetrating the cap rock. Relatively high salinities and temperatures are observed in the shallow ground water down-gradient from the points of leakage.

7 PRODUCTION WELL SITING

7.1 Initial Targeting Strategy.

The production target zone for KS-3, the first production well drilled by PGV, was sited based on drilling results and flow testing of KS-1 and KS-1A (Figure 4). The bottom hole location was targeted to penetrate a significant lost circulation zone that had been encountered in KS-1 at a depth of 7290 feet. A well spacing of 250 feet horizontal and 1000 feet vertical was planned between the bottom hole locations of KS-3 and KS-1A. At the time of drilling KS-3, KS-1A was scheduled for rework as a producer. The planned bottom hole spacing was considered to be adequate to prevent excessive pressure interference.

The drilling and well testing results from KS-3 confirmed the validity of the targeting strategy. Test results defined the characteristics and commercial viability of the low transmissivity reservoir. The distribution of commercially productive wells KS-3, KS-2, and HGP-A blocked out a 2000 foot by 3000 foot target zone which is likely to contain KS-3 type reservoir characteristics throughout. The resultant well siting strategy for production at the time of completion and testing of KS-3 was to drill directionally from Pad A and E in a radial pattern to cover the blocked-out low transmissivity reservoir.

7.2 KS-8 Target

The KS-8 target was developed based on drilling results from KS-7. KS-7 was targeted to intersect high angle fractures that had surface expression along the southern boundary of the property. This was done in an attempt to duplicate conditions of high transmissivity and low temperature encountered in Lanipuna 6 located along strike with the KS-7 bottom hole target location.

Unexpectedly, KS-7 encountered a high temperature, high pressure zone at 1688 feet. This zone was the first indication in the PGV resource area that reservoir pressure and temperature conditions were locally propagating to relatively shallow depths. Drilling of KS-7 was suspended because the high pressure zone was not suitable for injection and well design was not appropriate for completion as a producer. Injection data during the drilling of KS-7 indicated that permeability was low and that the fracture feeding the zone was in close proximity to the well bore but had not actually been penetrated.

Utilizing geologic data gathered from KS-7, a new target was established for KS-8. The target was based on the assumption that a high transmissivity, vertical fracture was very close to the KS-7 well bore. The strike of the fracture was assumed to be the N 63 E strike of the LERZ. KS-8 was targeted to intersect the suspected vertical fracture at a depth of 4600 feet. At this depth the fracture would be either a viable injection or production target. KS-8 was drilled as an injection well but a casing design was used to allow for conversion to production. At approximately 3400 feet, KS-8 encountered a high temperature, high pressure zone with apparent high transmissivity. The fracture geometry derived from the KS-8 drilling results is described in Section 4 and Sections 6.1 and 6.2.

7.3 Stepout Drilling from the KS-8 Target

The apparent high productivity of KS-8 confirms the KS-8 fracture as the new priority production target. The new target was established based on the following assumptions:

* The fracture is planar and dips 85 degrees N.

* The fracture strikes N 63 E parallel to the LERZ and intersects KS-8 at 3488 feet. (A suspected intersection at 3340 feet does not substantially affect the fracture geometry).

* The fracture is highly permeable to a depth of 7000 to 8000 feet and along strike for at least 1000 feet to the SW.

The bottom hole location of the proposed KS-11 production well is a target based on this fracture geometry (Figure 4). The well is expected to intersect the KS-8 fracture at a depth of 5000 feet. At this depth the high reservoir pressure should be readily controllable by well bore hydrostatic head, thus mitigating the problem of unexpected kicks such as those that occurred in KS-7 and KS-8. Other proposed wells including KS-4, KS-9, KS-10, KS-12, and KS-13 are located such that the KS-8 target fracture can be readily reached.

The long term producibility of the KS-8 target cannot be predicted based on available data. The pressure decline during long term production will be dependent primarily on the fracture length and depth of penetration. If the fracture is of very small dimensions, productivity will decline over time to a base level approaching that of the KS-3 type reservoir. The effect of fracture length will be modelled using the PGV numerical simulator and a range of possible decline rates can be established. The model will be refined as production effects on reservoir characteristics are observed.

8 INJECTION WELL SITING

8.1 Initial Targeting Strategy

As noted in Section 7, the KS-7 target was based on intersecting suspected permeable fractures along the southern boundary of the property (Figure 4). The target area was never approached by either KS-7 or KS-8, due to shallow intersection with high pressure zones. The original KS-7 injection target was at a depth of 5000 feet at a distance of 100 feet from the southern property boundary. This injection target cannot be pursued further because of permitting constraints. The target cannot be reached from currently permitted well pads without penetrating high pressure, high temperature zones . In order to avoid the high pressure fracture underlying Pad D and F, a well pad would have to be located directly above the target. This would be in violation of permitted limits of the drilling activities standoff from property boundaries.

8.2 KS-3 and KS-1A Target

As part of the well test program for KS-3 and KS-1A, injection tests were performed. These injection tests indicated that injectivity in the low transmissivity KS-3 type reservoir would result in injection capacities in the 200 to 300 kph range. Spinner surveys indicate that most injection was taking place below a depth of 6000 feet. Though significantly lower than the value anticipated for the KS-7 target, this injectivity is adequate for use during commercial power plant operation.

Based on the anticipated injection conditions of the original KS-7 target, only one injection well would be required for full power plant injection capacity. One additional injection well would provide 100% backup capacity. Injection based on KS-3 characteristics will require at least two injection wells to maintain full plant capacity and one backup well to provide redundancy.

The KS-3 type injection target can be readily accessed from any of the seven well locations on Pad A and E. The flexibility of targeting from these pads will allow adequate spacing of injection well bottom hole locations and maintenance of adequate distance between the injection and production zones.

8.3 Use of Other Wells Within and Contiguous to the PGV Property

8.3.1 KS-2

KS-2, located on Pad B, exhibits similar production characteristics to those of KS-1A and KS-3. It is assumed that injectivity would be sufficient to warrant use of the well as an injector. The well will require rework operations and testing before it can be permitted and placed in service as an injector. However, because the well is located approximately 60 feet above the power plant level, engineering and operational difficulties with handling the injection stream may preclude use of KS-2 as an injector.

8.3.2 HGP-A

HGP-A probably has injection capabilities similar to KS-3. The well could be a viable injector though considerable rework of the well would be required. The well is currently completed with cemented 9-5/8" casing to a depth of 2300 feet. An additional cemented casing string to a depth of at least 3500 feet would be required to meet permit requirements. Prior to installing a 7 inch cemented casing string, the existing 7 inch slotted liner would have to be removed. PGV experience in reworking uncemented liners that have been exposed to reservoir conditions indicate that this type of operation entails a high risk of failure.

8.3.3 Other Existing Wells

Two additional deep wells, Lanipuna 1 and Lanipuna 6, are located near the PGV project site. Because these wells are not within the permitted boundaries of the project and are not owned by PGV, they are not considered in the discussion of injection well alternatives.

8.4 Non-Condensible Gas and Thermal Breakthrough

Non-condensible gas breakthrough from injection to production zones can lead to a rapid decline in power plant efficiency and can swamp gas handling facilities. This is not likely to occur under PGV reservoir and power cycle conditions. Non-condensible gases liberated during the power cycle are injected and redissolved into the power plant injectate stream. Because no net loss of geothermal fluid takes place in the production cycle, relatively high concentrations of non-condensables can not accumulate. Injection into the KS-3 type reservoir returns the injectate to a pressure regime in which the gas will be highly undersaturated. Under these conditions, gas bubble evolution is not possible. Even in the event that injectate is recycled to the production zone, no increase in non-condensible gas content will take place because no mechanism of concentration is active either at the surface or within the reservoir.

Thermal breakthrough is also not considered probable under PGV reservoir conditions. Injection zones are located 1000 to 2000 feet below production zones and laterally displaced by 750 to 1000 feet. The density contrast between the injectate and the reservoir fluid will cause the denser injectate to sink, thereby remaining below the shallower production zones. Also the low transmissivity and extremely fine and diffuse fracture network within the KS-3 type injection zone will insure good dispersion of fluid and very low fluid migration velocities.

In the unlikely event that either non-condensible gas or thermal breakthrough does become a problem, alternative injection well sites are currently available. Injection targets can be reached from Pad E that will increase the distance between injection and production zones to as much as 2500 feet.

8.5 Production Zone Pressure Support

PGV reservoir characteristics as currently understood indicate that pressure support by injection will not be a critical factor in maintaining production capacity. Under natural state conditions the reservoir fluid is in the liquid phase despite the extreme reservoir temperatures. This provides evidence that deep recharge from sea and meteoric water is adequate to prevent drying out of the reservoir (See Section 6.5 and Figure 9). Significant mass flow takes place from the reservoir into the shallow ground water system as described in Section 5. The total mass removal from the reservoir by production will be approximately 1200 gpm. This is probably a small fraction of the natural loss rate from the reservoir and will therefore not have a significant impact on the overall reservoir pressure. The 7 year production history of HGP-A serves to confirm this view.

9 LIST OF FIGURES

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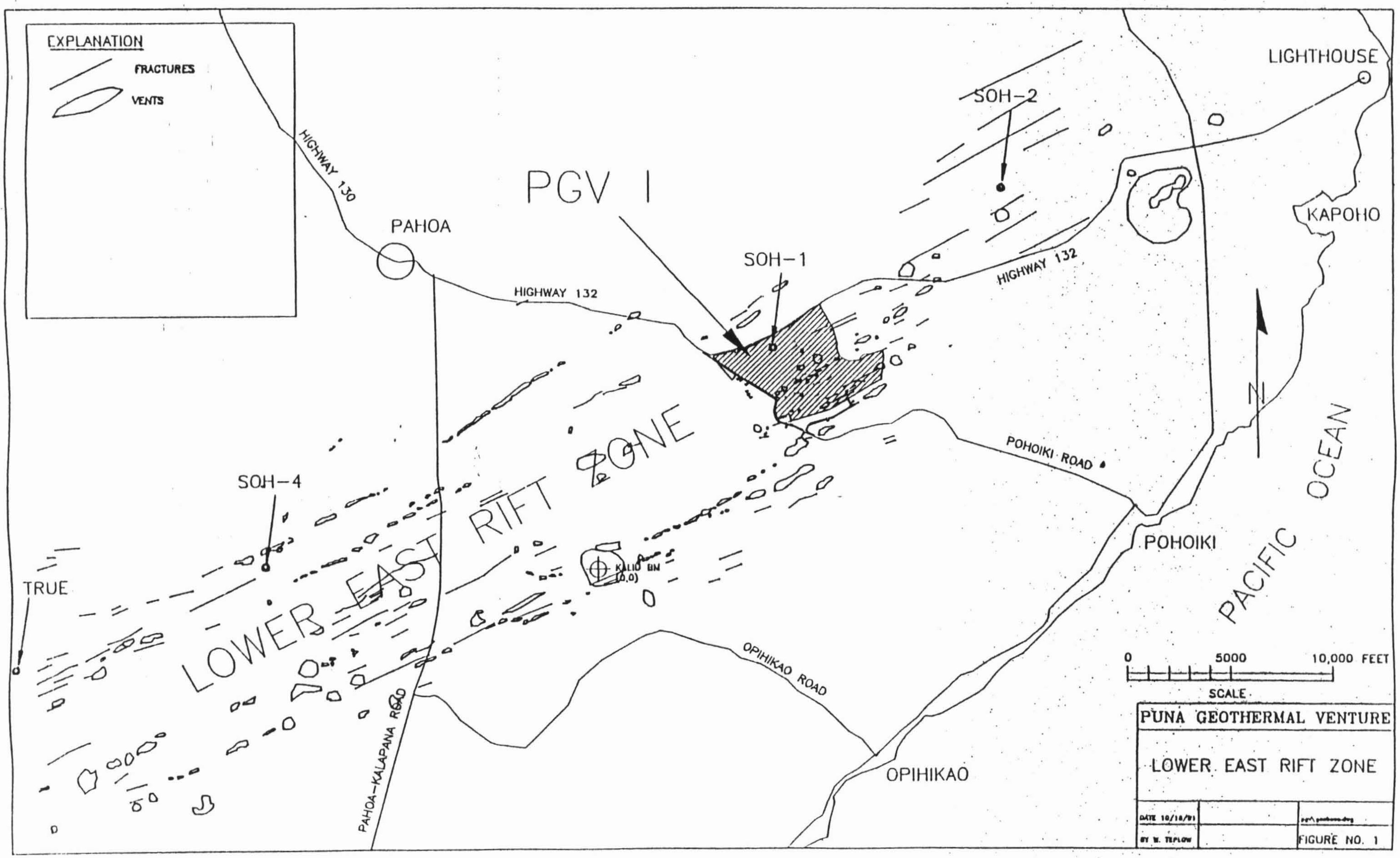
TABLE 1

SHALLOW GROUNDWATER CHEMISTRIES

	Pahoa (1991)	Kapoho (1991)	MW-1 (1991)	MW-2 (1991)	GTW III (1991)	Malama Ki (1991)
Sodium	16.0	86.0	41.2	320.0	2430.0	2420.0
Potassium	*2.3	7.0	12.0	19.7	238.0	142.0
Magnesium	3.0	30.0	11.9	15.9	167.0	210.0
Calcium	4.0	53.0	23.1	25.2	197.0	128.0
Silica	55.0	54.0	102.0	34.6	234.0	120.0
Alkalinity	*44.0	*61.0	29.0	52.0	34.0	*215.0
Chlorides	5.0	116.0	19.5	563.0	5225.0	5000.0
Sulfates	*21.0	*65.4	184.0	82.8	620.0	*681.0
Total Dissolved Solids	125	533	480	1170	10200	8880
pH	7.91	7.35	7.7	8.5	7.7	7.11
	*1960	*1961				*1960



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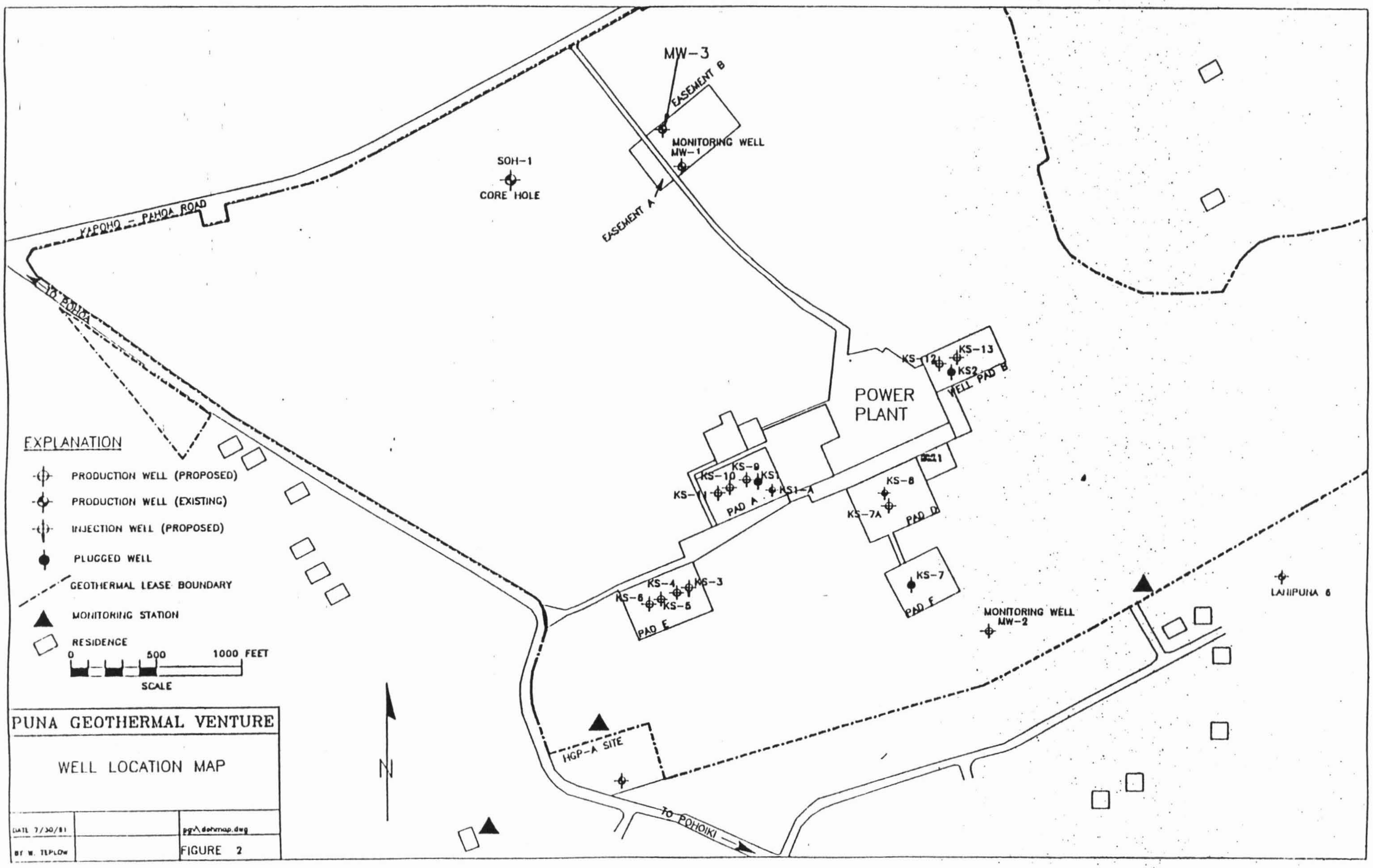

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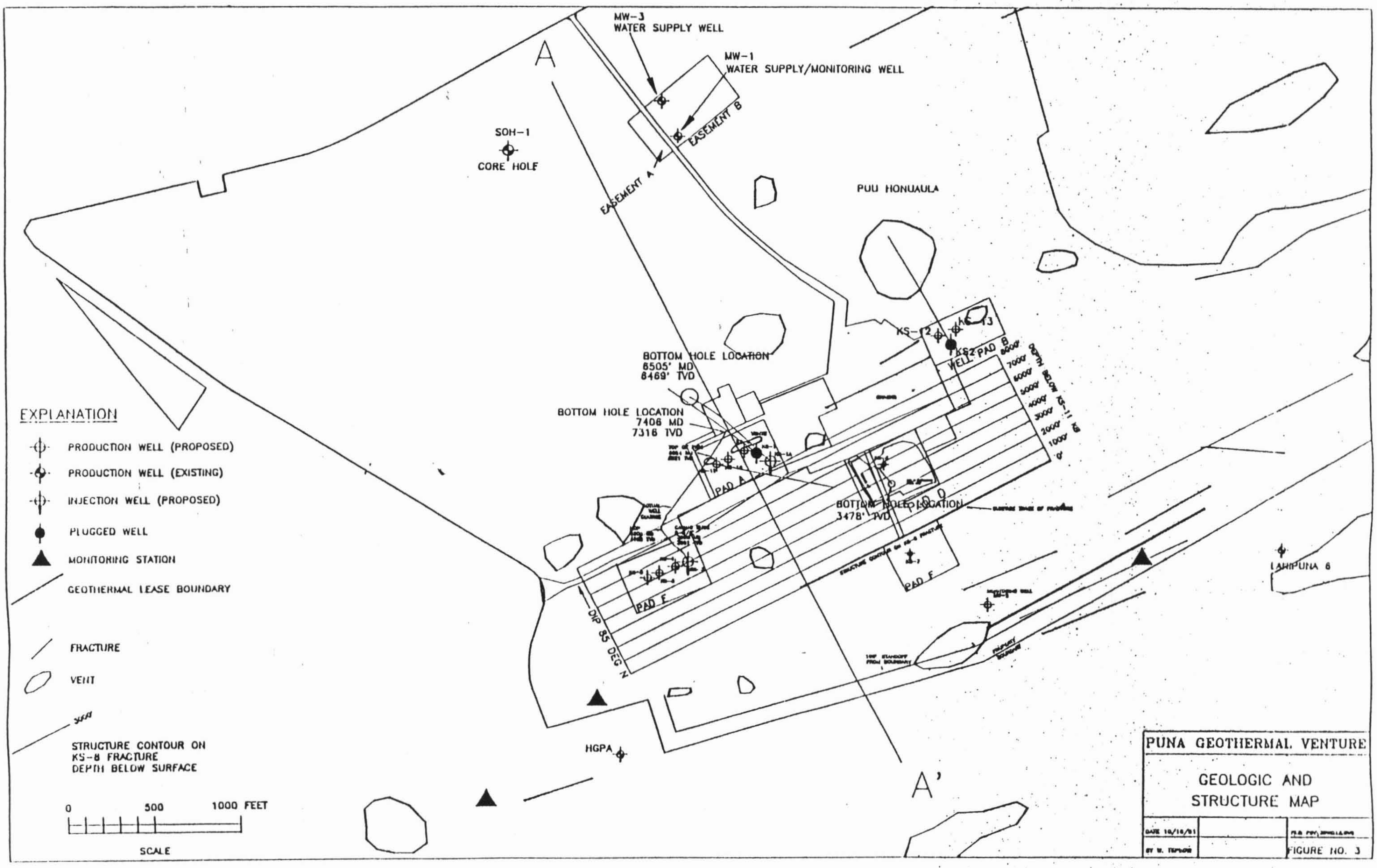

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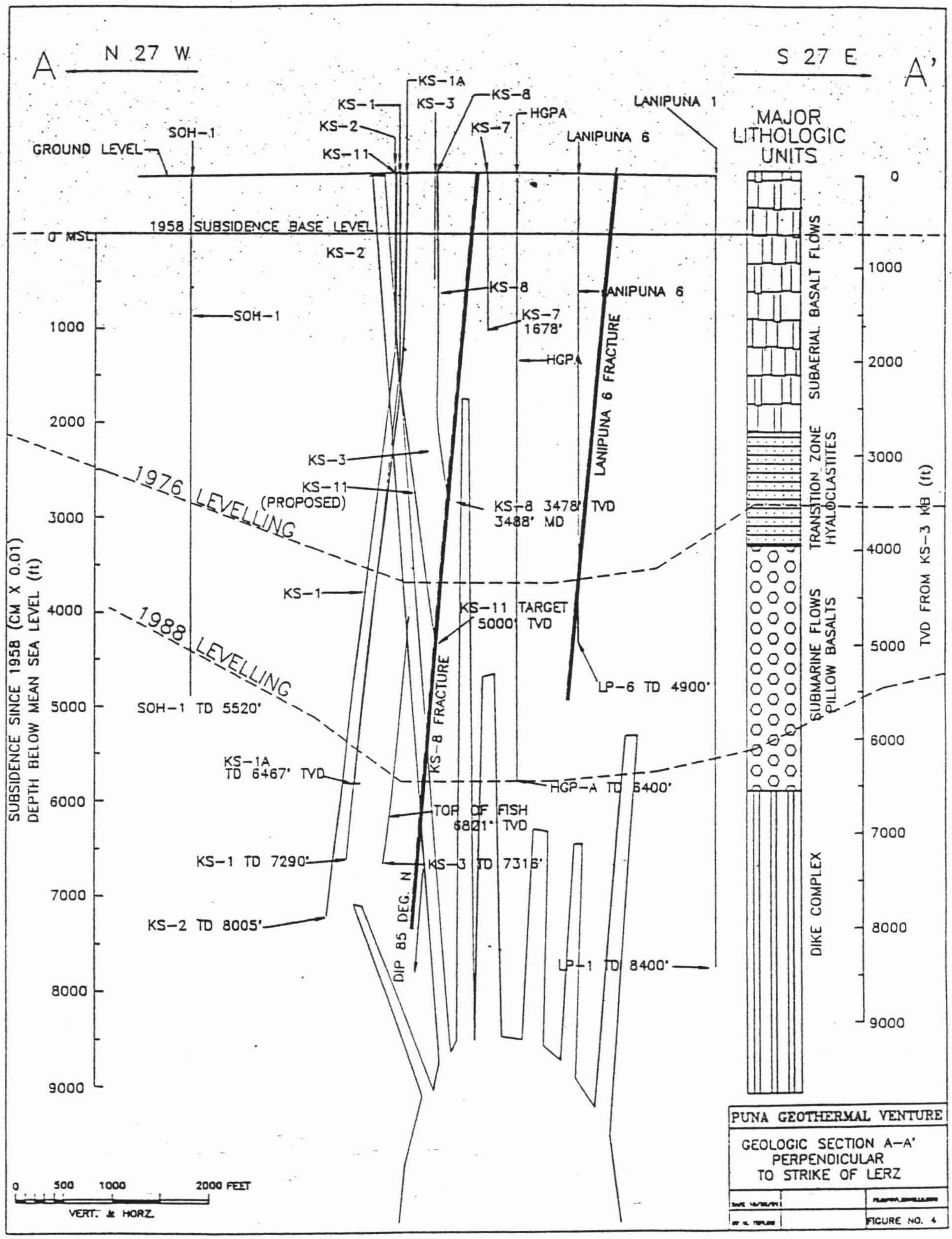
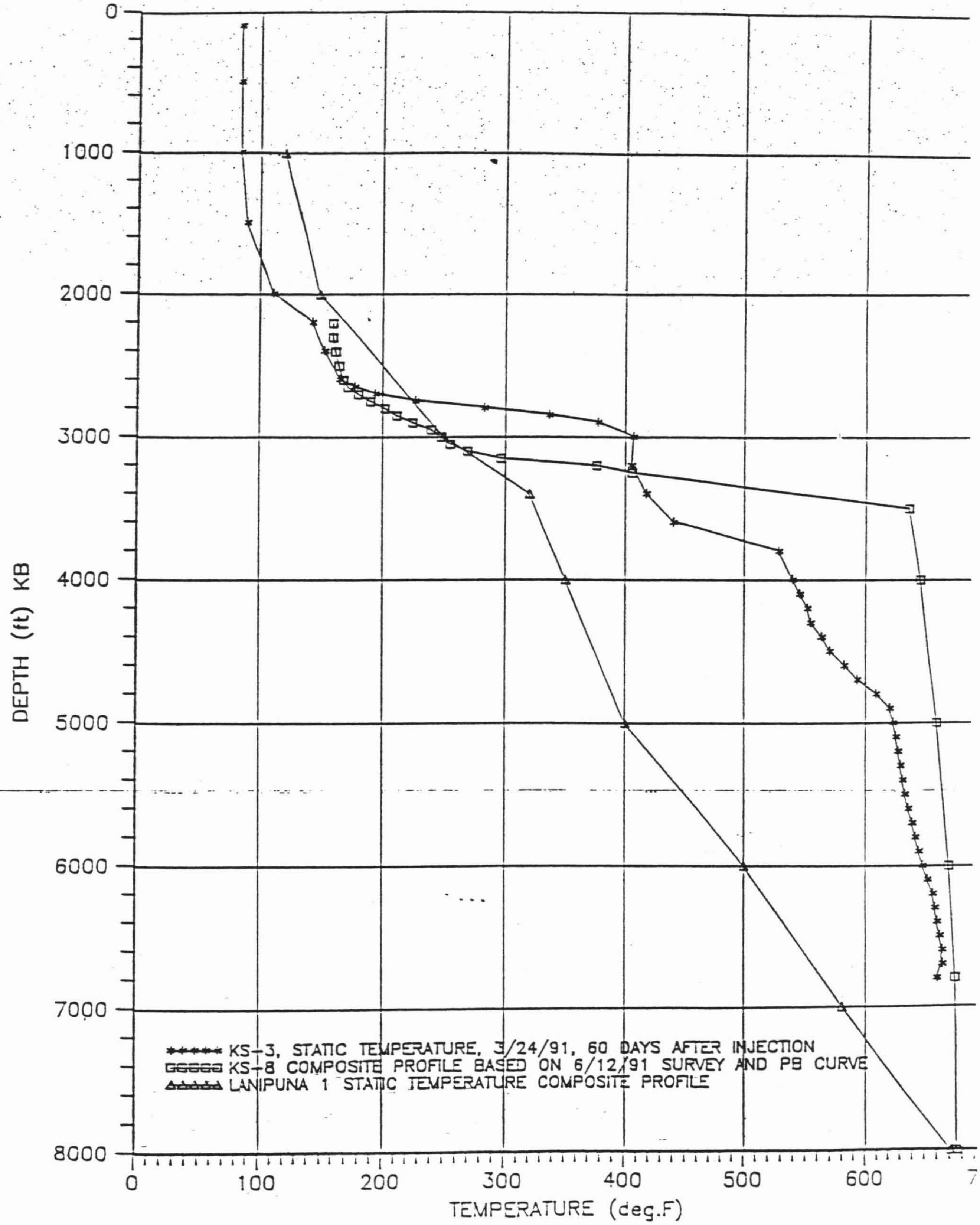
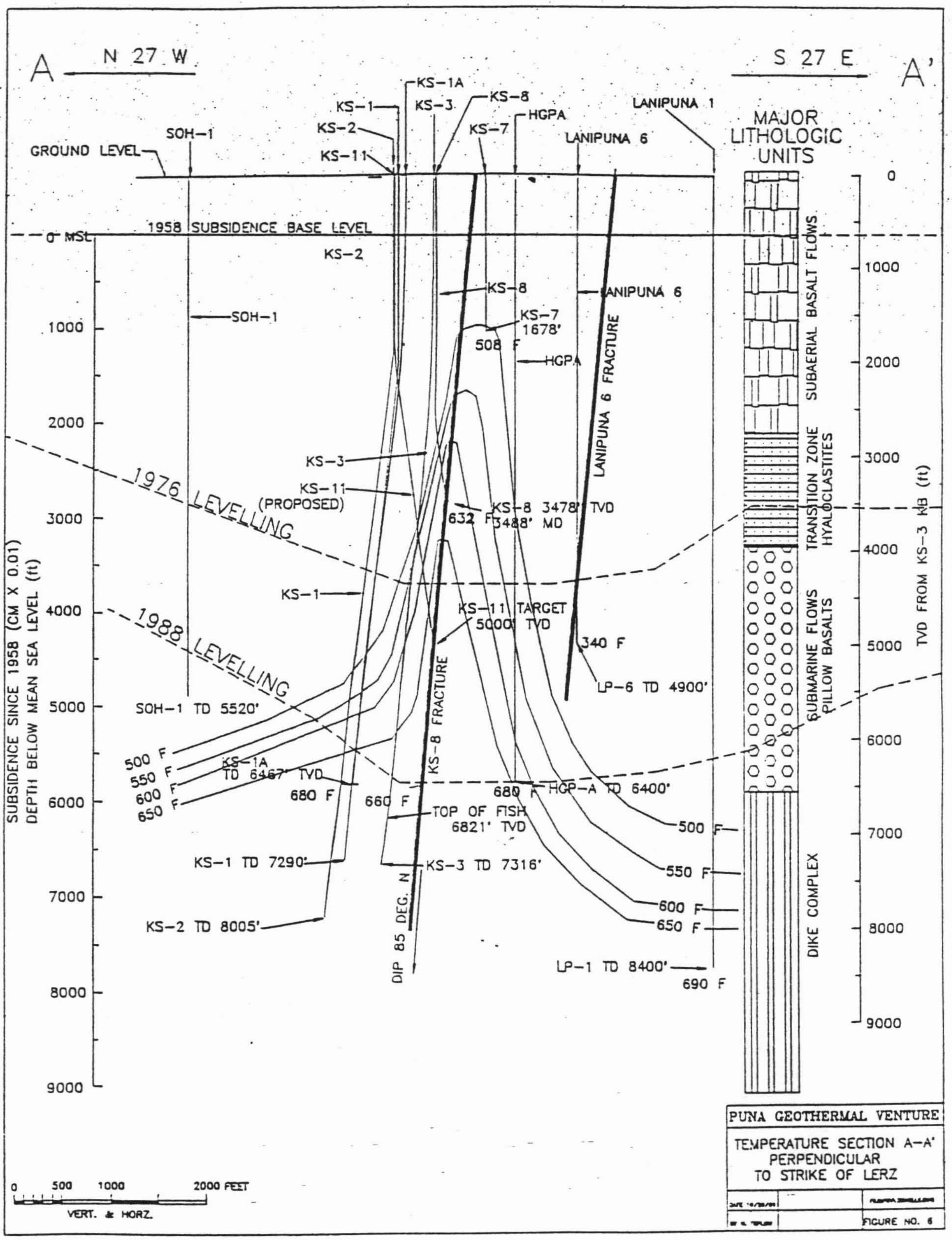


TEMPERATURE PROFILES KS−3, KS−8, AND LANIPUNA 1



FIGURE


A N 27 W
S 27 E A'
KS-1A
KS-1
KS-3
KS-8
KS-2
KS-7
HGPA
LANIPUNA 1
LANIPUNA 6
SOH-1
GROUND LEVEL
KS-11
MAJOR LITHOLOGIC UNITS
0 MSL
1958 SUBSIDENCE BASE LEVEL
KS-2
KS-8
LANIPUNA 6
SOH-1
KS-7 1678'
508 F
HGPA
LANIPUNA 6 FRACTURE
KS-3
KS-11 (PROPOSED)
1976 LEVELLING
632 F
KS-8 3478' TVD 3488' MD
KS-1
KS-11 TARGET 5000' TVD
340 F
1988 LEVELLING
LP-6 TD 4900'
SOH-1 TD 5520'
KS-8 FRACTURE
500 F
550 F
600 F
650 F
KS-1A TD 6467' TVD
680 F
660 F
680 F
HGP-A TD 6400'
TOP OF FISH 6821' TVD
500 F
KS-1 TD 7290'
KS-3 TD 7316'
550 F
600 F
650 F
KS-2 TD 8005'
DIP 85 DEG. N
LP-1 TD 8400'
690 F
SUBSIDENCE SINCE 1958 (CM X 0.01)
DEPTH BELOW MEAN SEA LEVEL (ft)
1000
2000
3000
4000
5000
6000
7000
8000
9000
SUBAERIAL BASALT FLOWS
TRANSITION ZONE HYALOCLASTITES
SUBMARINE FLOWS PILLOW BASALTS
DIKE COMPLEX
TVD FROM KS-3 KB (ft)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
0 500 1000 2000 FEET
VERT. & HORZ.
PUNA GEOTHERMAL VENTURE
TEMPERATURE SECTION A-A' PERPENDICULAR TO STRIKE OF LERZ
FIGURE NO. 6

DEEP PRESSURE PROFILES LOWER EAST RIFT ZONE

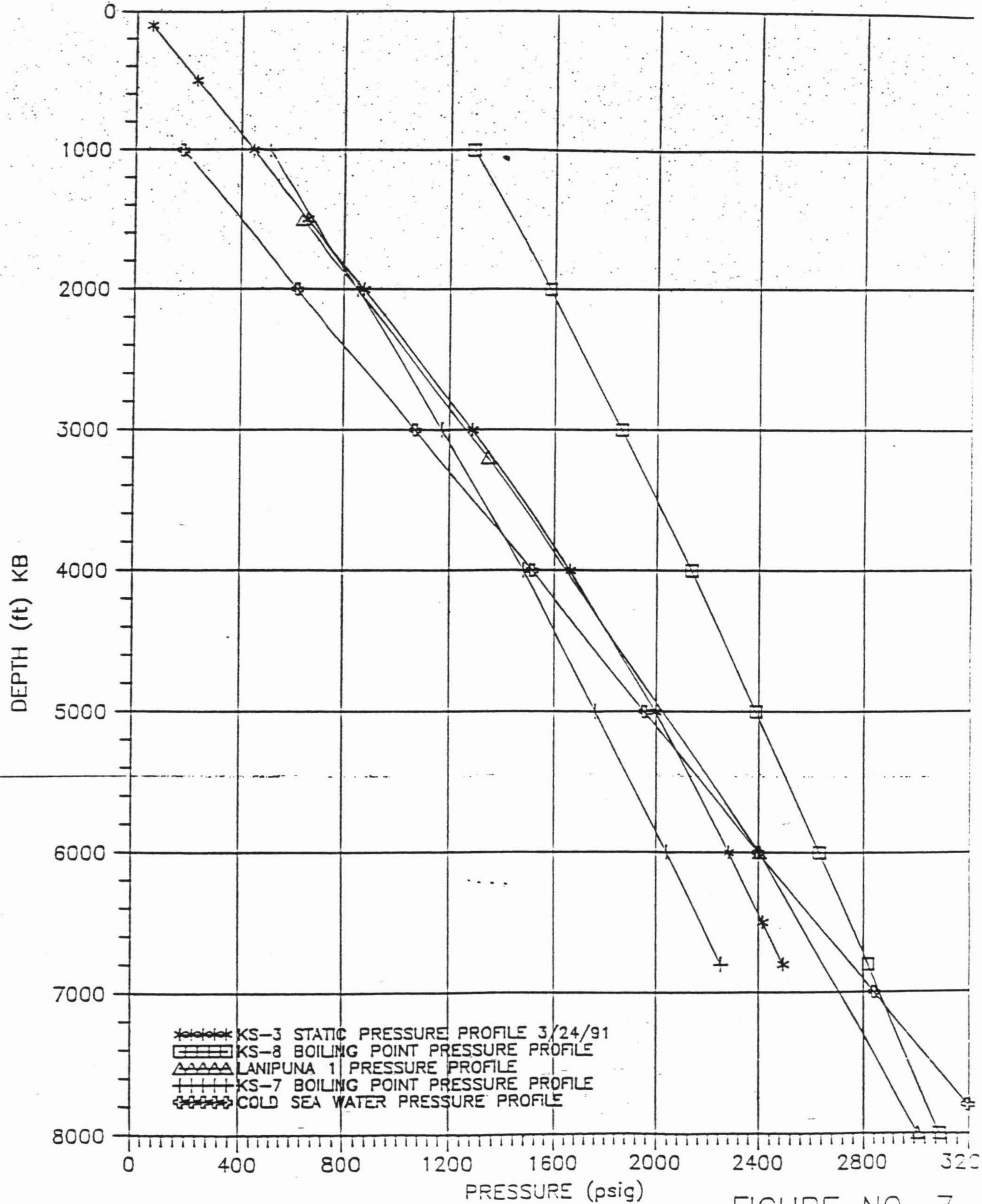
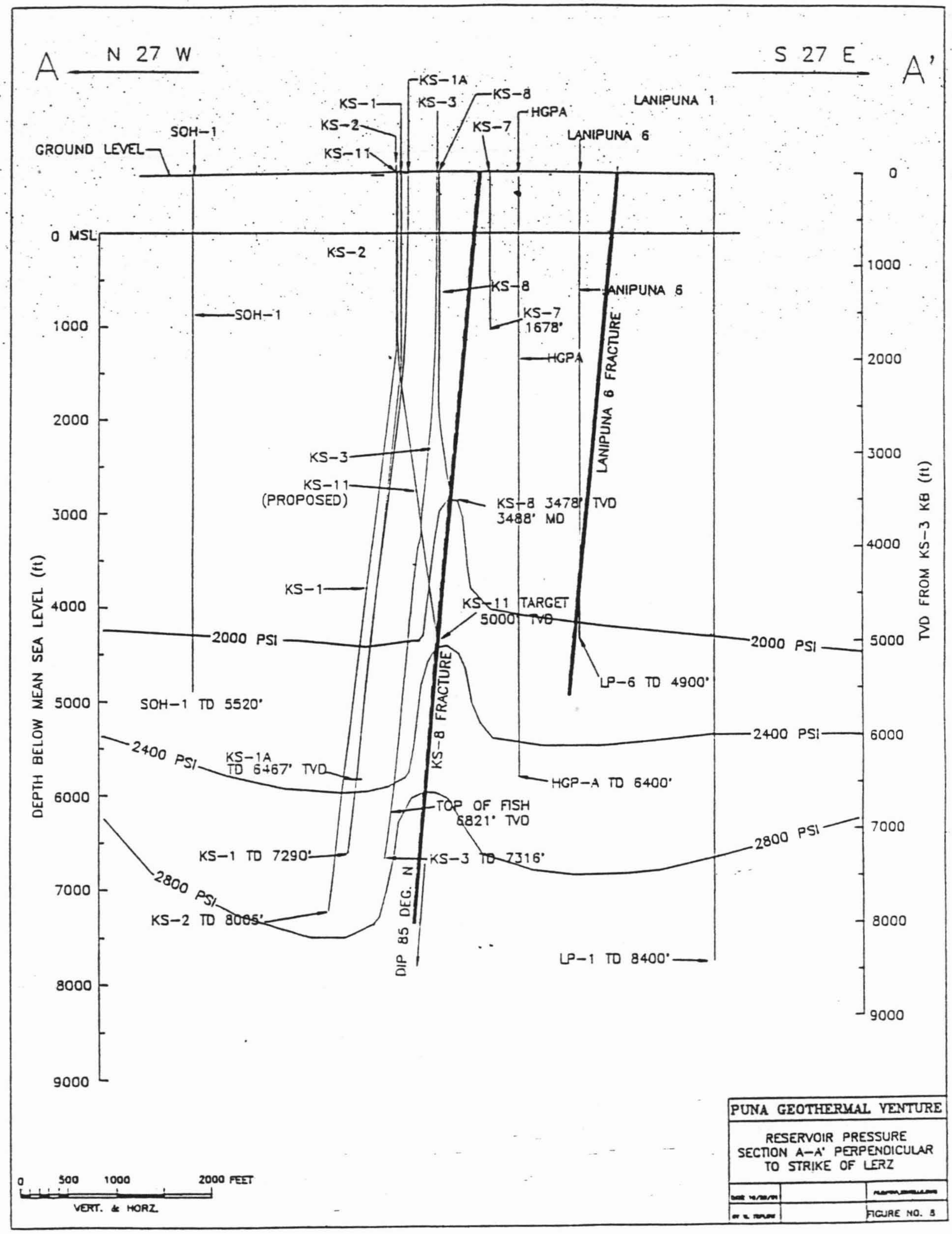
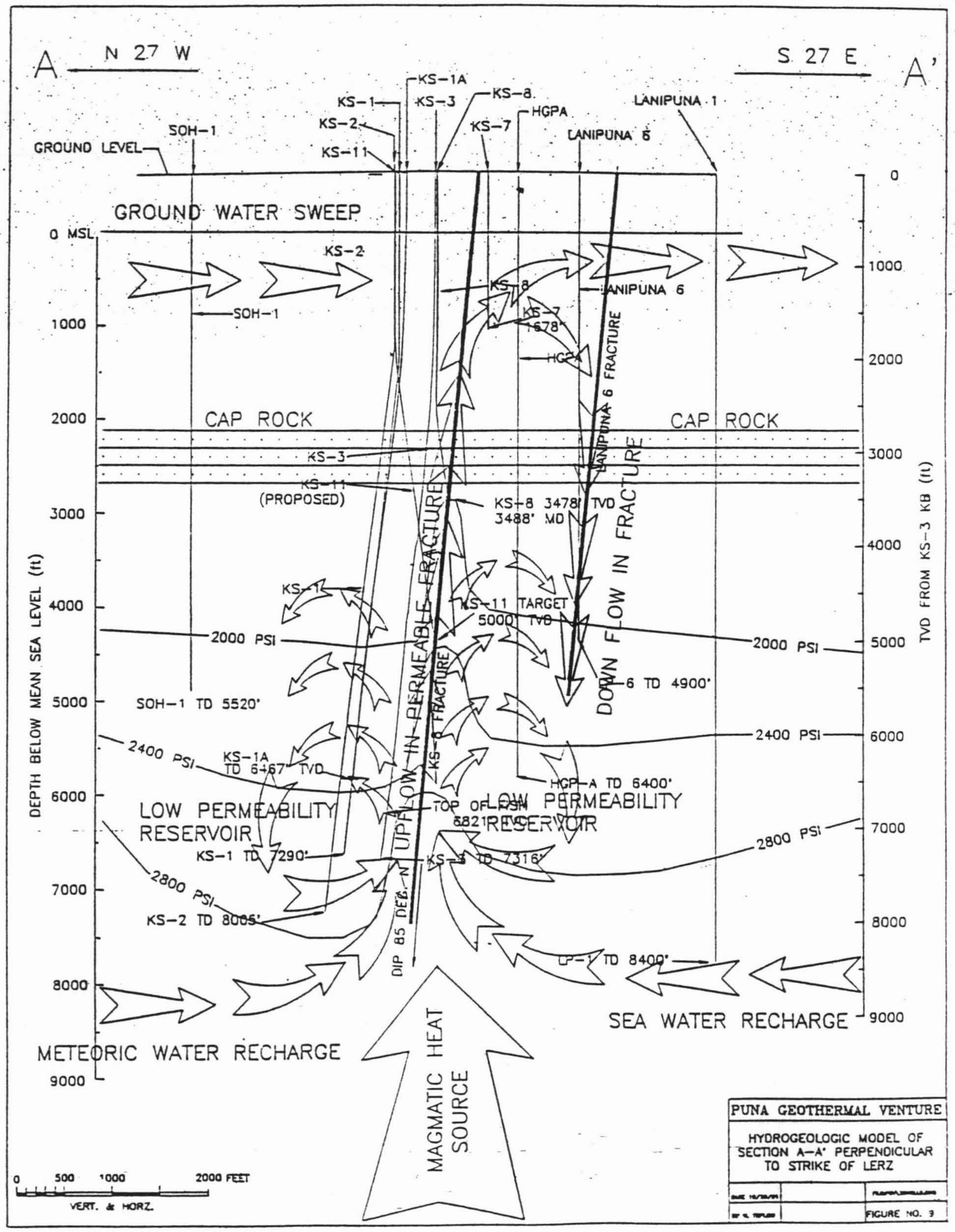


FIGURE NO. 7

CONFIDENTIAL

ATTACHMENT A




A
N 27 W
S 27 E
A'
KS-1A
KS-1
KS-3
KS-8
HGPA
LANIPUNA 1
KS-2
KS-7
SOH-1
LANIPUNA 6
GROUND LEVEL
KS-11
GROUND WATER SWEEP
0 MSL
KS-2
KS-8
LANIPUNA 6
SOH-1
KS-7
HGPA
LANIPUNA 6 FRACTURE
CAP ROCK
CAP ROCK
KS-3
KS-11
(PROPOSED)
KS-8 3478' TVD
3488' MD
UPFLOW IN PERMEABLE FRACTURE
DOWN FLOW IN FRACTURE
KS-1
KS-11 TARGET
5000' TVD
2000 PSI
2000 PSI
KS-8 FRACTURE
-6 TD 4900'
SOH-1 TD 5520'
2400 PSI
2400 PSI
KS-1A
TD 6467' TVD
HGP-A TD 6400'
LOW PERMEABILITY
RESERVOIR
LOW PERMEABILITY
RESERVOIR
TOP OF FSM
6821'
KS-1 TD 7290'
KS-3 TD 7316'
2800 PSI
2800 PSI
KS-2 TD 8005'
DIP 85 DEG. N
LP-1 TD 8400'
SEA WATER RECHARGE
METEORIC WATER RECHARGE
MAGMATIC HEAT SOURCE
DEPTH BELOW MEAN SEA LEVEL (ft)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
TVD FROM KS-3 KB (ft)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
0 500 1000 2000 FEET
VERT. & HORZ.
PUNA GEOTHERMAL VENTURE
HYDROGEOLOGIC MODEL OF SECTION A-A' PERPENDICULAR TO STRIKE OF LERZ
FIGURE NO. 3