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PRELIMINARY RESULTS AND STATUS REPORT OF THE HAWAIIAN SCIENTIFIC OBSERVATION HOLE PROGRAM

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ABSTRACT

The Hawaii Natural Energy Institute (HNEI), an institute within the School of Ocean and Earth Science and Technology, at the University of Hawaii at Manoa has drilled three Scientific Observation Holes (SOH) in the Kilauea East Rift Zone to assess the geothermal potential of the Big Island of Hawaii, and to stimulate private development of the resource. The first hole drilled, SOH-4, reached a depth of 2,000 meters and recorded a bottom hole temperature of 306°C. Although evidence of fossil reservoir conditions were encountered, no zones with obvious reservoir potential were found. The second hole, SOH-1, was drilled to a depth of 1,684 meters, recorded a bottom hole temperature of 206.1°C and effectively defined the northern limit of the Hawaii Geothermal Project-Abbott - Puna Geothermal Venture (HGP-A/PGV) reservoir. The final hole, SOH-2, was drilled to a depth of 2,073 meters, recorded a bottom hole temperature of 350.5°C and has sufficient indicated permeability to be designated as a potential "discovery". The SOH program was also highly successful in developing slim hole drilling techniques and establishing subsurface geological conditions.

INTRODUCTION

The Hawaiian Islands are located above a geologic "hot spot" in the earth's mantle that has been volcanically active over the past 70 million years. The Big Island of Hawaii has an obvious, large potential for geothermal energy resources, both for electrical generation and direct utilization. Since the drilling of the HGP-A well in 1976 and the discovery of the HGP-A/PGV geothermal reservoir along the eastern portion of the Kilauea East Rift Zone, geothermal power potential on the Big Island has been estimated to be in the range of 500 to 700 megawatts (Thomas 1987).

The Hawaii Deep Water Cable Program, which was initiated in 1981 by the Hawaiian and Federal Governments to explore the technical, environmental and financial dimensions of a cable system to transmit geothermally generated electricity from the Big Island to the load center on Oahu, was based on the assumption that the estimated reservoir size was realistic. However, at the time the estimate was made, no wells had been drilled outside the area adjacent to the HGP-A well, and the reservoir potential of the Kilauea East Rift Zone was essentially unknown, and certainly not proven. Further exploration and definition of the HGP-A/PGV reservoir area by subsequent developers did little to indicate reservoir potential beyond the immediate area. Although several production wells have been drilled recently on

Puna Geothermal Venture (PGV) property, approximately one quarter mile to the north of the HGP-A well, these wells have not had extensive flow testing, and currently, the only reservoir with a "known" or "proven" production capability is that tapped by the HGP-A well. Similarly, the discovery that has been reported by the True/Mid-Pacific Geothermal Venture on property owned by the Estate of James Campbell approximately seven miles to the west of the HGP-A well, has not had sufficient drilling or flow testing to classify the discovery as "proven".

The Scientific Observation Hole (SOH) program was planned and implemented in 1988 by the Hawaii Natural Energy Institute, an institute within the School of Ocean and Earth Science and Technology, at the University of Hawaii at Manoa. The SOH program was initially funded to drill four SOHs to a nominal depth of 1,200 meters (4,000 feet), to test the geological condition and the geothermal potential within Geothermal Resource Subzones (GRZ) along the Kilauea East Rift Zone, and to drill two holes in the Haleakala Southwest Rift Zone on the island of Maui. These holes were designed to assess the geothermal potential of these two areas by providing a general knowledge of rock types, alteration, and structures within the rift zones, the depth to potential geothermal reservoirs, the depth and composition of ground water, and the temperature of rock and fluids at depth. Although the SOHs are for scientific observation and monitoring purposes only and are prohibited by the terms of their permits from flow testing or production, flow capability of production sized wells can be estimated using injection techniques.

Initial attempts to permit the two SOHs on the island of Maui met with such intense local opposition, that the two holes scheduled to be drilled in the Haleakala Southwest Rift Zone were withdrawn from further consideration during the initial phase of the program. Experience during the drilling of the first hole in the Kilauea East Rift Zone caused further extensive modification of the drilling plan by increasing the targeted drilling depth from 1,200 meters (4,000 feet) to 2,000 meters (6,500 feet). Because of this and difficult drilling conditions resulting in increased drilling costs, the scope of the program was consequently modified to provide fewer, but deeper holes.

The SOH program specifically meets the University of Hawaii's stated mission of providing scientific and technology transfer to the private sector for utilization and commercialization and has provided a stimulus for private development of Hawaii's geothermal resources. To date, after the completion of three holes, effective

techniques have been devised to drill slim, rotary and core holes to depth in excess of 2,070 meters (6,800 feet), and has:

- established subsurface thermal continuity along the Kilauea East Rift Zone,
- defined the shallow limits of the northern boundary of the HGP-A/PGV reservoir, and
- discovered a potential geothermal reservoir in a previously untested area.

Present plans call for the permitting and drilling of additional SOHs in Phase II of the program in other areas of geothermal potential, not only on the Big Island and Maui, but also on Lanai and Oahu if sufficient interest and funds are available. Areas of geothermal potential on the Big Island and Maui are shown on Figure 1. If the SOHs are successful in locating or indicating additional geothermal reservoirs, the program will expand Hawaii's geothermal resource base not only for electrical generation potential, but also for direct utilization in such fields as food and materials processing, brine handling and utilization, agriculture, aquaculture, geothermal spas, and other uses involving the heat of the earth.

The SOH program has been described in more detail by Olson (1988), Olson, et al. (1990a) and Olson, et al. (1990b).

STATUS OF DEVELOPER ACTIVITY AND THE SOH PROGRAM

As of this date, PGV has drilled three geothermal wells in fallow sugar cane fields and papaya orchards on agricultural land near a residential development in the Kapoho GRZ. The first well drilled (KS-3) intersected a steam zone, which probably will not be produced due to chemical problems. The second well (KS-7) unexpectedly intersected a very shallow production zone and had to be abandoned. The third well (KS-8) also intersected the shallow production zone and will probably become an important producer. As of the end of 1991, PGV essentially had completed construction of its 25 megawatt (net) power plant, and was planning an operational test of the plant utilizing steam generated in boilers using county water. However, as of the writing of this paper the County of Hawaii had imposed a geothermal drilling moratorium which is currently in effect at the PGV project due to an accidental, uncontrolled venting of steam from the KS-8 well. Nevertheless, if the moratorium is lifted shortly, as expected, the power plant could be producing power for the Big Island as soon as PGV can complete the number of wells necessary to supply steam to the power plant.

True/Mid Pacific Geothermal Venture (T/MPGV) has drilled a well with three kick-offs in forested, conservation land within the Kilauea Middle East Rift GRZ. On the last kick off, True intersected a steam zone and, after a short flow test, announced a discovery. However, no details of the producibility of the well are currently known. The T/MPGV group is currently planning to drill a second well, but as of the writing of this paper had not prepared the site for drilling.

The objectives of the SOH program as stated in the enabling legislation are to stimulate geothermal development and to confirm the geothermal resources of Hawaii. The first goal of stimulating geothermal

development has been met, as two developers, PGV and T/MPGV are currently involved in exploration and development along the Kilauea East Rift Zone.

In spite of the unfavorable permitting, regulatory and business environment, and intense local opposition to geothermal development, the second goal of the SOH program has been partially met in that the SOH program has assessed a portion of the Kilauea East Rift Zone in which the active geothermal developers are operating. The program has been an outstanding success to date in developing effective drilling techniques, reducing drilling expenses, providing deep geologic sections along the area of interest, establishing thermal continuity within the KERZ, defining limits to the HGP-A/PGV reservoir, and discovering a potential reservoir in an untested area.

To date three of the four permitted SOHs have been drilled. The location of the SOHs, the GRZs, and the production wells drilled by PGV and T/MPGV are shown on Figure 2. Although all the necessary permits have been approved for SOH-3, the State of Hawaii has decided to defer the drilling of SOH-3 until additional SOHs are permitted with provisions to allow pumping or flow testing of the holes to obtain fluid groundwater and reservoir samples.

SOH-4

The first hole drilled, SOH-4, was drilled to a total depth of 2,000 meters (6,562 feet), and recorded a bottom hole temperature of 306.1°C (583°F). Although evidence of fossil reservoir conditions were found, no zones with obvious reservoir permeability were encountered. No problems were encountered in core drilling the upper section of subaerial basalt flows and dikes. However, severe rotary drilling problems with lost circulation and reaming were encountered in the upper 610 meters (2,000 feet) of the hole, resulting in large overruns in drilling costs. These problems were solved by slowly and carefully drilling blind for 50 to 100 meters (150 to 300 feet) through lost circulation zones instead of cementing whenever circulation was lost, by using thin cement mixtures to regain circulation, and opening the core hole with rotary tools to the final hole size in one pass instead of two. After casing was set and cemented, core drilling proceeded with only minor problems to the bottom of the hole in a heated section of submarine basalts. At a depth of approximately 1,200 meters (4,000 feet) State officials decided to deepen the hole to a depth of approximately 2,000 meters (6,500 feet) because temperatures of 200°C (400°F) or higher had not been recorded during drilling. At this time, the other scheduled SOHs also were targeted to depths of approximately 1,825 to 2,000 meters (6,000 to 6,500 feet). Total direct drilling costs for SOH-4 were \$1,404,805, or \$702.40 per meter (\$214.08 per foot). Drilling performance is shown graphically for depth versus cost for all the SOHs in Figure 3, and for depth versus time for all the SOHs in Figure 4. The temperature gradient of SOH-4 and the other SOHs are shown in Figure 5. Interestingly enough, SOH-4 was initially considered to be a "failure" by State officials because the bottom hole temperature was not as high as the 358°C (676°F) encountered in the HGP-A well, because of the large cost overrun, as compared to the cost estimated for the original 1,200 meter (4,000 foot) depth planned for the hole, and because the hole did not

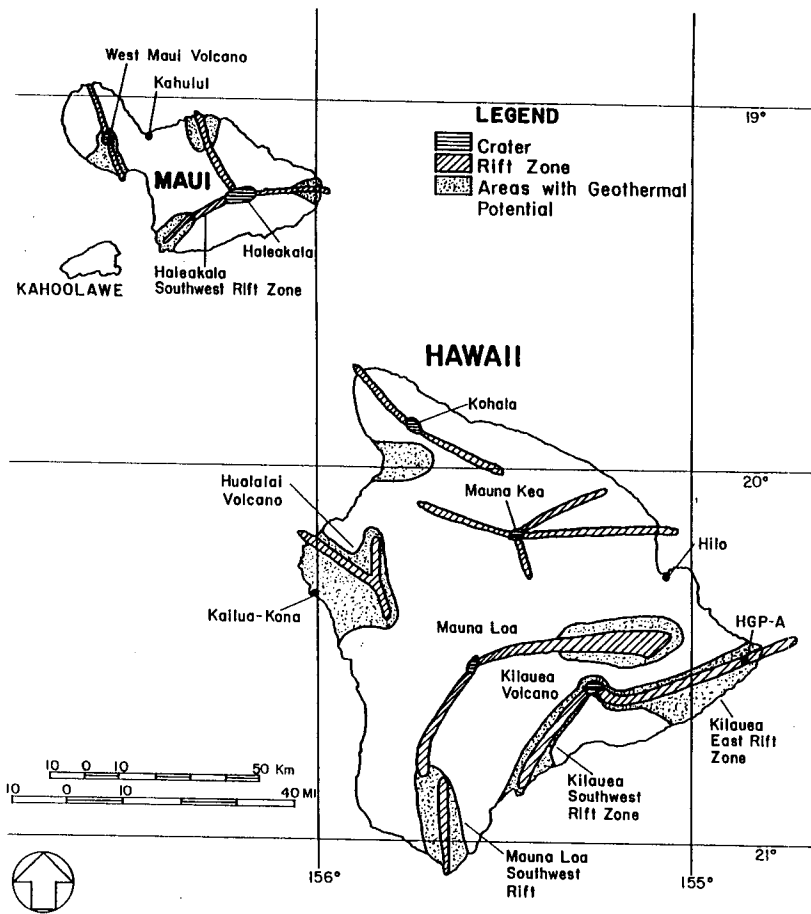


Fig. 1 Volcanic features and areas with geothermal potential on Maui and Hawaii (Source: Geothermal Resources of Hawaii, 1983)

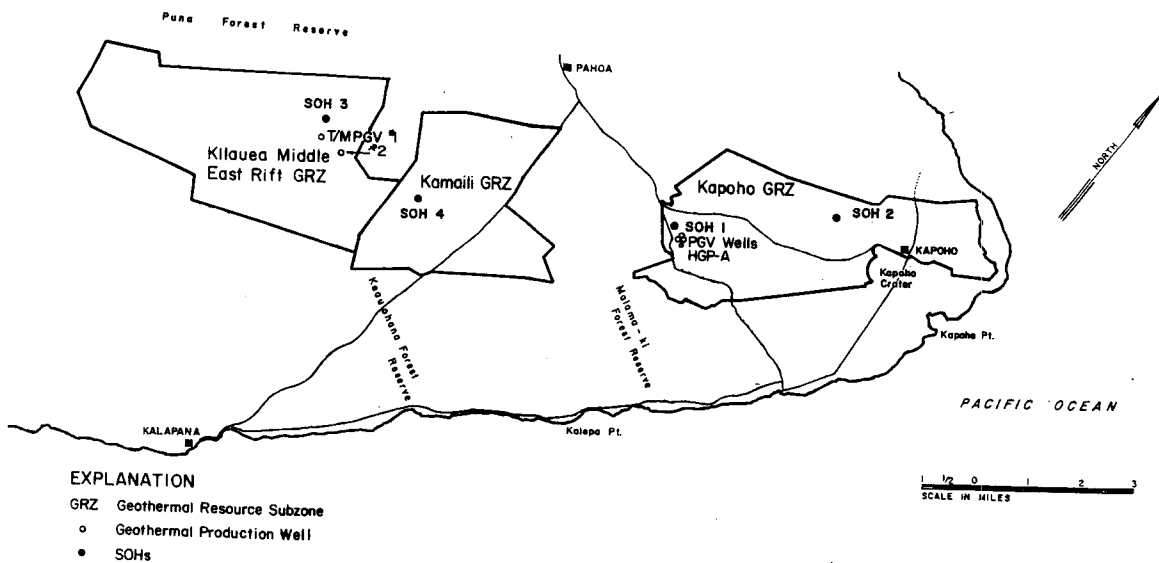


Fig. 2 Location of SOHs on the Big Island

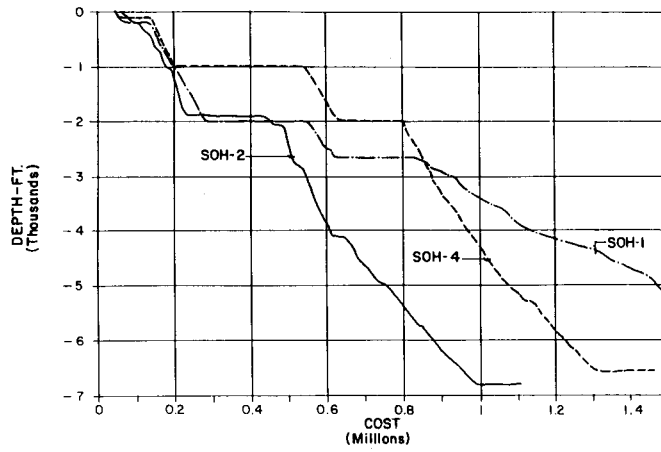


Fig. 3 SOH drilling performance depth vs. cost

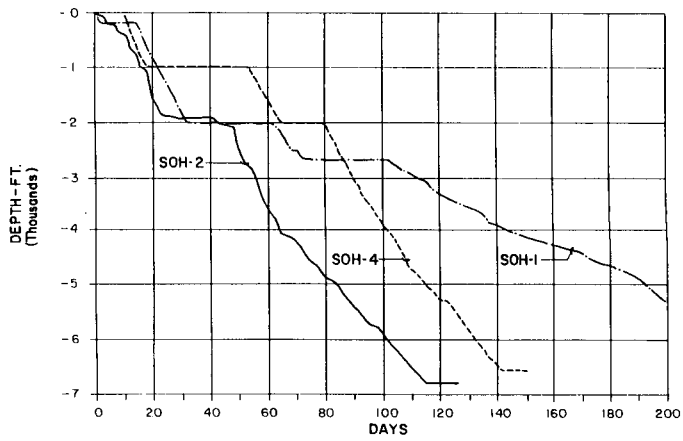


Fig. 4 SOH drilling performance depth vs. time

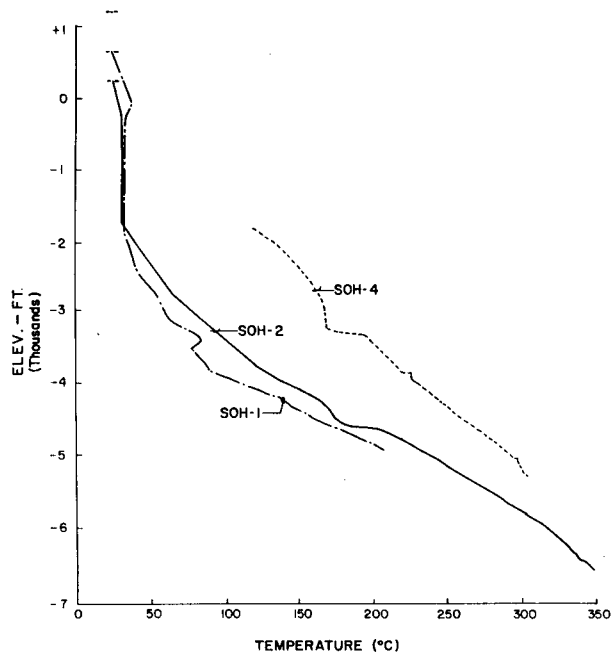


Fig. 5 SOH temperature vs. elevation

encounter a reservoir. This resulted in renewed efforts to educate the officials to the realities of drilling economics, programmatic goals, and expected results.

SOH-1

The second hole, SOH-1, was drilled to a total depth of 1,684 meters (5,526 feet) and recorded a bottom hole temperature of 206.1°C (403°F). The drilling and casing plan for the upper 610 meters (2,000 feet) was modified, utilizing the experience gained in the drilling of SOH-4, by omitting the initial 305 meters of 9-5/8 inch casing and using 7 inch casing from the surface to a depth of 610 meters (2,000 feet). This resulted in rapid progress with essentially no drilling problems and cost savings of approximately \$240,000 as compared to SOH-4 at a similar depth. When coring resumed below the casing, however, very severe drilling problems were encountered due to highly fractured, cool (<38°C or <100°F), submarine basalt, sands, and dikes, in the interval between 610 and 1,370 meters (2,000 to 4,500 feet), resulting in short bit life, short (15 to 45 centimeters or 6 to 18 inches) core runs, stuck drill rods and massive cost overruns. The fractured submarine basalt and dikes broke off in small fragments around and in front of the bit and rolled about the drilling surfaces, wearing the bit face matrix and gouging out the diamonds. The exterior gauge of the bits was reduced and the interior gauge enlarged resulting in short core runs which stuck in the core barrel, and resulted in the necessity of redrilling the hole to reach bottom. Core life averaged between 3 and 6 meters (10 to 20 feet), resulting in constant tripping of the rods to replace bits and causing the driller to "affectionately" refer to this interval as the "hole from hell". Below 1,370 meters (4,500 feet) the temperature increased rapidly, resulting in normal drilling runs, core recovery of nearly 100%, and long bit life, due to fracture filling or bonding of the fractures by thermal metamorphism. Total drilling costs were \$1,562,647 or \$927.76 per meter (\$282.78 per foot), causing the hole to be stopped approximately 300 meters (975 feet) short of its targeted depth.

SOH-2

The third hole, SOH-2, was drilled to a total depth of 2,073 meters (6,802 feet) and recorded a bottom hole temperature of 350.5°C (663°F). The drilling and casing plan was again modified to incorporate the lessons learned in the drilling of the first two holes. To reduce drilling costs, the upper 580 meters (1,900 feet) of the SOH was rotary drilled with no coring. Casing was set approximately 30 meters (100 feet) higher in SOH-2 than in the other two SOHs because of a sudden 4° deviation in the hole in an 8.2 meter (27 foot) interval between a depth of 567 to 575 meters (1,860 to 1,887 feet), which resulted in several drill collar twist offs and fishing jobs. After the casing was set, coring was attempted with unsatisfactory results similar to those encountered in SOH-1. At that time a decision was made not to attempt to fight the hole down by coring, and the hole, subsequently, was rotary drilled to approximately 1,250 meters (4,100 feet). As circulation was lost at the surface, only a few scattered rock samples were collected in the upper rotary portion of the hole. However, the dogleg caused by the sudden hole deviation, persisted through the casing and drilling continued to be plagued by repeated twist offs to the bottom of the hole. Luckily all the twist offs occurred inside the casing and fishing,

although time consuming and costly, did not result in major delays or loss of the hole. Temperature at a depth of 1,250 meters (4,100 feet) was 132.7°C (270.9°F) which was sufficient to bond the fractured submarine basalts (or the section previously had been subjected to higher temperatures with the same results), and coring proceeded rapidly and smoothly to the bottom of the hole. Subsequent injection testing indicated that a permeable interval between 1,488.3 and 1,505.7 meters (4,883 to 4,940 feet) with a temperature of 210.3°C (410.5°F) can be designated as a possible "discovery". Additional drilling in the vicinity of SOH-2 should intersect fracture permeability below a depth of 1,825 meters (6,000 feet) with fluid temperatures in excess of 300°C (572°F). Total drilling costs were \$1,098,760 or \$530.03 per meter (\$161.53 per foot), which represented a savings of greater than \$300,000 while drilling 73 meters (240 feet) deeper than SOH-4, and greater than \$460,000 while drilling 389 meters (1,276 feet) deeper than SOH-1.

Analysis of the drilling results indicates that the key to reducing costs involves more than drilling faster. Over the long run, staying out of trouble usually results in faster penetration rates and lower drilling costs. Consequently, after the experience with the twist offs in SOH-2, a decision was made to core drill the subaerial basalts and then open the hole by rotary drilling, which results in a straight hole and more data, rather than to attempt to reduce costs by not coring and running the risk of twist offs and possible loss of the hole.

PRELIMINARY SOH PROGRAM RESULTS

Very preliminary results from SOH program indicate that:

- Core (slim) holes can be successfully drilled to depths in excess of 2,070 meters (6,800 feet) and can be used to assess geothermal resource potential at substantial savings in drilling and permitting costs and environmental impact. Initial drilling results indicate that SOHs can be most efficiently drilled by a combination of rotary and core drilling techniques.
- It has not been possible to collect uncontaminated groundwater or reservoir fluids in the SOHs in a cost effective manner by bailing. To obtain reliable samples the holes must either be pumped or flowed. As groundwater and reservoir fluid chemistry is vital to the assessment of the geothermal potential of an area, future SOHs will be permitted to allow the sampling of downhole fluids by pumping or flowing.
- The geothermal potential of the Kilauea East Rift Zone has not been proven and additional production and assessment drilling must be completed before an accurate estimate of the size of the resource can be made.
- A single large geothermal reservoir (or several large reservoirs) probably does not exist along the KERZ. The geology of the geothermal reservoirs that do exist is probably highly complex and the reservoirs may be relatively small and discontinuous. SOH-1 essentially defined the northern boundary of the HGP-A/PGV reservoir, which has produced between 2 and 3 megawatts of electrical power with a plant factor of greater than 90% for over 7-1/2

years. Utilizing published data from HGP-A, the KS wells drilled by Thermal Power in the early 1980s, and SOH-1, reservoir conditions at a depth of 1,250 meters (4,100 feet) and a cutoff boundary of 200°C (392°F) indicate a narrow, easterly dipping resource approximately 800 meters (2,600 feet) wide that is open to the west, as shown in Figure 6. This isotherm map does not reflect the shallow reservoir intersected by PGV's KS-7 and KS-8 wells. Sufficient published data are not available to predict the vertical size and extent of the reservoir.

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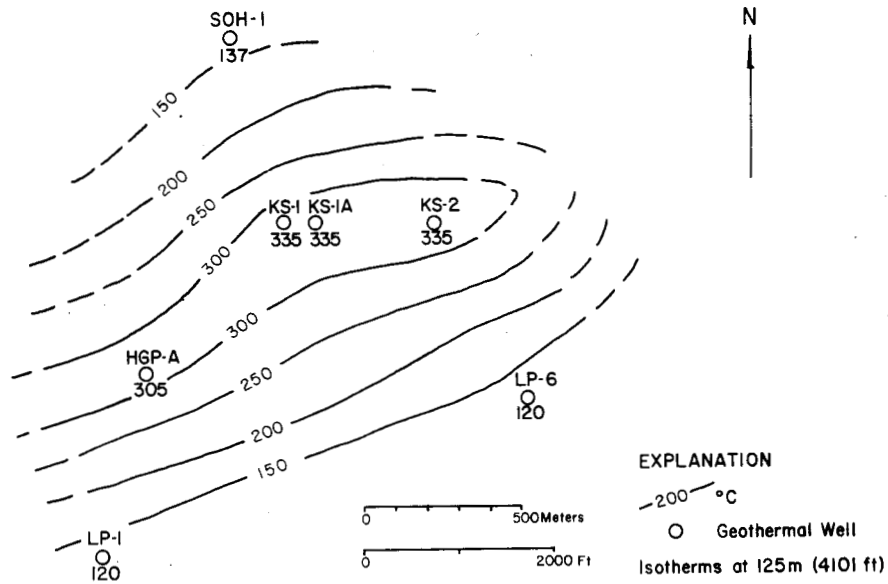


Fig. 6 HGP-A-PGV geothermal reservoir