SUMMARY OF RESULTS OF HGP-A WELL TESTING

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The experimental well, HGP-A, drilled under the auspices of the Hawaii Geothermal Project, is located on the island of Hawaii near the eastern rift of Kilauea volcano. Drilling was completed to a depth of 6450 feet in April 1976. The well is cased to 2230 feet below the surface, which is 600 feet above sea level, with a slotted liner running from the end of the casing to bottomhole. Cuttings and core samples obtained during drilling indicate that the region is composed of volcanic basalt with a profile that contains a zone of open fractures (3300-4500 feet) and a zone of partially sealed fractures (4500-6450 feet) as shown in Figure 1.

The well has undergone five flash discharge tests since an initial flashing on July 2, 1976. The maximum bottomhole temperature during quiescent periods has been measured at 358°C. Test water samples were taken at various times under varying flow conditions and analyzed. The median values for the downhole samples are shown in Table 1.

TABLE 1 HGP-A Geochemical Summary

pH	Less than 5
Electrical conductivity	3100 μmho/cm
Salinity	2.3°/oo
Chloride	925 mg/l
Silica as SiO_2	420 mg/l
Sulfide	100 mg/l
Sodium	600 mg/l
Potassium	123 mg/l
Calcium	40 mg/l
Magnesium	1 mg/l
Tritium	Less than 0.1 tritium unit or at least 12 years old

It is seen that the HGP-A discharge is a slightly saline water containing about 5% ocean water but with fairly high silica content.

Following installation of the separator-silencer, flow tests were run in November, December, January, and March. In the last three cases, pressure buildup tests were conducted after the well was shut in.

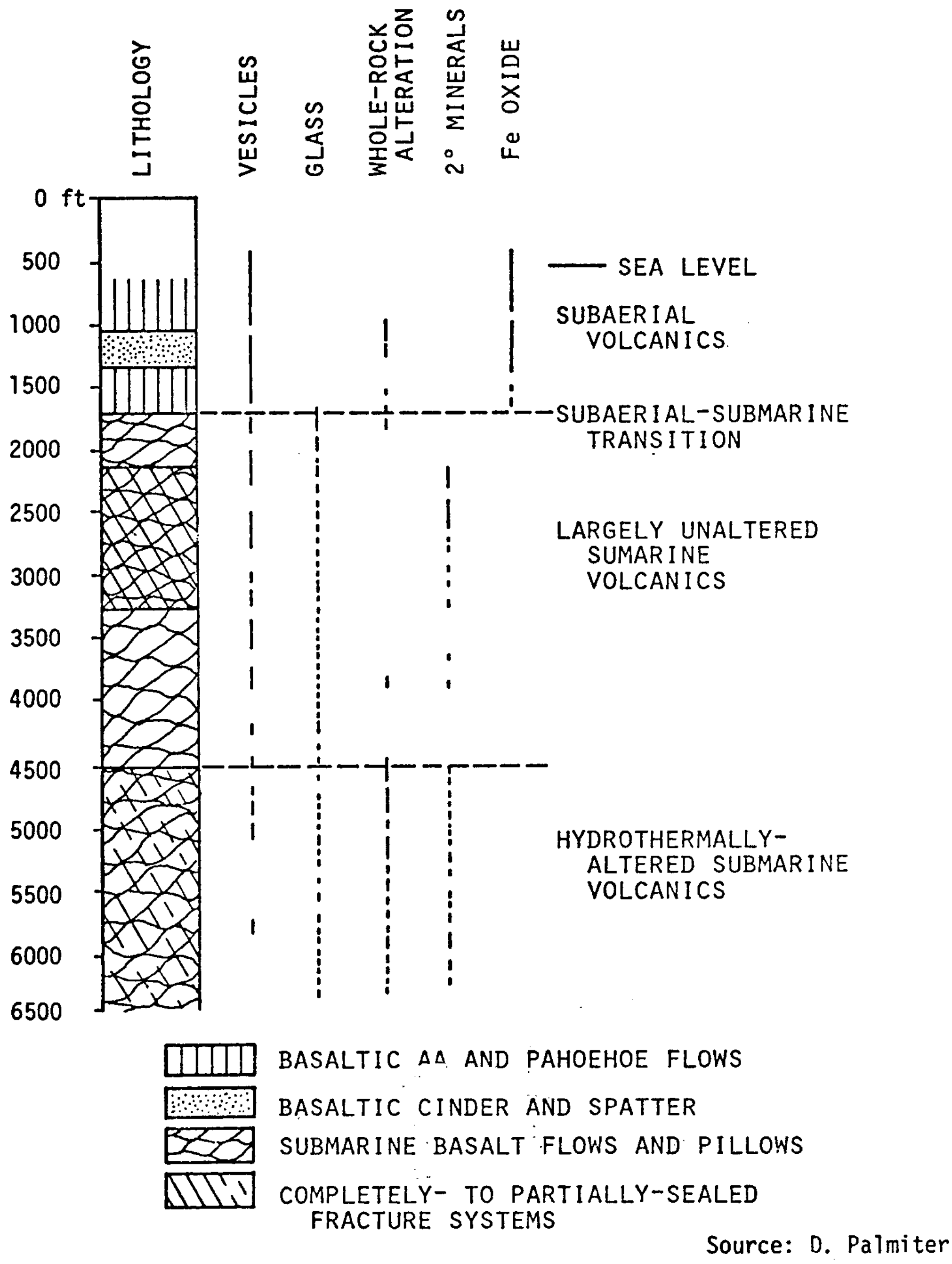

FIGURE 1. HGP-A LITHOLOGIC LOG FROM CORES AND CUTTINGS

Comparison of flow characteristics during the early stages of these four tests (Table 2) shows that with each subsequent test the flow rate has increased. A possible explanation for this improvement in well performance is that skin damage due to the use of drilling mud is being alleviated as each flow test partially cleans out embedded mud.

Table 2

COMPARISON OF DISCHARGE TESTS AT 25 HOURS AFTER INITIATION OF FLOW

	Nov.	Dec.	Jan.	Mar.
Wellhead Pressure (psig)	47	53	59	59
Wellhead Temperature (°C)	146	150	151	153
Lip Pressure (psig)	7.9	10.1	12.5	13.9
Weir Height (inches)	3-1/2	4	4-1/8	4-3/16
Mass Flow Rate (Klb/hr)	87.9	103.4	114.3	120.4
Water Flow Rate (Klb/hr)	24	34	36	38
Steam Flow Rate (Klb/hr)	63.8	70.0	78.0	82.7
Steam Quality (%)	73	68	68	69
Enthalpy (BTU/lb)	888	833	845	842
Thermal Power (Mw)	22.9	25.2	28.3	29.7

The January and March flow tests consisted of series of discharges in which the flow was throttled by placing orifice plates of various sizes in the discharge line. The results are summarized in Table 3. There is a substantial increase in wellhead pressure from 51 psig to 375 psig as the mass flow rate is reduced from 100% or 101 Klb/hr to 75% (76 Klb/hr) of wide open flow.

Table 3 PRELIMINARY THROTTLED FLOW DATA

Orifice Size (Inches)	Total Mass Flow Rate (Klb/hr)	Steam Flow Rate (Klb/hr)	Steam Quality (%)	Wellhead Pressure (psig)	Wellhead Temp. (°F)	Possible Electrical Power Output (MWe)
8	101	64	64	51	295	3.3
6	99	65	66	54	300	3.4
4	93	57	64	100	338	3.5
3	89	54	60	165	372	3.5
2-1/2	84	48	57	237	401	3.3
2	81	43	53	293	419	3.1
1-3/4	76	39	52	375	439	3.0

The electrical power output possible from these flow conditions was calculated assuming a turbine-generator efficiency of 75% as the steam expands from wellhead pressure to a back pressure of

4 inches of mercury. There is a broad power output maximum of 3.3 to 3.5 MWe over a range of wellhead pressures from 50 to 237 psig. This range will allow a wide latitude in the design of a wellhead generator system.

Pressure and temperature profiles taken during the throttled flow tests in January are shown in Figures 2 and 3. These profiles indicate that the fluid in the wellbore is at saturation conditions with a mixture of liquid and vapor flowing up to the wellhead, that is, with flashing occurring in the reservoir. Also shown in Figure 3 is the temperature profile 25 days after the well was shut in (zero flow rate). Examination of Figure 2 shows that the pressure profiles are essentially three constant slope lines meeting at the junction of the casing and slotted liner and at approximately 4300 feet. These constant pressure gradient lines indicate that the major production zones are near bottomhole and in the vicinity of 4300 feet.

Some limited information about the reservoir can be obtained by utilizing the theory for oil and gas wells. These standard petroleum engineering techniques, however, assume single phase flow, while the flow in HGP-A is definitely two-phase, so that extreme caution is required in interpreting the results of these analyses. Following the December discharge, a pressure buildup test was conducted, with bottomhole pressure being measured using two Kuster KPG pressure elements and recorders in tandem to ensure that pressure data were acquired in spite of equipment malfunction because of the high temperature. Figure 4 is a log-log type curve of the difference between bottomhole pressures during static (no flow) and flow conditions. It shows two distinct wellbore storage effects; the top of the second wellbore storage interval is indicated by the arrow A. Arrow B indicates the onset of the radial flow period, roughly 70 hours after the well is shut in. From these curves, the product of permeability and production zone thickness (kh) is calculated to be approximately 880 millidarcy-feet, with the pressure drop across the mud-damaged skin of the well being 560 psi.

Bottomhole pressure measurements made after HGP-A was shut in following the January test produced data and plots similar to those for the December test. However, close examination of the data shows that two consecutive straight-line approximations may be made to the Horner plot (Figure 5). Interpretation of this occurrence is that there are at least two different production layers in the wellbore with different kh values. The same effect is also present in the December data, but until it was reproduced in the January test, little credence was given to it. The results of these analyses are summarized in Table 4.

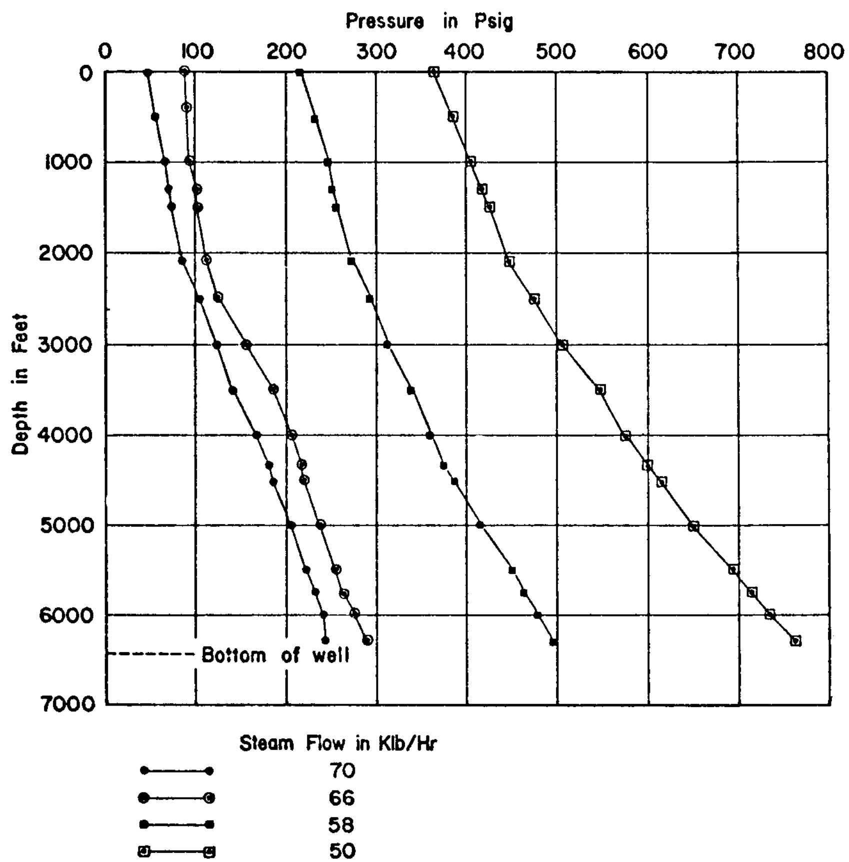

FIGURE 2. PRESSURE PROFILES FOR HGP-A

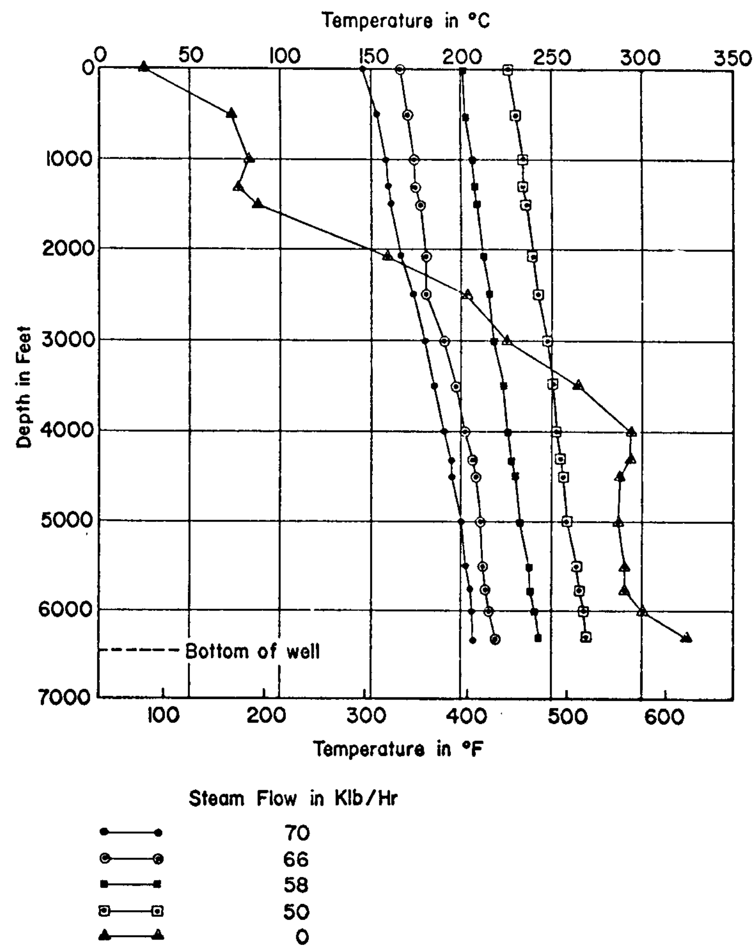

FIGURE 3. TEMPERATURE PROFILES FOR HGP-A

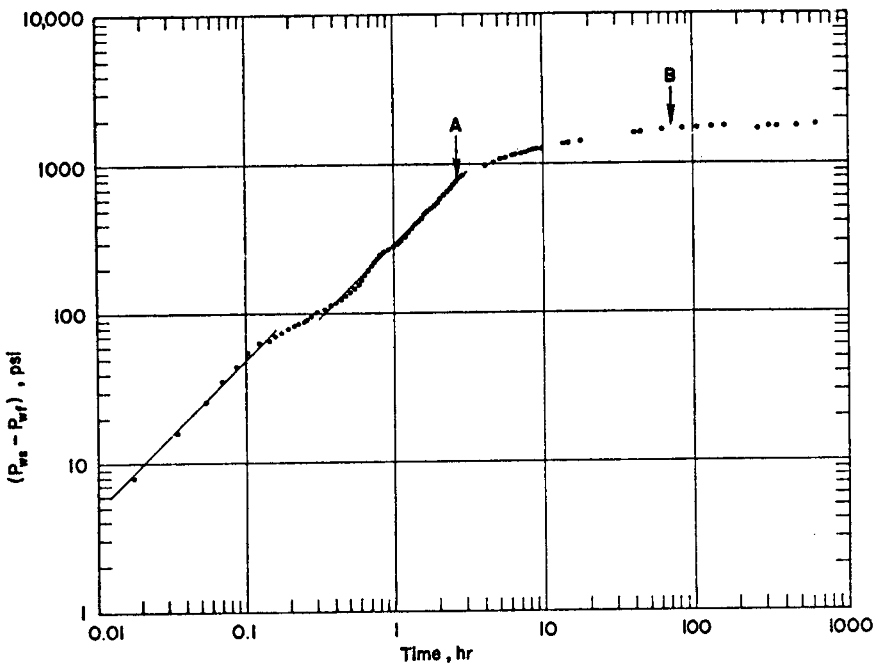

FIGURE 4. LOG-LOG PLOT OF DECEMBER PRESSURE BUILDUP TEST DATA

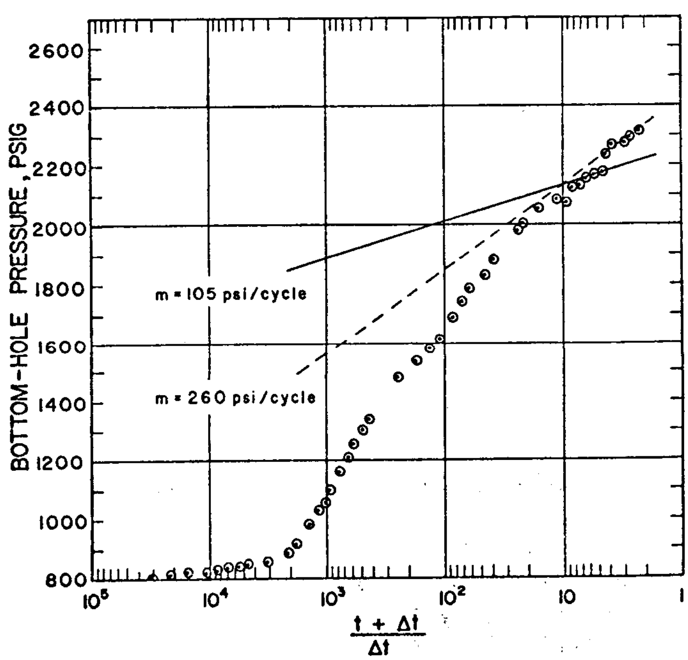

FIGURE 5. JANUARY/FEBRUARY PRESSURE BUILDUP TEST

Table 4 COMPARISON OF PRESSURE DRAWDOWN AND BUILDUP TESTS

	Constant Production Drawdown	December Buildup One Layer	December Buildup Two Layer	January Buildup Two Layer
Permeability thickness, kh, md-ft	1356	880	1553	1089
Apparent skin factor, s	-0.86	4.3	14.8	4.3
Pressure drop across skin, psi	---	561	1098	575
Flow efficiency	1	0.65	0.38	0.60

There is a substantial problem associated with the deposition of scale, primarily from dissolved silica. As an example, the muffler that was installed uses an annular region filled with cinders as a sound-absorbing agent. However, after only 16 days of flow, the scale deposited was sufficient to cement the cinders together so that removal required extensive chipping of the bound cinders.

A summary of the results of tests thus far is presented in Table 5.

Table 5 SUMMARY OF PRELIMINARY TEST RESULTS AND ANALYSES

Kapoho Geothermal Reservoir

1. Liquid-dominated
2. Tight Formation: Permeability Thickness ∿ 1000 md-ft
3. Very High Temperatures ∿ 350°C
4. High Formation Pressure ∿ 2000 psi
5. Slightly Brackish Water
6. Potentially Large Reservoir
7. High Silica Content

HGP-A Geothermal Well

1. During Flash Borehole Contains Steam and Water at Saturation
2. Flashing Occurs in Formation
3. High Wellhead Pressures ∿ 160 psi at 50 Klb/hr Steam
4. Producing Regions Probably at Bottomhole and 4300 Feet
5. Probably Has Severe Skin Damage
6. Potential Power Output ∿ 3.5 MWe
7. Flows Have Increased with Each Test