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ANALYSIS OF THE BEOWAWE GEOTHERMAL RESERVOIR

by

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INTRODUCTION

The Beowawe geothermal reservoir, located west of Carlin, Nevada and south of Highway 80 is characterized by many small hot springs near the Malpais fault. Information was provided on 16 wells, 7 Magma wells, 4 Sierra Pacific wells, 1 Batz well and 4 Chevron Resources wells. Temperature and pressure surveys, production tests, downhole pressure data, reports on the analysis of the data, well locations on a surface contour map, and a geologic map were provided by Chevron Resources.

This report summarizes the information and analysis of the data obtained. The data reviewed and summarized are:

1. Temperature
2. Flow rates
3. Well completions
4. Reservoir data
5. Geologic information

In addition, the report comments on additional testing and on the potential of the reservoir.

SUMMARY AND CONCLUSIONS

1. Maximum temperatures of the wells that have been drilled and produced, range between 357° F and 413° F, not including well B 2.

2. Intervals open to production in the wells drilled to date range over a considerable depth from a minimum at the top of the open interval of 113 feet in well B 2 to 9481 feet at the bottom of a partially cemented 7" liner in well Ginn 1-13.

3. Well flow rates of the wells have ranged as high as 800 kph, with the highest rate coming from V 3.

4. Reservoir kh (permeability-thickness product) is very high and appears to be well over 120 d-ft.

5. Calculations of reservoir ϕh (porosity-thickness product) from well tests range over three orders of magnitude so it is difficult to tell what the actual ϕh is.

6. The productive interval appears to lie along the Malpais fault plane and to spread out in a shallow reservoir from which the four Magma wells and B 33-17 were produced.

7. Additional testing is not recommended for the wells as they now exist.

8. A probable potential of 26 MWe appears to exist based on drilling 12 new wells at 500 foot spacing between wells B 2 and Ginn 1-13.

REVIEW OF DATA

TEMPERATURE

Temperature surveys were available on four Magma wells (B 2, V 1, V 2, and V 3), four Chevron wells (B 33-17, B 85-18, Rossi 21-19, and Ginn 1-15), and the Batz well. A plot of the shallow Magma wells and of B 33-17 temperature data versus depth are shown in Figure 1. The four Magma wells had temperature surveys run in 1961 by Middleton from 5 to 48 hours after shutin (References to reports are given in Tables 1 and 2). The maximum temperatures were as follows:

Well	Max. temp.	Depth	TD
B 2	373° F	525'	715
V 1	380	on btm-600'	655
V 2	380	on btm-690'	715
V 3	388	483' to 648'	767

As can be seen from Fig. 1, a temperature reversal occurred in B 2 to a minimum of 320° F at 625'.

Temperatures were also recorded while drilling and reported by Middleton on his completion profiles. The maximum temperatures were:

Well	Max. temp.	Depth
B 2	407° F	655'
V 1	407	715'
V 2	410	767'
V 3	414	608'

The more reliable maximum temperatures are those that were obtained during the survey after the wells had been flowed and then shut in because they would more nearly represent the temperature of the fluid produced from the reservoir.

Recent temperature surveys on three wells showed a loss of temperature from the 1961 surveys. The maximum temperatures were as follows:

Well	Max. temp.	Depth	Loss
33-17	370° F	700' to 800'	--
B 2	348	500' to 550'	25° F
V 2	366	650' to 720'	12

Well 33-17 also showed a reversal as did B 2 with the temperature decreasing to 311-319° F at 1050' to 1100'.

This temperature loss may be a real effect caused by a long and unknown production period of uncontrolled flow from some of these early wells. The long production time would cause a pressure drop in the reservoir around the producing wells. If the pressure fell below the saturation pressure based on the early temperature data, the temperature of the reservoir would also fall consistent with the pressure. When the wells stopped flowing, the pressure would increase but the reservoir temperature would not increase nearly as fast as the saturation temperature. This is because the amount of heat moving into the low pressure area would be low compared to the amount of heat carried away during the producing period, and it might take many years, or decades, of fluid leakage at the surface before temperatures would be restored again.

Another possibility is that cold water has leaked into the system. Both wells B 33-17 and B 2 show temperature reversals which may be caused by a cold water aquifer. With both hot and cold zones open in a wellbore, interzonal flow can occur within a wellbore. The flow would probably be from the cold water aquifer because of the greater density of the colder water giving rise to a higher pressure gradient. Of course, this effect could be modified by the type of source that provides the water to the respective aquifers.

Temperature data for the deeper wells are shown in Fig. 2 which also shows the data for the shallow well B 33-17. The Batz well is a cold well and does not appear to be in the geothermal system. Well B 85-18 shows a temperature reversal with a maximum of 357° F at 1800' to 1900'. The Rossi well shows a maximum of 402° F at 4900' with a short reversal at a deeper depth. The Ginn well shows a continuously increasing temperature being nearly isothermal at 413° F below 8500'.

The maximum temperatures of just over 400° F shown by the Rossi and the Ginn wells are on the low side for a good geothermal reservoir unless it is offset by a high kh of the reservoir. As will be discussed below, all the wells but one exhibit a high kh.

WELL COMPLETIONS

For proper interpretation and comparison of well flow rates, consideration should be given to well completions. Inasmuch as rates are to be presented and discussed in the next section of the report, it would be helpful to have a summary of the sizes of the inner strings in each well.

Such a summary is shown in Table 1. As can be see, there is considerable variation from 7" to 14" in the size of the inner string. The casing and liner sizes have a considerable effect on the capacity of a well to produce as will be discussed in the next subsection.

WELL FLOW RATES

A summary of the rate tests conducted on the wells and the references presenting the results of the tests are given in Table 2. Shown in this table are the dates, mass flow rates, enthalpy, and WHP (wellhead pressure) for the various tests.

Mass flow rates were reported by Middleton in 1961 for the four Magma wells. He obtained the total mass rate by adding together the steam rate and 0.7 times the water rate calculated from separator data. As mentioned in my report of 9 Feb 80 to Chevron Resources, there was an inconsistency between fluid enthalpy based on reservoir temperature and the rates calculated by Middleton.

The mass flow rates shown in Table 2 for the tests in 1961 on the four Magma wells are based on the fraction of steam from the separator which in turn was calculated on the basis of the enthalpy values shown in the table. The total mass rates are substantially lower than those given in the Middleton report, but they are still quite high except for B 2. The low rate on this well can be explained by the fact that the temperature is lower in this well and that it also has a temperature reversal which may indicate cooler water flowing into the wellbore.

A later test on V 2 after a 7" liner was installed, gave a much lower rate and indicated a lower enthalpy than the enthalpy based on the original temperature surveys. Both the smaller inner string and the lower enthalpy explain why the 1981 tests on V 2 had a much lower rate than the rates obtained in 1961.

The substantial effect of casing size on flow is illustrated in Fig. 3 for the four tests on the three wells. Though other factors enter into determining the rate at which a geothermal well will flow, it is very obvious that casing size is one of the important factors that control flow rate. It is planned to look at casing size, depth, temperature, and wellhead pressure in a later report.

The low rates on the Rossi well is because of the low reservoir kh around the well as will be brought out in the next subsection of the report. The low rate on the Ginn well is mainly a result of the long 7" liner in this well.

The low rate of B 33-17 is caused by low fluid enthalpy. From spinner surveys and from flowing temperature surveys, it appears that colder fluid is coming into the wellbore from below 1000' which helps explain the low enthalpy relative to the maximum temperature of 370° F at 700 to 800'.

The Dec 81 flow tests on B 85-18 gave considerable higher rates than the tests conducted in Dec 80 and Jan 81. This can be readily explained in that in the earlier tests, flow came from below the shoe of the 9-5/8" casing at 2937' while in the later tests, flow came from a higher temperature perforated interval between 1651' to 2188' after a bridge plug was set at 2500'. However, the lower temperature of 357° F relative to the V 1 temperature of 380° F with a 10" pipe means a lower enthalpy so that the well would not be expected to flow at as high a rate as did V 1 in 1961.

RESERVOIR PROPERTIES

Flow tests were made on several wells with the bottom hole pressures measured in the producing wells during flow and during buildup and in neighboring observation wells. Measuring pressures in static observation wells while an active well is produced is known as an interference test. In addition, injection tests were also made on two wells. These tests were made to determine the conductive capacity, kh, and the storativity, øch, of the geothermal reservoir. The øh is the porosity-thickness product and the c is the compressibility of the reservoir rock and its contained fluid. As a rough approximation, the øh of the reservoir can be determined by dividing the ϕch, determined from an interference test, by the compressibility of water at the prevailing reservoir temperature and pressure.

A summary of the tests is given in Table 3 along with references to the reports in which the data were presented and analyzed. Though there was some difficulty in analyzing the pressure data, the drawdown, buildup, injection, and interference tests indicated a high kh in the range of 120 to 800 d-ft. for all of the wells except Rossi 21-19, for which buildup tests indicated a kh less than 10 d-ft. The kh over 120 d-ft. is exceptionally high for a geothermal reservoir because all of the reservoirs that I have dealt with, except for one reservoir, had kh values less than 50 d-ft.

With a very high kh, the wells will have a small drawdown during flow; that is, the difference between the reservoir pressure and the flowing bottom hole pressure will be small. This is very advantageous because it means that most of the pressure difference available between the reservoir and the wellhead will be used in lifting the fluid to the surface. This gives considerable advantage to the use of larger size casing.

The ϕch shown in the fifth column of Table 3 ranges over three orders of magnitude between 1.2E-6 to 1660E-6 ft/psi. With a water compressibility of 5.8E-6/psi at 390° F, this gives a ϕh range of 0.2 to 290 ft. The 0.2 is unrealistically low and would mean a reservoir of extremely low porosity, which does not appear likely on the basis of the other tests and on well performance. Hence, the results of the interference analysis between B 85-18 and observation well Ginn 1-13 should probably be discarded.

With the large range in ϕch, it is difficult to say what the average ϕch is for the Beowawe reservoir. However, its value is not critical if the reservoir has recharge. The unknown factor, however, is the rate of recharge of geothermal fluid relative to the rate of production. This generally cannot be determined until after a reservoir has been on production for a considerable period of time.

In line with the question of recharge, is the question of where to inject the spent brine. It would be desirable to inject the brine back into the reservoir to help maintain the pressure but at a far enough distance that it would take many years before the cooler injected brine would effect the enthalpy of the produced fluid. On the other hand, if the recharge is great enough to nearly maintain the flowing bottom hole pressure, then the spent brine could be conveniently injected into another aquifer that might only be distantly connected with the geothermal reservoir. Insufficient information is available at this time as to which way to go.

The pressure buildup behavior presented in my report of 30 April 81 is indicative of a two porosity system, consisting of a highly conductive fracture system and a relatively low permeability matrix. This fact should be considered in designing and analyzing pressure drawdown, buildup, and interference tests. With a properly designed test and good data, the analysis of the data should provide greater confidence in the determination of kh and øch than can be given in the data shown in Table 3. It might also allow of a determination of the two parameters that characterize a fractured reservoir for use in possible future reservoir calculations.

GEOLOGY

A geologic picture of the Malpais fault is shown in Fig. 4 along with isotherms along the fault plane. This figure was provided by Chevron Resources and shows a 400° F isotherm at a depth as shallow as sea level, or about 5000 feet below the surface. The figure also indicates that flow is up the fault plane toward a shallow zone in the vicinity of the Magma wells. With the indicated high kh of the reservoir and the use of large casing such as 11-3/4", or 13-3/8", the shallow wells should be capable of large flow rates even though the reservoir temperature is not too high. However, wellhead pressures can become critical under these circumstances so that in the future, if a relatively shallow well is drilled, it should be carefully tested to get a rate-WHP curve. The rate-WHP curve can then be used to determine an optimum WHP for design of a turbine, or to determine whether it is feasible to drill and produce shallow wells.

ADDITIONAL TESTING

The testing of wells has been briefly mentioned above with the suggestions mainly referring to new wells. The question has been asked as to whether it would be desirable to do additional testing on wells that have already been drilled.

One of the main requirements for testing geothermal wells, with pressures also being measured in one or more observation wells, is that the pressure be effected only by an active producing, or injection well. Extraneous effects such as lingering effects from earlier tests, interzonal flow in a wellbore, or two separate zones open in a wellbore can make a proper analysis very difficult if not almost impossible. Several of the tests that have been described in the various reports were started before the effects of previous tests had disappeared, so that the observed pressures were affected by both the previous tests and by production from the active well. In addition, if more than one zone is open in a wellbore, as appears to be the case with B 2 and B 33-17, it can have an effect on the pressure behavior of an observation well. If the two zone well is a producer, than an unknown amount of fluid will be coming from the zone open in the observation well and the pressure behavior of the observation well cannot be correctly analyzed. If the two zone well is an observation well, then the pressure drop in the zone that is open to flow in the producer will result in interzonal flow in the observation well. Again the pressure behavior of the observation well cannot be correctly analyzed. Thus pressures measured in an observation well such as B 2 or B 33-17 could not be analyzed correctly. The same problem would exist if B 2 or B 33-17 were a producing well.

In addition to interference tests, wells can also be tested to determine a rate-WHP curve for determination of the number of wells required for a given size plant. To have any value, such wells should be completed with an optimum size casing. There is no point in testing a well, such as Ginn 1-13 with 7" casing, or a well with a cooler zone open such as B 33-17.

Based on the above discussion, I would not recommend additional testing of the currently available wells. In fact, if new wells are to be drilled before a commitment is made to put in a power plant, I would recommend that B 2 be completely cemented up and that an attempt be made to pull the liner from B 33-17 and to plug back to 850'. Without a liner, and without cooler fluid coming from below 850', the well might be capable of a production rate similar to B 85-18 when it was plugged back to 2500' and perforated from 1651' to 2138'. If the liner cannot be pulled, or it is not economical to spend the money, the well should be plugged to 850' anyway to avoid interzonal flow from occuring during possible future testing.

RESERVOIR POTENTIAL

The potential of a geothermal reservoir depends on its volumetric size, temperature, kh, øh, and recharge. For Beowawe, we have fairly good knowledge of kh and temperature, only fair knowledge of øh, and very little information as to size or of possible rate of recharge. From past performance of the reservoir, we can conclude that the reservoir probably has recharge because the long uncontrolled flow and continuous surface discharge from hot springs has not dried up the reservoir.

We can get an estimate of the potential of the reservoir by considering the area between Ginn 1-13 and the Magma and B 33-17 wells which is along the very high kh trend. The distance between B 2, the westernmost well of the Magma wells, and Ginn 1-13 is 7200'. If we use a conservative spacing of 500' between wells, we could locate 13 wells between B 2 and Ginn 1-13. Since 85-18 is already drilled, it appears that 12 new wells could be drilled and have a good probability of being productive wells because of the high kh in this area.

The actual production rate of the wells will depend mainly on the temperature within the productive zone and will be a function of casing size and WHP. Preliminary calculations indicate that Ginn 1-13 should have been able to produce at an initial rate of 600 to 800 kph with 9-5/8" casing and 100 psi WHP. Well V 3 showed an initial rate of about 800 kph with 14" pipe. However, with the lower current temperature, its rate today with its original completion would be somewhat less.

The potential power can be calculated on the basis of 12 new wells drilled at 500 foot intervals. For an average rate of say 500 kph, this would give a total mass flow rate of 6000 kph. If an 80 psig (92 psia) separator is used and the average reservoir temperature is 400° F, the fraction of steam from the separator is 0.093. This would give a steam rate of 6000 x .093 = 558 kph. With a steam requirement of 21 kph per MWe for an 80 psig turbine, this would result in 26 MWe of power.

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Petroleum
Engineering
Consultant

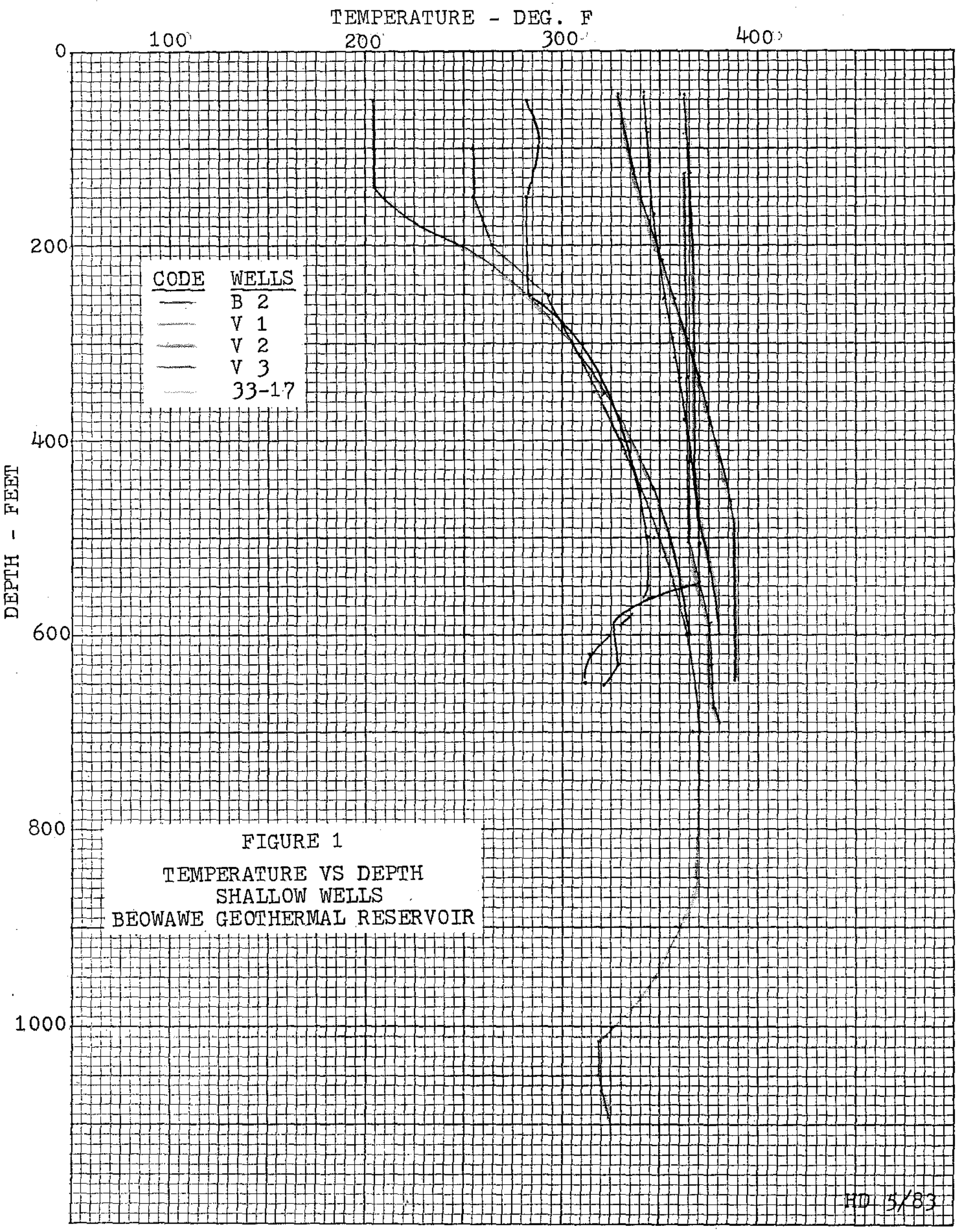

FIGURE 1

TEMPERATURE VS DEPTH
SHALLOW WELLS
BEOWAWE GEOTHERMAL RESERVOIR

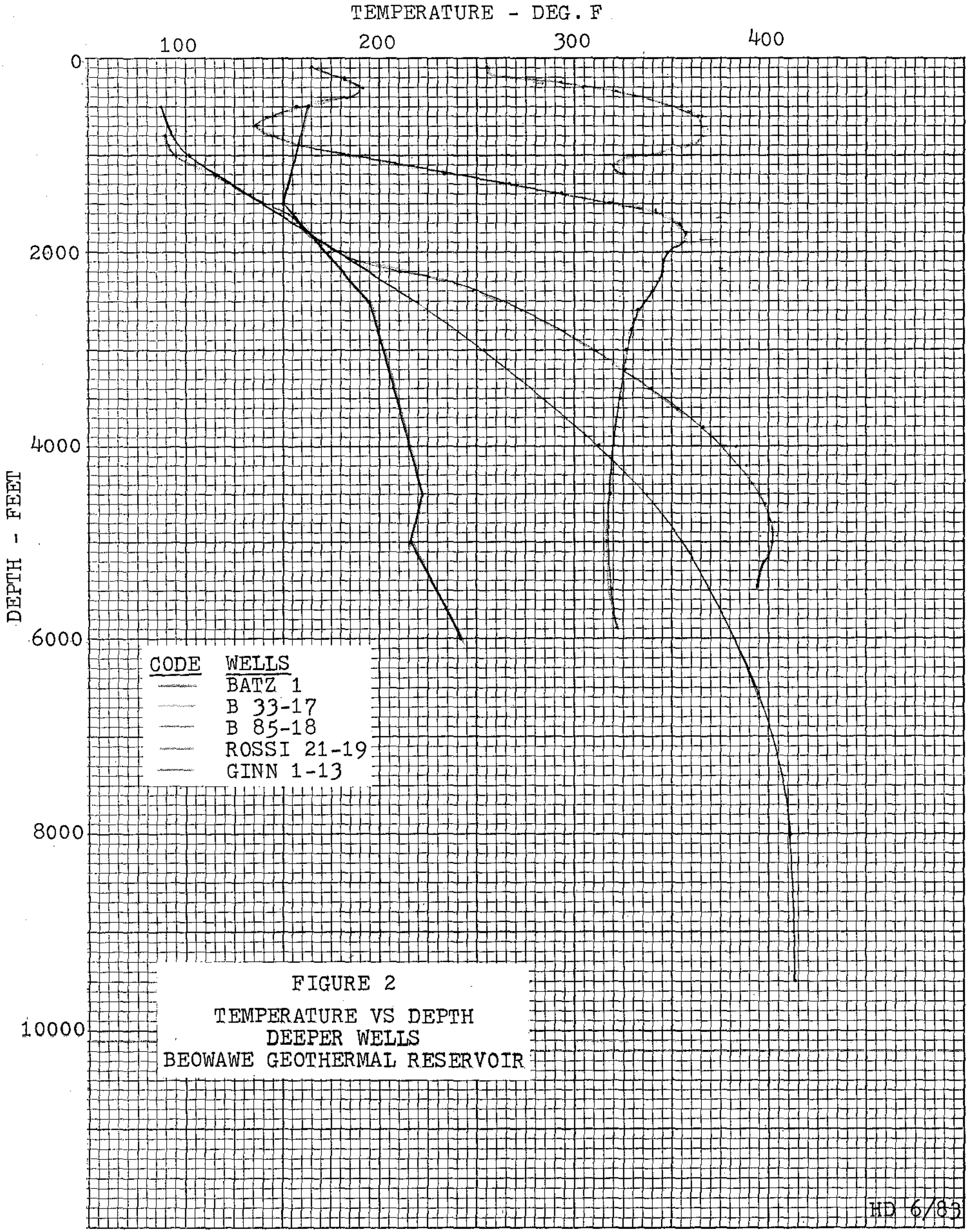

FIGURE 2

TEMPERATURE VS DEPTH
DEEPER WELLS
BEOWAWE GEOTHERMAL RESERVOIR

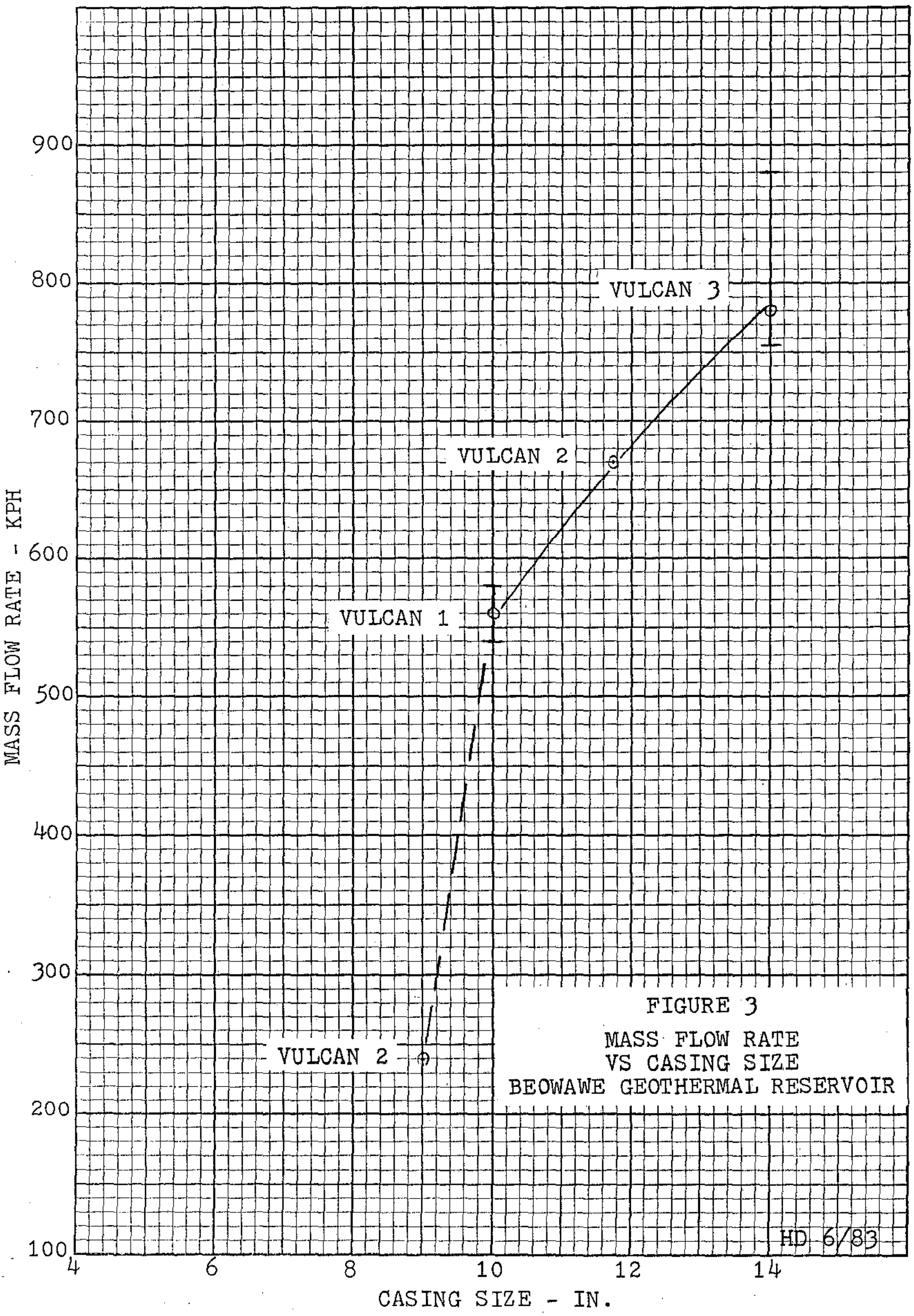

FIGURE 3
MASS FLOW RATE
VS CASING SIZE
BEOWAWE GEOTHERMAL RESERVOIR

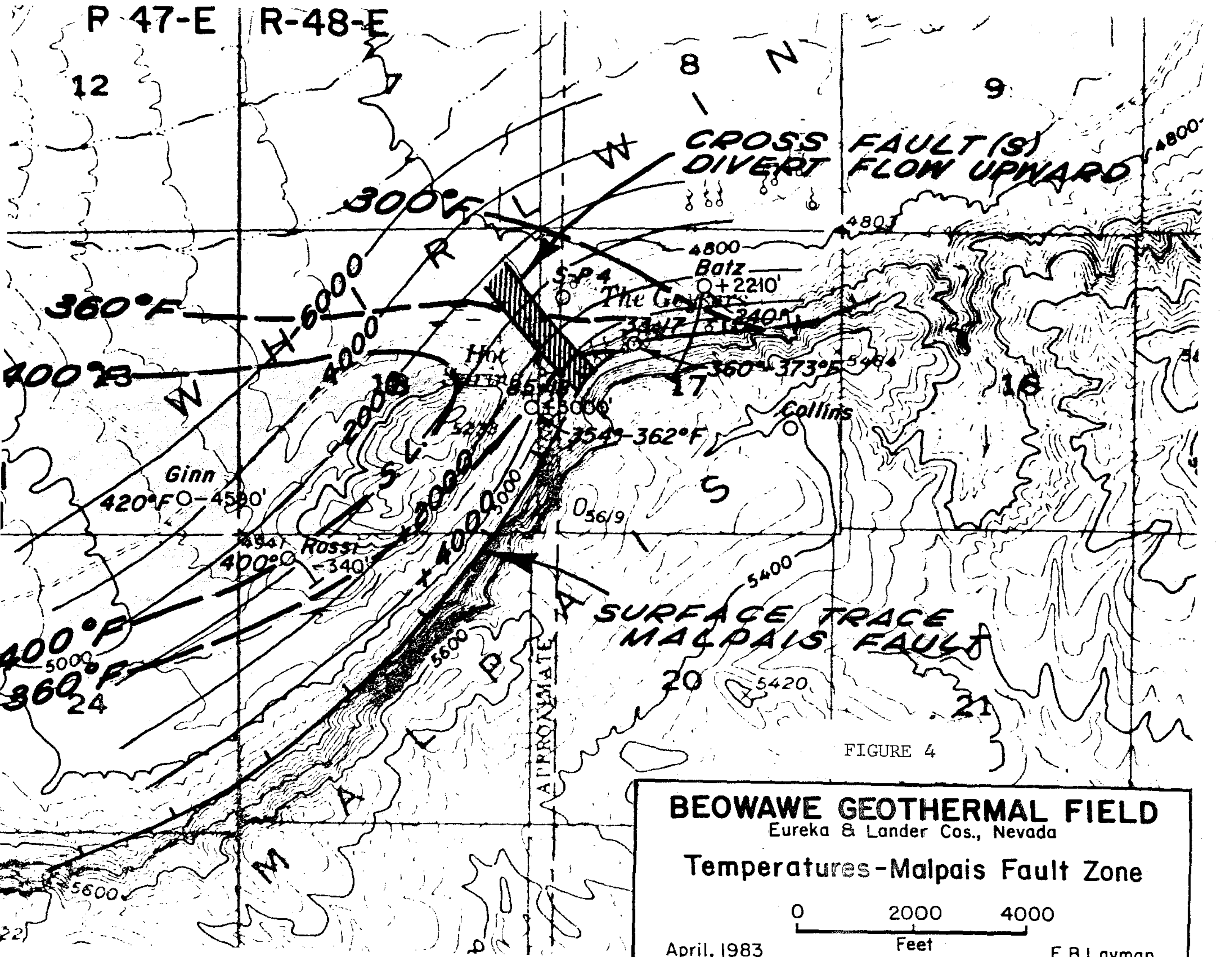

FIGURE 4

BEOWAWE GEOTHERMAL FIELD
Eureka & Lander Cos., Nevada

Temperatures-Malpais Fault Zone

0 2000 4000
Feet

April, 1983
E.B.Layman

TABLE 1

WELL COMPLETIONS
BEOWAWE GEOTHERMAL RESERVOIR

Well	Size in.	Depth range	TD ft.
B 2	13-3/8"	113' to surf.	715
V 1	10"	201' to surf.	648
V 2(orig.)	13-3/8 10-3/4 7" lnr	150' to surf. 308' to surf.	724
V 3(orig.)	14"	140' to surf.	767
(1965)	8-5/8	308' to surf. (fish in hole)	PB to 552
B 33-17	9-5/8 & 6-5/8" lnr	422' to surf. 315' to 1280'	1299
B 85-18 (recent)	13-3/8 & 6-5/8	1006' to surf. 758' to 2937' perf'd 1651'-2188'	5927 BP @ 2500'
Rossi 21-19	13-3/8 & 6-5/8" lnr	1996' to surf. 4178' to TD	7212
Ginn 1-13	7" lnr(a)	9481' to surf.	9563
Batz 1 (recent)	13-3/8" & 9-5/8" 2-7/8" tbg.	500' to surf. 400' to 2508' @ 5900' ?	6000'

(a) Unable to cement

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TABLE 2

SUMMARY OF FLOW RATE TESTS
BEOWAWE GEOTHERMAL RESERVOIR

Well	Date	Mass flow rate, kph	Enthalpy Btu/lb	WHP psi	Reference
B 2	8 Jul 61	62(a)	343(b)	21	1
V 1	7 Jul 61	583(c)	353(b)	96	1
		542		103	
		539		108	
V 2	6 Jul 61	676(d)	350(b)	97.5	1
		667		91	
	26 Jan 81	240(e)			2
	21 Feb 81	240	330		2
V 3	5 Jul 61	882(f)	362(b)	119	1
		780		117.5	
		755		116.5	
Rossi 21-19	14 Dec 79	150-280(g)		38-69	3
B 33-17	Feb 80	276		20I	4
	Jun 80	207			4
	8 Feb 81	166	282		2
	25 Feb 81	162	278-252		2
B 85-18	8 Jan 81	193			2
	Dec 80	169			5
	Jan 81	170	334		5
	4-8 Dec 81	323	326	72	5
	23-26 Dec 81	292	333	81+	5
Ginn 1-13	Dec 81	285(g)	375	100	6&7

(a) Based on steam rate from separator
(b) Based on bottom hole temperature and used to calculate rate
(c) With 10" pipe
(d) With 12 3/4 - 10 3/4" csg.
(e) With 7" lnr
(f) With 14" csg.
(g) With continuous nitrogen injection

1.	Middleton rpt.	Aug. 61
2.	Dykstra rpt.	29 Apr. 81
3.	Chev. Res. memo to file	31 Dec. 79
4.	Chev. Res. rpt.	25 Jul. 80
5.	Chev. Res. rpt.	15 Mar. 82
6.	Chev. Res. rpt.	16 Feb. 82
7.	Chev. Res. rpt.	14 Jul. 82

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TABLE 3

SUMMARY OF RESERVOIR PROPERTIES DERIVED FROM FLOW TESTS BEOWAWE GEOTHERMAL RESERVOIR

Active Well	Date	Type of test	kh d-ft.	ϕch in 10^{-6} ft/psi	Obs. Well	Ref (a)
V 2	Feb 81	DD	556			2
Rossi 21-19	Dec 79	BU(b)	1.5			3
		Inj. lwr	9.0			8
		Inj. upr	2.7			8
B 33-17	Feb 80	BU	750-800			4
	Jun 80	"	800			4
B 85-18	Dec 80	BU	240			5
	Jan 81	"	120			5
	Jan 81	Interf.	233	1160	V 2	2
	"	"	190	514	33-17	2
	4 Dec 81	"	573			5
	"	BU-Int.	550	30.4	Rossi 21-19	7
	"	DD-Int.	443	27.6	"	7
	12 Dec 81	BU	500			5
	"	"	803	28.3		7
	"	DD	822	27.4		7
		BU-Int.	299	4.6	Ginn 1-13	7
		DD-Int.	126	1.2	"	7
Ginn 1-13	Dec 81	BU	232			6
	Dec 81	DD	273	9.4		7
	"	BU-Int.	480	69.4	B 85-18	7
	"	"	580		Rossi 21-19	7
	"	DD-Int.	446	35.5	B 85-18	7
		DD-Int.	423	66.9	Rossi 21-19	7
Batz 1	Dec 81	Inj.	226			9
	Nov 82	Inj.(c)	850	509(d)		9

(a) For references 107 see Table 1
(b) Buildup incomplete
(c) After acidizing
(d) From type curve analysis

(8) Chev. Res. rpt. 6 May 82
(9) Chev. Res. rpt. 2 Dec 82

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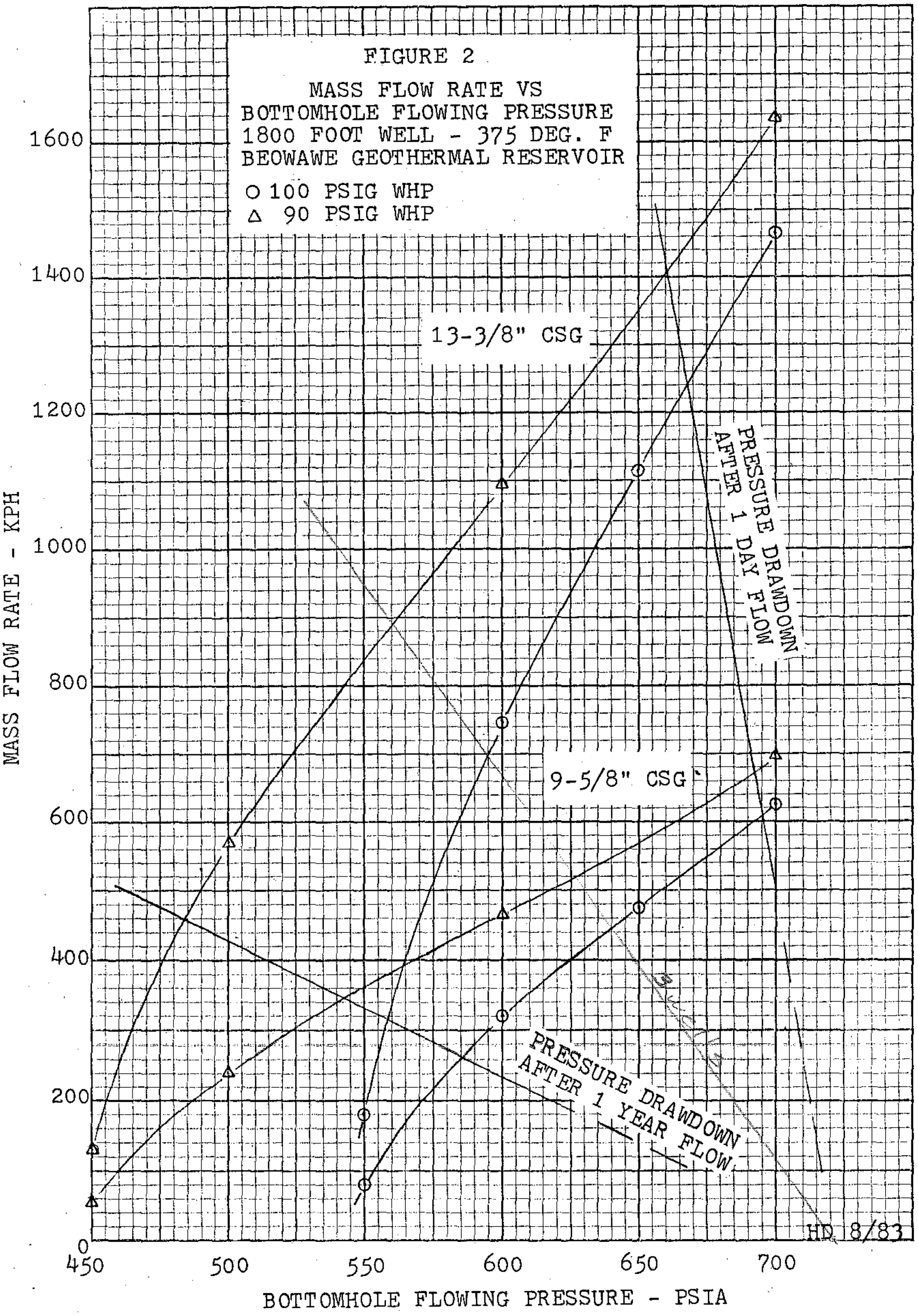

FIGURE 2

MASS FLOW RATE VS
BOTTOMHOLE FLOWING PRESSURE
1800 FOOT WELL - 375 DEG. F
BEOWAWE GEOTHERMAL RESERVOIR

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