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Lawrence Berkeley Laboratory University of California/Berkeley

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RESULTS OF RESERVOIR EVALUATION TESTS, 1976

EAST MESA GEOTHERMAL FIELD, CALIFORNIA

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ABSTRACT

Two interference well tests, conducted at the U.S. Bureau of Reclamation's East Mesa geothermal test facility in Southern California by the Lawrence Berkeley Laboratory, serve to better define the geothermal reservoir's geometry and hydrologic characteristics. Temperature profiles taken indicate that the reservoir is approximately 3000 feet thick and is located about 6000 feet below the ground surface. The temperature at depth is approximately 350°C. The two well tests, each of approximately 10 days' duration yield respectively reservoir transmissivities of 11,200 and 29,500 millidarcy-feet and compressibilities of 5.7×10^{-3} and 2.1×10^{-3} feet per psi. The tests also indicate the possible presences of a sealed fault and a leaky fault in the reservoir.

INTRODUCTION

The U.S. Bureau of Reclamation has drilled five geothermal wells at East Mesa in the Imperial Valley of California to investigate the possibility of obtaining high quality water supplies by desalting the hot fluids and to concurrently produce electrical energy. In order to help the Bureau in assessing the potential of the geothermal reservoir pierced by the wells, Lawrence Berkeley Laboratory (LBL) conducted well tests at the East Mesa field between January and April, 1976. The well tests serve to define the permeability and storage characteristics of the reservoir materials and to elicit information about the reservoir geometry. These reservoir data are imperative for a judicious exploitation and management of the available geothermal resource. This report presents the findings of the well tests.

PHYSIOGRAPHY AND GEOLOGY

The East Mesa Field is located 20 miles east of El Centro, California, in the Imperial Valley (Fig. 1). This valley is part of a large structural feature known as the Salton Trough, a sediment-filled depression forming the landward continuation of the East Pacific Rise and the Gulf of California (Swanberg, 1975). The East Pacific Rise is one of several geological sutures on the earth's crust along which adjoining crustal plates move apart, causing thinning of the crust and upward movement of molten rock from the mantle. This crustal extension is responsible for the formation of the Salton Trough, and provides the heat source for the several geothermal resource areas located in the Imperial Valley. Faulting is a consequence of this crustal extension and many faults occur within the Valley. Most of these faults trend NW and are right lateral strike-slip faults. The major active faults close to the field are the San Andreas Fault, located approximately 20 miles from the East Mesa Field on the eastern margin of the Imperial Valley, and the Imperial Fault, located approximately 15 miles to the west of the field. Three local faults have been mapped within the field itself.

The Imperial Valley is a broad depression, approximately 60 miles wide in the vicinity of East Mesa. It trends northwest to southeast, becoming wider southward toward the Mexican border and is about 60 miles long as measured from the Mexican border. The valley is bounded on the east by the Chocolate Mountains, which rise to over 2000 feet, and on the west by the Fish Creek and Coyote Mountains, which attain elevations of 3000 feet. To the north, the valley is approximately 25 miles wide and is occupied by the Salton Sea, which has a surface elevation of approximately - 230 feet. A greater part of the Imperial Valley south of the Salton Sea lies below sea level and receives benefit from the well-known irrigation systems of the all American and Coachella canals.

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Fig. 1. Location map of the East Mesa geothermal field, Imperial Valley, California.

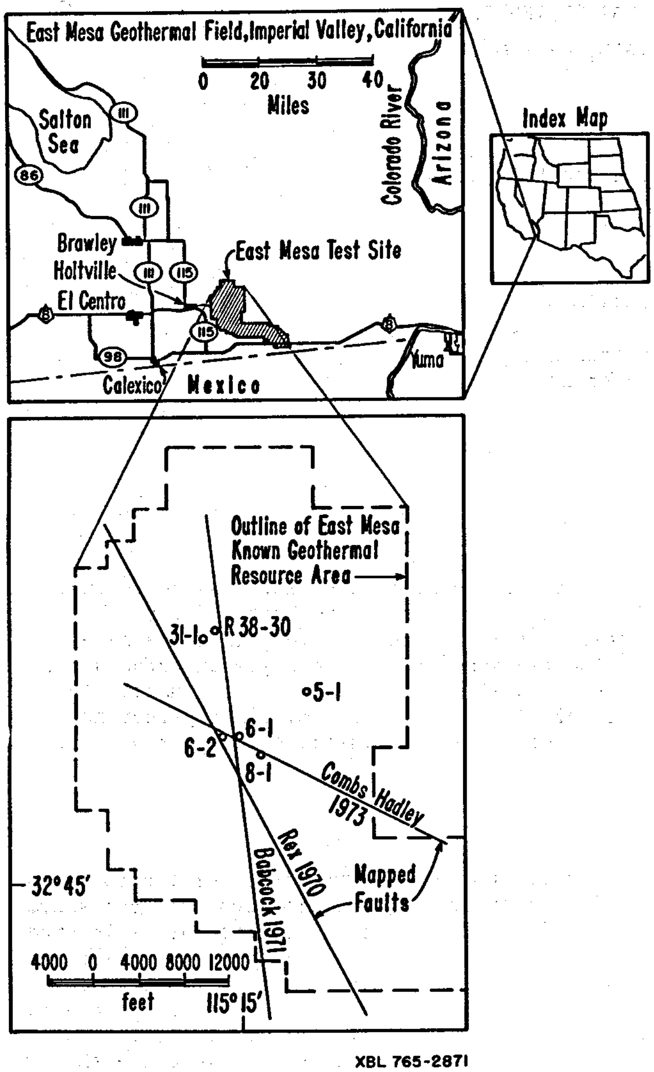

Fig. 2. Map of the well field at East Mesa.

Sea level constitutes a well-defined physiographic boundary between the irrigated, lower parts of the valley and the higher flanks of the valley on either side. These higher portions, called the West and East Mesas, rise to about 100 feet above sea level. The East Mesa exhibits a relatively flat, featureless desert-like terrain covered by alluvium and sand dunes. The geothermal well field under study is located near the western margin of the East Mesa on the eastern flank of the Salton Trough.

The reservoir rocks at East Mesa are essentially flat-lying, poorly consolidated, late Pliocene to late Pleistocene, deltaic sandstones, siltstones and clays believed derived from the Colorado River. They aggregate a total thickness of about 10,000 feet on top of crystalline basement rocks. A predominantly clay sequence, about 2000 feet thick, caps the reservoir and hence no surface evidence of geothermal activity is seen. Within the field, three supposedly vertical intersecting faults have been mapped (Fig. 1). It is thought that one or more of these faults and their intersections may act as vertical channels that allow hot water to rise from depth and cooler water to return to depth in a convective cycle. As mentioned, this convective regime is sustained by heat derived from the tectonic processes associated with the East Pacific Rise. The surface heat flow over the field is about five times that of the earth's average.

THE WELL FIELD

The Bureau has drilled five wells to an average depth of 6000 feet and installed wellhead equipment to contain the reservoir fluids, which exist under an artesian pressure of about 60 psi. A map of the East Mesa well field is presented in Fig. 2, and the salient features of the wells are summarized in Table 1.

WELL TESTS

Two interference tests were conducted at East Mesa between January and April, 1976. These tests involved the removal of fluid at a constant rate from one well (the production well) and monitoring the induced pressure changes in a neighboring well (the observation well). Temperature surveys of several wells were also run in conjunction with the well tests (Fig. 3 and Appendix C).

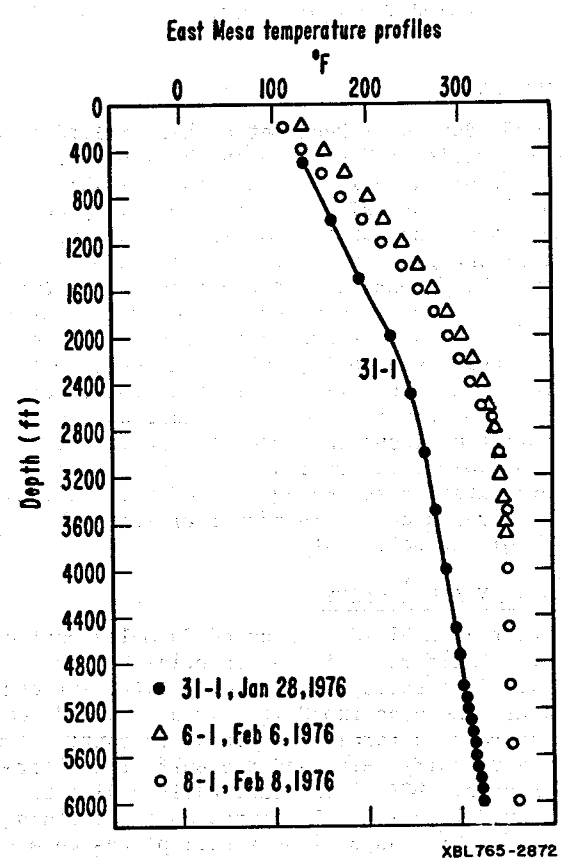

Fig. 3. Temperature profiles in wells 6-1, 8-1 and 31-1, East Mesa geothermal field, California.

TABLE 1. East Mesa Well Data
[after Mathias (2)]

Well	Depth		Bottom temp		Producing interval		Lower casing o.d.
	feet	meters	°F	°C	feet	meters	
6-1	8015	2443	399	204	6201-7982	1890-2433	7
6-2	5958	1816	340	188	4790-5959	1460-1816	7-5/8
5-1	6004	1830	315	157	5007-6004	1526-1830	7-5/8
8-1	6001	1829	354	179	4948-6001	1508 1829	7-5/8
31-1	6175	1882	309	154	5420-6175	1652-1882	7-5/8
R38-30	8890	2710	N/A	N/A	4890-8890	1491-2710	7

Distance Between Wells (feet)

	5-1	6-1	6-2	8-1	31-1
5-1	0	7080	8240	6680	10520
6-1	7080	0	1480	2320	9520
6-2	8240	1480	0	3680	8880
8-1	6680	2320	3680	0	11520
31-1	10520	9520	8880	11520	0

Since the geothermal wells at East Mesa are under artesian conditions, well flow could be achieved by simply opening the well head valves. Environmental concerns regarding the disposal of geothermal fluids limited test production flow rates to about 100 gpm. Also of concern was the prevention of steam formation in the well bore. During the production tests the main valve on the production well was completely opened and the hot water flow was throttled back by means of an orifice plate with a 3/4 inch diameter aperture. The orifice plate limited the flows to about 100 gpm, depending on the well head pressures, and also maintained sufficient back pressures to prevent steam formation within the well bore. Wellhead temperatures and pressures were measured by means of a thermocouple and a bourdon tube placed upstream of the orifice plate. Once past the orifice, a portion of the fluid flashed to steam and the rate of flow of the remaining liquid portion was measured by passing the liquid through a weir box arrangement with a clock driven water level recorder. Total flow was calculated using the liquid flow rate and the fractional part of total flow converted to steam at the recorded well head temperatures and pressures.

The pressure changes in the observation wells were measured using a sensitive downhole quartz crystal pressure gauge capable of resolving pressures to within 0.01 psi. The gauge was placed downhole at an appropriate depth dictated by the temperature profile of the well and the temperature limitations of the tool. Pressure information from the gauge was fed electronically to a microprocessor and recorder located in a home trailer. Data could be recorded automatically at intervals as small as one second.

The first interference test consisted of placing the pressure tool in well 6-1 at a depth of 1100 feet and recording, at ten minute intervals, the pressure changes caused by flowing well 6-2, 1500 feet away, at a rate of 90 gallons per minute for 11 days. At the end of 11 days well 6-2 was closed and pressure buildup in 6-1 was recorded for an additional six days. While the pressure drop in well 6-1 was sufficiently large to permit analysis, simultaneous pressure readings taken in well 8-1, 2300 feet away from 6-1, and at a 1500 foot depth, did not show any measurable drop in pressure that could be attributed to the production from 6-2.

The second interference test involved well 31-1 and well R38-30, the latter drilled by a private company (Republic Geothermal) on leased acreage. The pressure tool was placed in R38-30 at 1500 feet and well 31-1, located 1250 feet distant, was flowed at 130 gpm for 10 days. After 10 days the well was closed and the build-up pressures in R38-30 recorded for an additional 7 days. The pressure and flow rate data for each test are contained in the appendices.

RESULTS AND INTERPRETATION

A segment of the water pressure data collected from 6-1 is shown in Fig. 4. It can be seen from this figure that the pressure data exhibits considerable background noise. Whether this noise is caused by the instrument-cable system or whether it represents the reservoir response to natural phenomena such as microseisms, is not fully known.

The interference test between wells 6-2 and 6-1 indicated that the pressure data from the latter had a noise level of about 0.5 psi about the mean. The maximum change in the mean pressure induced at 6-1 by the production at 6-2 was only about 0.7 psi over 11 days. In order to remove the effects of the noise on the pressure data and to enable meaningful interpretation of the response of the reservoir to the fluid withdrawal at well 6-2, a non-linear regression technique was employed. Ten minute data was fitted to a curve of the form

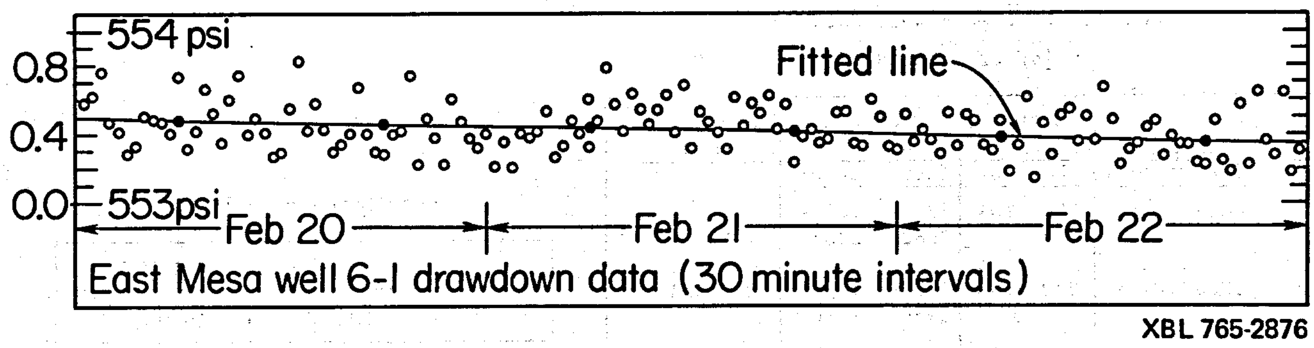

Fig. 4. Water pressure data from well 6-1 showing the noise level in the measurements.

$P(t) = C_1 + C_2 e^{\alpha_1 t} + C_3 e^{\alpha_2 t}$, where t is time, P is pressure, and the subscripted variables are parameters for optimizing the curve fit. Data from 8-1 was also treated the same way.

Analysis of the drawdown data from the first interference test indicated that in the region of wells 6-2 and 6-1, the transmissivity and the storativity parameters of the reservoir could be represented by kH = 11,200 millidarcy feet and ϕCH = 4.7 x 10^{-3} feet per psi, where k is permeability, H is reservoir thickness, ϕ is porosity an and C is the combined compressibility of water and rock.

It was mentioned earlier that no measurable change attributable to production from 6-2 could be observed in 8-1. This may merely be due to 8-1 being farther away from 6-2 than 6-1. Or, it may imply the presence of some geological feature (a barrier boundary?) which effectively cuts off communication between 6-2 and 8-1. Further detailed interference tests will be needed to examine the position.

Data from the second interference test yielded a kH value of 29,500 millidarcy feet and ϕCH = 2.1 x 10^{-3} feet per psi, suggesting that the reservoir is relatively more permeable in the vicinity of wells 31-1 and R38-30. The calculated parameters are in substantial agreement with the earlier tests conducted by the Bureau of Reclamation and with the average permeability values calculated from synthesized well log data. In Figs. 5 and 6, the drawdown data from the two interference tests are shown plotted on a log-log paper and fitted, using a curve matching technique (Ferris et al., 1962; Witherspoon et al., 1967) to the analytical solution of Theis.

An important extension of the curve matching technique used for interpretation is that deviations of observed data from the type-curve can be used to interpret the existence of discontinuities within the reservoir. It is seen from Fig. 5 that after about 100 hours, the observed drawdowns are consistently less than those predicted by the

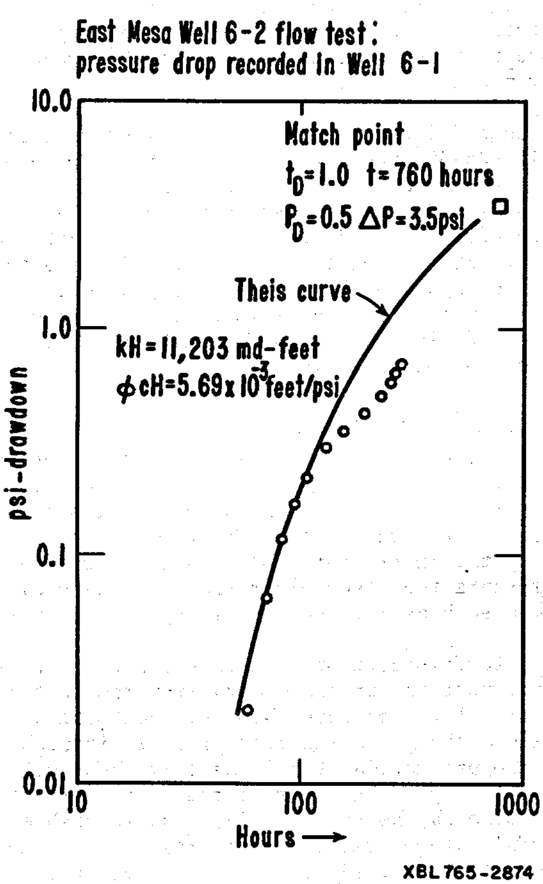

Fig. 5. Interference test 1: Log-log plot of drawdown data from well 6-1.

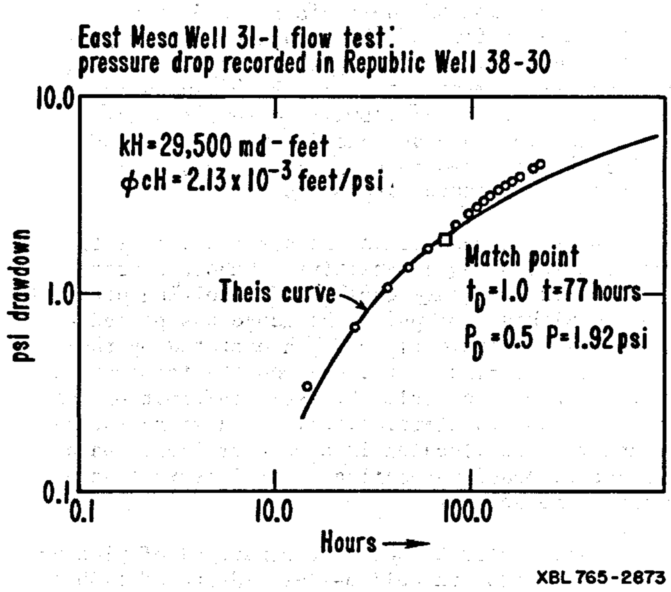

Fig. 6. Interference test 1: Log-log plot of drawdown data from well R38-30.

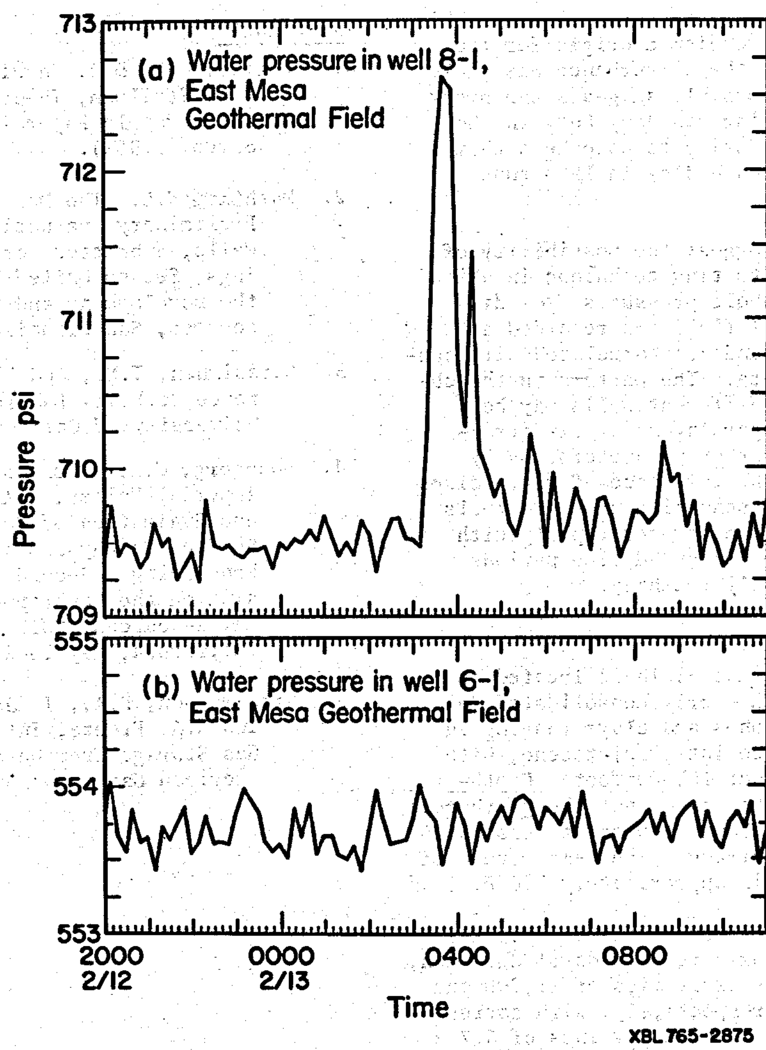

Fig. 7. Water pressure data from wells 8-1 and 6-1, with the former showing an anomalous 3 psi peak.

Theis curve, indicating the possible presence of a leaky or recharge boundary in the vicinity of 6-1. Such a boundary may be formed by a permeable fault acting as a conduit to transport water into the reservoir as the reservoir pressure is lowered. Computations based on the magnitude of the departures suggest that the boundary may be located 200 to 1700 feet from 6-1 depending on direction. With only two wells used in the test, it is not possible to uniquely determine the location of the boundary relative to 6-1.

It should be mentioned here that the observed departure might be caused by other factors. As can be seen from Table I, well 6-2 produces from between 4800 and 6000 feet below ground level, while well 6-1 is open to a different depth interval, namely 6200 to 8000 feet. It is not clear if this offset between the producing intervals of the two wells might have caused the departures observed in Fig. 4.

Unlike the deviations seen in Fig 5, the observed data in Fig. 6 indicate consistently higher drawdowns than the type curve after about 90 hours, suggesting the possible presence of a barrier boundary in the vicinity of R38-30. Computations on the magnitude of deviations indicate that such a barrier boundary may exist 1,100 to 2,400 feet from R38-30, depending on direction. Again with only two wells used in the test it is not possible to uniquely fix the orientation of the boundary relative to R38-30. An impermeable boundary may arise due to the existence of a sealed fault or a zone of greatly diminished permeability.

It seems reasonable to conclude that the inferred boundaries are to be attributed to the existence of the three intersecting faults in the well field (Fig. 1). There is need for further long duration interference tests to understand these structural elements more clearly.

PORE WATER PRESSURES AND MICROSEISMS

A few hours before the first flow test was commenced, a pressure anomaly of 3 psi above noise level was recorded in well 8-1 (Fig. 7). Concurrent pressure records in well 6-1 did not contain this anomaly. The Bureau maintains a seismic net at the site and a check of the seismic net records revealed a small seismic event had occurred at about the same time as the pressure anomaly. This suggests a probable microseismic origin for the observed anomaly. That the disturbance was picked up at 8-1 and not 6-1 possibly suggests the presence of an enrgy absorbing boundary between the two wells. It is interesting to note here that a fault mapped by Combs and Hadley in 1973 runs between the two wells.

These observations suggest the possibility of developing a reservoir testing technique in which records of passive downhole pressures from different wells in the well field are recorded at small time increments, and are correlated with concurrent microseismic data. The pattern in the observed correlations in different wells may be amenable to analysis regarding reservoir structure, permeability and other parameters. Very little is known about the influence of microseisms on pore pressures since sensitive pressure tools required to measure pore pressures rapidly with high resolution and over extended time periods have become available only recently.

SUMMARY AND CONCLUSIONS

The East Mesa Geothermal Field is located in a broad valley filled with poorly consolidated deltaic sandstones, siltstones and clays ranging in age from late Pliocene to late Pleistocene, with a total thickness of about 10,000 feet. Depth-temperature profiles taken show that the geothermal reservoir extends from about 3000 to at least 6000 feet below the ground surface. The temperature of the reservoir at depth is approximately 350°F.

Two interference tests, East Mesa 6-2 and East Mesa 31-1, each of approximately 10 days' duration, indicate reservoir transmissivities of 11,200 and 29,500 millidarcy feet respectively, with corresponding reservoir compressibility values of 5.7 x 10^{-3} and 2.1 x 10^{-3} per psi.

The interference tests also yielded information about the structure of the reservoir. A no-flow boundary, possibly a sealing fault, is thought to be located in the vicinity of well R38-30, and a leaky boundary, possibly an open fault acting as a fluid recharge conduit, may exist in the vicinity of well 6-1.

The reservoir tests indicate that the reservoir is moderately permeable, somewhat heterogeneous, and fairly extensive. Further long duration interference tests are needed to more accurately determine the nature and location of geologic boundaries, and to assess the degree of heterogeneity in the reservoir.

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APPENDIX

Table 1

East Mesa 6-1 Temperature Profile (2/6/76)	
Depth ft	Temp. °F
100	112.4
200	132.4
300	146.6
400	155.8
500	167.7
600	179.4
700	185.3
800	201.5
900	209.9
1000	219.8
1100	229.5
1200	239.2
1300	248.4
1400	255.8
1500	263.6
1600	271.6
1700	280.1
1800	287.5
1900	293.9
2000	301.1
2100	307.5
2200	314.3
2300	319.6
2400	324.2
2500	328.0
2600	331.4
2700	334.1
2800	336.5
2900	338.7
3000	340.6
3100	342.2
3200	343.7
3300	345.2
3400	346.4
3500	347.8
3600	349.0
3700	350.0

Table 2

Smoothed Data Used in 6-1 Drawdown Analysis		
Time (t) hrs	Pressure psi	Δ P psi
46	553.872	.000
58	.851	.021
70	.806	.066
82	.752	.120
94	.698	.174
106	.648	.224
118	.604	.268
130	.566	.306
142	.533	.339
154	.505	.367
166	.480	.392
178	.456	.416
190	.433	.439
202	.409	.463
214	.382	.490
226	.352	.520
238	.316	.556
250	.272	.600
262	.220	.652
274 ← well closed	.156	.716

Curve fit:
$$P(t^*) = 1.12048 + 5.16897\, e^{-3.07743 \times 10^{-4} t^*} - .918103\, e^{-1.34148 \times 10^{-8} t^*}$$

Where: t = (34 hrs + t) x 60 min/hour

Table 3

6-1 Buildup: Smoothed Data			
Hrs Total Elapsed	Hrs From Shutin	Pressure psi	Δ P psi
280	6	.165	.707
292	18	.168	.704
304	30	.179	.693
316	42	.199	.643
328	54	.226	.646
340	66	.262	.610
352	78	.307	.565
364	90	.362	.510
376	102	.429	.443
388	114	.508	.364
400	126	.603	.269
412	138	.717	.155
424	150	.854	.018

Data obtained by adjusting fitted buildup curve to fitted drawdown curve. Presence of leaky boundary effects in drawdown data made buildup analysis fruitless. Data given here for completeness.

Table 4

East Mesa 8-1 Temperature Profile (2/8/76)	
Depth ft	Temp. °F
0	75
100	99.3
200	110.8
300	122.0
400	131.0
500	140.0
600	153.1
700	163.3
800	174.7
900	185.2
1000	196.8
1100	208.1
1200	218.3
1300	229.2
1400	239.3
1500	258.0
1600	256.8
1700	266.0
1800	273.0
1900	280.9
2000	288.1
2100	294.7
2200	300.7
2300	306.6
2400	312.3
2500	325.9
2600	347.5
2625	348.0
2650	348.2
2675	348.4
2700	348.5
2800	348.8
2900	349.2
3000	349.4
3500	350.7
4000	351.8
4500	352.8
5000	353.9
5500	356.6
6000	360.8

Table 5

East Mesa 31-1 Temperature Profile (1/28/76)	
Depth ft	Temp. °F
500	134.4
1000	164.5
1500	193.0
2000	222.6
2500	246.9
3000	262.7
3500	273.7
4000	385.1
4500	294.8
4750	299.8
5000	304.3
5100	306.3
5200	308.2
5300	311.3
5400	313.9
5500	316.2
5600	317.6
5700	318.5
5800	320.2
5900	322.0
6000	323.0

Table 6

R38-30 Drawdown Analysis: Smoothed Data		
Time hrs	Pressure psi	Δ P psi
0	726.180	0
15	725.840	.34
26	725.500	.68
38.5	725.100	1.08
49	724.800	1.38
62	724.480	1.70
77.5	724.100	2.08
86	723.900	2.28
100	723.600	2.58
111	723.400	2.78
121	723.200	2.98
143	722.800	3.38
154.5	722.600	3.58
169	722.400	3.78
183	722.200	3.98
196.0	722.000	4.18
215	721.800	4.38
234.5	721.600	4.58

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