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ANALYSIS OF PRODUCTION AND RESERVOIR PERFORMANCE AT THE CASA DIABLO GEOTHERMAL PROJECT

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Introduction

The Mammoth-Pacific geothermal project at Casa Diablo has been in production since January, 1985. The plant generates 7-8 MW of electric power using a binary system supplied by geothermal fluid production from four wells that produce about 3500 GPM of 340° F, low salinity geothermal fluid. The wells produce from a fault/fracture system that is apparently continually recharged from a deep "reservoir" with no significant drawdown in pressure or decline in flow rate over the 2 year period.

Prior to the start of production a series of well tests were conducted to determine the pumped flow capacity of the original four wells and to determine reservoir properties from pressured drawdown and build-up analysis. Since the start of operations a continuous record of production rate, flowing bottom-hole pressure, and temperature has been maintained. The well tests and production records have been evaluated to determine the nature of the reservoir and reservoir permeability and other properties. This paper presents the results of that evaluation.

Geology & Hydrology

The Long Valley KGRA exists in the collapsed caldera of a volcano that exploded 750,000 ybp. The caldera has been active since that time and has been partially filled by eruptions of tuffaceous and ryholitic material, basalt flows and the creation of several volcanic vents and other features such as the Inyo Domes. The magma body is apparently growing and possibly intruding to shallower depths causing, over time, the formation of a resurgent dome in the west central part of the caldera and considerable seismic activity.

The geology of the caldera is very complex. At depth, the remaining rocks of the original granites and metasediments exist as a large scale rubble of the collapse. These rocks occur at various depths throughout the caldera. Only a few wells have been drilled deep enough to find these rocks, but geophysical data combined with well data, indicates depths of several thousand feet. Overlying the granites and metasediments is a thick layer of tuffaceous material known as the Bishop Tuff. These rocks were erupted during and after the explosion of the caldera and occur in layers of varying thickness over most of the caldera area. Well records indicate Bishop Tuff sequences several thousand feet thick in several areas. In some cases Bishop Tuff is interbedded with rhyolites and other rocks and surface outcrops have been mapped at several places in the caldera.

In most of the caldera, but particularly in the area of the resurgent dome, the Bishop Tuff is overlain by sequences of rhyolite flows that are of variable thickness but are recorded as several hundred to 2000 ft. in some wells. The rhyolites appear to be the result of an intermittent series of eruptions and surface flows over time. Near and on the surface rhyolites are often interbedded or overlain by basalts of varying age. The basalt flows are most common in the western caldera on the southwest margin and around the resurgent dome. Finally, the partial filling of the caldera until relatively recent time by a lake resulted in the accumulation of lacustrine and deltaic deposits, particularly in the large area southeast of the resurgent dome. Glacial moraines and alluvial deposits are the dominant surface materials at the caldera/sierra boundary.

As the result of the collapse of the caldera, subsequent magma intrusion and resurgence, and continuous seismic and tectonic activity, the entire long valley area is heavily faulted with caldera ring fault(s) circumscribing the entire valley and a large number of active and dormant faults which generally trend in a northwest-southeast direction. These fault trends and the fractured zones proximate to the faults are generally characterized by fumeroles, hot springs, volcanic vents, hydrothermal alteration of surface and subsurface rocks, and high thermal gradients.

The complex geology of the caldera and its location near a major source of meteoric precipitation in the Sierras gives rise to an equally complex hydrologic system that can be described as one of the largest geothermal systems in the U.S. Intense field geologic work, geophysical and geochemical studies, and well drilling by industry and government agencies has resulted in a large volume of data about the system. The data available indicate general system where meteoric water from the Sierras enters the subsurface system through the caldera ring faults and other faults near the base of the mountains, and flows deep into the system coming into contact with the basement rocks heated by the magma body. The water is continually heated as it flows under hydraulic head through the basement rocks and, possibly, the Bishop Tuff in a general east-southeast direction. Various estimates of the temperature of this hot water reservoir reach 219°C at depth based on geochemistry. Flow through the system is relatively slow with residence time of 2000-3000 yrs. being estimated based on chemistry.

While most of the fluid eventually exits in the Hot Creek Springs and Lake Crowley, some reaches the surface at various points throughout the caldera by traveling up faults and fractures to form the hot springs and fumeroles found at Casa Diablo, Hot Bubbling Pool, and other places. This flow to the surface requires the existence of an open flow path in the fault plane and is highly subject to occasional closure and re-opening of the flow path(s) by chemical deposition and seismic activity. The large amount of evidence of hydrothermal activity at certain points on defined faults, and the lack of evidence of activity in non-faulted areas, indicate that while the Long Valley geothermal system is pervasive at depths of 2-4 miles, access to the system for commercial development is probably limited to a few sites where fluid reaches or approaches the surface in sufficient volume and at a temperature to be useful.

Casa Diablo is one of those locations. The hot springs and fumeroles of the area have been described for over 100 years. Extensive well drilling since the early 1960's has defined, with considerable clarity, a geology and hydrologic system consistent with the overall Long Valley model. Casa Diablo lies on the west margin of a graben block, known as the Keystone graben, that extends in a south-southeasterly direction from the resurgent dome and appears to reach a convergence at a point to the southeast of Casa Diablo. The exact extent of the graben and the definition of its composite faults is not completely defined, but continued drilling will eventually complete the picture.

The graben in the area of Casa Diablo is formed by the Taylor-Bryant (TB) fault and several smaller faults with surface exposure that together trend in a shallow arc from southeast to northwest enclosing the Casa Diablo area within the arc. The surface geology consists of recent rhyolite flows to the north and northeast with several areas of hydrothermal alteration. The south-southwest border is composed of basalt flows. The low area between the resurgent dome rhyolite flows and the faulted basalt flows is a marshy area with fluvial and other sediments punctuated by hot springs and occasional mud pots.

Depending on location, wells drilled in the area encounter basalts or sediments down to 50-100 ft of surface and then enter a sequence of rhyolite flows that extend to about 1000 ft. from surface. Detailed lithology from mud logs indicate considerable differentiation within the rhyolites with significant alteration and calcite deposition noted in fissures and fractures. Below the rhyolites, wells enter a thick sequence of Bishop Tuff that has been measured in one well to a depth of 4510 ft. At the rhyolite-tuff boundary there is some interbedding. High temperatures and geothermal fluid flows have been encountered in virtually every well drilled at Casa Diablo, although, as will be discussed below, some wells are better than others. Fluid entry points and maximum temperature points are not at uniform depth and appear to be confined to relatively thin intervals in the wells.

Development of Casa Diablo

The development area of the Casa Diablo project is relatively small comprising 40-80 acres. Present plans call for expanding the productive area in the north-northeast direction and potentially to the southeast following the evidence of fault trends and hydrothermal features, and the results of reservoir engineering and geologic evaluation.

The first wells were drilled at Casa Diablo as water wells and very shallow wells to exploit the hot springs. Commercial geothermal exploration did not occur until eight wells known as Endogenous Nos. 1-7 and M-1 were drilled by cable tool to depths of 400-800 ft. in 1959-1962. Temperature measurements were taken and the wells were completed with surface casing and open hole. None of the wells were logged and no mud logs were made except as notes on the drilling reports. All of the wells were tested in 1961 and 1963 which indicated that high flow rates of water in excess of 300° F could be obtained from shallow depths. While the flow rates varied and some difficulty with calcite deposition occurred due to steam flashing, the tests generally confirmed a geothermal resource in the immediate area of Casa Diablo. In 1979 Union Oil Co. drilled a well to 5265 ft. total depth which found basement rocks at 4510 ft. and recorded two high temperature peaks at about 400 ft. in rhyolite and 2200 ft. in Bishop Tuff.

Following an analysis of available data and completion of a resource assessment, the Ben Holt Company drilled four producing wells and an injection well at Casa Diablo and recompleted Union Mammoth No. 1 in late 1983 and early 1984. The production wells, known as Mammoth Binary Power (MBP) Nos. 1,2,4, and 5, were completed with shaft turbine pumps at depths of 650-670 ft. at locations which generally followed the surface expression of the Taylor-Bryant fault or local cross fault traces. All the wells were logged and detailed mud logs were obtained. Temperature surveys were run shortly after completion.

Subsequent to the startup of plant operation in November, 1984 MBP-3 was drilled; MBP No. 2 was abandoned; a third injection well was drilled; and a production test well has been drilled at a location to the southeast of Casa Diablo.

Well Test Program

In June, 1984 as the Mammoth Binary Power plant was nearing completion, a series of flow tests were conducted by MBPC and Pacific Resources Management, Inc. (PRMI) to determine: the stabilized flow rates to be expected from the four wells then available; if additional wells were necessary; if the two injection wells were adequate; and to obtain, if possible, any reservoir information that could be derived from pressure build-up/drawdown tests.

The test program was designed to test each well individually and to maximize the amount of reservoir data that could be obtained. The program included several steps.

1. Static pressure/temperature (P/T) profiles were taken in each well including the injection wells.

2. Each well would be produced on pump as a constant rate for a fixed time period to record flow rate, temperature, flowing BHP, and pump efficiency. The pumps had only one speed and attempts

to control rates by varying back pressure proved futile.

3. BHP was recorded during production startup and shut-in to obtain drawdown and build-up data.

4. Pressures were recorded in offset wells to determine if interference would occur between wells.

The pressure/temperature profiles were obtained uneventfully and a wireline pressure recorder was installed in Endogenous No. 2 to record interference effects if they occurred. Flow rates were measured using an orifice meter. Fluid temperature was measured by a thermocouple at the wellhead. BHP was measured using a nitrogen bubbler tube where the bottom end of the tube was set just above the top of the pump. Annulus pressure was also measured. All data points were electronically connected to a digital read-out and plotter which recorded a total of eight data points each 5 seconds.

The data measurement and recording system used during the tests was complicated and not without problems in operation such as premature disconnection of recorders and N_2 supply. Despite the problems a significant amount of data was collected and the objectives of the tests were satisfied.

Test Results

All four producing wells are completed with slotted liners in the rhyolite. The mud logs and wireline well logs show very similar characteristics in each well with some variation, particularly with depth, from well to well. Well MBP No. 4 is described here as an example.

In MBP No. 4 the well logs and the mud log on the well were analyzed to determine the apparent location of fractures and matrix porosity. The mud log indicates that the well entered rhyolite at about 80 ft. The lithology to TD varies including altered rhyolite and intervals of glassy rhyolite and demonstrates considerable calcite deposition in fissures and fractures. The Neutron-Density Logs indicate an interval of apparently high porosity from about 415 ft. to 485 ft. The high porosity is not continuous through the interval but appears to be concentrated in 4 or 5 streaks. The interval corresponds to a zone of rhyolite glass that extends above and below the interval. The caliper log indicated an extreme deviation to increased hole size over the interval with hole size diminishing to near bit gauge above and below the interval. About 10% lost circulation was recorded over the interval from 413 ft. to 443 ft. Temperatures recorded during drilling reached a maximum in the upper part of and just above the 415 ft.-485 ft. interval.

A second interval from about 595 ft. to 620 ft. appears to include a number of high porosity streaks and some minor temperature increases were recorded during drilling. Lost circulation occurred deeper in the well at 648 ft. The porosity measurements recorded by the Neutron-Density logs and the caliper deviation is generally equal to the deviation recorded for the upper interval.

It would appear that the well penetrated one or more fractures in the interval 415 ft. to 485 ft. and that these fractures are the major source of fluid flow in the well. An exact determination of the depth of a fracture or the thickness is not possible since the brittle nature of the rhyolite (glass) probably caused the rock to shatter and break up immediately about the wellbore as the succession of fractures was penetrated. It is possible that the fracture interval is the intersection of the Taylor-Bryant fault the surface trace of which passes within 40 ft. of the well surface location.

Two separate flow tests were run on the well with nearly identical results. The first test was run for almost 2 days starting at about 19:40 of June 28, 1984. After several false starts, due to mechanical problems with the pump motor, a sustained flow was established at about 22:45 on June 28. The maximum flow rate of about 1,020 gallons per minute (GPM) was maintained for about 5 minutes. The flow rate was then reduced to allow a check of the bottom-hole pressure (BHP) data recording. The rate fluctuated between 250 and 800 GPM for about an hour while the BHP recorder was determined to be correct.

At midnight on June 28, 1984, production was increased gradually to about 890 GPM and a sustained flow was started. At this flow rate the fluid temperature was recorded continuously as 347° F. BHP was recorded as 230.6 psig with about 300 ft. of fluid over the pump.

Flow was maintained for about 5 hours after which the well was shut-in. During the flow period the rate declined gradually from 890 GPM to 810 GPM at shut-in with no change in BHP. Over that period the fluid level showed some fluctuation, but generally declined from about 300 ft. to 291 ft. over the pump while pump discharge pressure increased from 480.1 psig to 494.1 psig. Fluid temperature remained essentially constant at 347° F.

The second flow test was conducted on July 6, 1984. During this test, flow rates were held relatively constant at four successively higher rates over a total test period of about 6 hours. The results of this test are summarized in Table 1.

It is apparent that MBP No. 4 is an extremely good producing well which is probably being supplied by an extensive fracture system. The water produced was very clean and is very low salinity. While there is no direct evidence, the high flow rates, very low drawdown, high temperature, and proximity to the fumeroles and the Taylor-Bryant fault trace offer the possibility that the well penetrates a fault or the fractured area immediately proximate to the fault that is a primary fluid channel.

There is no pressure build-up analysis on this well since the small pressure drawdown offers no opportunity for significant build-up to occur.

Analysis of the other wells indicated similar geology and reservoir conditions.

In MBP No. 1 fluid entry was defined as an interval between 595 ft. and 628 ft. which is very similar to the rhyolite glass interval in MBP No. 4. The flow tests were plagued with mechanical problems and a good test was not obtained until July 7 when the well demonstrated rates of 472-632 gpm at BHP between 208.9 and 194.9 psi respectively. BHP drawdown was determined to be 19-33 psi. The average PI is 22 GPM/psi. No pressure build-up or drawdown data of value was obtained.

In MBP No. 2 the fluid entry point(s) are less clearly defined and appear to be inflows through fractures and fissures in the rhyolite too small to be apparent on logs or to cause notable fluid loss during drilling. The well ultimately had more tests run than any other well. Over a series of short duration flows the well demonstrated an ability to produce in the range of 500-600 gpm but with a considerable 50-80 psi drawdown over the period of the test. The well is apparently highly sensitive to flow rate and is not well connected to the hydrothermal system. A 100 minute flow on June 29, 1984 demonstrated a decline in flow rate from 639 gpm to 360 gpm with a corresponding decline in FBHP from 143.1 psi to 117.1 psi. Following shut-in pressure build-up to original BHP required about 3 hours.

MBP No. 5 exhibits geology and fluid entry characteristics very similar to MBP No. 4 with the exception that MBP No. 5 is on the up-thrown side of the TB fault. Fluid entry appears to be from a fractured interval at 410 ft.-450 ft. Four flow tests of short duration were run on the well. The last three tests demonstrated maximum flow of 524 GPM with a more stable range around 350-400 GPM and pressure drawdowns 40-50 psi. A fifth test run on July 3, 1984 indicated a range of flow rates from 525-646 GPM with maximum drawdown of 88 psi.

It is apparent from the production tests that performance by the wells is not uniform and that various geologic and other factors appear to influence flow rates and the drawdown/build-up response of the individual wells. Fluid entry points are rather readily defined from a combination of data and analysis. Correlation of well performance and general geology leads to the conclusion that the most favorable performance is obtained from the wells located close to and on the down side of the Taylor-Bryant fault (MBP No. 4 & No. 1) while apparently restricted performance was obtained from MBP No. 5 (on the up side of the Taylor-Bryant fault) and from MBP No. 2 which seems to have been completed in an area where fluid connectivity through faults and fractures is not good. Both the latter wells exhibited drawdowns during production that continued throughout the test indicating a restricted fluid source.

Pressure and Build-up Analysis

In some respects the pressure build-up and drawdown tests were disappointing but as a secondary objective of the test program some very interesting results were obtained. The test of MBP No. 4 demonstrated flow rates to the maximum of pump capacity with a measured drawdown of only 2-3 psi. When production was stopped or started build-up and drawdown occurred almost instantaneously so that only one or two data points at most were obtained allowing no analysis. Intermittent pump problems and malfunctions of the N_2 system prevented any useful data collection from MBP No. 1 except to note that pressure response was very rapid following high flow rates. Only MBP No. 2 and No. 5 demonstrated sufficient drawdown or build-up to allow analysis to be done. We are then in the curious position of being able to analyze only the two least productive wells with results that probably form the base line of data regarding reservoir properties at Casa Diablo.

A series of five flow tests were run on MBP No. 5. BHP build-up analysis was done following three of the flow periods. All of the build-up analyses were re-evaluated using computer techniques in 1987. While all three contributed useful information the build-up following the second test was considered most useful. This analysis was done using cross-plotting techniques described by El-Hadidi for vertically fractured wells. Analysis indicates virtually no afterflow. The log-log plot indicates two linear flow intervals separated by a possible radial flow segment. The plot ends with an apparent radial or pseudo radial flow - segment. Other cross plot techniques indicate linear flow separated by possible radial flow segments. The parts of the data that indicate linear flow represent the surface of the fracture intersecting the well bore. The pseudo radial flow portion of the build-up curve is used to calculate Kh for the well. Pressure build-up on successive days following further flow tests indicated virtually identical performance except that the radial flow portion separating the two linear segments diminished leaving one linear portion followed by a radial flow portion. Calculated Kh from the radial flow portion increased with each test as shown in Table 2.

Among other problems MBP No. 5 had considerable lost circulation during drilling and the improved performance may well be the result of cleaning out of fractures during testing. The well does however appear to be somewhat limited in flow capacity as demonstrated by the significant drawdown in the well even during the fifth test and, as will be seen, during sustained production. This overall result is interpreted to mean that despite a very high Kh and apparent connection to a fracture/fault system the well does not have the same level of access to the flow system as do MBP Nos. 1, 3, and 4.

A series of three pressure build-up analyses in MBP No. 2 demonstrated very similar but lower level performance to MBP No. 5.

Analysis of Results

The very high Kh values, the lack of any definable after flow even in wells where some drawdown had occurred, and the virtual lack of any drawdown in MBP No. 4 seems to indicate that flow in the system is entirely fault/fracture dominated with no matrix flow. It seems clear when combined with the geology of the system, as shown in the lithology and well logs, that wells drilled into the Casa Diablo geothermal system must contact either the Taylor-Bryant fault, one or more of the fracture zones nearby the fault, or a well connected cross fault/fracture zone.

As a result of the flow test program and the reservoir evaluation that followed the program, MBP No. 3 was drilled to provide additional flow capacity for the plant. The location of MBP No. 3 was sited based on the apparent location of the TB fault intercept at a depth essentially equivalent to MBP No. 4. Unfortunately no logs were run on the well and the lithology log is of limited value. No controlled flow tests or pressure build-up/drawdown analyses have been done. A temperature profile indicates inflow at approximately the same depth as in MBP No. 4.

Production History Evaluation

Continuous operation of the Mammoth-Pacific plant at Casa Diablo began in January, 1985 with production from MBP No. 1. The other wells began production on a continuous basis in March and April, 1985. Plant changes, shutdowns and modifications occurred with some frequency throughout early 1985 but full operation was finally achieved in late 1985. Performance of the plant and wells since that time has been generally good with production through most of 1986 and the first half of 1987 being relatively consistent. This "stabilized" production period has been used to assess the reservoir and its properties by attempting to calculate production histories that would match the actual history based on assumed reservoir conditions.

Sources of Data

The data measuring and recording system at Casa Diablo has changed considerably over the time period included in this study. These changes have some influence on the use of data for analysis and require that certain adjustments be made to some data.

Production Rates - Prior to December, 1986 total flow was recorded as plant inlet volume on an orifice meter. Individual well volumes were estimated from pump curves based on amperage. The total fluid production was then apportioned back to each well based on pump curve rates. Only MBP No. 3 was directly measured by vortex meter. Orifice meters were installed on MBP Nos. 1, 4, and 5 in December, 1986. Completion of full instrumentation on the wells had not been completed as of the time of this study, however, it appears that an 8-10% adjustment in previously recorded flow rates is warranted. Also in December, 1986 flow rates began to be reported at 60° F rather than actual flowing temperature. The result would be a correction of 1.0932 reducing the apparent or reported flow volume. The temperature correction is for standardization purposes only. The reservoir volume is at reservoir temperature and is the volume that is used for analysis. Flow rates were recorded three times per day.

Fluid Temperature - Flowing fluid temperature is recorded three times each day from a dial thermometer at wellhead.

Bottom Hole Pressure - BHP is obtained from a surface reading of an N_2 bubbler tube on each well. The bottom of the bubbler tube is located just above the pump. All readings until recently were taken at surface. Prior to April, 1986 the fluid of height above the pump discharge was recorded. Since April, 1986 the calculated BHP is reported. There is no N_2 correction from surface to BHP.

Prior to the start of analysis all the data was reviewed for obvious errors and inconsistencies. All BHP data was corrected to the mid-point of fluid entries. To the extent possible, all data were corrected for known and quantified systemic recording or reporting errors. This error correction is not considered to embrace all such errors that might be required.

Overall Production History

In general, the wells supplying the plant have performed well since the start of operation. MBP Nos. 1, 3, and 4 supply relatively equal (at April, 1987) shares of total production. MBP No. 5 is a weak producer that is brought on intermittently as needed. MBP No. 2 was abandoned for mechanical reasons in 1985. Total production averages 3500 GPM of 340° F fluid. Large variation in flow rates is more often a function of plant and/or pump operation than any apparent well or reservoir problems.

Individual Well History/Analysis

Production rate, pressure, and temperature data for each well was obtained on a daily basis from January 1, 1985 to April 30, 1987 and was entered into a computer database. Corrections were made to the data as noted above and data points with obvious errors were noted. The data for each well was then plotted in several graphical forms to obtain a portrayal of the data over the full time frame.

In attempting to model certain aspects of the Casa Diablo system by matching calculated results to actual performance several assumptions were made and complications were considered.

1. The wells were assumed to produce from an infinite acting, recharged reservoir so that Pe was kept constant for the study period. Pe was taken as the measured SIBHP adjusted to the mid-point of fluid entry.

2. Flow rate was selected as the variable to be matched.

3. It was assumed that changes in pump efficiency, instrument deterioration, and recording errors could not be modeled or compensated.

4. Because of the relatively narrow range of data such as BHP for MBP Nos. 3 and 4, relatively small changes in input values were found to cause large variations in results.

MBP No. 3 - As the first well evaluated MBP No. 3 was used to establish a model form and equation. It became quickly apparent that the high volume and low drawdown could not be accommodated by matrix flow models and required a form of fracture flow/linear flow model. In practice, however, use of a linear flow model requires more definitive knowledge of fracture dimensions than is available. Based on the geology of the "reservoir," an infinite line source model was chosen as most representative of the conditions extant in the Casa Diablo reservoir:

$$q = \frac{0.2065\ Kh\ (Pe-Pw)}{\mu w \beta w\ \ln\ (2D/rw)}$$

where "D" is the distance from the well to the line source - in this case the TB fault.

The production histories in terms of daily flow rate and flowing BHP are presented as Exhibits III-VI. The flow rates indicate considerable variability while BHP is much less variable. Reasonably good matches to the flow rates were obtained in MBP Nos. 1, 3, and 4 considering that the flow rate is not always correlatable to BHP. It was found, however, that good matches were obtained over the short periods of production/pressure stability and that these periods established a base for assessment of the fluctuation periods.

The primary difficulty in matching flow rate is the very low difference between Pe and Pw. In MBP No. 4 Pe-Pw averages 11.4 psi with a standard deviation of 1.4 psi. A change of 1 psi has a major effect in these circumstances.

In MBP No. 4 a relatively good match of flow rates was attained at Kh = 456,100 md. ft. used over the period April 1, 1986 to April 30, 1987.

In MBP No. 3 matching was generally better than for MBP No. 4 despite the same low differential between Pe and Pw using an average Kh of 554,000 md. ft. over the same period. Average Pe-Pw over the period is 9.7 psi with a standard deviation of only 1.9 psi.

The best match was obtained in MBP No. 1 where Pe-Pw averaged 25.2 psi with a standard deviation of 3.7 psi. In this well, Kh found to be about 195,000 md. ft. While this is considerably lower than MBP Nos. 3 and 4, it is consistent with the well location and geology and with well performance.

Table 1. Well Test MBP No. 4 (July 6, 1984)

Flow Rate (GPM)	Duration of Flow (minutes)	Avg. BHP (psig)	Avg. Fluid Temperature (°F)	Fluid Level (ft.)
610	55	227.9	345	310
720	65	226.8	353	310
800	100	226.0	348	289
950	65	225.9	348	288

Table 2

Date	Kh
6/27/84	74,101 md. ft.
6/28/84	199,898 md. ft.
6/29/84	417,455 md. ft.

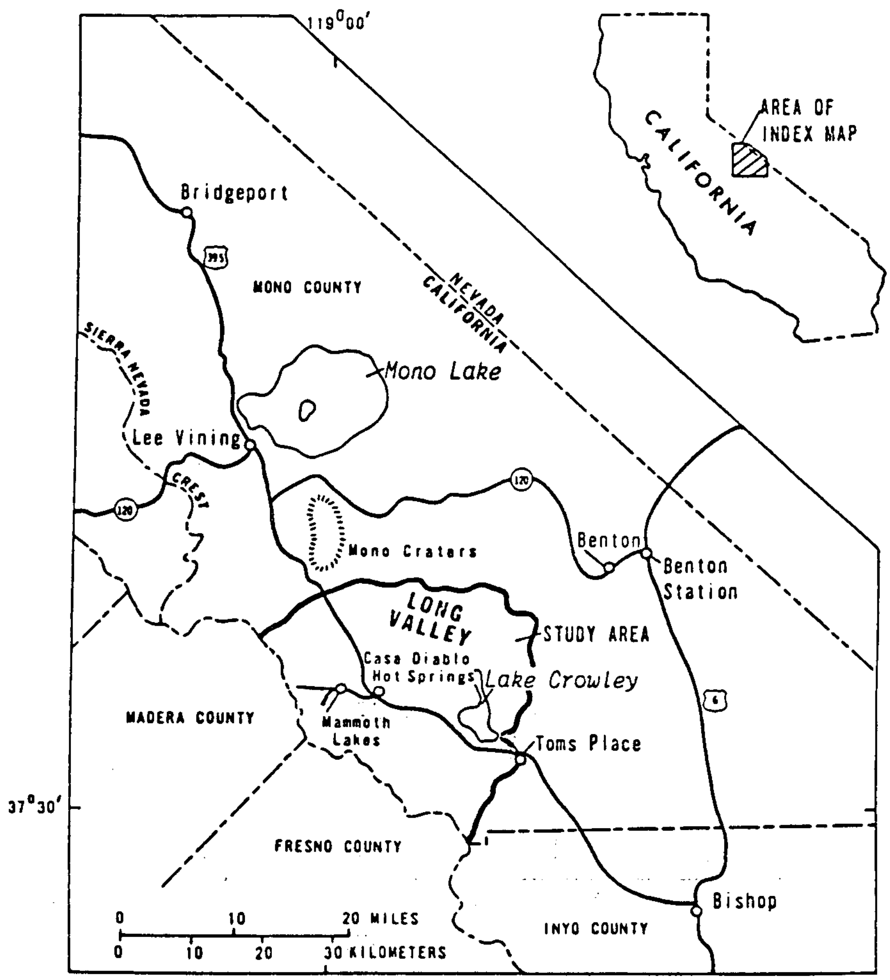


Figure 1. Regional location map - Long Valley (After Sorey et al.)

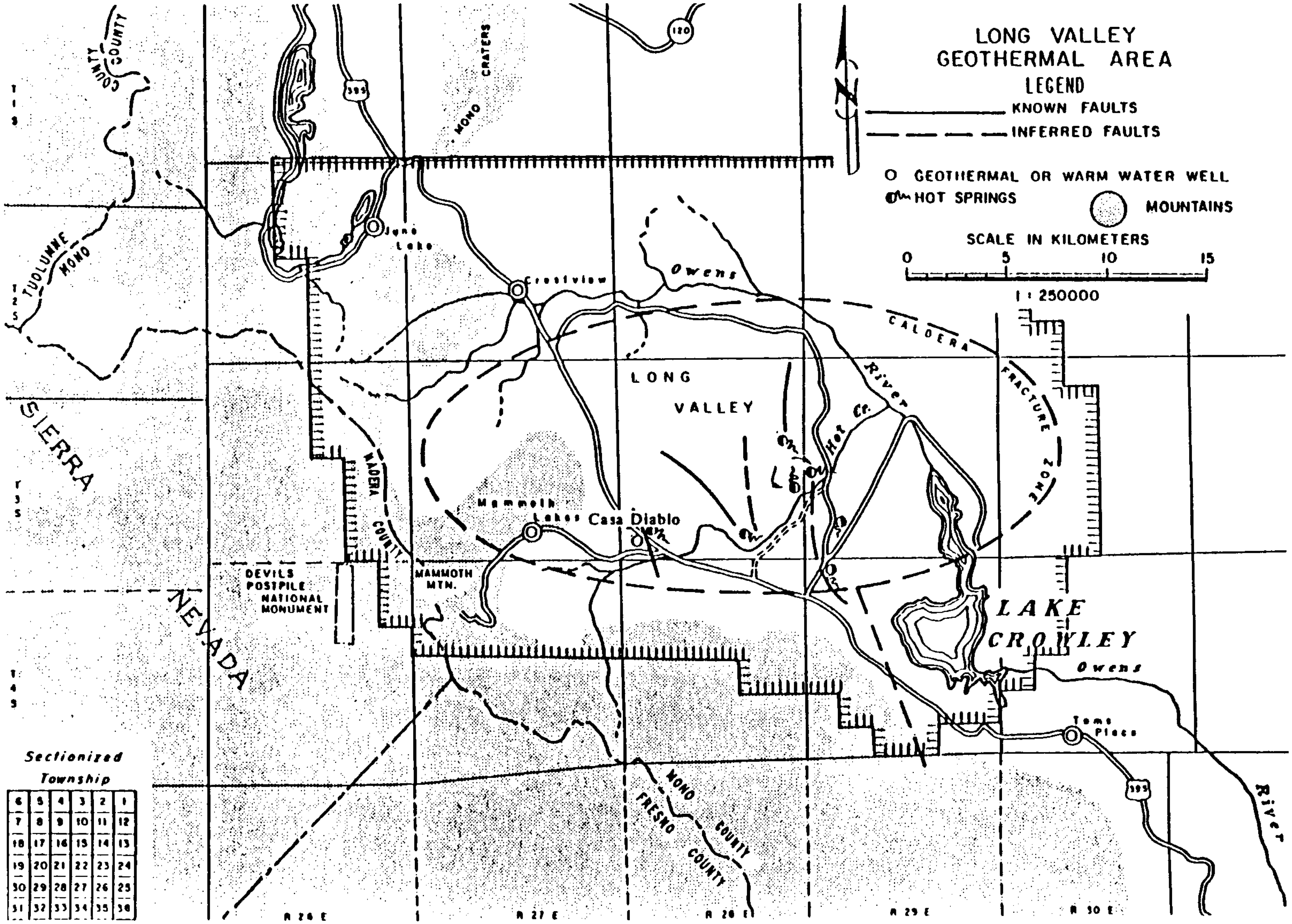


Figure 2. Area location map - Casa
Diablo and Long Valley
(After Sorey et al.)

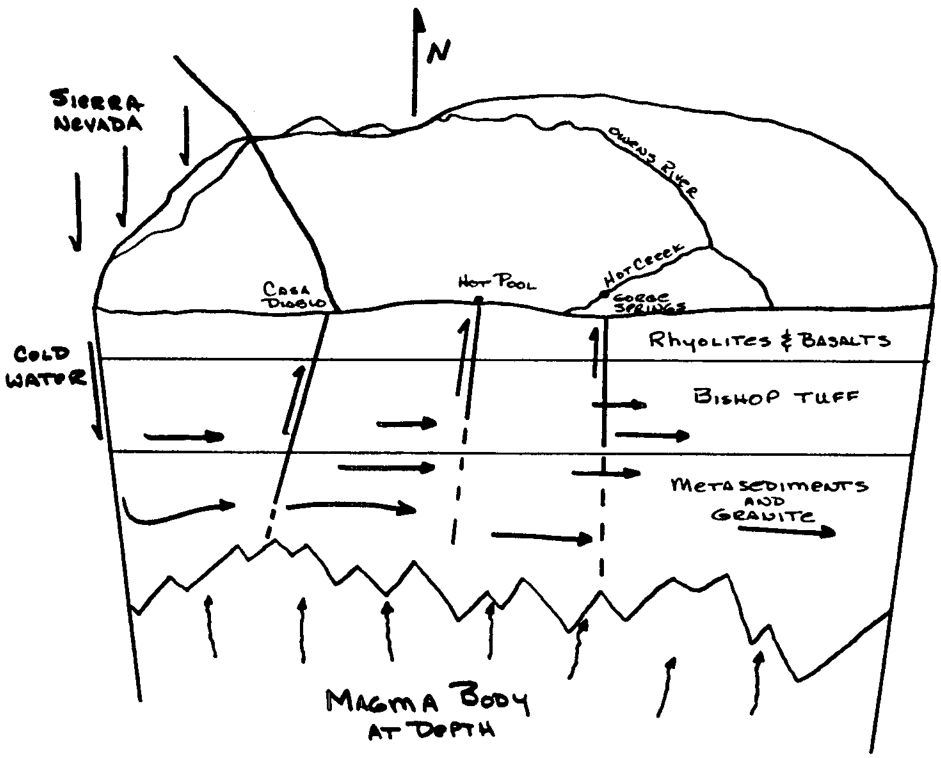


Figure 3. Conceptual model of Long Valley geologic and hydrologic system (After Sorey et al.)

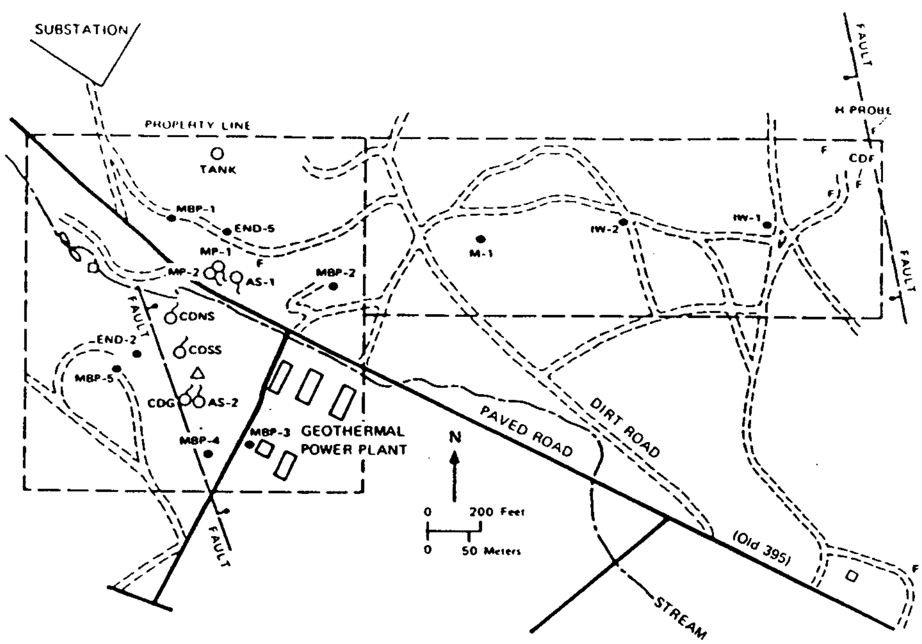


Figure 4. Casa Diablo well location map (After Farrar et al.)

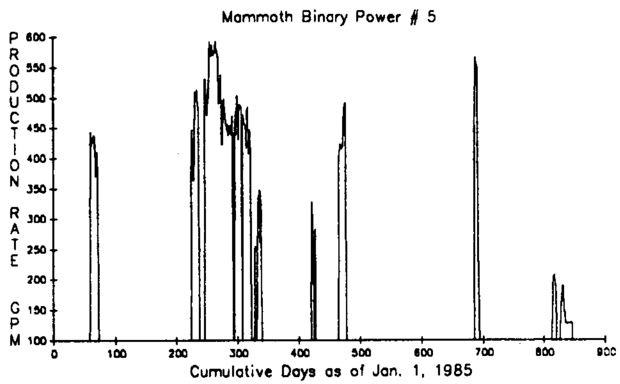
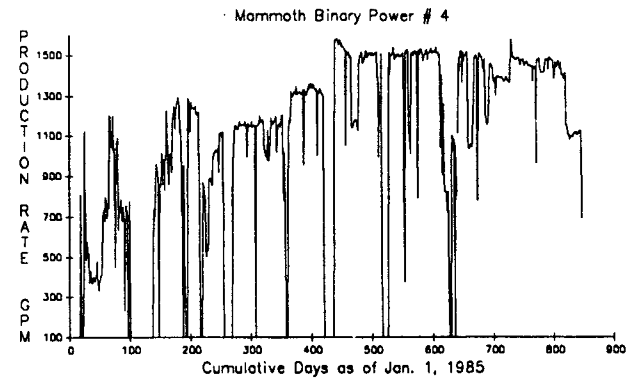


Figure 5a. Pressure buildup test on MBP No. 5 on June 27, 1984



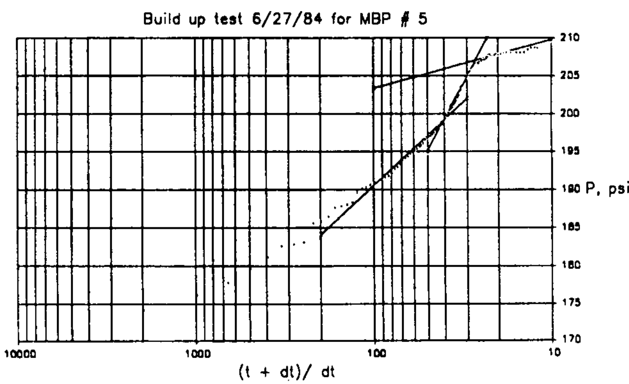


Figure 5b. Production rate performance - MBP No. 5. January 1, 1985 to April 30, 1987

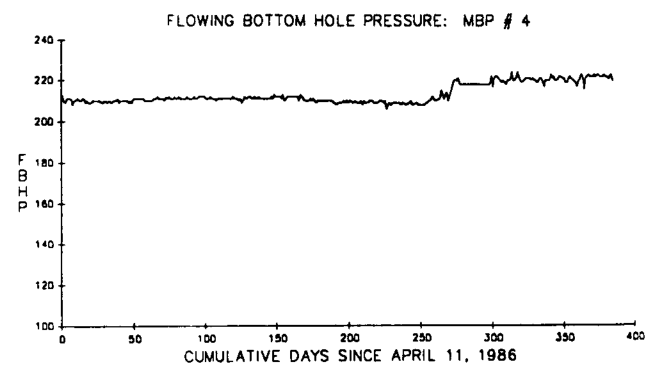


Figure 6. Flowrate and FBHP (uncorrected)- MBP No. 4. January 1, 1985 to April 30, 1987

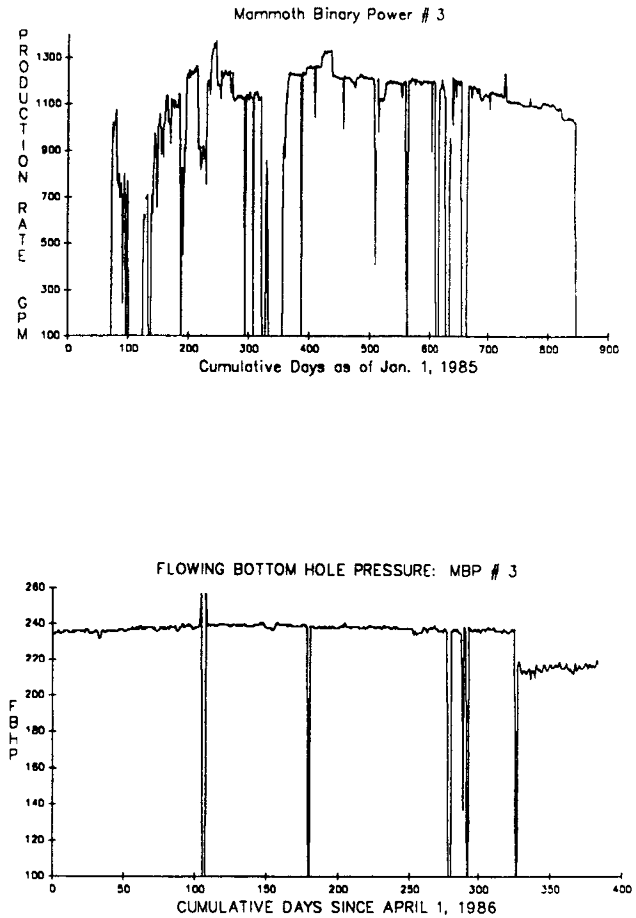


Figure 7. Flow rate and FBHP (uncorrected) - MBP No. 3. January 1, 1985 to April 30, 1987

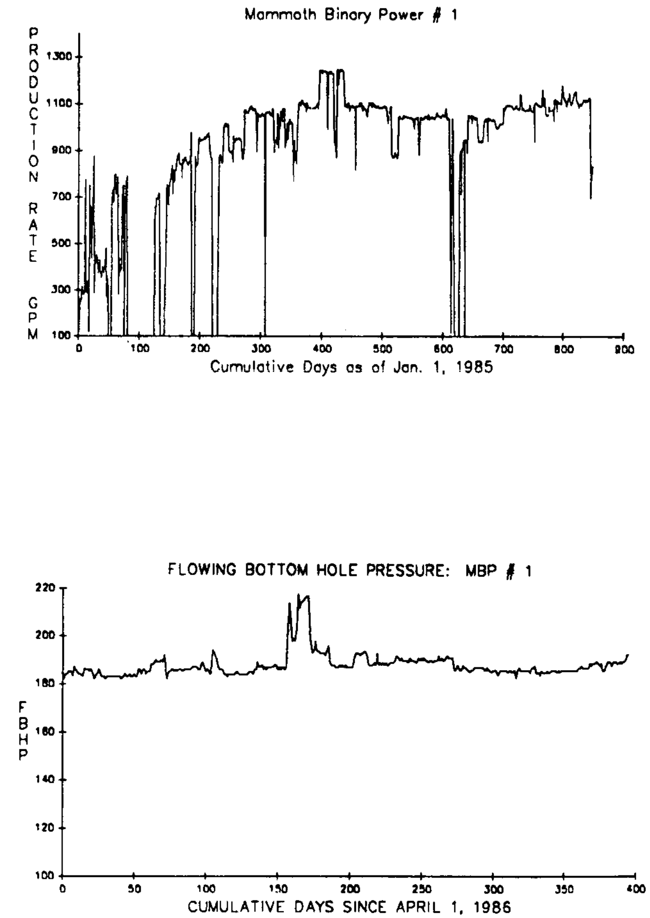


Figure 8. Flowrate and FBHP (uncorrected) - MBP No. 4. January 1, 1985 to April 30, 1987