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A SUMMARY OF WELL-TESTING ACTIVITIES AT LAWRENCE BERKELEY LABORATORY, 1975-1983

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A SUMMARY OF WELL TESTING ACTIVITIES AT LAWRENCE BERKELEY LABORATORY, 1975-1982

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ABSTRACT

This paper presents well test data collected from various geothermal fields by the geothermal group at Lawrence Berkeley Laboratory. The paper describes the type of well tests conducted, the instrumentation used and the data collected. Experience gained through interpretation of the data has helped identify problems in test procedures and interpretative methods.

INTRODUCTION

Since 1975 the geothermal group of the Earth Sciences Division of the Lawrence Berkeley Laboratory (LBL) has carried out extensive well testing in geothermal resources throughout the western United States and in northern Mexico (Figure 1). Data from these production, injection, interference, variable-rate, and multiple-well tests represent considerable experience in geothermal well test procedure, instrumentation, and data acquisition. Interpretation of the data has yielded many opportunities to identify and record classical reservoir engineering and geohydrologic problems.

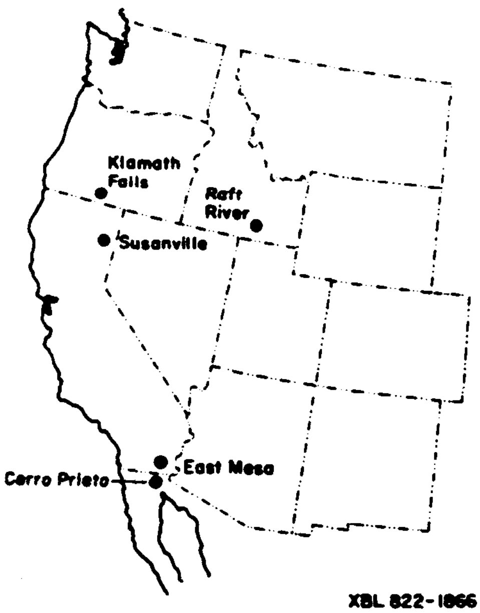

Figure 1. Location map of geothermal resources tested by LBL.

In response to the many requests LBL has received for the accumulated well test data and associated information, a report entitled "Well Test Data from Geothermal Reservoirs (1975-1982)" (Bodvarsson and Benson, 1983) has been prepared. The report documents the reservoirs tested, the various tests conducted, and the data obtained. It also describes the techniques and instrumentation used to collect the data. The present paper summarizes that report and provides excerpts of the information it contains.

GEOTHERMAL WELL TESTS

The geothermal reservoirs tested to date by LBL are widely varied both geologically and hydrogeologically, and include high-temperature (300°C), low-temperature (60°C), single-phase (liquid), and two-phase systems. The range of boundary conditions encountered include systems that are closed, open, confined, semiconfined, fault-charged, and fracture-controlled. Permeabilities ranging from several millidarcies to hundreds of darcies have been calculated from the data. Negative skin values and very high positive skin values have been computed in either naturally fractured or hydraulically fractured wells. Even very clear evidence of a near-wellbore turbulent flow regime has been detected in a fractured, liquid-water hydrothermal system.

The well tests conducted within each resource include production, injection, and interference tests, and as such are varied in type, duration, and sophistication. A variety of well test instrumentation, ranging from quite simple to highly sophisticated, is used, including: gas- and fluid-filled capillary tubing, quartz crystal pressure gauges, float type water-level gauges, wellhead and downhole temperature gauges, and other commercially-available or LBL-designed and fabricated instrumentation.

Table 1 lists the well tests conducted by LBL. Available information about these tests includes: test descriptions, instrumentation used, brief results of data interpretation, the calculated hydrologic parameters, and special or unique characteristics of geothermal (or hydrologic) systems inferred from the data.

The following are selected examples of well tests performed by LBL. Descriptions of other well tests are given by Bodvarsson and Benson (1983).

Table 1. Well Tests.

Geothermal Reservoir	Type of Test	Production Well(s)	Observation Well(s)	Injection well(s)	Test Dates
Raft River	production	RRGE 2	--	--	9/12/75 - 9/13/75
Raft River	interference	RRGE 2	RRGE 1	--	9/30/75 - 10/30/75
Raft River	production	RRGE 1	--	--	11/ 4/75 - 11/ 7/75
East Mesa	interference	6-2	6-1, 8-1	--	2/13/76 - 2/24/76
East Mesa	interference	31-1	38-30	--	4/ 1/76 - 4/12/76
East Mesa	interference	6-2, 6-1	6-1, 8-1, 31-1, 44-7, 38-30	--	2/10/77 - 4/13/77
East Mesa	interference	38-30	56-30, 31-1, 16-29	18-28	7/14/77 - 7/18/77
East Mesa	interference	16-29	56-30, 31-1, 16-30,	18-28	7/26/77 - 7/30/77
East Mesa	interference	38-30	56-30, 31-1, 16-30, 78-30	18-28	8/24/77 - 10/ 5/77
East Mesa	injection	--	--	5-1	12/ 1/77 - 12/ 6/77
East Mesa	production	8-1	--	--	12/16/77 - 12/20/77
East Mesa	interference	8-1, 44-7, 6-2	6-1, 48-7	46-7	1/ 6/78 - 3/29/78
East Mesa	production	6-2	--	--	4/17/78 - 4/21/78
East Mesa	production	6-1	--	--	5/ 2/78 - 5/ 4/78
Cerro Prieto	interference	M-50, M-51, M-90, M-91	M-101	--	1/14/78 - 3/30/78
Cerro Prieto	interference	M-53	M-104, M-10	--	5/16/78 - 7/24/78
Susanville	interference	LDS Church	Naef	--	7/26/78 - 11/29/78
Susanville	interference	Davis, S. Pool, LDS Church	Suzy 3, Suzy 4 Naef, LLB #2	--	12/10/78 - 1/ 8/79
Susanville	production	WEN-1	--	--	3/ 3/82 - 3/ 8/82
Klamath Falls	interference	YMCA #2	YMCA #1, Adamcheck, Glen Head	--	12/ 2/79
Klamath Falls	interference	CW-1	Parks, Adamcheck Glen Head	--	10/24/79 - 10/25/79
Klamath Falls	interference	CW-1, CW-2	Parks, Olson, Stanke, C.C.	--	9/29/81 - 9/30/81
Klamath Falls	interference	CW-2	Parks, Stanke, Olson	Museum	2/ 8/82 - 2/12/82

CERRO PRIETO GEOTHERMAL RESOURCE BAJA CALIFORNIA, MEXICO

Resource Description

The Cerro Prieto geothermal resource is located near Mexicali, in Baja California, Mexico. The producing field is situated in the alluvial plain of the Mexicali Valley, which is part of the seismically active Salton Trough/Gulf of California rift basin system. The field is made up of a thick sequence of essentially deltaic deposits that are discordant upon a granite and metasedimentary basement. Several major strike-slip faults have been identified within the resource.

Lithologic studies indicate that several major producing intervals lie at depths of 500 to 1900 m. The resource is a liquid-dominated system which shows boiling near the producing wells. Fluid temperatures in the resource range from 260° to 350°C. It is thought that secondary matrix porosity and permeability may play important roles in the hydrology of the reservoir.

To date (1982), approximately 100 deep wells have been drilled into the reservoir (Fig. 2). Roughly 33 of these wells, ranging in depth from 1000 m to 2500 m, supply a steam-water mixture to the geothermal power plant, operational since April 1973. The artesian production rate of the water-steam mixture from the wells is now close to 4300 tonnes/hr.

The following well tests were performed by LBL during the period January through July 1978. The tests were undertaken as part of a joint effort of LBL and Comisión Federal de Electricidad de México (CFE) to conduct a comprehensive investigation of the entire Cerro Prieto geothermal field.

[abstracted from Berméjo M. et al., 1978; Domínguez A. et al., 1981; Puente C. and de la Peña, 1978; Schroeder et al., 1978; and Lyons and van de Kamp, 1980]

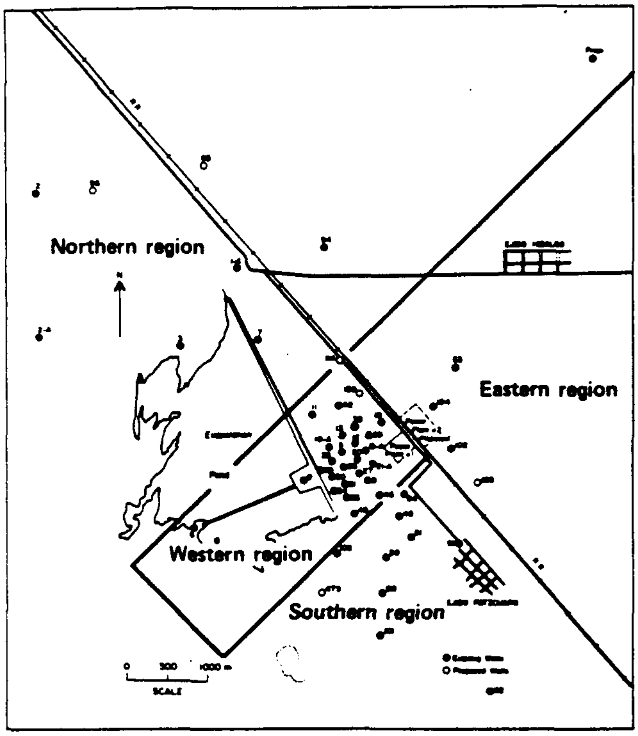

Figure 2. Well location map, Cerro Prieto geothermal resource.

Wells M-50/M-51/M-90/M-91 Interference Test, January 14-March 30, 1978

The first interference test utilized four production wells: M-50, M-51, M-90 and M-91. Well M-101 was monitored for interference effects (Fig. 3 and Table 2). These wells are located approximately 1.5 km from the main producing field. The producing interval of well M-91 is somewhat deeper than those of the other three wells.

The producing wells were flowed at variable flowrates with overlapping intervals of 4 days to 2 weeks. A total of 30 days of drawdown and 15 days of recovery were observed. Pressure changes were measured in well M-101 using 304 m of nitrogen-filled, 0.14 cm I.D. stainless steel tubing connected to a Paroscientific Digiquartz pressure transducer at the surface.

Since there were multiple producing wells, a least squares matching routine was used in which multiple producing wells and variable flow rates can be accounted for. An excellent match of the observed and calculated data was obtained, resulting in a calculated transmissivity of 1.5 x 10^6 md·ft/cp and a storativity of 2.3 x 10^{-2} ft/psi.

[abstracted from Schroeder et al., 1978]

Table 2. M-50/M-51/M-90/M-91 Interference Test, January 14 - March 30, 1978.

WELL Classification	TEST DESCRIPTION Fluid Flow	ΔP (psi)	Distance to Production Well(s) (m)	INSTRUMENTATION (P) Pressure (T) Temperature (Q) Flowrate	ANALYSIS* kh/μ md·ft/cp (m^3/Pa·s)	ch ft/psi (m/Pa)
M-50 production	4 days (2/23-2/27) stepwise variable @ 1.4-19-53-61-42-1.3 kg/s			(Q) James method and weir box		
M-51 production	14 days (2/7-2/21) stepwise variable @ 1.6-42-66-80-66-75-80-30-36-33-1.6 kg/s			(Q) James method and weir box		
M-90 production	16 days (2/16-3/1) stepwise variable @ 1.6-15-28-35-41-53-58-39-5.5 kg/s			(Q) James method and weir box		
M-91 production	12 days (1/29-2/9) stepwise variable @ 47-50-55-72-80-85-86-60-2.2 kg/s			(Q) James method and weir box		
M-101 observation		5.0	960 (to M-50) 1285 (to M-51) 530 (to M-90) 1480 (to M-91)	(P) Paros. with 304 m of nitrogen gas-filled 0.14-cm I.D. tubing	1.5 x 10^6 (4.5 x 10^{-7})	2.3 x 10^{-2} (1.1 x 10^{-6})

* computer-assisted analysis

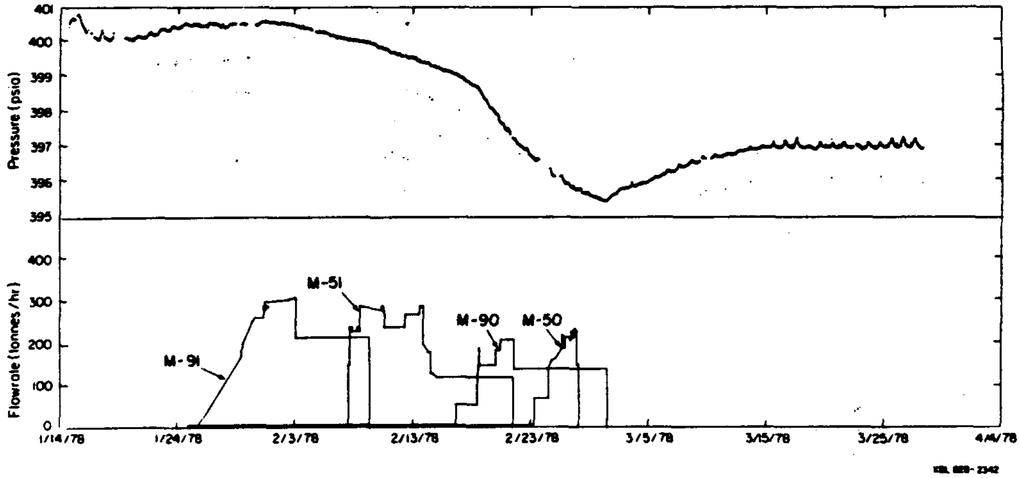

Figure 3. M-101 interference data (M-50/M-51/M-90/M-91 interference test).

KLAMATH FALLS GEOTHERMAL RESOURCE, OREGON

City Well #1 Interference Test (October 24-25, 1979)

The test involved pumping City Well #1 at stepwise variable rates of 16, 30, 35 and 43 l/s, for a total of 15 1/2 hours, while interference effects were monitored in the Parks, Adamcheck and Glen Head wells, 55 m, 305 m, and 430 m away, respectively (Figs. 4 and 5 and Table 3). A maximum flowrate of 43 l/s was held constant for 7 1/2 hours, during which a maximum drawdown of 33 psi was recorded in the well by electric probe. A Productivity Index (Q/ΔP) of 2.0 x 10^{-7} $m^3/s{\cdot}Pa$ was obtained for this well.

Water-level changes in the Adamcheck and Glen Head wells were monitored with Leupold-Stevens continuous-recording water-level devices. A downhole Paroscientific pressure transducer was used in the Parks Well. Background data were obtained from the wells for several months prior to the test. Analyses of data indicate extremely high reservoir permeability, which is attributed to the fractured nature of the reservoir rock.

[abstracted from Benson et al., 1980b and Benson, 1982b]

Table 3. CW-1 Interference Test, October 24-25, 1979.

WELL	TEST DESCRIPTION			INSTRUMENTATION	ANALYSIS •	
Classification	Fluid Flow	ΔP (psi)	Distance to Production Well(s) (m)	(P) Pressure (T) Temperature (Q) Flowrate	kh/μ md·ft/cp (m^3/Pa·s)	ch ft/psi (m/Pa)
CW-1 production	15.5 hrs stepwise variable @ 16-30-35-43 l/s	33		(T) RTD at wellhead (Q) orifice plate and bourdon tube		
Parks observation		0.52	55	(P) Paros. downhole	3.3 x 10^7 (9.9 x 10^{-6} possible barrier boundary	9.1 x 10^{-4} (4.0 x 10^{-8})
Adamcheck observation		0.25	305	(P) L.-S. water-level recorder †	2.6 x 10^7 (7.8 x 10^{-6}) possible barrier boundary	1.1 x 10^{-3} (4.8 x 10^{-8})
Glen Head observation		0.25	430	(P) L.-S. water-level recorder †	1.7 x 10^7 (5.1 x 10^{-6})	1.4 x 10^{-3} (6.2 x 10^{-8})

• type curve analysis
† in nonartesian wells, pressure changes are recorded by measuring changes in water level in the wells

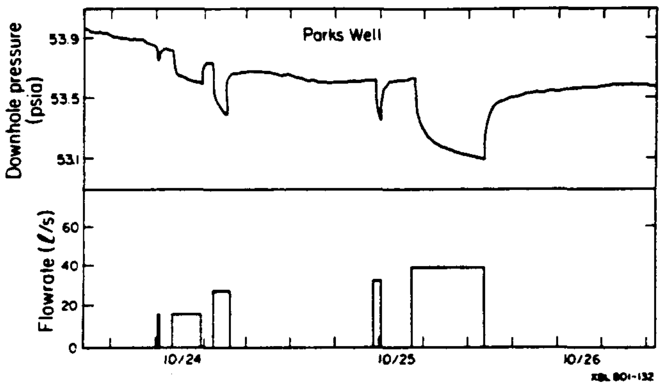

Figure 4. Parks well interference data (CW-1 interference test).

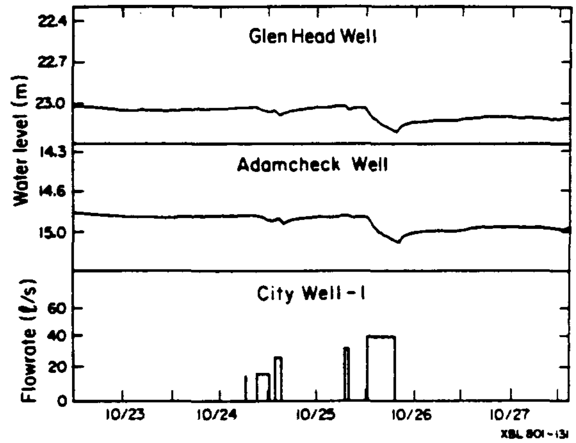

Figure 5. Glenhead/Adamcheck interference data (CW-1 interference test).

SUSANVILLE GEOTHERMAL RESOURCE, CALIFORNIA

WEN-1 Production Test (March 3-7, 1982)

Well WEN-1 was produced for five days at stepwise variable (artesian) flowrates of 13, 27, 42, and 39 l/s (see Fig. 6 and Table 4). The first three rates were held constant for 12 hours each, and the third rate for 75 hours. Pressure and temperature measurements were recorded at the wellhead and downhole for the duration of the test and for approximately 12 hours after the well was shut in. Downhole pressure data were obtained with a Hewlett Packard quartz crystal gauge, and wellhead pressure was measured with a Paroscientific gauge. Downhole and wellhead temperatures were measured with a Gearhart-Owen temperature gauge, and a thermocouple, respectively. Flow rates were measured with an orifice plate and differential pressure gauge.

Semilog analysis of drawdown data indicates a reservoir transmissivity of approximately 3.3×10^6 md·ft/cp (9.9×10^{-7} m^3/Pa·s). The Productivity Index (Q/ΔP) for this well varied with each change in flow rate, indicating non-Darcy flow in the reservoir.

[abstracted from Benson, 1982a]

CONCLUSIONS

A report describing well tests conducted by LBL has been prepared (Bodvarsson and Benson, 1983). The report describes individual well tests in detail, focusing on instrumentation, well test design, and the data collected. This paper summarizes the contents of that report.

Table 4. WEN-1 Production Test, March 1-8, 1982.

WELL Classification	TEST DESCRIPTION Fluid Flow	ΔP (psi)	INSTRUMENTATION (P) Pressure (T) Temperature (Q) Flowrate	ANALYSIS • kh/μ md·ft/cp (m^3/Pa·s)	ch ft/psi (m/Pa)
WEN-1 production	5 days stepwise variable @ 13, 27, 42, 39 l/s	31.5	(P) H.P. downhole Paros at wellhead (T) G.O. downhole thermocouple at wellhead (Q) orifice plate	3.3×10^6 (9.9×10^{-7}) P.I. = 4.5×10^{-7}, 2.7×10^{-7} 2.0×10^{-7}, 2.1×10^{-7} m^3/s·Pa †	

• semilog analysis
† appears to be non-Darcy flow in reservoir

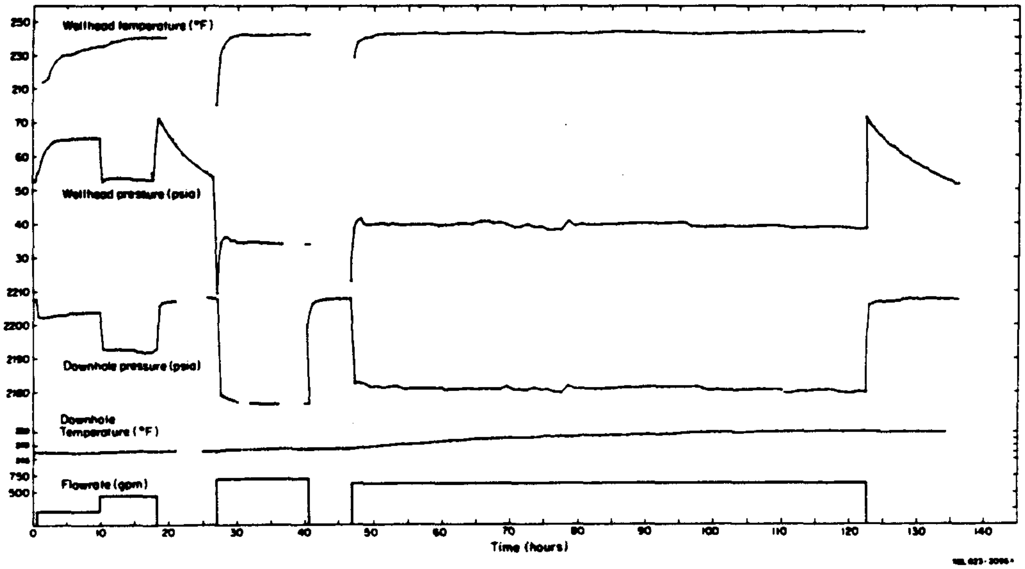

Figure 6. WEN-1 production data (WEN-1 production test).

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NOMENCLATURE AND ABBREVIATIONS

c	total compressibility	ft^{-1} (Pa^{-1})
h	reservoir thickness	ft (m)
k	permeability	md (m^2)
P	pressure	psi (Pa)
Q	volumetric flow rate	l/s
T	fluid temperature	°C
φ	porosity	fraction
μ	dynamic viscosity	cp (Pa·s)

G.O.	Gearhart-Owen Temperature Gauge
H.P.	Hewlett Packard Quartz Pressure Gauge
L.-S.	Leupold-Stevens Water-Level Recorder
Paros.	Paroscientific Digiquartz Transducer

REFERENCES

Benson, S. M., 1982a. Well test data analysis from a naturally fractured liquid-dominated hydrothermal system. In Proceedings of Geothermal Resources Council Annual Meeting, October, 1982. Berkeley, Lawrence Berkeley Laboratory, LBL-14511.

Benson, S. M., 1982b. Hydrogeology of the Klamath Falls Hot Water Resource. Berkeley, Lawrence Berkeley Laboratory, LBL-14793, in preparation.

Benson, S. M., Goranson, C. B., and Schroeder, R. C., 1980b. Evaluation of City Well 1, Klamath Falls, Oregon. Berkeley, Lawrence Berkeley Laboratory, LBL-10848, 9 p.

Berméjo M., F. J., Cortez A., C., and Aragón A., A., 1978. Physical and thermodynamic changes observed in the Cerro Prieto geothermal reservoir. In Proceedings, First Symposium on the Cerro Prieto Geothermal Field, Baja California, Mexico. Berkeley, Lawrence Berkeley Laboratory, LBL-7098, pp. 300-332.

Bodvarsson M., and Benson, S. M., 1983, Well Test Data from Geothermal Reservoirs (1975-1982. Berkeley, Lawrence Berkeley Laboratory, LBL-13295.

Domínguez A., B., Lippmann, M. J., and Berméjo M., F., 1981. Recent results of the well drilling program at Cerro Prieto. In Proceedings Seventh Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, SGP-TR-55, p. 35-40.

Lyons, D. J., and van de Kamp, P. C., 1980. Subsurface geological and geophysical study of the Cerro Prieto geothermal field, Baja California, Mexico. Berkeley, Lawrence Berkeley Laboratory, LBL-10540, 95 p.

Puente C., I., and de la Peña L., A., 1978. Geology of the Cerro Prieto geothermal field. In Proceedings, First Symposium on the Cerro Prieto Geothermal Field, Baja California, Mexico. Berkeley, Lawrence Berkeley Laboratory, LBL-7098, pp. 17-40.

Schroeder, R. C., Goranson, C. B., Benson, S. M., and Lippmann, M. J., 1978. Well interference tests at the Cerro Prieto geothermal field. In Proceedings, First Symposium on the Cerro Prieto Geothermal Field, Baja California, Mexico. Berkeley, Lawrence Berkeley Laboratory, LBL-7098, pp. 357-365.