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FINAL REPORT OF THE DEPARTMENT OF ENERGY RESERVOIR
DEFINITION REVIEW TEAM FOR THE BACA GEOTHERMAL
DEMONSTRATION PROJECT

Norman E. Goldstein, William R. Holman,
and Martin W. Molloy

June 1982

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**FINAL REPORT OF THE
DEPARTMENT OF ENERGY RESERVOIR DEFINITION REVIEW TEAM
FOR THE
BACA GEOTHERMAL DEMONSTRATION PROJECT**

Editors

Norman E. Goldstein

**Earth Sciences Division
Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720**

**William R. Holman
and
Martin W. Molloy**

**U.S. Department of Energy
1333 Broadway
Oakland, California 94612**

June 1982

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INTRODUCTION AND PURPOSE

M. W. Molloy, A. William Laughlin, and N. E. Goldstein

The geothermal potential of the Valles Caldera, New Mexico, was recognized in the early 1960's after the drilling of four exploratory wells (Bond 1 and Baca 1 to 3) in the Sulphur Creek area, and confirmed in 1970 with the drilling of the discovery well (Baca 4) in the Redondo Creek area of the caldera. Union Oil Company leased approximately 100,000 acres of the Baca Ranch in April 1971 and began an active drilling program. By the end of 1976, Union Oil Company (Union) had drilled ten more wells in Redondo Creek (Baca 5A, 6, and 9 through 16), and two more wells in nearby Sulphur Creek (Baca 7 and 8).

In 1977, the Department of Energy (DOE) issued a Program Opportunity Notice soliciting cooperative participation from industry for the development of a geothermal demonstration power plant. As a result of this initiative, Union, Public Service Company of New Mexico, and DOE signed a cooperative agreement in 1978 for the development of a 50-MW demonstration power plant at the Baca site in Redondo Creek.

Prior to the agreement, five of the 11 Union wells flowed at commercially acceptable rates and pressures. One wellbore had collapsed, but the remaining four wells provided 320,000 lb/hr of steam at line pressure, or about one-third the power plant requirements. Union estimated that approximately 10 more successful wells were needed to supply the additional 600,000 lb/hr for the proposed plant.

Subsequent drilling yielded only two successful wells of the 13 drilled (including redrills). As a consequence, steam production was increased to only 353,000 lb/hr.

On May 1, 1981, Union formally notified DOE of their inability to find sufficient steam production to support the power plant. Union suggested that a modified program of deep drilling be undertaken to test the permeability of possible sub-Bandelier reservoir rocks. Union further suggested that hydraulic fracture of two marginal wells in the Bandelier Tuff be attempted in order to increase their permeability.

DOE accepted Union's suggestions, and the DOE Baca Project Manager, Mr. Art Wilbur, formed the DOE Baca Reservoir Definition Review Team. The Team's responsibilities were to: "provide independent review of Union's reservoir program results, conclusion and plans; and provide DOE with the best possible basis for assessing whether the project can succeed technically." Review Team members were selected to cover the critical technical disciplines that are unique to the Baca project (Appendix 1). The DOE Team received technical briefings from Union's geologists and reservoir engineers. Members studied Union's data and reports in their areas of specialty and shared their evaluations with Union's technical staff.

Disappointing results were obtained from the deep drilling and hydrofrac program for a variety of reasons, and in January 1982 the three parties to the agreement decided to terminate the project. The DOE Program Manager asked the Review Team to prepare this final report. Individual sections were prepared by the specialists involved in those aspects of the work; all team members reviewed the overall document and contributed to the Summary and Conclusions.

This report is intended to serve as a constructive summary of the lessons learned during geothermal resource development at Baca. The three main objectives are to provide a concise analysis of the technical work performed in connection with reservoir development, to elucidate the problems encountered during developmental drilling, and to suggest methods or procedures that geothermal developers might follow to avoid the reservoir definition problems encountered.

REGIONAL GEOLOGY

Dennis L. Nielson

The Baca Geothermal Demonstration Power Project is located within the central portion of the Valles Caldera in north-central New Mexico (Fig. 1). On a regional basis, the caldera is located at the western margin of the Rio Grande Rift, where the rift is intersected by the northeast-southwest-trending Jemez Lineament, a zone of late Tertiary to Quaternary volcanic activity (Fig. 2).

The following description is from Doell et al. (1968) and Smith and Bailey (1968); the reader is directed to those publications for a more complete discussion. Caldera formation began about 1.4 million years ago with the eruption of the Otowi Member of the Bandelier Tuff. About 300 km³ of material was erupted at this time to form the Toledo Caldera. About 1.1 million years ago, an eruption comparable to that of the Toledo Caldera formed the Valles Caldera with the emplacement of the Tshirege Member of the Bandelier Tuff. Subsequent rhyolitic activity has resulted in extrusion of domes in the moat area of the Valles Caldera. Rhyolite and ash flow tuff eruptions continued until 100,000 years ago.

Following the formation of the Valles Caldera, the resurgent Redondo Dome was formed by continued upward pressure from the still-molten magma chamber. As a result of this doming, a complex series of faults developed across the crest of the dome. The Baca Geothermal Demonstration Power Project is located within the center of this dome. The geothermal system is believed to be controlled by normal faulting that developed during the formation of the resurgent dome.

XBL 824-2116

Figure 1. Map showing the Baca location in the Valles Caldera, New Mexico.

Figure 2. Generalized regional geologic map of the Valles Caldera area, New Mexico.

STRUCTURE, STRATIGRAPHY, AND PERMEABILITY IN THE REDONDO CREEK PROJECT AREA

Jeffrey B. Hulen

Thermal fluid flow in the Baca geothermal reservoir, as defined by drilling to date, is both stratigraphically and structurally controlled. Stratigraphic permeability is provided by volcanoclastic sediments and non-welded tuffs, primarily within the Quaternary Bandelier Tuff. Structural permeability is developed along faults and associated fractures that form the central downdropped block (medial graben) of the Valles Caldera.

The Redondo Creek project area is situated within the medial graben, a major northeast-southwest-trending structure developed near the structural apex of resurgent doming within the Valles Caldera (Smith and Bailey, 1968). High-angle faults forming the graben are a major control on thermal fluid flow within and near the project area. This relationship is strongly indicated at the surface by alignment of fumaroles, gas seeps, and thermal springs, as well as by zones of bleaching and alteration. These hydrothermal phenomena lie along fault traces at Redondo Creek (Fig. 3; Dondanville, 1971, 1978) and along similar structures in the Sulphur Creek area, immediately to the northwest (Goff and Gardner, 1980). Fault control of fluid flow at depth is indicated by the correlation between fracture/fault zones interpreted in Union well logs, steam or hot water entries in Union wells, and faults mapped at the surface (Figs. 3 and 4; Behrman and Knapp, 1980). Union's detailed analysis of dipmeter data from wells in Redondo Creek showed a preferred northwest-southeast orientation of fractures. It would appear, therefore, that the geothermal anomaly in Redondo Creek is conditioned by the intersection of these fractures with northeast-southwest-trending faults. Apparent displacements on these high-angle faults range from a few

EXPLANATION

	Younger Caldera-Fill Deposits (Quaternary)		Contact
	Redondo Creek Rhyolite (Quaternary)		Fault, bar and ball on downthrown block
	Older Caldera-Fill Deposits (Quaternary)		Borehole location and number with surface projection of well course
	Bandelier Tuff (Quaternary)		Outer limit of surficial alteration

XBL 827-10618

Figure 3. Geologic map of the Redondo Creek project area, Valles Caldera, New Mexico.

XBL 827-10619

Figure 4. Geologic section through the northeastern portion of the Redondo Creek project area, Valles Caldera, New Mexico.

hundred to at least 1400 ft. Zones of intense hydrothermal alteration in welded Bandelier Tuff were penetrated by several wells (Union Geothermal, 1973-1981). These zones probably mark former fault- and fracture-controlled flow channels, now hydrothermally sealed.

The Baca reservoir is primarily confined to the 1.4 to 1.0 million-year-old Bandelier Tuff (Doell et al., 1968). The catastrophic eruption of this tuff led, in stages, to formation of the Valles Caldera. The Bandelier is generally less than 1000 ft thick outside the caldera (Dondanville, 1978), but locally exceeds 6000 ft in thickness within the Redondo Creek project area (Figs. 3 and 4) at the caldera's southwestern margin. The tuff is described in Union's lithologic logs (1973-1981) as dominantly welded, glassy to devitrified rhyolite tuff (almost certainly of ash-flow origin), with sparse to abundant quartz and feldspar (mostly sanidine) phenocrysts, rare biotite, and variable pumice content. Restricted intervals in the Bandelier are described as breccia of unspecified origin. In several deep Union drill holes, the basal 1000 ft of the formation is relatively pumice rich (Dondanville, 1978) and moderately to strongly welded.

Immediately above the base and scattered throughout the Bandelier Tuff are non-welded tuff beds and well-sorted, tuffaceous sandstones, some of which may represent pyroclastic base surge deposits. These rocks are not continuous throughout the project area, but can be correlated between neighboring wells (Fig. 4). These units are essentially flat lying in the northeastern portion of the project area. Elsewhere within the caldera, surface mapping reveals that the Bandelier dips radially outward from the resurgent dome by as much as 23° (Smith et al., 1970).

The tuffaceous sandstones within the Bandelier range in thickness from a few feet up to 360 ft; the non-welded tuffs range from a well-defined 9 ft to vaguely defined intervals in excess of 250 ft. These permeable units, which aggregate less than 8 percent of the total formation thickness in any given well, appear to be important stratigraphic controls on thermal fluid flow at Baca -- second only to the steeply-dipping medial graben faults cited as major fluid flow channels by Dondanville (1971, 1978) and Behrman and Knapp (1980). Of 23 major steam or hot water entries identified in the Bandelier by Union Geothermal (1973-1981), Behrman and Knapp (1980), and Grant and Garg (1981) in 14 deep Baca wells, seven occur within tuffaceous sandstone units, and five within thin (less than 100 ft), discrete, non-welded tuff horizons. Non-producing Bandelier sandstones and non-welded tuffs encountered in the wells are generally much more intensely altered than enclosing welded tuffs. This relationship suggests that these permeable units were formerly thermal fluid conduits, but have become impermeable through interstitial deposition of secondary alteration minerals.

Within the project area the Bandelier tuff is eroded and locally concealed beneath Quaternary "caldera fill" deposits (Fig. 3) consisting of landslide debris as well as volcanic and lake sediments. These deposits seldom exceed 1000 ft and are separated in time from the Bandelier by the Redondo Creek Member of the Quaternary Valles Rhyolite.

The Bandelier rests unconformably on the Pliocene Paliza Canyon Formation (Bailey et al., 1969), a 700- to 1300-ft sequence of dense, propylitized flow rocks with locally interbedded tuff and volcanoclastic sandstone. Grant and Garg (1981) identify three important thermal fluid entries in the Paliza Canyon. One of these occurs in andesite porphyry and may be structurally

controlled; another occurs in a poorly consolidated tuff and is probably a stratigraphic aquifer; the third is at the bottom of a well, where the nature of the controlling permeability cannot be determined.

Union's deep wells penetrating through the Paliza Canyon Formation encountered up to 540 ft of friable, poorly sorted arkosic and volcanoclastic sandstones, occasionally with interbedded tuffs. These sandstones have been logged as the Oligocene Abiquiu Formation (Goff and Kron, 1980) and as the Miocene Santa Fe Sandstone (Smith et al., 1970). They may be too unconsolidated to support commercial production in the Redondo Creek area. The Santa Fe, for example, actually flowed into well Baca 14, which then required extensive remedial cementation (Behrman and Knapp, 1980).

The Permian Abo Formation, disconformably underlying the Santa Fe/Abiquiu Sandstones, was reached in three Redondo Creek wells and drilled through in two. In Baca 12 (deepening), the formation is apparently 1650-ft thick, and in Baca 22 (Redrill 3), about 800 ft of Abo was penetrated above an apparent major fault zone (Fig. 4). The Abo "red beds" consist of interbedded arkosic siltstones and sandstones, which are locally anhydrite rich. Drilling in the Abo was hindered by severe lost-circulation problems due either to stratigraphic or structural permeability. Despite these lost circulation problems, the Abo yielded no thermal fluid production. This paradox may be interpreted in at least three ways. First, existing fractures were opened by overpressured drilling fluids and subsequently closed as reservoir production pressures decreased. Second, the Abo was deficient in formation fluid where it was penetrated by Union wells. Third, fractures were blocked by drilling fluids and detritus (formation mud damage).

Baca 12 (Deepening) and 22 (Redrill 3) were drilled to test the reservoir potential of rock units below the Abo Formation. Targets included possible solution voids in the Pennsylvanian Madera Limestone, permeability developed by weathering of the erosion surface of the underlying Precambrian granite, and fault/fracture zones in the granite basement. Baca 22 (Redrill 3) was lost just after the Madera was reached. Baca 12 (Deepening) penetrated about 950 ft of Madera before drilling about 470 ft into the granite. Although a maximum temperature of 646°F was recorded,* both units proved to be impermeable.

Other structural features recognized by Behrman and Knapp (1980) within the project area are the low-angle faults and possible cooling joints in the welded tuff. Low-angle faults with arcuate surface traces mapped within the project area (Fig. 3) apparently form the sole of shallow landslide blocks. These landslides incorporate "caldera-fill" deposits, Redondo Creek Rhyolite, and the uppermost Bandelier Tuff (Fig. 4), and are not important in controlling the Baca geothermal resource.

Behrman and Knapp (1980) suggest that cooling joints in welded Bandelier Tuff may control thermal fluid flow or cause lost circulation in several Union wells. Cooling joints are typical features of welded ash-flow tuff and are common in the Bandelier outside the Valles Caldera (Ross and Smith, 1961). Distinguishing joints from tectonically produced fractures is difficult in drill cuttings or E-logs. Whatever their origin, features identified on well logs as joints seem to be confined to specific horizons within the Bandelier and may be useful for correlation of reservoir zones within the caldera.

*For comparison, the temperature at the same depth (approximately 10,000 ft) at the Fenton Hill HDR site was 400°F.

In summary, Union wells in the Redondo Creek area show that the Baca geothermal system is apparently confined to stratigraphic and structural aquifers in the Bandelier Tuff and Paliza Canyon Formation. Significant thermal fluid production has not been encountered below these units. Lost circulation zones encountered in the Paliza Canyon and underlying Abo Formations were unproductive, and may be attributed to closed fractures, lack of formation fluids, or mud damage. The underlying Santa Fe and Abiquiu Sandstones may be too friable to permit commercial production (Behrman and Knapp, 1980).

The underlying Madera Limestone and Precambrian granite basement were impermeable in the single well (Baca 12, Deepening) tested.

The importance of faults and fractures in controlling flow and storage of thermal fluids in the Redondo Creek area has been stressed by Behrman and Knapp (1980). The occurrence of warm springs on the margin of the Caldera and the presence of stratigraphic aquifers within the Bandelier Tuff suggest that there could be good hydraulic communication between faults of the resurgent dome and caldera boundary faults.

GEOPHYSICS

M. Wilt, N. E. Goldstein, and S. Vonder Haar

Reconnaissance geophysical studies were performed over the Valles Caldera by Union Geothermal to obtain regional structural information and to identify anomalous areas with geothermal potential. Gravity and magnetic methods were used to determine regional structure and to estimate basement depth. Electrical and electromagnetic methods (dc resistivity, electromagnetics, tellurics and magnetotellurics) were used to locate regions of anomalously low resistivity that may be associated with geothermal reservoirs. These surveys were performed early in the development of the prospect; large areas were surveyed at low station density. In Redondo Creek, station density was higher, but less than adequate for detailed subsurface mapping.

Valles Caldera is characterized by a broad gravity low and a resistivity low in the western half. The depressed gravity principally results from the lower-density material that filled the caldera after its collapse. Gravity modeling indicates that the depth to Precambrian basement is greater than 3 km under Redondo Creek and as great as 5 km in the deepest parts of the caldera (Segar, 1971; Wilt and Vonder Haar, 1982). For contrast, the Precambrian is 500 m deep at Fenton Hill (Jiracek et al., 1975). Gravity modeling suggests that the caldera and the Redondo Creek graben are inclined to the southeast, toward the Rio Grande rift, so that the boundary faults on the western side of the graben have shallower dips than those on the eastern side.

Lower resistivities in the western half of the caldera seem to be caused by more intense hydrothermal alteration and high-temperature saline waters at depth. Resistivities are generally high at Redondo Creek, except at the

surface over hydrothermally altered regions, and at depth in the restricted area of the well field. Magnetotelluric soundings reveal a deep low-resistivity zone (Fig. 5) that correlates well with the productive depths in Baca 11 and 13 (Wilt and Vonder Haar, 1982). Resistivity is much higher in areas where drilling encountered hot but dry conditions, indicating that the low resistivity is principally due to the presence of hot fluids. Telluric profile data, useful in locating lateral changes in resistivity, define a 10-km² area of anomalously low resistivity at depth. All the successful deep wells at Baca lie within this zone. Improved definition of this 10-km² region is therefore important for future drilling and reservoir production estimates.

Geophysical surveys helped Union Geothermal locate a low-resistivity anomaly at depth in Redondo Canyon. Union considered additional investigations, including active seismic, MT, EM, and SP surveys. At that time, however, the structural and topographic complexities of the narrow canyon and the difficulties of interpretation led Union to the conclusion that further geophysical work would not significantly contribute to the delineation of productive drilling targets. Additional magnetotelluric and telluric measurements are necessary if the cause of the anomaly is to be determined more exactly and if the low-resistivity zone is to be mapped in more detail. A geophysical technique that has proved successful in locating continuous fluid-filled fractures in other geothermal systems is the self-potential (SP) method (Corwin and Hoover, 1979; Morrison and Corwin, 1981). This cost-effective technique may prove useful for identifying fault/fracture zone drilling targets at Baca.

Figure 5. Composite plot of layered-model inversions for magnetotelluric soundings along a profile through Redondo Creek.

GEOCHEMICAL INDICATORS OF RESERVOIR CONDITIONS

J. M. Delany and A. H. Truesdell

Geochemical methods are useful for determining the chemical and thermodynamic state of geothermal reservoirs, as well as for monitoring production-induced chemical changes. The chemical composition of geothermal fluids collected at the wellhead can be used to estimate compositions and temperatures of deep reservoir fluids and to evaluate whether processes such as boiling, fluid flow, recharge, etc. occur within the reservoir. As geochemical analyses are rather simple and inexpensive, considerable effort is usually devoted to their employment in the exploration and development of geothermal fields. Geochemical data made available by Union from production flow tests from 1972 through 1981 consist of 35 analyses for nine Redondo Creek wells (accompanying production data are available for six of the wells).

Comparison of average concentrations of chemical constituents from Baca 4, 6, 11, 13, 15, and 20 (Hartz, 1976, 1977; Christensen and Atkinson, 1981) indicates that fluids from all wells within Redondo Creek originated from a common reservoir. Re-evaluation of the Baca geochemical data indicates original fluid inhomogenities, and that local and general boiling are characteristic of the Baca reservoir. Local boiling (associated with all wells) occurs in response to the pressure drop induced at the wellbore by production. A cooled zone around the well is indicated by silica geothermometer temperatures (Truesdell, 1976) that are about 30 to 60°C lower than the reservoir temperatures. General boiling is verified by the existence of a two-phase liquid-steam zone in the central portion of the field (Union, 1978; Grant and Garg, 1981) that probably existed before development.

Na/K/Ca geothermometer temperatures (Fournier and Truesdell, 1973) of well fluids are in agreement with measured downhole data, and can be directly associated with feed point locations identified by Grant and Garg (1981) and Riney and Garg (1982) within the Bandelier Tuff and Paliza Canyon Formation (Table 1). Na/K/Ca temperatures for wells that penetrate the two-phase zone (Baca 4, 11, 15, and possibly 20), and for wells that produce only from the liquid zone (Baca 6, 13, and probably 23 and 24), can be used to reconstruct aquifer chloride and enthalpy relationships (Fig. 6). The wide range in chloride content (2500 to 3750 ppm), shown by the solid symbols in Figure 6, along with the relatively narrow temperature interval of production, is interpreted to result from minor convective circulation within the reservoir. This feature is consistent with conductive heating from below, as shown by the high temperatures encountered by the deepening of Baca 12. Chloride concentration variations do not suggest dilution within the reservoir. Analyses for Baca 23 and 24 yield computed reservoir temperatures ($T_{Na/K/Ca}$) that are considerably lower than those for the other producing wells, supporting the interpretation that there is little convective mixing. However, interpretation of the chemistry of Baca 22, 23, and 24 is made difficult by the limited amount of data and lack of duplicate analyses.

The geochemical data for well fluids that have been collected by Union at Baca have not been fully interpreted. Preliminary evaluation has been useful in defining reservoir temperatures (and enthalpy), chemistry, zones of boiling, and the locations of production horizons. Additional sampling would allow for a detailed geochemical interpretation of processes occurring at depth within the reservoir.

Table 1. Geochemical analyses of Baca wells.

Baca well	No. of chemical analyses and year ^a	T _{Na/K/Ca} this study (°C/°F)	Zones of primary permeability		
			Depth (ft ASL)	Formation	Reservoir temp (°F)
4	16 (1973)	286/547	4546	Bandelier	~500 ^c
	1 (1981)		4349	Bandelier	<566 ^b
6	3 (1972-1973, 1975)	273/523	5058	Bandelier	~500 ^b (>524) ^c
			4033	Bandelier	>550 ^c
11	6 (1974-1976)	290/554	5075	Bandelier	~536 ^b
			3102	Paliza Canyon	>600 ^b
13	6 (1974-1976)	285/545	4836	Bandelier	~500 ^b (491) ^c
			3377	Paliza Canyon	>525 ^b (>500) ^c
15	1 (1976)	286/547	6610	Bandelier	>465 ^b (~500) ^c
			3755	Paliza Canyon	>540 ^{b,c}
20	3 (1980)	261/502	5165	Bandelier	~488 ^a
			4450 ^e	Bandelier	490 ^d
22	1 (1981)	275/527	No downhole P/T analysis available.		
23	1 (1981)	253/487	5526	Bandelier	~450 ^c
24	1 (1981)	258/496	3273	Bandelier	>500 ^c

^a No production testing was conducted between 1976 and 1980.

^b Grant and Garg (1981).

^c Riney and Garg (1982).

^d Christiansen and Atkinson (1981).

^e Measured depth along wellbore.

XBL 823-1962

Figure 6. Enthalpy-chloride plot of steam from production wells in the Redondo Creek area. The variation in chloride content for wells 4, 6, 11, 13, 15, 20, 23, and 24 is shown by the solid symbols with an enthalpy value of ~400j/g for a fluid flashed to one atmosphere at an elevation of ~9000 feet. Aquifer chloride values (half-shaded symbols) were completed using the reservoir temperature ($T_{\text{Na/K/Ca}}$), and the total produced fluid values (open symbols) are shown plotted on a dilution trend toward pure steam.

DRILLING PROBLEMS

M. W. Molloy and A. William Laughlin

By the end of 1981, Union Geothermal had drilled 19 wells, deepened two wells, and redrilled 10 wells within the project area (Fig. 7). Union experienced serious drilling or completion problems in 23 (74%) of these 31 attempts and lost nine (29%) of the wells. Union considers only five (16%) of the wells to be commercial producers. (One new well is commercial, but one well regarded as commercial prior to the agreement was lost.)

Drilling and completion problems encountered at Baca are described in Pye (1981) and summarized in Table 2 and Appendix 2. Failed fishing operations (which generally arose from stuck pipe or twist-offs) were the major cause of lost or damaged wells. Eight wells (25%) were lost from this cause alone.

These problems stem primarily from the numerous lost circulation zones and the underpressured reservoir (pressures generally 600 to 900 psi less than hydrostatic as measured from the wellhead). To flush cuttings to the surface under these circumstances, Union used aerated water as a drilling fluid. This severely aggravated the corrosion of drill pipe and casing, increased the likelihood of stuck drill pipe, and allowed no forewarning of pressure "kicks" when drilling. By adding caustic, Unisteam, and ammonium hydroxide to control pH, Union was able to reduce corrosion to an acceptable level. The other difficulties continued to plague the project until its termination.

The two deepened wells (Baca 12 and 22) were particularly afflicted by lost circulation problems. Because the known productive formations had to be cased off in order to drill deeper, it was first necessary to seal off

XBL 823-2097

Figure 7. Location of the Baca wells in the Redondo Creek area.

Table 2. Summary of drilling problems at Baca project.

	Lost wells	Totals	Percent
Fish in hole (lost, sidetracked)	Baca-50H-90H&RD, -180H&RD1 -200H, -220H, - 22RD3	8	26
Casing and liner (worn, collapsed)	Baca-9-RD, - 17RD	2	6
	Total - lost wells	10	
Drilling difficulties			
Extensive fishing	Baca-50H, - 90H, -19, -200H, -220H, -23 Reempl., -24	7	23
Sidetracked fish	Baca-24	1	3
Extensive steam/ water entries	Baca-40H, -5A, -24 (also Baca 1)	3	10
Bad sloughing	Baca-50H, -90H&RD, -10 -11, -14	6	19
Casing & liner (break, collapsed, unable to run)	Baca-6 deep	1	3
Damaged production zone (from fishing)	Baca-10	1	3
Bridged wellbore	Baca-6 deep	1	3
Wellbore scaling	Baca-60H, -11, -14	3	10
	Total - drilling difficulties	23	

a Baca 5 OH.

all lost circulation zones. This took 42 cement plugs in Baca 12 and would have taken more than 31 plugs in Baca 22 had that well been completed to the planned depth.

The high rate of mechanical failures in Union's Baca wells resulted in a significant loss of information on geologic structure, stratigraphy, and hot water/steam entry, in addition to increased drilling costs and lost steam production capacity. In certain wells, e.g., Baca 24, the information that was lost might have improved the targeting of subsequent wells by constraining conceptual geologic models of potential production zones and features controlling permeability.

FRACTURE STIMULATION EXPERIMENTS

C. W. Morris, R. J. Hanold, and C. F. Pearson

The DOE-sponsored Geothermal Well Stimulation Program group performed hydraulic fracture treatments on two wells. The treatment in Baca 23 was a large hydraulic fracture stimulation of a 231-ft interval from 3300 to 3531 ft (details of the treatment are contained in Table 3). This zone was non-productive prior to stimulation. The frac fluid was pumped at high rates to assure a wide fracture opening and to enhance proppant placement.

From post-stimulation temperature surveys, the zone cooled by the frac fluids was estimated to be more than 300 ft in height at the wellbore. A 6-hr production test, using a modified drillstem test (DST) technique, was utilized to evaluate the stimulation job. The well was flowed at a steady rate of about 21,000 lb/hr, and pressure data obtained downhole provided an indication of the wellbore storage effects, fracture flow effects, and reservoir transmissivity. Conventional transient pressure analysis of the data yielded a reservoir permeability-thickness of 2500 md-ft. This compares closely with results from other wells in the area. Although the linear flow indicators in the pressure data were weak, the length of the fracture was calculated to be about 300 ft. The maximum recorded temperature during the test was 342°F, which indicated that the near-wellbore area had not recovered from the injection of cold fluids.

Following the modified DST, a 49-hr flow test was performed to determine the well's productive capacity. The results showed that the well could produce approximately 120,000 lb/hr total mass flow at a wellhead pressure of 45 psig, although the rate was continuing to decline. Union then performed a

Table 3. Comparison of Baca 23 and Baca 20 stimulation treatments.

	Baca 23	Baca 20
Date performed	March 22, 1981	October 5, 1981
Stimulation interval	231 ft	240 ft
Stimulation depth	3300-3531 ft	4880-5120 ft
Water pre-pad	3600 bbl	3000 bbl
Gelled water frac fluid	4000 bbl	5700 bbl
Proppants	97,200 lb of 20/40 mesh sintered bauxite; 82,800 lb of 20/40 mesh resin-coated sand	120,000 lb of 16/20 mesh sintered bauxite; 120,000 lb of 12/20 mesh sintered bauxite
Pumping rate	40-75 BPM	40-80 BPM

long-term flow test. The pressure and temperature data obtained in the well during this test indicated that two-phase flow was occurring in the formation, with the steam fraction estimated at more than 50 percent. This two-phase flow condition has been observed in other wells in the field. Of greater concern is the lower productivity observed during this long-term test. Analysis of the long-term test data by Riney and Garg (1982) indicated a permeability-thickness value of 4340 md-ft (Table 4). The mass flow rate dropped to about 70,000 lb/hr with a wellhead pressure of 37 psig. Since the well recovers productivity following each shut-in period and then exhibits the same decline again, the cause of the rate decline is probably not due to scaling in the formation. Partial closing of the fracture is possible, but the productivity loss is more likely the result of permeability reduction associated with two-phase flow effects in the formation. The relatively low formation temperature in the completion interval also contributes to the well's poor productivity. It was concluded that future stimulation treatments at Baca should be conducted in deeper and hotter portions of the formation.

The second treatment was conducted in Baca 20 and consisted of a large hydraulic fracture stimulation of a 240-ft interval from 4880 to 5120 ft. Prior to the treatment, this isolated zone was essentially nonproductive. A comparison between the Baca 23 and Baca 20 stimulation treatments is presented in Table 3. The increased treatment volume, increased proppant pack, and the exclusive use of larger diameter sintered bauxite proppants were justified in an attempt to produce very large, highly conductive fractures. Calcium carbonate was employed as the fluid-loss additive during the early stages of the treatment to maximize the fracturing fluid efficiency. The frac fluid was again pumped at high rates to enhance proppant placement throughout the created fractures.

During both treatments, acoustic emissions were monitored using a removable seismometer package in a neighboring well located within 1 km of the stimulated zone. The orientation and size of the hydraulic fractures could then be inferred from the locations of acoustic emissions generated during the hydraulic stimulation experiments (Albright and Pearson, 1982). During the Baca 23 treatment, the events were distributed along a northeast-southwest-trending vertical zone nearly 600 m long. During the Baca 20 treatment, the events did not seem to be localized along a definable fracture. Instead the events occurred within a rectangular volume about 400 m on a side and 40 m thick. Since these acoustic emissions are caused by local increases in pore pressures associated with the hydraulic fracturing process (Pearson, 1981), the size of the seismic zones is related to the reservoir volume that was pressurized during the hydraulic stimulation. Some of these acoustically active volumes may not remain in communication with the wellbore during subsequent production tests.

From post-stimulation temperature surveys, the zone cooled by the frac fluids was estimated to be less than 100 ft in height and to be located near the bottom of the open interval. A 6-hr production test was performed, again using the modified DST method, and a steady rate of about 21,000 lb/hr single-phase flow was maintained to the wellbore. Pressure and temperature data were obtained downhole, and conventional transient pressure analysis techniques were applied to the data. The analysis yielded a reservoir permeability-thickness of about 1000 md-ft. The length of the fracture was calculated from the pressure data to be about 280 ft. Numerical simulation of a high-conductivity fracture in a low-permeability formation supports this interpretation, although the solution is not unique. The maximum recorded temperature during this test was 320°F, indicating that the near-wellbore area had not recovered from the injection of cold fluids. Additional temperature surveys were run in the well following the DST, which indicated that the fluid was entering the wellbore in the lower part of the open interval.

Following the modified DST, a 14-day flow test was performed by Union to determine the well's productive capacity. The well initially produced approximately 120,000 lb/hr total mass flow, but declined rapidly to a final stabilized rate of approximately 50,000 lb/hr (wellhead pressure of 25 psig) under two-phase flow conditions in the formation. The steam fraction was estimated at more than 85 percent. Because of the poor performance of the well, an acid cleanout of the fracture was recommended to remove the calcium carbonate that was used as the fluid-loss additive during the hydraulic fracture treatment. This material was used with the expressed intent of performing an acid cleanout should the fracture conductivity show damage. The possibility of such damage with insoluble fluid-loss additives such as

100-mesh sand has been a concern in prior stimulation experiments. Although the pressure data do not indicate that the fracture conductivity has been damaged, the possibility remains that the calcium carbonate has plugged the natural fractures and flow paths in the formation that intersect the artificial fracture.

The results of the two stimulation experiments performed at the Baca project area yield the following conclusions:

1. Large hydraulic fracture treatments were successfully performed on both Baca 23 and Baca 20. Production tests indicated that high conductivity fractures were propped near the wellbore and that communication with the reservoir system was established.
2. Productivities of Baca 23 and Baca 20 have declined to 70,000 and 50,000 lb/hr, respectively, since the fracture treatments. The probable cause is permeability reduction associated with two-phase flow effects in the formation. This implies that major fluid-producing features were not intersected by the created fractures.
3. The ability of Baca 23 to produce substantial quantities of fluids at a high wellhead pressure is limited, because of the low formation temperature in the shallow treatment interval and the low permeability formation. The productivity of Baca 20 is severely restricted because of the low-permeability formation surrounding the created fractures. This reservoir is particularly sensitive to these factors because of its low initial pressure.
4. Although the stimulation treatments did not result in high productivity wells at Baca, the hydraulic fracturing techniques show promise for future stimulation operations and as a valid alternative to redrilling. If major fluid producing features could be intersected by hydraulic fractures, it is believed that stimulation could result in wells whose productivity would match the better wells in the field.

RESERVOIR DEFINITION AND CONCEPTUAL MODEL

Sabodh Garg and T. David Riney

The surface locations of the 19 wells that have been drilled in the Redondo Creek area to date are shown in Figures 3 and 7. In their attempt to increase well productivity or to overcome drilling and completion problems, Union Geothermal plugged many of the original boreholes and employed deviation drilling to obtain successive redrill holes at a given well site.

Nearly all of the production from the wells comes from fractures or thin stratigraphic interbeds in the Bandelier Tuff, which is 4500 to 6500 ft thick in the Redondo Creek area. Cores of the Bandelier Tuff from Baca 13 indicate that interstitial permeability of the welded tuff is less than 1 md and porosity is 4 to 10 percent. Recent deep drilling at wells Baca 12 and 22 failed to find productive formations below the tuff. The maximum temperatures measured in the wells were generally 550 to 600°F.

Since the bulk of the reservoir permeability is in a fracture network, the performance of a well depends to a large degree on whether it intersects one or more fractures, how large each intersected fracture is, and how well it is connected to the rest of the network. The well is open to reservoir fluid at the depth(s) where it intersects such a fracture; for the balance of its depth the well penetrates rock that is hot but essentially impermeable. Analysis of the downhole data (drilling records, downhole pressure and temperature surveys, surface fluid characteristics) indicates that stratigraphic permeability primarily occurs in two zones across the portion of the reservoir penetrated by the Baca wells (Grant and Garg, 1981). The deeper zone closely corresponds to the contact between the Bandelier Tuff and the underlying

Paliza Canyon Formation. The apparently more permeable shallower zone lies within the tuff. The reservoir pressures define a straight line of slope 0.348 psi/ft when plotted against elevations above sea level. This corresponds to a hydrostatic gradient at approximately 500°F. The initial temperature contours constructed from the downhole data dome upward, and an initial two-phase region at the crest of the dome is penetrated by several Baca wells (Fig. 8). All of the Baca wells induce flashing in the near-wellbore formation upon production.

Chemical analyses of the discharge fluids from Baca wells indicate that the reservoir fluid has relatively low salinity (<9000 ppm) with a noncondensable gas content (principally CO₂) of about 0.4 to 1.5 percent by mass. The effect of the noncondensable gas content on the fluid state has been examined using an equation of state for a mixture of pure water and carbon dioxide (Pritchett et al., 1980). The probable extent of the two-phase region in the Baca reservoir is found to be very sensitive to the CO₂ content of the fluid. The boiling pressure for the mixture is significantly greater than for pure water. The two-phase region at Baca is larger than would be anticipated if the pressure-temperature were interpreted without accounting for the presence of the CO₂.

Various tests have been performed on the wells in the Redondo Creek area to evaluate the productivity of the wells and the reservoir characteristics. Production tests performed include two-phase tests, separator tests, pressure drawdown and buildup tests (and chemical analyses of the produced fluids). In a two-phase test of productivity the well is flowed to the reserve pit, and the pressure drop across an orifice plate is used to estimate the flow rate. A typical separator test consists of flowing the well through a separator

Figure 8. Inferred reservoir temperature along a section between wells Baca 12 and Baca 17, showing the boundary between the liquid and two-phase regions. The reservoir fluid is assumed to contain 0.8% CO₂ by mass.

vessel and measuring steam and water phases individually to evaluate the well's flowing capacity with respect to producing pressure and time, steam fraction, fluid enthalpy, and composition of fluids. The separator tests provide sufficient flow data for analysis of the downhole pressure data during buildup. Lack of downhole measurements during production preclude reliable analysis of the drawdown data.

Analysis of the buildup behavior of the wells has been completed for most of the wells on which separator tests were performed (Riney and Garg, 1982). The interpretation relies on simulated two-phase well-test calculations for guidance (Garg and Pritchett, 1980) and analysis of the downhole measurements to establish the reservoir conditions in the production zone. It considers the effects of the CO₂ content and fracture permeability of the reservoir, the two-phase and single-phase portions of the buildup response, and the fact that the downhole pressure/temperature gages are usually located hundreds of feet from the primary production zone. A summary of the results is shown in Table 4. Lack of data for the effective porosity and compressibility of the fractured reservoir formation, and the flashing of pore fluid near wellbore, make calculation of the skin effect (impairment or improvement in the near-wellbore permeability) meaningless.

In addition to the above described flow tests on individual wells, two field-wide pressure interference tests were conducted (1975-1976 and 1981) to evaluate the hydraulic connectivity of the fracture network. Analysis of the 1975-1976 test yielded a permeability-thickness product (kh) of around 6000 md-ft (Hartz, 1976; Garg and Rice, 1982). This value is significantly lower than the permeability-thickness product measured at other geothermal fields, where products range from 20,000 to more than 100,000 md-ft.

Non-productive Baca wells have been used as injection wells. The ability of these wells to accept high injection rates implies that all permeable zones may not be productive zones. Detailed analysis of Baca 20 (prior to hydrofracturing) shows that the primary production zone is at ~ 4000 ft depth, whereas most of the injected fluid enters a deeper fractured zone below ~ 5000 ft (Riney and Garg, 1982). The fracture produced during the stimulation of Baca 20 apparently intersects the lower fluid-accepting zone, rather than a production zone.

In summary, analysis of the downhole data and fluid production/injection data for the Baca wells indicates the following:

1. Performance of a well in the Redondo Creek area depends primarily upon whether it intersects one or more fractures and how well the fracture(s) is connected to the rest of the fracture network.
2. Production from these wells is primarily from the shallower of two fractured or permeable stratigraphic zones in the Bandelier Tuff.
3. There is a two-phase region initially present near the top of the Baca reservoir system. All of the Baca wells induce flashing in the near-wellbore formation during production.
4. The effective values of the key parameters kh and ϕh are significantly lower at Baca than at other, more productive geothermal systems.

Table 4. Depth, temperature, pressure, and kh of production zones for Baca wells.

Well	Permeable horizons		T (°F)	P (psig)	kh (md-ft)	Remarks
	Thickness (ft)	Elevation (ft ASL)				
4	4800	4546	~500	1170	5050	Commercial
6	3700	5058	524	968	6480	Commercial
	4750	4033	----	----		
10	3000	5746	~500	750	5100	Productivity damage during drilling
	4500	4252	~535	1260	(Union)	
11 ^a	4000	5075	>525	1100	3500	Commercial
	6000	3102	~575	1850	(Union)	
13 ^a	4500	4836	491	1100	2600	Commercial
	6000	3377	>500	1600		
15	2525	6610	~500	450	23,800	Commercial
	5505	3755	----	1405		
20	4000	5165	488	975	3030	Marginal ^b
	5750	3567	549	1443		
	5000	4237	507	1313	----	Sub-commercial ^c
21	2840	6559	436	519	10,250	Sub-commercial
22	Insufficient data for analysis.		----	----	----	Sub-commercial
23 ^c	3250	5526	450	835	4340	Sub-commercial
24	5502	3273	>500	1525	15,900	Commercial

^a Wells cycle. kh values may be suspect.

^b Prior to hydraulic fracturing.

^c After hydraulic fracturing.

PREDICTION OF RESERVOIR PERFORMANCE

G. S. Bodvarsson and C. F. Tsang

Two of the most important factors that control the producibility of a geothermal resource are the reservoir capacity and the generating capacity. The reservoir capacity may be defined as the mass of hot fluid in place, whereas the generating capacity is a measure of the rate at which energy can be extracted from the reservoir. Reliable estimates of these factors must be obtained before a proper development plan for a resource can be designed; these estimates must also be periodically updated as more field data become available during exploitation of the field.

Union (1978) used two different methods to estimate reservoir capacity: a depletion equation (mass balance) and analysis of interference test data. Calculations based on the depletion equation assume that the reservoir is fully confined; i.e., no recharge. Interference test data from well Baca 10 were used to estimate the reservoir capacity on the basis of a simple reservoir model (Theis solution). Both methods yielded 4.7×10^{12} lb of fluid in place. However, both methods are based solely on pressure measurements, and do not distinguish between hot and cold fluid in place.

Bodvarsson et al. (1980) estimated the reservoir capacity by volumetric means using existing geological, geophysical, and well data. Magnetotelluric data (line B-B') were used to estimate the north and south boundaries. The eastern boundary of the reservoir was assumed to coincide with a major fault zone of the medial graben; the western boundary, with the ring-fracture zone (Fig. 9). Using results from core data analyzed by Core Laboratories, Inc. in 1975 and resistivity logs, the porosity-thickness product was estimated

Figure 9. Base map of the Valles Caldera showing shallow temperature gradients ($^{\circ}\text{F}/100\text{ ft}$), geophysical survey lines (e.g., A-A'), and specific faults. The estimated hot reservoir boundary is indicated by broken lines.

to be 100 ft. Using all these factors, they calculated a reservoir capacity of 2.2×10^{12} lb of hot fluid in place.

In light of the ambiguity of the data and the many assumptions used in each approach, the reservoir capacity estimates agree reasonably well with each other.

Two independent studies have addressed the question of the generating capacity of the Baca field. Union (1978) used a lumped-parameter model, and Bodvarsson et al. (1980) used a distributed parameter model. A lumped parameter model is one in which the entire reservoir is considered as one (or several) mixing cell(s), thus neglecting spatial variations of reservoir parameters and the thermodynamic evolution during exploitation. Lumped-parameter techniques were developed in the oil and gas industry, and are presently widely used in the evaluation of geothermal systems. The results based on the lumped-parameter model indicate that the Baca reservoir could ultimately sustain a 410-MWe power production over 30 years without injection, and 900 to 1200 MWe if injection were employed.

Bodvarsson et al. (1980) used a distributed model, which considers spatial variations in dependent variables and reservoir parameters, to estimate the performance of the reservoir on the basis of a power production of 50 MWe. Because data were limited, they used a rather coarse grid-block representation of the reservoir and an optimistic modeling of the production region. All wells were located within a 500-acre area. The results of the simulations showed that for cases of variable mass flow and constant steam production, very limited waste water would be available for injection. Consequently, injection was not considered. On the basis of these assumptions,

their results indicated that the wells within this production area may sustain 50 MWe of power production for 25 to 50 years. They concluded that the main factor controlling the generating capacity of the Baca reservoir was its low transmissivity (permeability-thickness) value inferred from well-test data. The low transmissivity would cause very localized boiling in and around the production region and, consequently, a very rapid pressure decline. The low transmissivity indicates a rather coarsely fractured system, and thus it is not altogether surprising that the success rate of intercepting permeable, fluid-filled fractures has been low in the new wells.

Comparison of the studies by Bodvarsson et al. (1980) and Union (1978) shows that the generating capacity estimates are an order of magnitude higher in the case of the lumped-parameter model. The reason for this large discrepancy is that the lumped-parameter method inherently assumes that a uniform pressure decline will occur in the reservoir; the transmissivity of the reservoir does not enter the calculations. In cases of localized boiling (low transmissivity), the lumped-parameter method will grossly overestimate the ultimate generating capacity of the reservoir. Thus we believe that the distributed-parameter model estimates of the generating capacity of the Baca reservoir are the more realistic of the two.

In summary, studies of the reservoir capacity and generating capacity of the Baca reservoir have indicated the following:

1. Three different methods for estimating the reservoir capacity all gave results in the range of 2 to 4×10^{12} lb of fluid in place.
2. Although such a reservoir capacity should be adequate to produce approximately 400 MWe for 30 years, the actual generating capacity is much less because of the low transmissivity of the Baca reservoir.

3. The low transmissivity requires the use of distributed parameter models rather than the simpler, lumped-parameter models for estimating the generating capacity of the reservoir.

4. Using a distributed parameter model, Bodvarsson et al. (1980) estimated that a 500-acre production area at Baca may sustain 50 MWe power production for 25 to 50 years. This assumes the reservoir has infinite transmissivity in the 500-acre production area. If one includes the effects of individual wells, the estimate should be lower.

5. In general, it may be advantageous to develop a geothermal field as a phased process, beginning with an initial power production of 10 or 20 MWe and building to a large power production in several stages. In this way, the developer obtains data and gains experience at each stage that helps to determine how to advance the power production to the next stage.

SUMMARY AND CONCLUSIONS

Despite the high temperatures encountered at depth, the geothermal resource underlying Redondo Creek has proved to be difficult to develop and exploit because of low permeability, scarcity and unpredictability of the major production zones, and difficult drilling. The low reservoir pressure requires very high temperatures just to drive fluid to the surface.

The complexity and limitations of the major production zones were not recognized until Union began infill drilling in 1979. Union recognized that productivity was impaired in some of the earlier wells. However, it took extensive drilling throughout the project area to define the areal extent of productivity impairment factors (M. Gulati and R. Dondanville, 1982, personal commun.).

Failure of many infill wells forced Union to develop a well-targeting model (Behrman and Knapp, 1980) that emphasizes fracture permeability along the major faults that form the structural graben. Other potential avenues of fluid flow, such as the east-west faults, columnar jointed units, or permeable sands, were not integrated into the targeting of subsequent wells.

The failure of this fault model to successfully target production wells appears to have been the major contributor to Union's decision to halt developmental drilling in May 1981. Attempts to explore for deeper production zones were unsuccessful, and the DOE Project was terminated by mutual agreement in January 1982.

The extensive data made available by Union's development of the Baca project area has significant value for understanding this and similar geothermal reservoirs. Further conclusions of the Review Team are:

- Geochemical conclusions from the Baca wells were very limited. Further sampling and interpretation of such data can yield valuable information regarding conditions within the reservoir, as has been illustrated for many geothermal fields.
- Careful analysis of well data has shown that a two-phase zone is present in some part of the reservoir, and that the extent of this zone is very sensitive to the CO₂ content of the reservoir. Identification of two-phase zones in a geothermal reservoir is necessary to understand its behavior under exploitation.
- Although geophysics helped Union Geothermal locate a low-resistivity anomaly at depth beneath Redondo Canyon, the initial surveys were not followed up with more detailed investigations that might have delineated the extent of the resource.
- Stimulation of sub-commercial geothermal wells is a possible alternative to drilling new wells. Although two stimulation tests at Baca were technically successful, sustained commercial production was not obtained. For low-permeability reservoirs, hydraulic fracturing will yield commercial production only if the induced fracture intercepts major avenues of fluid flow.
- The early estimate that the ultimate power-generating capacity of the Baca reservoir would be 400 MWe for 30 years is believed to be far too high. The estimate was based on a lumped-parameter model that greatly overestimated the generating capacity of the resource. Subsequent studies have shown that in dealing with low-permeability reservoirs such as Baca,

a distributed parameter model is necessary for a realistic assessment of the reservoir.

- The project has yielded very important information regarding exploration and exploitation of low-permeability, fractured geothermal reservoirs.

Structure	Dennis Nielson* and Jeffrey Hulen, Univ. of Utah Research Inst.
Geophysics	Norman E. Goldstein,* Michael Wilt,* Lawrence Berkeley Laboratory
Geochemistry	Alfred Truesdell,* U.S. Geological Survey Joan Delany, Lawrence Berkeley Laboratory
Stratigraphy	A. William Laughlin,* Los Alamos National Laboratory

Chin-Fu Tsang,* Gudmundur Bodvarsson,* Lawrence Berkeley
Laboratory
Sabodh Garg,* T. David Riney,* S-Cubed (formerly Systems,
Science and Software)

Hydrofracturing R. J. Hanold, C. F. Pearson, Los Alamos National Laboratory
C. W. Morris, Republic Geothermal Inc.

DOE San Francisco Operations Office

William R. Holman,* Geothermal Loan Guaranty Office

Martin W. Molloy,* Geothermal Energy Division

***Review Team members.**

APPENDIX 2. DRILLING PROBLEMS, BACA PROJECT

Baca well	TD (ft)	BHT (°F)	Steam (lb/hr)	Notes
4 OH	5048	N/A	N/A	Deep drilling halted by steam/water entry. Possible "interval discharge."
4 deep	6378	>532	47,500	
5 OH	2878	N/A	-	2459' drillpipe in hole.
5 A	6973	~ 485	-	Temperature reversal @ 3500'.
6 OH	3715	~ 500	45,400	30% liner slots plugged with clay powder. Attempts to run slotted liner failed, bridged, casing collapsed, closed in.
6 deep	4810	~ 505	38,500	
9 OH	3518	N/A	-	Bad sloughing, extensive fishing.
9 RD	5303	N/A	-	Sidetracked 250' stuck pipe, hazardous conditions from worn and damaged casing.
10	6001	~ 555	44,000 @ 16 psi	Planned for 7500', production interval damaged during fishing.
11	6924	>627	116,000	Drilling stopped because of sloughing redbeds, "interval discharge." Severe production decline from carbonate scale deposit.
12 OH	9212	~ 585	-	
12 RD	10,637	646	-	Limestone and basement granite test.
13	8228	~ 580	54,000	
14	6824	~ 545		Plugged back to 5780' due to sloughing. Serious scaling (silica) from injected fluid.
15	5505	~ 540	105,000	"Interval discharge" indicated @ 2525' near casing shoe.
16	7002		44,000	Possible "interval discharge," with water existing wellbore @ 3600' and 5400'.
17 OH	5791		N/A	Plugged back and sidetracked
17 RD	6254		N/A	@ 3056'; initially productive, casing collapsed.

APPENDIX 2 (continued)

Baca well	TD (ft)	BHT (°F)	Steam (lb/hr)	Notes
18 OH	4597		N/A	Potentially productive, drill pipe and tools left in hole.
18 RD1	2766		-	Lost bit in hole, sidetracked.
18 RD2	5250		-	Non-productive.
19	5610		32,000 @ 10 psi	Junk and fish recovered, sub-commercial.
20 OH	6863		-	542' fish sidetracked in hole.
20 RD	6374	549	30,000	
21	3000	436	34,000 @ 75 psi	Sub-commercial.
22 OH	6017		N/A	Potentially productive, 1771' fish in hole.
22 RD1	6485		41,000 @ 45 psi	Sub-commercial.
22 RD2	6006		20,000 @ 8 psi	Sub-commercial.
22 RD3	8846		-	Deep production test, stopped by fish in hole.
23	5746		-	Non-productive.
23 Recompl.	3515	450	48,000 @ 51 psi	Possibly commercial.
24	5502		33,000	Deep production test, stuck drill pipe @ 5502'.
Subtotals		19	Original holes (OH)	
		10	Redrills (RD)	
		2	Deepenings	
Total		31	Drilling actions	

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