

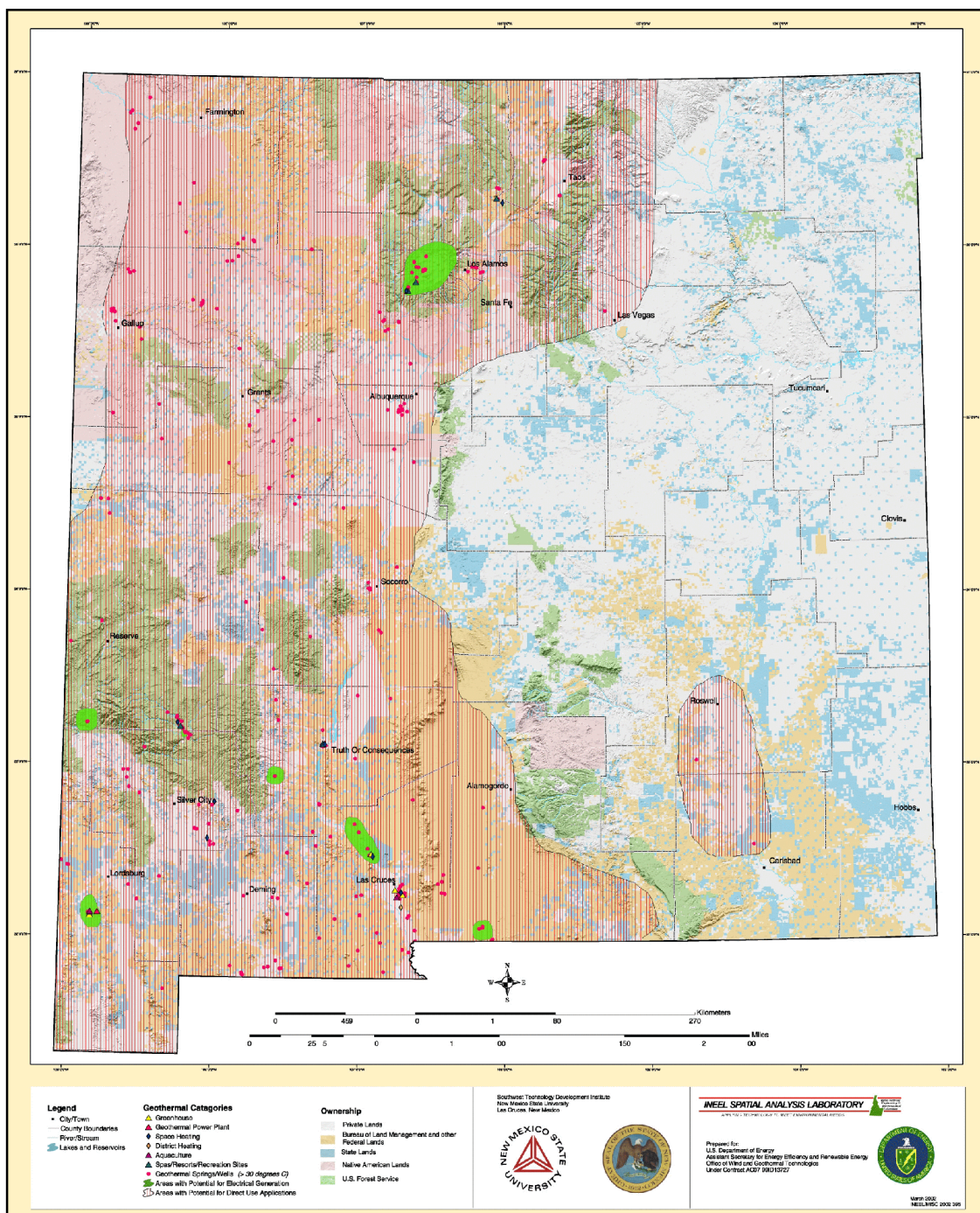


# GEO-HEAT CENTER

## Quarterly Bulletin

OREGON INSTITUTE OF TECHNOLOGY -KLAMATH FALLS, OREGON 97601-8801

PHONE NO. (541) 885-1750



## NEW MEXICO GEOTHERMAL RESOURCES & UTILIZATION

**GEO-HEAT CENTER QUARTERLY BULLETIN**

ISSN 0276-1084

**A Quarterly Progress and Development Report  
on the Direct Utilization of Geothermal Resources**

<b>CONTENTS</b>	<b>Page</b>
<b>Geothermal Resources and Utilization</b> The Editor	<b>1</b>
<b>Geothermal Energy in New Mexico</b> James C. Witcher	<b>2</b>
<b>Geothermal Potential of Valles Caldera, New Mexico</b> Fraser Goff	<b>7</b>
<b>Hot Dry Rock (HDR) Geothermal Energy R&amp;D Fenton Hill, NM</b> Dave Duchane and Don Brown	<b>13</b>
<b>Truth or Consequences, New Mexico</b> John W. Lund and James C. Witcher	<b>20</b>
<b>Gila Hot Springs</b> James C. Witcher and John W. Lund	<b>25</b>
<b>Geothermal Energy at NMSU</b> James C. Witcher, et al.	<b>30</b>
<b>Lightning Dock KGRA</b> James C. Witcher, et al.	<b>37</b>
<b>Masson Radium Springs Farm</b> James C. Witcher and John W. Lund	<b>42</b>
<b>J &amp; K Grower's, Las Cruces, NM</b> John W. Lund	<b>45</b>
<b>Faywood Hot Springs</b> James C. Witcher	<b>46</b>
<b>Ojo Caliente - America's Oldest Spa?</b> James C. Witcher	<b>47</b>
<b>Radium Hot Springs</b> John W. Lund	<b>48</b>

Front Cover: New Mexico map courtesy of USDOE.  
Facing page: Aldershot greenhouse photo courtesy of  
Jack Whittier, Las Cruces, NM.

**PUBLISHED BY**

GEO-HEAT CENTER  
Oregon Institute of Technology  
3201 Campus Drive  
Klamath Falls, OR 97601  
Phone: 541-885-1750  
Email: [geoheat@oit.edu](mailto:geoheat@oit.edu)

All articles for the Bulletin are solicited. If you wish to contribute a paper, please contact the editor at the above address.

**EDITOR**

John W. Lund  
Typesetting/Layout - Donna Gibson  
Graphics - Tonya "Toni" Boyd

**WEBSITE** <http://geoheat.oit.edu>

**FUNDING**

The bulletin is provided compliments of the Geo-Heat Center. This material was prepared with the support of the U.S. Department of Energy (DOE Grant No. FG01-99-EE35098). However, any opinions, findings, conclusions, or recommendations expressed herein are those of the author(s) and do not necessarily reflect the view of USDOE.

**SUBSCRIPTIONS**

The bulletin is mailed free of charge. Please send your name and address to the Geo-Heat Center for addition to the mailing list.

If you wish to change your bulletin subscription, please complete the form below and return it to the Center.

Name \_\_\_\_\_

Address \_\_\_\_\_

\_\_\_\_\_ Zip \_\_\_\_\_

Country \_\_\_\_\_

# GEOTHERMAL RESOURCES AND UTILIZATION IN NEW MEXICO



Yes, New Mexico is part of the United States; however, the state license plates make sure by stating: "New Mexico, USA." We tend to think of the state as desert and cactus, with Santa Fe and Taos as "neat" vacation spots. But, the state has much more -- extensive and well utilized geothermal resources. Most of the geothermal publicity has been focused on Fenton Hill, site of the Hot Dry Rock (HDR) work from the early-1970s to the middle-1990s, and Valles Caldera, an industry exploration site that was not brought to production. However, two of the nation's largest geothermally-heated greenhouse operations are located in the state (Burgett and Masson), along with a major aquaculture raising facility (AmeriCulture), and the heating of a university campus (New Mexico State University). Spas and resorts heated with geothermal are also scattered around the state. The majority of these geothermal projects are described in articles in this issue of the Quarterly Bulletin.

Two U.S. Department of Energy (USDOE) national laboratories: Sandia National Laboratories in Albuquerque and Los Alamos National Laboratories near Santa Fe, have both been actively involved in geothermal R&D, especially in developing high-temperature logging tools and the HDR work at Valles Caldera. The Southwest Technology Development Institute, (SWTDI) on the New Mexico State University campus has been actively involved in geothermal technical assistance for over 20 years, under the leadership of Dr. Rudi Schoenmackers, and have an experimental greenhouse and aquaculture facility on campus to allow potential developers to "get their feet wet" before developing a large commercial-sized project. They have been successful in getting several commercial operations going in the state, as well as having part of the New Mexico State University campus supplied with geothermal heat.

More recently, in April of this year, a Geothermal State Working Group was established under the USDOE *GeoPowering the West* initiative. The local contacts for this

group are Roger Hill at Sandia National Laboratories (rrhill@sandia.gov) and Chris Wentz, Energy Conservation Division, NM Energy, Minerals and Natural Resources Department (cwentz@state.nm.us). A key source of information was unveiled at this meeting: a new map of the New Mexico Geothermal Resources (presented on the cover of this issue of the Quarterly Bulletin). This 28 by 33 inch map, prepared by SWTDI, and the Idaho National Engineering and Environmental Laboratory (INEEL) for the USDOE, shows not only the various geothermal uses in the state, but also public land ownerships, and areas that have potential for geothermal electric generation and direct use applications. Copies can be obtained at INEEL from Patrick Laney (email: ptl@ineel.gov; phone: 208-526-7468) or on-line at: [geothermal.ineel.gov/images/nm\\_geothermal\\_map.jpg](http://geothermal.ineel.gov/images/nm_geothermal_map.jpg).

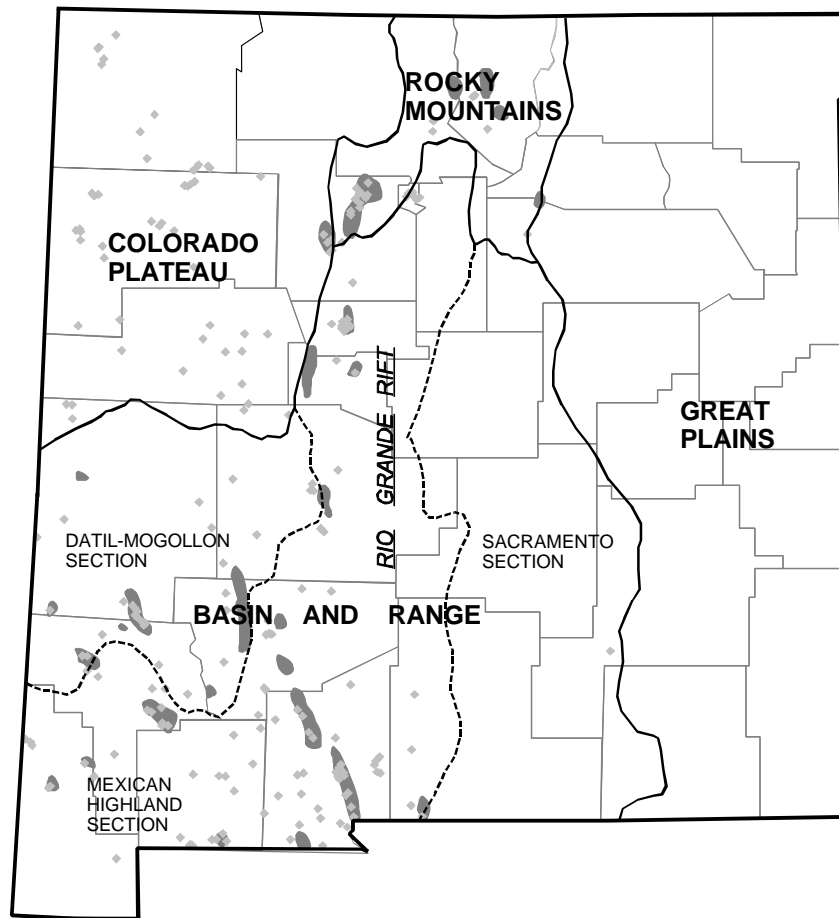
In support of geothermal energy development in New Mexico, Governor Gary E. Johnson on April 2, 2002, proclaimed the 4<sup>th</sup> of April as "GEOTHERMAL ENERGY: HOT NEW OPPORTUNITIES FOR NEW MEXICO DAY." This proclamation stated in part: "The State of New Mexico has been blessed with an abundance of geothermal energy resources which are known to exist in 20 of New Mexico's 33 counties, and New Mexico's substantial geothermal resources are suitable for both electric generation and a variety of direct-use applications."

The following articles are based on several field trips that the editor has taken to New Mexico--the most recent this past summer, arranged by James Witcher of SWTDI. Most of the information and especially the geologic descriptions are from Jim's extensive knowledge of the geothermal resources of the state. His enthusiasm and love of geology, has done much to help promote geothermal development in the state. My thanks to him, Rudi Schoenmackers, Damon Seawright, Dale Burgett, Allen Campbell, and the people of Truth or Consequences for their assistance in preparing this issue of the Quarterly Bulletin. — The Editor



# GEOHERMAL ENERGY IN NEW MEXICO

James C. Witcher  
Southwest Technology Development Institute  
NMSU, Las Cruces, NM



*Figure 1. Physiographic provinces and major geothermal fields in New Mexico (Witcher, 1995).*

## INTRODUCTION

Important economic growth in New Mexico has occurred during the last decade and a half with direct-use of geothermal energy. New Mexico has taken the nation's lead in geothermal greenhouse acreage with more than half of the state's acreage now heated by geothermal. In some recent years, geothermal greenhouse gross receipts have exceeded those of field grown chile and ranked as high as fifth in over all agriculture sector gross receipts. New Mexico is appealing to the greenhouse industry for several reasons, including a good climate, inexpensive land, a good agricultural labor force, and the availability of low-cost geothermal heat. More than half of this geothermal development is directly-tied to the geothermal program at the Southwest Technology Development Institute (SWTDI) at New Mexico State University (NMSU) in Las Cruces.

## GEOHERMAL PROGRAM AT NEW MEXICO STATE UNIVERSITY

The geothermal program at Southwest Technology Development Institute at New Mexico State University in Las Cruces has actively recruited out-of-state greenhouse businesses in past years, and has stimulated the creation of entirely new businesses and assisted existing businesses through an integrated program of geological studies, engineering, and marketing assistance that is centered around business incubator facilities, the NMSU Geothermal Research Greenhouse (GRG) and NMSU Geothermal Aquaculture Center (GAC). During the last 15 years, five clients have leased the GRG. Of the five, three were new business startups; while, two were out-of-state businesses, interested in moving operations to New Mexico. With the large geothermal resource base in the state, future economic benefits may be enormous.

## RESOURCE BASE

Many types of geothermal resources occur in New Mexico. This is largely due to the geologic and physiographic diversity of the state. Four major physiographic provinces are found in the state and each has unique geologic heritage, geothermal characteristics, hydrogeology, demographics and therefore, potential (Figure 1). The Colorado Plateau (CPP) has elevated heat flow, and many deep-seated and confined aquifers that can provide mostly low-temperature 'conductive' geothermal resources. The Basin and Range (BRP) and Southern Rocky Mountains Provinces (SRMP) also have elevated heat flow and youthful faulting and volcanism. The Rio Grande Rift (RGR) is a subset of these two provinces. Low-to-intermediate temperature 'convective' resources are currently utilized in BRP and SRMP, especially in southwestern New Mexico. In north-central New Mexico, a large Pleistocene rhyolitic volcanic complex straddling the rift in the Jemez Mountains has the only known high-temperature 'convective' resource in New Mexico. The Great Plains Province (GPP) generally has normal or low heat flow that is typical of a stable continental setting and only has limited potential for deep-seated low-temperature geothermal resources.

The only known high-temperature geothermal system in New Mexico is found on the southwest side of Redondo Peak, a resurgent dome in the Valles Caldera (Goff, this Bulletin). The Valles reservoir is under pressured and liquid-dominated with a base temperature in excess of 260°C (500°F).

Locally, small vapor-dominated systems overlie the liquid dominated system; where, boiling and permeability is lower. In the 1970s and early-1980s, the Baca Land and Cattle Company and UNOCAL Geothermal performed exploration and drilling on the Valles geothermal system. In 1977, a 50-MWe power plant was proposed as a part of collaboration of UNOCAL Geothermal, Public Service Company of New Mexico (PNM), and the U.S. Department of Energy (USDOE). In 1982, the project was terminated due to a failure to obtain the necessary fluid production from drilling and from various disputes over land and water use. Since 1982, strategic parts of the Valles system were drilled as a part of the Continental Scientific Drilling Program (CSDP)(Gardner, et al., 1989). Also, of note, the national Hot Dry Rock (HDR) program used a site at Fenton Hill, just outside of the Valles Caldera on the caldera rim and west of the Valles geothermal system beneath Redondo Creek and Sulfur Creek (Duchane & Brown, this Bulletin. Most recently, the Baca Land Grant portion (Baca Land and Cattle Company lands) of the Valles Caldera has been sold to the federal government for \$101 million and designated the Valles Caldera National Preserve by the U.S. Congress and signed into law by President Clinton in July 2000. Any near-future geothermal development of the Valles geothermal system is uncertain at this time. However, based upon the results of exploration and drilling in the 1970s and 1980s, at least 20 to 30 MWe of geothermal power potential is probably present. On the other hand, the outflow plume of the Valles geothermal system has much potential for low-temperature direct-use heating as far south as Jemez Pueblo. Carbonate (calcite and aragonite) scaling potential and hydrogen sulfide corrosion

potential is high at all potential sites along the south-flowing outflow plume beneath San Diego Canyon of the Jemez River.

Current space heating and geothermal greenhouse and aquaculture development in New Mexico is in the BRP and RGR with wells less than 980 ft depth. The currently used resource represents discharge from deeply-penetrating, large-scale, regional groundwater flow systems in fractured bedrock which sweeps up heat at depth and concentrates it in the near surface, and structurally-controlled upflows and associated shallow lateral outflow plumes. All of these systems are found in structurally high terrane in normal fault footwalls or horst blocks, and are preferentially associated with extensional fault accommodation or transfer zones. The higher temperature systems are always associated with the vergent boundaries of northwest-trending pre-rift basement-cored Laramide orogeny compressional uplifts that are broken by north-trending extensional faulting. Maximum temperatures of these geothermal systems are probably limited to 300 and 350°F at depths less than 3,000 to 4,000 ft. Water quality of the systems is generally between 1,000 and 3,500 mg/L total dissolved solids (TDS) and usually represents a sodium chloride to chloride-sulfate-bicarbonate chemistry, depending upon the bedrock host rocks. Hydrogen sulfide is only present in trace amounts at a few sites and carbonate scaling potential varies from site to site.

## CURRENT GEOTHERMAL USE

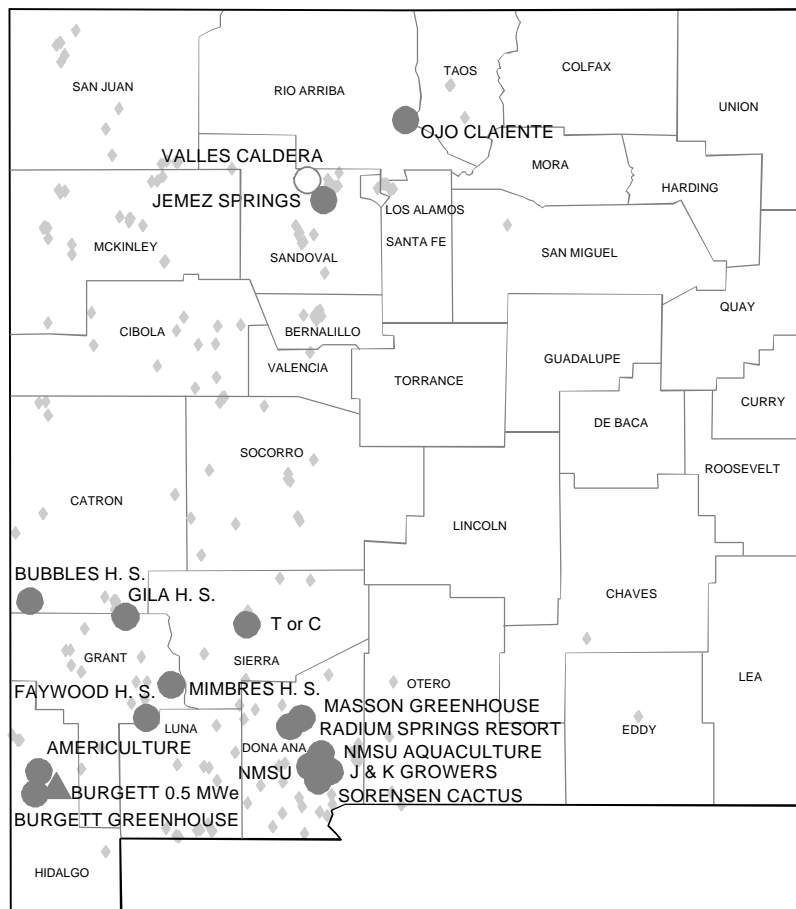
### Electric Power

Geothermal electrical power production is currently done in conjunction with the large 30-acre Burgett Geothermal Greenhouse in the Animas Valley near Cotton City (Figure 2). The Burgett power plant provides a model for how geothermal electrical power may best be accomplished in New Mexico. The Burgett facility has evolved into a cascaded system; where, 230°F well production is fed into the power plant heat exchangers at a rate of 1,200 gallons per minute (gpm) and the 185°F outflow from the power plant is used for space heating of the greenhouses. The Burgett power plant applies binary power technology. A heat exchanger allows the geothermal water to heat a low boiling-point working fluid that is isolated in a closed loop across the turbine, condenser, and heat exchanger. The Burgett power plant consists of three modular 0.3 MWe units that use isopentane, a hydrocarbon working fluid. Power produced by the plant is used on location at the greenhouse.

### Geothermal Aquaculture

The AmeriCulture Fish Farm at Cotton City in southwest New Mexico (Figure 2) raises tilapia from eggs produced on site. AmeriCulture markets and sells a disease-free Tilapia fry to growers and researchers nationwide for grow out to full size. Tilapia is a fish that is growing in popularity for its taste. In recent years, local Red Lobster seafood restaurants have added Tilapia to the menu.

Geothermal offers several advantages for fish culture. For instance, AmeriCulture is heated at much lower costs than fossil fuels with a downhole heat exchanger installed in a 400-ft depth well. Many species have accelerated growth rates in



**Figure 2.** *Location of hot springs and geothermal wells (diamonds), and geothermal utilization in New Mexico (Withcer, 1995).*

warm water. In addition, the geothermal water can be used as a growth medium; thereby, adding to the agriculture receipts in the state without consumptive use of valuable freshwater supply.

### Geothermal Space and District Heating

The aridity and high elevation of New Mexico creates significant heating loads on winter nights. Where shallow geothermal resources are collocated with large heating demands, space and district heating is favorable and can compete with fossil fuel costs. Many of these sites are also favorable for spas.

In operation since 1982, a district geothermal heating system on the NMSU campus in Las Cruces uses up to 260 gpm of 143°F water that is produced from less than 980 ft depth. Geothermal water is passed through a heat exchanger to heat freshwater that is fed as needed into space and domestic hot water loops on campus. The geothermal water with heat removed is injected into the reservoir margin beneath the NMSU golf course. Geothermal heating is used in the dorms, academic buildings, and athletic facilities on the eastern third of the campus. Geothermal heat also provides domestic hot water for showers in the dorms and athletic facilities.

At Gila Hot Springs, geothermal space and district heating is applied to a trailer court, rental cabins, a store, and several homes. A 300 ft depth flowing well provides 165°F water for heating.

### Geothermal Spa and Pool Heating

There are a number of resorts and spas that use geothermal fluids for heating the various soaking tubs and swimming pools throughout the state. These include three in Grant County at Faywood Hot Springs, Mimbres Hot Springs and Gila Hot Springs; one each in Rio Arriba County at Ojo Caliente; Sandoval County at Jemez Springs; Dona Ana County at Radium, and several in Truth or Consequences. This latter location has approximately eight spas using the geothermal water in thermal baths and swimming pools at slightly over 100°F. A recent reference on New Mexico Hot Springs gives additional details on this natural resource (Bischoff, 2001).

### Geothermal Greenhousing

The most important geothermal use in New Mexico is for greenhouses (Figure 2). Geothermal greenhousing accounts for more than half of the greenhouse acreage in the

state. In fact, New Mexico leads the nation in geothermal greenhouse acreage. Table 1 lists the geothermal development in New Mexico.

The success and growth in the geothermal greenhouse industry in New Mexico can be attributed to several factors including a good climate with abundant sunshine and low humidity, inexpensive land, collocation of geothermal resources with a supply of freshwater, a good agricultural labor force, and the availability of favorable shallow geothermal resources. Current geothermal greenhouses use wells less than 1,000 ft depth with resource temperatures ranging from 143 to 240°F.

### ECONOMIC IMPACT

A measure of the importance of geothermal greenhousing is found in Table 2. Altogether, a total of 52 acres are heated with geothermal and represent a capital investment of over \$18 million, a payroll of more than \$4 million, and gross receipts exceeding \$12 million. This places geothermal greenhouse sales among the top 10 agriculture sectors in the state. The Burgett Geothermal Greenhouse near Cotton City is the largest employer and business in Hidalgo County. The Masson Radium Springs Farm geothermal greenhouse is the largest employer in northern Dona Ana County.

### POLICY AND FUTURE DEVELOPMENT

Over the last 25 years or more, the geothermal policy at the federal level and in most of the geothermal industry has predominantly focused on electrical power generation. When one looks at the resource base and success that has accrued to regions like California and Nevada, this is an attractive and seductive approach to developing policy and committing resource exploration and development budgets. However, in New Mexico more than 5,000 MWe is produced by traditional fossil fuels and only about 40 to 45 percent of this electric power is used in state. The Valles geothermal resource in the Jemez Mountains is the only resource with proven reserves that exceed 20 MWe. This is the only resource in the state with a probable magma heat source. Development of this site by industry is tentative due to its designation as a national preserve. However, this site could provide a politically-attractive opportunity for the Pueblos of northern New Mexico to be energy self-sufficient and at the same time proactively protect tradition interests, cultural sites, and water rights in the Jemez Mountains, and generate income for the tribes and for the management of the preserve.

Inferred reserves at other sites in New Mexico are all probably less than 5 MWe. Small-scale geothermal electric power at these sites only makes good sense if it is done in conjunction with cascaded direct-use and the generated power is used on site to assist or augment a direct-use operation. For comparison, the gross receipts or cash flow of an acre of

greenhouse that grows potted plants is equivalent to 1 to 2 MWe of electric power generation with wholesale energy sales of \$0.10 per kilowatt-hour. Federal and state geothermal policy should emphasize direct-use geothermal endeavors in New Mexico over standalone electric power generation. Federal royalty rules for direct-use and regulatory requirements for low- and intermediate-temperature drilling on federal lands are impeding geothermal development in the state and should be modified to provide a realistic framework for development. Currently, all geothermal direct-use is done on private and state mineral properties except for a small 2-acre geothermal greenhouse east of Las Cruces. In addition, the BLM has designated the Las Cruces East Mesa as a Known Geothermal Resource Area (KGRA). A KGRA designation, coupled with current minimum acreage lease application requirements, certainly puts a chill on long-range land use planning for geothermal and any large-scale district heating endeavors as Las Cruces grows across the resource which it is poised to do in the next 5 to 10 years. Developers have enough permitting issues with city, county, and state governments.

### CONCLUSIONS AND FUTURE POTENTIAL

Geothermal is more than energy. Geothermal is a potentially powerful vehicle for important rural economic development. The future of direct-use geothermal in New Mexico may include chile and onion drying, cheese and milk processing, additional aquaculture, greenhouses and district heating. Small-scale electric power generation is very likely to occur in a cascaded mode with direct-use development. The accessible geothermal resource base is vast and the options for economic utilization are many. However, oppressive federal royalty and leasing rules are stalling use of the federal geothermal resource of direct-use applications and much needed economic development in rural areas.

### REFERENCES

- Bischoff, M., 2001. *Touring New Mexico Hot Springs*. A FalconGuide, The Globe Pequot Press, Guilford, CT.
- Gardner, J. N.; Hulen, J. B.; Lysne, P.; Jacobson, R.; Goff, F.; Nielson, D. L.; Pisto, L.; Criswell, C. W.; Gribble, R.; Meeker, K.; Musgrave, J. A.; Smith, T. and D. Wilson, 1989. "Scientific Core Hole Valles Caldera #2b (VC-2b), New Mexico—Drilling and Some Initial Results," *Geothermal Resources Council Transactions*, Vol. 3, Davis, CA, pp. 133-139.
- Witcher, J. C., 1995. "A Geothermal Resource Data Base - New Mexico." Southwest Technology Development Institute, New Mexico State University, Las Cruces, NM.

**Table 1. Geothermal Utilization in New Mexico**

Site	Max. T (°F)	Peak Flow (GPM)	Energy 10 <sup>9</sup> Btu/yr	Capacity MWt	Application
Catron County	120	50	1	0.2	Resort & Spa - Bubbles Hot Springs near Glenwood (Lower Frisco Hot Springs)
Dona Ana County	148	250	36	6.0	District Heating (NMSU)
Las Cruces area	148	60	3	0.3	Greenhouse - STDI (NMSU)
Radium Springs	135	25	<1	<0.1	Aquaculture - STDI (NMSU)
	145	200	10	3.1	Greenhouse - J & K Growers
	170	1,000	77	12.9	Greenhouse - 2 <sup>nd</sup> largest nationally, Masson Radium Springs Farm
	112	10	1	0.1	Baths - Radium Hot Springs Resort
Grant County	130	50	1	0.2	Resort & Spa - Faywood Hot Springs
	135	50	1	0.2	Resort & Spa - Mimbres Hot Springs
	165	75	3	0.4	District Heating / Resort & Spa Gila Hot Springs
Hidalgo County	230	2,000	184	19.0	Greenhouse - Largest nationally, Burgett Geothermal Greenhouses
Cotton City	185	200	11	0.7	Aquaculture - AmeriCulture Inc.
Rio Arriba County	115	60	1	0.2	Resort & Spa - Ojo Caliente
Sandoval County	155	50	1	0.2	Resort & Spa - Jemez Springs Bathhouse
Sierra County	110	1,000	8	0.7	Resort & Spa - Several spas in Truth or Consequences
<b>Total</b>			<b>339</b>	<b>44.3</b>	<b>Note: Energy use is estimated.</b>

**Table 2. Details of Geothermal Greenhouses**

Site	Location	Product	Size	Employees/ Jobs	Payroll	Capital Investment	Sales Gross	Energy Use	Energy Savings
			Acres	Persons	1000 \$/yr	1000\$	1000 \$/yr	10 <sup>9</sup> Btu/yr	1000 \$/yr
Burgett Geothermal	Animas/ Cotton City	Cut Roses	32	90	2,080	11,200	4,000	184	736
Masson Radium Springs	Radium Springs	Potted Plants and Flowers	16	136	1,988	5,600	7,395	77	308
J & K Growers	Las Cruces	Potted Plants and Flowers	2	16	234	700	870	10	40
Sorensen Cactus	Las Cruces	Decorative Cactus	1	8	117	350	435	4	16
		<b>Totals</b>	<b>51</b>	<b>250</b>	<b>4,419</b>	<b>17,850</b>	<b>12,700</b>	<b>275</b>	<b>1,100</b>



# GEOHERMAL POTENTIAL OF VALLES CALDERA, NEW MEXICO

Fraser Goff  
Los Alamos National Laboratory  
Los Alamos, NM

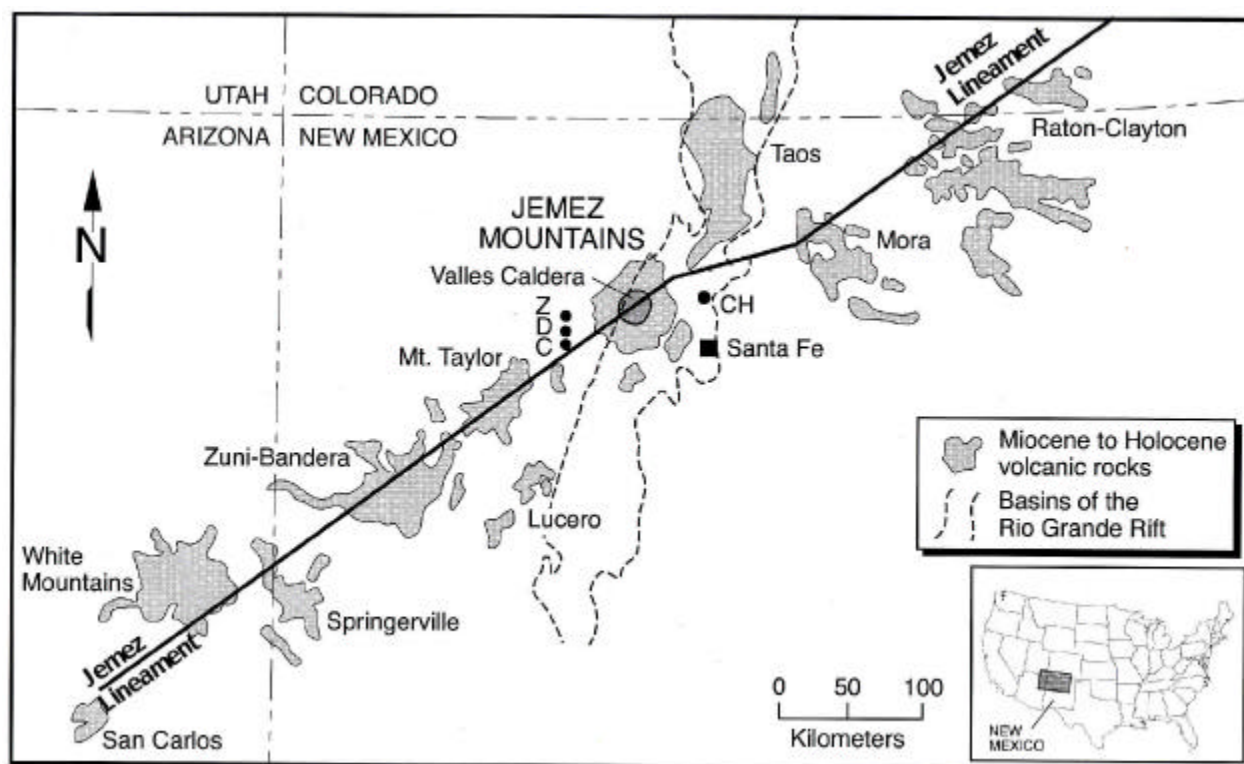
Valles caldera is a large, Quaternary silicic volcanic complex that contains a hot, but relatively small, liquid-dominated geothermal resource (210° to 300°C; 20 MWe proven). The portion of the caldera having geothermal significance is now part of the recently created Valles Caldera National Preserve. Past development problems, small size, an uncertain power market, and new public status make future development of the Valles geothermal resource uncertain.

## GEOLOGIC AND GEOPHYSICAL SETTING

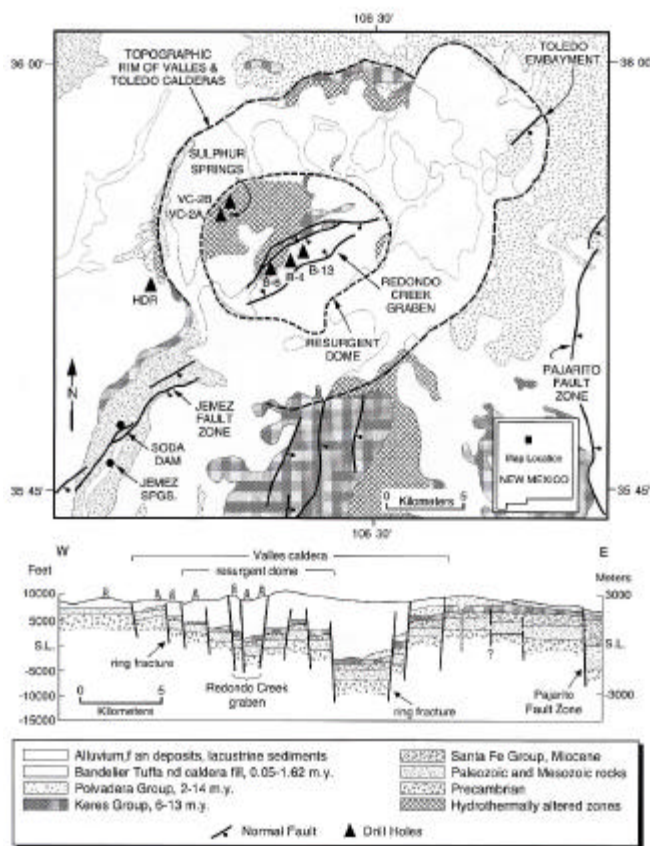
Valles caldera is a 22-km-diameter resurgent cauldron that formed in the approximate center of the Jemez Mountains volcanic field (JMVf) at about 1.2 Ma (Figures 1 and 2) (Smith and Bailey, 1968). The JMVf consists primarily of calc-alkaline basalt, andesite, dacite, and rhyolite erupted from about 13 Ma to 55 ka (Toyoda, et al., 1995; Goff and Gardner, in press). Volumetrically, two-pyroxene andesite domes and lavas are most abundant (about 1,000 km<sup>3</sup>), but volcanism culminated with formation of the Valles and comparably sized Toledo calderas, their high-silica rhyolite ignimbrites

(Bandelier Tuffs), and post-caldera rhyolitic products (roughly 600 km<sup>3</sup>) (Gardner, et al., 1986). The JMVf lies at the intersection of the Jemez Lineament (JL) and the western margin of the Rio Grande Rift (RGR). The JL is an alignment of volcanic centers formed in Miocene to Holocene time along what is thought to be a reactivated Precambrian structure (Aldrich, 1986). There are no age or compositional progressions along the JL, but by far the largest volume of erupted material occurs in the JMVf. The RGR is an intraplate zone of E-W extension and consists of a series of half-grabens extending from southern Colorado into northern Mexico. The northern RGR first formed about 25 Ma. Pleistocene volcanism associated with the RGR has been predominately basaltic (Riecker, 1979).

Geothermal and scientific drilling from 1959 to 1988 produced enormous amounts of information on the internal stratigraphy, structure, geophysical character, hydrothermal alteration, and hydrothermal fluids within the Valles caldera (Nielson and Hulen, 1984; Goff et al., 1989; Goff and Gardner, 1994). A generalized east-to-west cross section of



**Figure 1.** Location map of the Jemez Mountains and Valles Caldera with respect to other volcanic centers of the Jemez Volcanic Lineament and the Rio Grande Rift. Regional thermal sites mentioned in the text are the San Ysidro area to the southwest and the Chimayo area to the east (C = C spring, CH = Chimayo well, D = Double spring, and Z = Zia hot well).



**Figure 2.** *Map and E-W cross-section of the Valles Caldera region showing general geology and structure, and the locations of various thermal features and geothermal wells mentioned in the text. Well symbols shown on cross-section denote zone of subsurface stratigraphic control and do not necessarily denote any particular well. Geochronology is from Gardner, et al. (1986), and Goff and Gardner (in press).*

the caldera region (Figure 2) shows typical relations among the major stratigraphic groups of the JMVf and relations to Tertiary basin-fill rocks of the RGR, Paleozoic to Mesozoic rocks of the Colorado Plateau, and Precambrian basement. Drilling and geophysics have revealed that the caldera is structurally asymmetric, being much deeper on the east than on the west (a "trap door" caldera) (Heiken and Goff, 1983). Miocene sedimentary rocks of the RGR thicken eastward toward the axis of the rift. Particularly noteworthy in the structure is the horst beneath the mountains between the eastern caldera ring fracture and the Pajarito fault zone. The Pajarito fault zone bounds the western and deepest part of the RGR. Because of this horst, the caldera depression and the RGR form separate hydrologic basins.

Several geophysical and geochemical studies show that the JMVf is underlain by magma. For example, Valles caldera is aseismic and has multiple, low velocity zones extending into the upper mantle (Steck, et al., 1998). Convective heat flow within the caldera can exceed 5000 mW/m<sup>2</sup>; whereas, deep conductive heat flow just outside the

caldera is as high as 400 mW/m<sup>2</sup> (Goff, et al., 1989; Morgan et al., 1996). Petrologic models suggest that the youngest post-caldera rhyolites represent a new magma batch separate from the older Bandelier magma chamber (Wolff and Gardner, 1995). Valles intracaldera gases have <sup>3</sup>He/R<sub>a</sub> ratios of <=6 R/R<sub>a</sub> (R/R<sub>a</sub> = helium ratio of sample gas divided by the helium ratio of air). These values are similar to those of mid-ocean ridge basalt, indicating a mantle/magmatic source for the excess helium-3 (Goff and Gardner, 1994). These combined data indicate that Valles is underlain by a potent magmatic heat source probably replenished by periodic injections of mantle basalt (Goff and Janik, 2002).

## GEOHERMAL SETTING AND CHARACTERISTICS

Hot and/or mineralized fluids discharge from many locations within and outside of the RGR, but few sites contain boiling fluids or release free gas (Summers, 1976). Within a 50-km radius of Valles caldera, gaseous fluids occur in a large cluster of springs and a well to the southwest (San Ysidro area; C, D, and Z) (Figure 1) and in an aquifer along the east margin of the RGR to the east (Chimayo area). The chemistries of these fluids are variable. San Ysidro fluids (25° to 55°C; CH) (Figure 1) are mineralized due to circulation in late Paleozoic to Mesozoic sedimentary rocks of the San Juan Basin (Vuataz and Goff, 1986). Chimayo fluids are cool (<25°C) and derive their mineralization from circulation in Tertiary basin-fill sediments of the RGR and nearby Paleozoic carbonate rocks on the east margin of the RGR (Cumming, 1997). These regional fluids do not resemble those inside Valles caldera (Summers, 1976).

Valles caldera contains a classic, liquid-dominated reservoir (<=300°C), which is overlain by a low-pressure vapor cap and is recharged by local meteoric water (Dondanville, 1978; Goff, et al., 1985; Goff and Gardner, 1994). The reservoir (210° to 300°C, 2 to 10 x 10<sup>3</sup> mg/kg chloride) is most extensive in fractured caldera fill tuffs and associated sedimentary rocks located in specific structural zones. A detailed reservoir model and descriptions of the various hot springs have been published previously (Goff and Gardner, 1994, and references therein). Free gas issues at Sulphur Springs and from smaller springs and fumaroles within the resurgent dome of the caldera. Free gas also emerges from several thermal features along the Jemez fault zone (JFZ), southwest of the caldera. The latter hot springs discharge from a hydrothermal outflow plume that flows in the subsurface from the Valles geothermal reservoir down the JFZ (Goff, et al., 1988).

Acid-sulfate springs, mud pots, and fumaroles issue from Sulphur Springs and other canyons within the southwestern resurgent dome of Valles caldera (Figure 2). These areas are characterized by intense argillic to advanced-argillic alteration. Kaolinite, silica, pyrite, sulfur, alunite, gypsum, jarosite, and other complex sulfates are deposited in acid-leached, intracaldera rhyolites and sedimentary deposits (Charles et al., 1986). Two scientific core holes (VC-2a and VC-2b) were drilled in the Sulphur Springs area in 1986 and 1988 to examine the vapor cap and underlying liquid-dominated reservoir (Hulen et al., 1987; Goff and Gardner, 1994). Maximum depth and temperature were 1.76 km and 295°C.

Conventional geothermal wells were drilled in the resurgent dome of Valles caldera from 1959 to 1983 (Baca-1, Baca-4, etc.) to explore and develop the geothermal system (Figure 2). Maximum drilled depth and temperature were 3.2 km and 342°C in Baca-12 (Nielson and Hulen, 1984). The system proved to be too small in volume for economic development. The geochemistry of Valles spring and well discharges was previously described by Truesdell and Janik (1986) and Goff and Janik (2002), among others.

The hot dry rock concept (HDR) was developed and tested in Precambrian igneous and metamorphic rocks beneath the west margin of the caldera from 1972 to 1998 (Figure 2; Grigsby et al., 1984). During circulation experiments, cold water was pumped down an injection well, forced through artificially fractured reservoir rocks, and extracted from a nearby production well. The cold water dissolved minerals lining the fractured rocks and absorbed CO<sub>2</sub> and other gases while reaching thermal equilibrium (T=160°C). The depth of circulation was greater than 2.5 km when the project was in operation. Details of this project are summarized in another paper of this volume.

### **VALLES CALDERA NATIONAL PRESERVE**

After two years of negotiations, the White House reached an agreement to buy and permanently protect the 95,000-acre Baca ranch as a national preserve. The ranch and the caldera are roughly coincident in aerial extent. A bill appropriating the money (\$101 million) was passed by the U.S. Congress and signed by President Clinton late in 1999. Authorizing legislation, called the Valles Caldera Preservation Act, H.R. 3288/S. 1892, passed the House and Senate and was signed by President Clinton on July 25, 2000.

The newly created Valles Caldera National Preserve is managed by a board of trustees appointed by the President and will be opened to the public within two years. Members of the Valles Caldera Trust hold regular board meetings to share information with the public as they formulate plans for the Preserve. Before the Valles Preserve is opened to the general public, the archeology, geology, animal and plant ecology, grazing potential, and Native American heritage are undergoing intensive investigation and reevaluation. Elk hunting and limited cattle grazing are income-producing activities conducted during 2002. Limited hiking will commence in 2003. For more information on the Preserve, contact [www.vallescaldera.gov](http://www.vallescaldera.gov).

A holdout geothermal interest remains on the Preserve that has not yet been purchased by the federal government. It is presently not known if geothermal development will be a viable income-producing activity for the Valles caldera, considering its new public status.

### **VALLES (BACA) GEOTHERMAL SYSTEM**

The Baca cooperative geothermal demonstration project in Valles caldera began in July 1978 (the Baca name originates from the first, post-1850s owners of the land grant and cattle ranch, roughly coinciding with the caldera boundary). The cooperative project was jointly sponsored by the U.S. Department of Energy (DOE), Union Oil Company

(Unocal), and Public Service Company of New Mexico (PSCNM). When the joint project began, Unocal claimed that a 400-megawatt electrical (MWe) resource existed within the caldera, but when the project terminated by mutual agreement in January 1982, Unocal had only proven 20 MWe of resource. Unocal drilled roughly 23 wells and redrills during their lease of the Baca geothermal rights from about 1970 to 1984. After the cooperative agreement was signed, only 2 of 13 wells drilled by Unocal were successful. All the wells were hot but few wells encountered sufficient permeability to be considered production wells. This project, which was supposed to showcase development of liquid-dominated geothermal reservoirs, became extremely frustrating, expensive, and non-productive. PSCNM actually bought two 25 MWe low-pressure steam turbines for use on the initial power plant but when the project terminated, these turbines were sold to the Mexican government for pennies on the dollar (the turbines are now running in the Los Azufres geothermal field, Mexico). The unfortunate history of these efforts is documented in several reports (Kerr, 1982; Goldstein and Tsang, 1984; Mangold and Tsang, 1984).

Although reservoir waters in Valles are 210 to 300°C and maximum measured temperatures in underlying rocks are 340°C at roughly 3200 m depth, the fluids are extremely localized. There is little fluid continuity among the successful wells. In addition, reservoir fluids are under pressured because the depth to fluids is <=500 m and the reservoir is overlain by rocks filled with low-pressure vapor. Unocal encountered many drilling problems. In the end, five or six wells were suitable as production wells. Wells displayed highly variable permeability and porosity along their courses. Permeable horizons in one well did not correlate with those in other wells. Inter-connectivity among the wells was extremely bad and bulk reservoir permeability was low. Permeability was restricted to fault zones and short lateral horizons cutting intracaldera Bandelier Tuff and associated rocks, and to zones in precaldera Tertiary volcanic rocks and sediments. Attempts to find permeability in underlying Paleozoic and Precambrian rocks were unsuccessful.

Along with the drilling and development problems, there were legal and economic controversies evolving over the hydrologic relationship of the Valles reservoir to the hot springs in San Diego Canyon, southwest of the caldera (Erickson, 1977; All Indian Pueblo Council, 1979; State of New Mexico, 1980; Balleau, 1984). Basically, Native American groups and resort owners contended that development of the Valles geothermal resource would deplete or terminate water flow from the hot springs and hot aquifers in San Diego Canyon. This issue was never resolved in court because the cooperative geothermal project was terminated. However, results from scientific core holes drilled from 1984 to 1988, and other research studies prove that a hydrothermal outflow plume from the Valles reservoir feeds the hot springs in San Diego Canyon (Goff and Shevenell, 1987; Goff et al., 1988).

### **CONCLUSIONS**

With the above facts in mind, several conclusions can be stated about the Valles geothermal resource:

1. After years of work and considerable expense, only 20MWe of geothermal reservoir capacity is proven in Valles caldera. Geothermal developers occasionally state that Valles contains as much as 1000 MWe of undiscovered power but these claims are unsubstantiated. The shallow heat contained within Valles rocks is immense but extracting large quantities of hot fluids from these rocks has been exceptionally difficult.
2. Finding undiscovered hot fluids in Valles to power more than 20MWe will be difficult. The Redondo Creek graben and fault zone is the only known area within Valles where successful production wells were drilled. Even there, most wells were sub-commercial. Ten more wells were drilled in western sectors of the caldera near Sulphur Springs but no useable production well exists in these supposedly favorable locations.
3. The sustainability of the known 20MWe resource is unknown. Because the Valles geothermal reservoir displays such poor hydraulic conductivity, it is not known if the reservoir will produce sufficient volume of fluids at required pressures to keep a geothermal plant operational for 20 years. This can only be evaluated once flow tests are conducted, the first plant goes online, and long-term well performance is documented.
4. The hydraulic conductivity within the Valles reservoir is extremely poor. Reinjecting reservoir fluids from the power plant, whether conventional or binary, could easily wander into zones that are not connected to existing production zones, or could short circuit to production wells along a fault or fracture system. Evaluating the performance of reinjection can only be done after the first plant goes online.
5. Exploitation of the Valles reservoir will have an unknown impact on the hot springs and aquifers in San Diego Canyon (Williams, 1986; Trainer, et al., 2000). Past experience at many other geothermal systems shows that production of reservoir fluids can have dramatic detrimental impacts on surface thermal features (e.g., Hunt and Scott, 1998). The local Pueblos revere the hot springs and some spring waters in the Jemez Springs area are used by resorts and religious institutions for recreational purposes. Unless those groups share in the development scheme, any new geothermal project will probably go to litigation soon after it gets started. As an example, a recent seismic project funded by DOE to be conducted in the Jemez Mountains was delayed by threats of litigation from Native American groups (Baldridge et al., 1997). This project included some *shallow* drilling. It is highly likely that a new Valles geothermal project will face similar obstacles.
6. The original geothermal development plan proposed by Unocal envisioned a transmission line connecting a power plant in the Redondo Creek area to Los Alamos via a typical, surface 115-kV power line. With creation of the Valles Preserve, a transmission line would likely be constructed underground to minimize visual environmental impacts, raising development costs substantially. The path of the line may have to be changed because of new archeological discoveries. This will probably require an amended or new Environmental Impact Statement.
7. The geothermal wells drilled by Unocal are probably not reusable, contrary to what is suggested by some geothermal developers. They were plugged and abandoned to California standards (2000 feet of cement and bentonite plugs, well heads removed, upper 15 feet or so of casing cut off, and then buried). Few rational developers would want to reopen high-temperature wells that have unknown casing problems and that are 20 to 30 years old.
8. Worldwide, the average cost of installed geothermal capacity is roughly \$2M per MWe (Grant, 1996). The local cost of power produced by traditional means in New Mexico is around 1 to 3 cents per kWh. It is highly likely that power produced by geothermal energy in Valles caldera will be considerably more expensive than the above costs. Because of small size and high cost, generating geothermal power in Valles only makes sense if the cost is subsidized.
9. Los Alamos and Sandia National Laboratories are required by DOE to use 7% green energy in their future power mix. Geothermal power would satisfy those requirements. However, there are other sources of green power being developed in the region (Mike Hinrichs, 2001). Thus, geothermal energy is not the sole option of green power for these institutions.

#### ACKNOWLEDGMENTS

Jim Witcher of the Southwest Technology Development Institute (Las Cruces, New Mexico) requested that I write this manuscript. I wish to give thanks to my many wonderful colleagues who worked with me in Valles caldera since 1978. The figures were crafted by Anthony Garcia and the text was reviewed by Don Hickmott, both at Los Alamos National Laboratory. This effort was funded by the Valles Caldera Geologic Mapping Project of Los Alamos National Laboratory, an outreach activity donated to the Valles Caldera National Preserve.

## REFERENCES

- Aldrich, M. J., 1986. "Tectonics of the Jemez Lineament in the Jemez Mountains and the Rio Grande Rift," *Journal of Geophysical Research*, v. 91, p. 1753-1762.
- All Indian Pueblo Council, 1979. "Transcript of Proceedings of a Public Hearing on August 30, 1979 in Albuquerque, New Mexico, on the Environmental Impact Statement, Geothermal Demonstration Program," *Report DOE/TIC-10287*, U.S. Department of Energy, Washington, DC, 289 pp.
- Baldrige, W. S.; Braile, L.; Fehler, M. and F. Moreno, 1997. "Science and Sociology Butt Heads in Tomography Experiment in Sacred Mountains," *EOS, Transactions American Geophysical Union*, v. 78, p. 417, 421-423.
- Balleau, W. P., 1984. "Quantitative Analysis of Existing Conditions and Production Strategies for the Baca Geothermal System, New Mexico," *Water Resources Research*, v. 20, p. 601-618.
- Charles, R. W.; Vidale, R. and F. Goff, 1986. "An Interpretation of the Alteration Assemblages at Sulphur Springs, Valles Caldera, New Mexico," *Journal of Geophysical Research*, v. 91, p. 1887-1898.
- Cumming, K. A., 1997. "Hydro-geochemistry of Groundwater in Chimayo, New Mexico," *MS thesis*, Northern Arizona University, Flagstaff, AZ, 117 pp.
- Dondanville, R. F., 1978. "Geologic Characteristics of the Valles Caldera Geothermal System, New Mexico," *Geothermal Resources Council Transactions*, v. 2, p. 157-160.
- Erickson, J. R., 1977. "Hydrology—Jemez Mountains, New Mexico," Open file report, *Union Oil Company*, Santa Rosa, California, 35 pp.
- Gardner, J. N.; Goff, F.; Garcia, S. and R. Hagan, 1986. "Stratigraphic Relations and Lithologic Variations in the Jemez Volcanic Field, New Mexico," *Journal of Geophysical Research*, v. 91, p. 1763-1778.
- Goff, F. and J. N. Gardner, 1994. "Evolution of a Mineralized Geothermal System, Valles Caldera, New Mexico," *Economic Geology*, v. 89, p. 1803-1832.
- Goff, F. and J. N. Gardner, in press. "Late Cenozoic Geochronology of Volcanism and Mineralization in the Jemez Mountains and Valles Caldera, North-Central New Mexico," in (G. Mack, K. Giles, and V. Lueth, eds.) *The Geology of New Mexico*. New Mexico Geological Society, Socorro, 20 pp.
- Goff, F. and C.J. Janik, 2002. "Gas Geochemistry of the Valles Caldera Region, New Mexico and Comparisons with Gases at Yellowstone, Long Valley and Other Geothermal Systems," *Journal of Volcanology and Geothermal Research*, v. 116, p. 299-323.
- Goff, F. and L. Shevenell, 1987. "Travertine Deposits of Soda Dam, New Mexico, and Their Implications for the Age and Evolution of the Valles Caldera Hydrothermal System," *Geological Society of America Bulletin*, v. 99, p. 292-302.
- Goff, F.; Gardner, J. N.; Vidale, R. and R. Charles, 1985. "Geochemistry and Isotopes of Fluids from Sulphur Springs, Valles Caldera, New Mexico," *Journal of Volcanology Geothermal Research*, v. 23, p. 273-297.
- Goff, F.; Gardner, J.; Baldrige, W.; Hulen, J.; Nielson, D.; Vaniman, D.; Heiken, G. Dungan, M. and D. Broxton, 1989. "Excursion 17B: Volcanic and Hydrothermal Evolution of the Valles Caldera and Jemez Volcanic Field," *New Mexico Bureau of Mines and Mineral Resources*, Memoir 46, p. 381-434.
- Goff, F.; Shevenell, L.; Gardner, J. N.; Vuataz, F.-D. and C. O. Grigsby, 1988. "The Hydrothermal Outflow Plume of Valles Caldera, New Mexico, and a Comparison with Other Outflow Plumes," *Journal Geophysical Research*, v. 93, p. 6041-6058.
- Goldstein, N. E., and C. F. Tsang, 1984. "A Review of Lessons Learned from the DOE/Union Baca Geothermal Project," *Geothermal Resources Council Bulletin*, June 1984, p. 7-11.
- Grant, M. A., 1996. "Geothermal Resource Management," *Geothermal Energy New Zealand Limited*, Auckland, New Zealand, 143 pp.
- Grigsby, C. O.; Goff, F.; Trujillo, P. and D. Counce, 1984. "Geochemical Behavior of a Hot Dry Rock Geothermal Reservoir." in (Baldrige, W.S., Dickerson, P., Riecker, R., and Zidek, J., eds.) *Rio Grande Rift*, New Mexico Geological Society Guidebook 35, p. 265-270.
- Heiken, G. and F. Goff, 1983. "Hot Dry Rock Geothermal Energy in the Jemez Volcanic Field, New Mexico," *Journal of Volcanology and Geothermal Research*, v. 15, p. 223-246.
- Hinrichs, M., 2001. Personal communication. Los Alamos National Laboratory, Los Alamos, NM.
- Hulen, J. B.; Nielson, D.; Goff, F.; Gardner, J. N. and R. Charles, 1987. "Molybdenum Mineralization in An Active Geothermal System, Valles Caldera, New Mexico," *Geology*, v. 15, p. 748-752.



- Hunt, T. M. and B. J. Scott, 1998. "Recovery of Natural Thermal Features After Field Testing: New Zealand Examples." *Geothermal Resources Council Transactions*, v. 22, p. 49-54.
- Kerr, R. A., 1982. "Extracting Geothermal Energy Can Be Hard," *Science*, v. 218, p. 668-669.
- Mangold, D. C. and C. F. Tsang, 1984. "Workshop on CSDP Data Needs for the Baca Geothermal Field: A Summary," *Lawrence Berkeley National Laboratory*, Report LBL-17695, 132 pp.
- Morgan, P.; Sass, J. and R. Jacobson, 1996. "Heat Flow in VC-2A and VC-2B, and Constraints on the Thermal Regime of the Valles Caldera, New Mexico." in (Goff, F., Kues, B., Rogers, M., McFadden, L., and Gardner, G., eds.) *The Jemez Mountains Region*: New Mexico Geological Society, Guidebook 47, p. 231-236.
- Nielson, D. L. and J. B. Hulen, 1984. "Internal Geology and Evolution of the Redondo Dome, Valles caldera, New Mexico," *Journal of Geophysical Research*, v. 89, p. 8695-8711.
- Riecker, R. R. (ed.), 1979. "Rio Grande Rift: Tectonics and Magmatism," *American Geophysical Union*, Washington D.C., 438 pp.
- Smith, R. L. and R. A. Bailey, 1968. "Resurgent Cauldrons," *Geological Society of America*, Memoir 116, p. 613-662.
- State of New Mexico, 1980. "The Application of Marcel and Thomas Abousleman for An Alternative Point, and New Place and Purpose of Use from Surface Water to Geothermal Water, and to Appropriate the Underground Waters of the State of New Mexico, Testimony of R. F. Dondanville." in *The State of New Mexico court transcripts*, 02541-B, RG-32624, Natural Resources Department, Albuquerque, April 10, 1980, 2 volumes.
- Steck, L. K.; Thurber, C.; Fehler, M.; Lutter, W.; Roberts, P.; Baldridge, W. S.; Stafford, D. and R. Sessions, 1998. "Crust and Upper Mantle P-Wave Velocity Structure Beneath Valles Caldera, New Mexico: Results from the Jemez Teleseismic Tomography Experiment," *Journal of Geophysical Research*, v. 103, p. 24,301-24,320.
- Summers, W. K., 1976. "Catalog of Thermal Waters in New Mexico," *New Mexico Bureau of Mines & Mineral Resources*, Hydrologic Report 4, Socorro, NM, 80 pp.
- Toyoda, S.; Goff, F.; Ikeda, S. and M. Ikeya, 1995. "ESR Dating of Quartz Phenocrysts in the El Cajete and Battleship Rock Members of Valles Rhyolite, Valles Caldera, New Mexico," *Journal of Volcanology and Geothermal Research*, v. 67, p. 29-40.
- Trainer, F. W.; Rogers, R. J. and M. L. Sorey, 2000. "Geothermal Hydrology of Valles Caldera and the Southwestern Jemez Mountains, New Mexico." *U.S. Geological Survey*, Water Resources Investigations Report 00-4067, 115 pp.
- Truesdell, A. H. and C. J. Janik, 1986. "Reservoir Processes and Fluid Origins in the Baca Geothermal System, Valles Caldera, New Mexico," *Journal of Geophysical Research*, v. 91, p. 1817-1833.
- Vuataz, F. -D. and F. Goff, 1986. "Isotope Geochemistry of Thermal and Non-Thermal Waters in the Valles Caldera, Jemez Mountains, New Mexico," *Journal of Geophysical Research*, v. 91, p. 1835-1853.
- Williams, J. M., 1986. "A Discernment of Two Opposing Reports on the Hydrological Effects of a Hydrothermal Power Plant," *Los Alamos National Laboratory*, Report LA-10691-MS, 26 pp.
- Wolff, J. and J. N. Gardner, 1995. "Is the Valles Caldera Entering a New Cycle of Activity?" *Geology*, v. 23, p. 411-414.



# HOT DRY ROCK (HDR) GEOTHERMAL ENERGY RESEARCH AND DEVELOPMENT AT FENTON HILL, NEW MEXICO

Dave Duchane & Don Brown  
Los Alamos National Laboratory Associates  
Los Alamos, NM

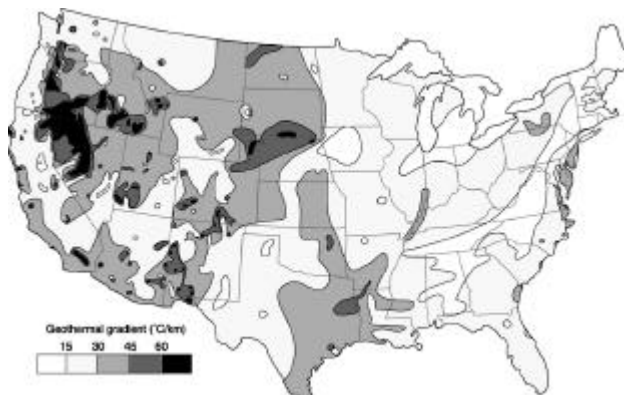
## INTRODUCTION

Conventional geothermal technology entails the production of useful energy from natural sources of steam or, much more commonly, hot water. These hydrothermal resources are found in a number of locations around the world, but they are the exception rather than the rule. In most places, the earth grows hotter with increasing depth, but mobile water is absent. The vast majority of the world's accessible geothermal energy is found in rock that is hot but essentially dry -- the so-called hot dry rock (HDR) resource.

The total amount of heat contained in HDR at accessible depths has been estimated to be on the order of 10 billion quads (a quad is the energy equivalent of about 180 million barrels of oil and 90 quads represents the total US energy consumption in 2001). This is about 800 times greater than the estimated energy content of all hydrothermal resources and 300 times greater than the fossil fuel resource base that includes all petroleum, natural gas, and coal. (Tester, et al. 1989). Like hydrothermal energy resources already being commercially extracted, HDR holds the promise for being an environmentally clean energy resource, particularly with regard to carbon dioxide emissions, which can be expected to be practically zero.

The total HDR resource base noted above was calculated by summing the thermal energy content of rock beneath the landmasses of the world at temperatures above 25°C (77°F), from the surface to a depth of 30,000 ft (9,150 m). Obviously, much of this HDR resource resides in rock that is only marginally warmer than 25°C and is thus of such low-grade that it is not practical to recover it. In addition, a large part of the resource may be located in parts of the world where its exploitation may not be economically worthwhile. Nevertheless, with such a large resource base, the potential for HDR to be a major contributor to the world's energy supply makes its development well worth pursuing, especially when considered in light of its environmental advantages.

One method of evaluating the potential for HDR development in a region is to examine its geothermal gradient -- the rate at which the earth gets hotter with depth. The geothermal gradient varies widely from place to place, being much higher in tectonically active regions and in areas of volcanic activity. Figure 1 shows a geothermal gradient map of the United States. It is apparent from this map that HDR resources at useful temperatures (above 100°C) are abundant in many parts of the west.



**Figure 1.** *A geothermal gradient map of the United States. There are many high-gradient areas in the western part of the country.*

## THE LOS ALAMOS HDR CONCEPT

Although the fact that the earth gets hotter with depth has been known for a very long time, it wasn't until about 1970 that a team of scientists and engineers at Los Alamos National Laboratory developed a plan to access the HDR resource and bring its contained heat to the surface for practical use. As described in a patent issued in 1973 (Potter, et al. 1974), the original Los Alamos HDR development concept entailed drilling a well into hot crystalline rock, using water under pressure to create a large vertical fracture in the hot rock, and then drilling a second well to access that fracture at some distance above the first wellbore. The system would be operated by injecting pressurized cold water through the first well into the deeper part of the fracture and, after passing it across the hot surface of the fracture, returning the water to the surface as superheated fluid through the second wellbore. After extracting its useful energy, the same water would be recirculated to mine more heat. Larger systems would be developed by creating multiple fractures spaced along a single set of well bores inclined toward the horizontal at depth. As described below, this original concept was to be significantly modified as researchers learned more about the characteristics of the engineered geothermal reservoirs created during hydraulic fracturing operations.

## THE LOS ALAMOS HDR DEVELOPMENT PROGRAM

With sponsorship by the U.S. Atomic Energy Commission, fieldwork to demonstrate the feasibility of extracting useful energy from HDR began at Los Alamos in the early 1970s. After a number of preliminary drilling and fracturing experiments, a site at Fenton Hill, NM, about 40 miles west of Los Alamos was chosen for the establishment of the world's first HDR circulation system. The Fenton Hill site is located in the Jemez Mountains of north-central New Mexico, on the western flank of the Valles Caldera just outside the ring fault structure, where the local geothermal gradient is on the order of 65°C/km (3.6°F/100 ft). It is just off a paved state highway that facilitates the transport of personnel, supplies, and equipment. At the time of its selection, the land, which is owned by the US Forest Service, had recently been burned over and was available for scientific work on a permit basis.

### THE PHASE I SYSTEM

The first HDR reservoir at Fenton Hill was created, tested, and enlarged in stages, with work beginning in 1974 and continuing through 1979. The ultimate configuration of the Phase I reservoir, as tested during the 9-1/2-month continuous flow test in 1980, is shown in Figure 2 (Brown 1995). The first deep borehole (GT-2) was drilled in 1974, to a final depth of 9619 ft (2932 m) in a host rock of jointed granodiorite, with a bottom-hole temperature of 180°C (356°F). After creating a hydraulic fracture from the bottom of GT-2, a second borehole (EE-1) was directionally drilled directly beneath the bottom of GT-2 to intersect this hydraulic fracture, but only a seepage flow connection was obtained. In an attempt to connect the two boreholes with another

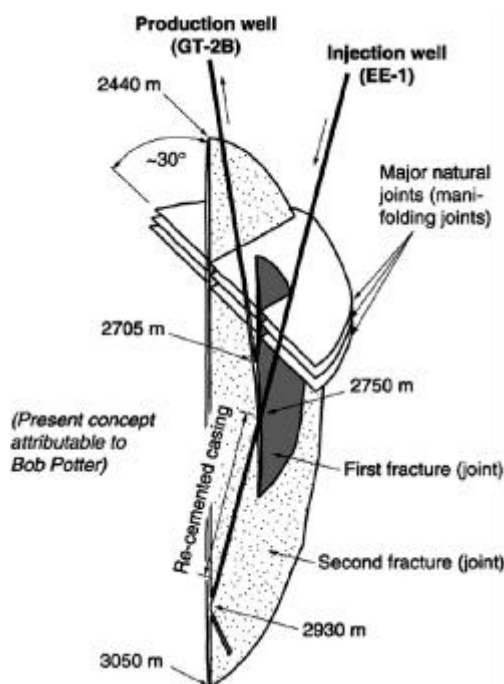
hydraulic fracture, a larger fracture was created in what was thought to be the short open-hole interval below the casing in EE-1, with the expectation that this fracture would grow *upward* and intersect GT-2 (since the first fracture created from the bottom of GT-2 had apparently not grown downward). But again, only a very modest flow connection was obtained (less than 1 gpm). (Actually, this fracture was initiated at a depth of about 9000 ft (2750 m), up and behind the casing in EE-1, since the cement had been over displaced during cementing operations, leaving the bottom 600 ft of the casing without cement.)

Following additional injections into EE-1, temperature logging and micro-seismic surveys, GT-2 was redrilled twice--in a direction roughly across the micro-seismically determined north-south strike of the target hydraulic fracture created from EE-1. The second redrilling in mid-1997 (GT-2B, as denoted in Figure 2) finally succeeded in producing a satisfactory flow connection to EE-1, resulting in the first-ever fracture connection between two boreholes in deep crystalline rock and ultimately, the world's first HDR reservoir.

The first three flow tests of the initial reservoir, the first lasting 5 days, the second lasting 75 days, and the third lasting 28 days respectively, produced a rapid cooldown of the reservoir, indicating that only a small heat transfer surface was accessible to the circulating fluid. The third flow test, operated under conditions of high back pressure, confirmed that only one vertically oriented joint was being accessed -- the small darkly shaded joint shown in Figure 2. Compared to the 75-day flow test, where the flow impedance decreased from 15 to 3 psi/gpm (1.3 kPa/L/s) as the flow path rapidly cooled, under high back pressure operation, the flow impedance varied from 2 to 0.5 psi/gpm (0.9 to 0.2 kPa/L/s) with continuing circulation (and much less cooling).

After recementing the bottom 600 ft (183 m) of the casing in EE-1, a series of additional hydraulic fracturing operations resulted in first opening the larger vertical joint shown in Figure 2--which was initiated from the bottom of the casing in EE-1 at a depth of 9600 ft (2930 m)--and then opening (at higher pressure) the inclined manifold joints connecting the two vertical joints. These additional pressure-stimulations resulted in the final Phase I reservoir configuration in Figure 2, with the injected flow leaving EE-1 at a depth of 9600 ft, flowing up the larger vertical joint and then down the set of inclined manifold joints, down the small vertical joint initially opened at 9000 ft (2743 m) in EE-1, and finally out the production well, GT-2B!

During the final flow test of the Phase I reservoir in 1980, the temperature of the produced fluid declined from an initial value of 156°C to 149°C (313 to 300°F), at a near-constant flow rate of 90 gpm (5.7 L/s) and an injection pressure of 1200 psi (8.3 MPa). Measurements and modeling showed that the reservoir was small by commercial standards, with an estimated stimulated volume on the order of 600,000 cubic meters (21 million cu. ft). The scientific data and engineering experience acquired during testing of the Phase I research reservoir provided the basis for the development of the larger, hotter, and deeper Phase II, engineering-scale HDR system.



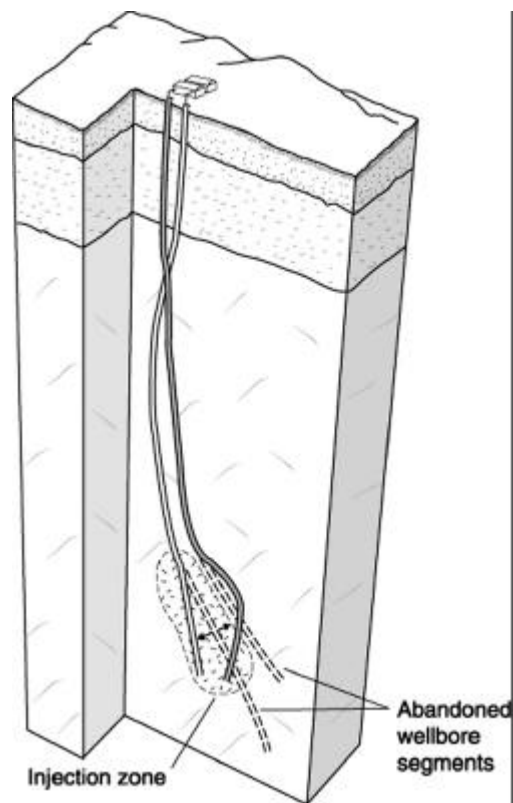
**Figure 2.** Conceptual view of the Phase I HDR reservoir at Fenton Hill, NM.

## THE PHASE II SYSTEM

In 1979, when construction of the Phase II HDR system was begun, experience with the Phase I reservoir had provided little reason to doubt the validity of the original Los Alamos HDR concept. The Plan for the Phase II system called for the creation of multiple vertically fractured reservoirs. The deeper wellbore penetrated to about 14,400 ft (4,400 m) with the last 3300 ft (1,000 m) inclined to the east at an angle of 35° from the vertical. The second wellbore was drilled to a total depth of about 13,100 ft (4000 m), with the last 3300 ft angled at 35° from the vertical and positioned above the sloped portion of the deeper wellbore. Between 1982 and 1984, numerous hydraulic fracturing operations were conducted at several points along the sloped portion of the lower wellbore. All of these failed to connect the two well bores. Fortunately, advances in seismic science were making it possible to more-precisely locate the origins of microearthquakes generated during the hydraulic fracturing. This in turn, gave researchers a much better picture of where the reservoir fractures were located and how they were extending.

The most extensive hydraulic fracturing operation was conducted in the lower wellbore at a depth of about 11,700 ft (3,560 m), by the injection of 5.7 million gallons (21,500 m<sup>3</sup>) of water at surface pressures of about 7000 psi (48 MPa). Seismic data indicated that the reservoir created during this operation was developing in a 3-dimensional manner as a 300-ft (91-m) thick ellipsoidal region with its longer axis approximately along the trajectory of the wellbore. It was apparent that no reasonable amount of additional hydraulic fracturing would lead to a connection between the two well bores. With this information in hand, the decision was made to redrill the lower portion of the upper wellbore to penetrate the reservoir region as indicated by the seismic data. When this was done, a small amount of additional hydraulic stimulation in the redrilled wellbore led to the establishment of a number of hydraulic connections between the two wells. The deeper wellbore had been damaged during the course of the multiple hydraulic fracturing experiments, so it was considered prudent to block off its lower portion and redrill it nearby through the reservoir region. With this accomplished, the Phase II reservoir was finally ready for testing. A cross section of the underground portion of the Phase II HDR system is shown in Figure 3

The volume of the Phase II reservoir has been estimated in a number of ways. The seismic volume includes the entire fractured region, while the fluid accessible volume encompasses all parts of the reservoir, even dead-end joints, that are reached by the injected fluid. However, perhaps the most meaningful definition of reservoir volume is the flow-accessible or heat transfer volume, which includes only those portions of the reservoir that are accessible to the circulating fluid. From a practical standpoint, it is only this part of the reservoir that can provide energy to the circulating water and, ultimately, to the energy production facility at the surface. A number of different techniques involving seismic, pressure, and tracer measurements have been employed to determine the



**Figure 3.** *Conceptual view of the Phase II HDR reservoir at Fenton Hill, NM.*

volume of the Phase II reservoir. These indicate a fluid accessible volume of 15-20 million cubic meters and a heat-transfer (flow accessible) volume of about 6-8 million cubic meters (1.6 to 2.1 billion gallons) (Brown, et al 1999). Much of the fluid-accessible but flow-inaccessible part of the Phase II reservoir lies in the fractured region that is on the opposite side of the injection well from the production wellbore. Obviously, another production well placed in this region would greatly increase the productive capacity of the Fenton Hill Phase II HDR system. In any event, the Phase II reservoir is many times larger than the Phase I system in which cooling was observed.

## REASSESSMENT OF THE HDR RESERVOIR CREATION PROCESS

The difficulties encountered in creating the Phase II HDR reservoir led to a significant revision in the concept of the effects of hydraulic fracturing, at least in deep, essentially closed systems like the Phase II reservoir region at Fenton Hill. The idea that hydraulic pressure causes competent rock to rupture and create a disc-shaped fracture was refuted by the seismic evidence. Instead, it came to be understood that hydraulic stimulation leads to the opening of existing natural joints that have been sealed by secondary mineralization. Over the years additional evidence has been generated to show that the joints oriented roughly orthogonal to the direction of the least principle stress open first, but that as the hydraulic pressure is increased, additional joints open.

The deep earth stresses at Fenton Hill were difficult to determine because of the temperatures involved and the fact that conventional hydraulic fracturing stress measurement techniques were unreliable in a multiply jointed crystalline rock mass, where the tensile strength of the unflawed rock was of the order of 5000 psi (34 MPa) (Brown, 1989). Since the Fenton Hill HDR site is situated near the west-bounding fault structure for the extensional Rio Grande Rift, it was not surprising to confirm, through fracturing and other stress determination techniques, that the least principal effective earth stress was oriented east-west (orthogonal to the direction of the rift structure), with a modest value of about 10 MPa at 3500 m (1450 psi at 11,500 ft). In contrast, other measurements determined that the maximum effective earth stress was vertical and equal to the overburden stress (59 MPa [3,500 psi] at 3500 m). The intermediate effective earth stress was oriented north-south, with a value determined by joint opening and closing stress measurements, to be on the order of 30 MPa.

The principal difference between the Phase I and Phase II HDR reservoirs was the change in the orientation of the main fluid-conducting joints. Between these two regions of Precambrian plutonic and metamorphic rock, there exists a significant brecciated shear zone on the order of several tens of meters thick. Above this interface, as shown in Fig. 2, the continuous joints were essentially vertical and interconnected by inclined "manifolding" joints. In the Phase II reservoir region below this shear zone, there was apparently a more-or-less continuous joint set, striking N29W and dipping 76° to the east, and with an opening stress level of about 31 MPa (4,500 psi). That joint set appeared to control the overall flow impedance of the reservoir.

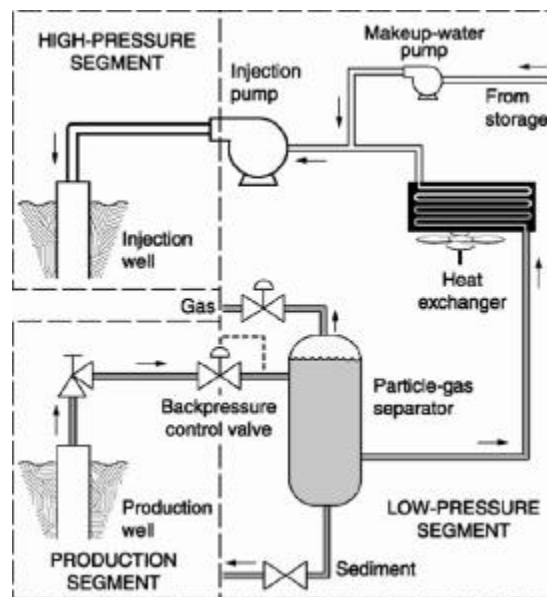
The flow impedance and fracture-extension pressures of the multiply-connected Phase I reservoir (Fig. 2) were controlled by the set of inclined manifolding joints that exhibited an opening stress of about 15 MPa (2,200 psi). This difference in opening stress levels for the "manifolding" joints between the two reservoirs -- 15 MPa vs. 31 MPa -- explains the principal difference between both their fracturing and circulating pressures.

This new understanding mandates modifications in the conceptual design of HDR systems. Perhaps most important, because reservoirs are three dimensional, but typically elongate, as determined by a combination of the earth stresses and the joint structure, a three-well system with an injection well located approximately in the center of the reservoir and production wells at each end will allow the highest production rates by holding open a number of the previously high-impedance interconnecting joints without inducing reservoir growth at the boundaries. In this design, the production wells act as pressure relief points, thereby permitting the use of injection pressures so high that they would lead to additional hydraulic fracturing if these pressure sinks were not in place. Additional evidence has shown that the majority of the resistance to flow (flow impedance) is concentrated in the region of the production wellbore(s) (Brown, 1996). The best way to obtain a reservoir with a long lifetime, therefore, is to separate the well bores by as great a

distance as is feasible. These two important lessons were learned at Fenton Hill, but budget considerations precluded drilling any additional well bores. The system as tested and reported below therefore represented far less than what we now know to be the optimal design of an HDR system.

## CONSTRUCTION OF THE PHASE II SURFACE PLANT

With the Phase II reservoir and well bores finally in place, work between 1987 and 1991 concentrated on the design and construction of a surface plant that would allow the reservoir to be flow-tested in a manner simulating the operation of a commercial HDR facility (Ponden, 1991). The layout of the main closed-loop portion of the completed surface plant is shown in Figure 4.



**Figure 4.** *Layout of the closed-loop portion of the Phase II HDR surface plant.*

The heart of the plant was the injection pump. This unit provided the pumping power to force the water down the injection wellbore, across the reservoir, up the production wellbore, and back to its own inlet. Both wellheads were equipped with a variety of valves to allow bypass flow and to provide protection against over pressure as well as to control normal circulation.

Beyond the production wellhead a series of pressure-letdown valves allowed control of the production well back pressure. Strainers and a particle/gas separator assured that any contaminants picked up by the circulating fluid in its passage through the reservoir would be removed before the water was returned to the injection pump for reinjection (in practice, only dissolved gases and almost no suspended solids were found in the produced fluid). The surface piping then delivered the water to a heat exchanger, which cooled it to ambient temperature. From the heat exchanger, the surface line entered the makeup-water building where water was added to replace the small amount lost in circulation through

GHC BULLETIN, DECEMBER 2002  
the reservoir. From this point, the fluid was returned directly

to the inlet of the injection pump. The production piping string was designed to allow for thermal expansion in those parts of the loop where hot fluid would be present.

The entire loop was highly automated. Important operating parameters such as temperature, pressure, flow-rate, etc., were automatically measured and recorded at frequent intervals. Numerous safety measures were in place to assure that the plant would shut itself down in the event that any of a number of parameters moved out of a selectable control range. It was found entirely feasible to operate the plant for extended periods of time with no on-site personnel; a fact that has important economic implications for the ultimate commercialization of HDR technology.

Two reciprocating pumps, powered by diesel engines and capable of producing pressures of up to 5,000 psi (34.5 MPa), were originally installed at Fenton Hill to provide the needed injection pressure. The plan was to operate the pumps on alternating cycles of 10 days each, with pump maintenance, such as changing the oil in the diesel drivers, being performed during each pump's idle period. Both these pumps failed due to a materials problem associated with their construction about 2 months after long-term flow testing began. They were eventually replaced with a centrifugal pump that proved to be both reliable and efficient. Aside from this single, but very significant, problem, the operation of the surface plant was practically trouble-free over the entire term of the flow testing program.

## FLOW TESTING OF THE PHASE II HDR SYSTEM

A number of short flow tests of the Phase II reservoir were conducted during 1986-1987, prior to the construction of the permanent surface plant. These tests established the viability of the system for longer-term circulation experiments and provided guidelines for the establishment of reasonable operating parameters, particularly the maximum injection pressure that could be maintained without inducing reservoir growth as evidenced by seismic activity and excessive water consumption.

In March 1992, after the completion of the surface plant and a few short preliminary circulation tests, a long-term flow test (LTFT) of the Phase II HDR reservoir was initiated. Although this test was originally scheduled to encompass a year of continuous circulation, the pump failure described above resulted in an interruption of circulation on July 31, 1992, after 112 days of operation. This interruption combined with subsequent budget shortfalls resulted in a LTFT program that spanned more than three years and involved three steady-state segments as well as several shorter circulation periods, with the total circulation time amounting to somewhat over 11 months. Table 1 summarizes operating data from the steady-state segments of the LTFT.

The results reported in Table 1 do not reflect the significant amount of work conducted during the periods between the steady-state test segments. When steady-state operations were not possible, shorter experiments were con-

ducted to investigate specific characteristics of the Phase II reservoir and evaluate techniques to improve the productivity of the system.

As shown in Table 1, the 1995 steady-state operating segment was broken into four stages. In the first stage, the conditions of the first two steady-state segments were reestablished. The latter three stages involved manipulations of the production schedule to confirm the advantages of operating scenarios that had been briefly explored during the interim periods. In the second stage, the back pressure was raised to a higher level to reduce the net pressure drop across the reservoir. In the third stage, one-half-hour daily shut-ins of the production well were employed to repeatedly jack open the fluid-carrying joints, which experience had shown tended to slowly close with time under steady-state circulation.

**Table 1. LTFT Steady-State Operating Data**

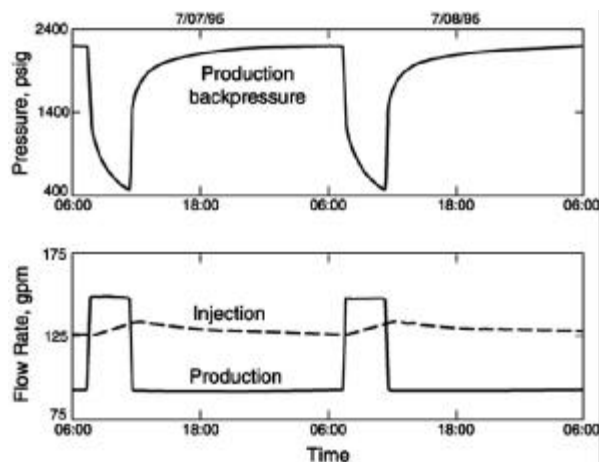
Steady-State Segment:	First	Second	Third			
Time Frame:	Mar-Jul, 1992	Feb-Apr, 1993	May-Jul, 1995			
Duration, Days:	112	55	66			
<u>Injection</u>						
Pressure, psi	3960	3960	3960			
Flow Rate, gpm	106	103	120-128			
<u>Production</u>						
	<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>		
Back pressure, psi	1400	1400	1400	2200	2200	2200-500
Flow Rate, gpm	90	90	105	94	98	92-150
Temperature, °C	183	184	184	181	183	183-189
<u>Water Loss</u>						
Rate, gpm	12.5	6.8	18	21	18	a
% of Net Injected						
Vol (b).	12	7	14	18	15	a
<hr/>						
a.	Water loss data were meaningless during segment 3D.					
b.	After subtracting loss due to a small leak in the injection wellbore that immediately returned a small fraction of the injected fluid to the surface.					

a. Water loss data were meaningless during segment 3D.

b. After subtracting loss due to a small leak in the injection wellbore that immediately returned a small fraction of the injected fluid to the surface.

In the fourth stage, the potential for load-following operation of the HDR system was explored (Brown 1996). During this stage, as shown in Figure 5, the fluid production rate was increased rapidly each day, maintained at a rate about 60% higher than its baseline for a period of 4 hours, and then rapidly decreased to its former level. This was accomplished by manipulating the back pressure on the production wellbore using the plant's automated control system. Injection continued at a relatively steady pace throughout this stage of the test.

The steady-state segments of the LTFT demonstrated a number of characteristics of HDR reservoirs that have great significance from the standpoint of economic energy production: Routine fluid production for long periods with no human intervention showed the potential for the operation of HDR systems with minimum manpower. The rapid attainment



**Figure 5.** *Injection and production conditions during the last two cycles of the load-following flow test of the Phase II HDR reservoir at Fenton Hill, NM.*

of repeatable operating conditions after either short or long shut-in periods indicated that HDR reservoirs have the long-term stability required for predictable energy production. The capability to rapidly and repeatedly adjust production rates, as illustrated in Figure 5, highlighted the potential for manipulating the production rate to produce more energy from HDR reservoirs at periods of peak demand when power is most valuable.

Production temperatures were stable throughout the term of the LTFT, and predictive modeling indicated that the Phase II reservoir could have operated for many years without an appreciable decline in the temperature of the produced fluid. Tracer data collected during all three of the test segments indicated that the reservoir is a dynamic entity, with cooler flow paths closing and new flow paths through the hot rock developing as circulation progressed, providing additional evidence that long thermal lifetimes can be expected for HDR reservoirs.

Experience from the LTFT, as well as earlier static pressurization tests, showed that the rate of water-loss declines with time at constant reservoir pressure. In this regard, it is important to note that the reservoir pressure was maintained at operating levels during the seven months between the first and second steady-state test segments, but allowed to decay during the 2-year period between the second and third test segments. The water-loss rates during the third segment reflect this fact.

Geochemical problems were essentially non-existent during the LTFT. Concentrations of dissolved solids rapidly reached about 3,500 ppm (about one-tenth the salinity of seawater) and then remained steady. Dissolved gases reached an equilibrium level of less than 2,000 ppm, with carbon dioxide being the preponderant species. The gases remained in solution during closed-loop circulation because even the production side of the loop was maintained at a pressure in excess of 600 psi (4 MPa).

The LTFT led to several observations important to the design and operation of HDR systems. Evaluation of pressure changes at the injection and production wellheads when system shutdowns took place indicated that the resistance to flow through an HDR reservoir is concentrated near the production wellbore where the rate of pressure change is greatest (Brown, 1996). This implies that increasing the distance between the well bores by a large amount to create a larger reservoir would lead to only minor increases in the pumping pressure required to circulate a given amount of fluid. During one short experiment, the production well was closed in for a number of hours on a daily basis while injection continued at the normal rate. On the third day of the experiment, an anomalously large flow was noted shortly after the production well was re-opened. This event occurred at the end of second steady-state flow segment and remains unexplained. The effect did not appear to persist through the beginning of the third steady-state test segment two years later. The sudden flow increase did, however, provided further evidence that pressure manipulations can have a profound effect on HDR reservoir productivity.

The LTFT was of small scale. Only 4 to 6 MW of thermal power was produced and, at the temperatures of the produced fluid, less than 0.5 MW of electricity could have been generated if it had been possible to convert that thermal energy to electric power. The LTFT was also of limited duration. Practical HDR plants would have to operate for several tens-of-years to repay the substantial up-front investment required for drilling and reservoir creation. The data generated did show, however, that the Fenton Hill system could have generated significant excess energy beyond that required to operate the plant, and modeling indicated a long reservoir lifetime. Thus, in spite of its limitations, the LTFT provided results that greatly enhanced our understanding of HDR systems and moved HDR technology significantly closer to the demonstration of commercial viability.

## OUTGROWTHS OF THE FENTON HILL PROGRAM

The pioneering HDR work at Fenton Hill demonstrated that energy from HDR could be routinely extracted for practical use. It stimulated worldwide interest in HDR technology (Duchane, 1998). Germany and Japan both participated with funds and personnel in the work at Fenton Hill during the 1980s. HDR programs were subsequently founded around the world, first in Europe, then in Japan. In the late 1980s, the European Community initiated a large field program at Soultz-sous-Forêts in France, and two field programs were begun in Japan. Most recently field operations have gotten underway in Australia. Today there is a large community of experts in HDR. New innovations have sprung up as well. In Japan, 3-well systems have been evaluated and in Europe downhole pumping from a low-productivity hydrothermal system (a "hot-wet rock" or HWR reservoir) has been implemented.



Related applications of HDR technology and advanced exploitation techniques have also been considered (Duchane, 1993). Perhaps the most promising concept entails the cogeneration of clean water and energy. Treated sewage could be used as a source of feed water for an HDR system. Under the high-temperatures and pressures of the reservoir, the water would be sterilized. Purified water as well as thermal energy could then be recovered at the surface. Under the proper conditions a variety of organic wastes from industries such as food processing, paper, lumber milling, and the like could be treated via an HDR reservoir. Seawater could even be desalinated, provided proper measures were put in place to handle the large volume of salts that would be returned to the surface along with the superheated water. Cogeneration of these two most precious commodities--energy and clean water--via HDR could provide an answer to two critical problems facing the world of tomorrow.

### STATUS OF HDR TECHNOLOGY TODAY

Three major issues must be resolved for HDR to become a significant contributor to the commercial energy market. The first of these is productivity. Reservoirs must be created that produce an economic rate of return in relation to the investment. The second issue is longevity. We must show that reservoir lifetimes are sufficient to warrant the large up-front investment required to establish an HDR system. The third issue is universality. It must be shown that reservoirs such as Fenton Hill can be the rule rather than the exception.

Research and development work to date, both here in the U.S. and in other parts of the world, has made a significant start toward resolving these issues, and routes to assuring positive answers to all the remaining questions have been proposed. Implementation is now essential. In fact, what is most needed today is an HDR facility that produces energy for market in order to build the track record that will make this technology an attractive investment to power producers around the world. Programs underway in both Europe and Australia show promise of developing the first commercially viable HDR system. Once this becomes a reality, HDR may rapidly move toward becoming a major clean energy resource of the twenty-first century.

### REFERENCES

Brown, D. W., 1989. "The Potential for Large Errors in the Inferred Minimum Earth Stress When Using Incomplete Hydraulic Fracturing Results," *Int. J. of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*, Vol. 26, No. 6, pp 573-577.

Brown, D. W., 1995. "The U.S. Hot Dry Rock Program- 20 Years of Experience in Reservoir Testing," in *Proceedings, World Geothermal Congress*, May 18-31, 1995, Florence, Italy, International Geothermal Assn., Inc., Auckland, New Zealand, vol 4, pp 2607-2611.

Brown, D. W., 1996. "Experimental Verification of the Load-Following Potential of a Hot Dry Rock Geothermal Reservoir," in *Proceedings Twenty-First Workshop on Geothermal Reservoir Engineering*, Stanford University, Stanford, CA, Jan 22-24, pp 281-285

Brown, D. W.; DuTeaux, R.; Kruger, P.; Swenson, D. and T. Yamaguchi, 1999. "Fluid Circulation and Heat Extraction from Engineered Geothermal Reservoirs," *Geothermics*, Vol, 28, No. 4/5, pp 553-572.

Duchane, D. V., 1992. "Industrial Applications of Hot Dry Rock Geothermal Technology," *International conference on industrial uses of geothermal energy* (Sept 2-4, 1992: Reykjavik, Iceland). Los Alamos National Laboratory report LA-UR-92-2380, Los Alamos, NM.

Duchane, D. V., 1998. "The History of HDR Research and Development," in *Draft proceedings of the 4<sup>th</sup> International HDR Forum*, Sept 28-30, Strasbourg, France.

Ponden, R. F., 1991. "The Design and Construction of a Hot Dry Rock Pilot Plant," in *Proceedings, Geothermal Energy Program Review IX*, March 19-21, San Francisco, CA, US Dept. of Energy document CONF-9103105, pp 149-151.

Potter, R. M.; Robinson, E. S. and M. C. Smith, 1974. "Method of Extracting Heat from Dry Geothermal Reservoirs," U.S. Patent #3,786,858.

Tester, J. W.; Brown, D. W. and R. M. Potter, 1989. "Hot Dry Rock Geothermal Energy-A New Energy Agenda for the 21<sup>st</sup> Century," Los Alamos National Laboratory report LA-11514-MS.

# TRUTH OR CONSEQUENCE, NEW MEXICO - A SPA CITY -

**John W. Lund**  
**Geo-Heat Center**

**James C. Witcher**  
**Southwest Technology Development Institute**  
**NMSU, Las Cruces, NM**

## INTRODUCTION

Truth or Consequences (TorC), named after the popular 40s and 50s radio quiz show on NBC, is located in south-central New Mexico on the banks of the Rio Grande. It is known for its “hot springs” and spas that use 100 to 110°F temperature water for hot baths, swimming pools and space heating. The original 19<sup>th</sup> century name for the town site area was Las Palomas Hot Springs, but the area had no permanent residents. Las Palomas, meaning place of doves, actually refers to a town site several miles south of TorC; where, hot spring visitors were forced to stay. The TorC town site grew into the small village of Hot Springs in the early 20<sup>th</sup> century and until March 1950, it was just one of hundreds of other small “hot spring” resort areas that was dependent on the tourist trade. In early 1950, Ralph Edwards, the moderator of the NBC radio program “Truth or Consequences” announced a nationwide contest for the program to annually visit a small city, if the city changed its name to that of the radio program. Hot Springs, New Mexico voted to change its name by a four-to-one margin and won the Ralph Edwards’ contest. Thus, the city no longer needed to be confused with other “hot spring” communities, but had its own unique name, Truth or Consequences or TorC as the town is commonly called in New Mexico today. Every year since 1950, Ralph Edwards has been coming back to celebrate the anniversary of the name change with a parade and other activities.

It is said that Indians in the region used the springs as “neutral grounds” long before Europeans settled the area. Indian tribes no doubt gathered here without conflict for the trading, religious purposes, to bathe, and to alleviate ailments. During the latter half of the 1800s, several large ranches were established across the area, and cowboys from one of these ranches, the John Cross Ranch, built the first adobe bathhouse over Geronimo Springs (Photo 1 and 2). The town of Hot Springs (TorC) proper really began with the construction of Elephant Butte Dam and Reservoir in 1912. Elephant Butte Dam was completed in 1916, as a part of the Rio Grande Project, one of the first large-scale irrigation projects in the west under the Reclamation Act of 1902. The town was incorporated in 1916 as Hot Springs and became the county seat of Sierra County in 1937. From the early 1900s, the hot mineral springs baths and hotels started developing into popular and permanent business (Photos 3 and 4).



**Photo 1.**

*The earliest known photo of people enjoying the health benefits of the hot mineral springs—thought to be from 1860s or 70s (Courtesy of Geronimo Springs Museum Archives).*



**Photo 2.**

*This old structure, one of the first to be built in the downtown, was a bathhouse built by the John Cross Cattle Co., for use by its cowboys—dated around 1882 (Courtesy of Geronimo Springs Museum Archives).*



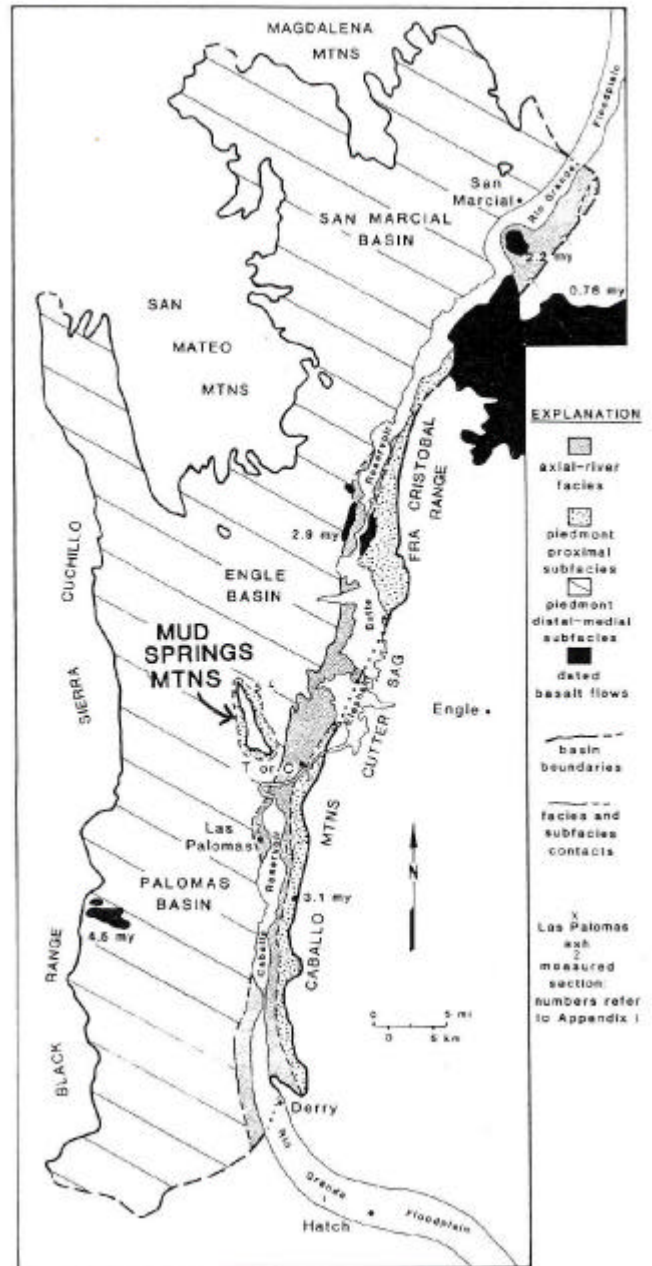
**Photo 3.** *One of the first bathhouses and hotels built in Hot Springs (Courtesy of Geronimo Springs Museum Archives).*



**Photo 4.** *From the early-1900s showing one of the hot mineral springs baths and hotels that had developed (Courtesy of Geronimo Springs Museum Archives).*

## GEOLOGY AND HYDROGEOLOGY

TorC overlies a bedrock constriction along the Rio Grande between the upstream Engle basin to the north and the Palomas basin to the south. The Engle and Palomas basins are major half grabens within the southern Rio Grande rift. The intersection of a northwest-trending horst block, the Mud Springs Mountains uplift, and the north-trending Caballo Mountains horst forms a bedrock constriction for surface and groundwater flow between the basins (Figure 1). The bedrock geology in the area of the TorC geothermal system is complex and shows compressional structures of Laramide (Late Cretaceous to Eocene) internal to the Later Tertiary rift Mud Springs Mountains horst block (Kelley and Silver, 1952). Thermal water discharges into Rio Grande fluvial terrace deposits of Latest Pleistocene to Holocene age from overturned, but steeply dipping Pennsylvanian limestone at or near the contact with the Devonian Percha Shale (Figure 2). Other unconfirmed flows may originate from the buried



**Figure 1.** *Structural geologic setting of the Truth or Consequence area.*

shallow pediment built on vertically-oriented Ordovician limestone, dolomite and sandstone and fractured Precambrian granite. However, the Precambrian granite appears to act as an aquitard as no thermal flows are noted on the south bank of the Rio Grande or in the vicinity of Carrie Tingley Hospital where granite is exposed. Other possible bedrock control is indicated by a small Pleistocene reverse fault (?) that displaces Paleozoic Limestone over early Pleistocene axial fluvial ancestral Rio Grande deposits or Palomas Formation, an upper Santa Fe Group basin fill unit of the Palomas basin (Wells and Granzow, 1981).



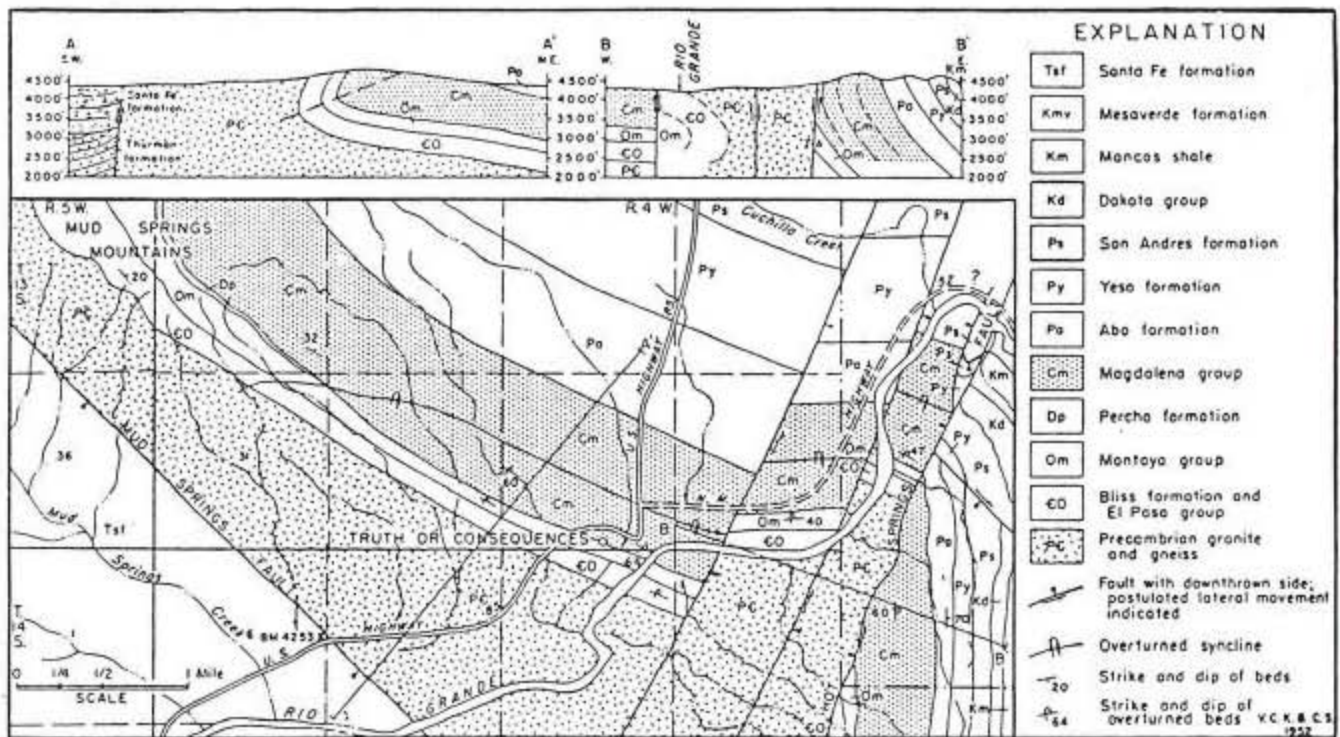


Figure 2. Geology and cross sections of the Truth or Consequence area (from Kelley and Silver, 1952).



Figure 3. Map of Truth of Consequence showing distribution of temperatures of thermal water from artesian wells, April 26, 1940 (after: Theis, Taylor and Murray, 1942).

Hot springs and thermal wells are found only in the center of TorC in a small area about a quarter of a mile radius in sec 33, T 13 S, R 4 W (Figure 3). The thermal waters at TorC range from 36 to 45.6 °C and they are sodium chloride type with total dissolved solids generally between 2600 and 2700 mg/L (Summers, 1976; Witcher, 1995). End member thermal waters have chloride concentrations exceeding 1350 mg/L and silica concentrations between 41 and 45 mg/L. Shallow near surface mixing with non-thermal groundwater is indicated by generally lower chloride concentration and lower temperature. The ultimate discharge of the thermal water is to the Rio Grande directly or indirectly via subsurface flow and mixing with non-thermal water. Theis and others (1941) estimated the total discharge of the geothermal system to be about 3.5 cfs or about 2,260,000 gpd based upon flow measurements in the Rio Grande downstream. Theis and others (1941) estimated the natural heat loss of the system at 180,000 calories per minute (42,850 Btu/hr).

In 1935, the New Mexico State Engineer declared a 38 mi<sup>2</sup> area around TorC as the "Hot Springs Underground Water Basin." On July 1, 1937 the Hot Springs Underground Water Basin was closed to additional appropriation of thermal water and the basin was closed to further non-thermal appropriation in 1945. Almost all production of thermal water at TorC comes from drilled or shallow dug wells ranging from a few feet depth to 258 feet depth. Artesian surface flow of several tens of gallons per minute is common. Theis and others (1941) reported the results of short-term pump test of several wells with specific capacities of 10 to 34 gpm/ft, transmissivities of 34,000 to 52,000 ft<sup>2</sup>/min, and storage coefficients of  $1.2 \times 10^{-3}$  to  $1.8 \times 10^{-8}$ .

Fluctuations occur in artesian head of spring and well discharges, and are related to diurnal and seasonal use of the water and level of the Rio Grande. Several years ago, the Rio Grande was dredged as a requirement to remove sediment build up allowing greater channel capacity to prevent flash flooding and flooding if the upstream Elephant Butte Dam has large spill way and controlled releases. As a result of this, the artesian head dropped at several spas and temperature drops were noted, especially when no release of water from the Dam to the Rio Grande was occurring. In order to remedy the problem, the U. S. Bureau of Reclamation bulldozed an earthen dam below the thermal area to bring the level of the Rio Grande up during low flow periods. This approach has successfully resolved the artesian head and temperature drops.

## GEOTHERMAL USE

Two early demonstration projects using geothermal energy were the Carrie Tingley Hospital and the Senior Citizens' Center. Both projects were funded by the New Mexico Energy and Minerals Department and constructed in the early-1980s. At the hospital, geothermal waters at 105°F were supplied to heat a swimming pool which was used for physical therapy treatments for crippled children. The hospital has since been located to Albuquerque; however, the geothermal system remains intact at the physical plant. A low-temperature space heating system demonstration project was

constructed at the Senior Citizens' Center. The geothermal water is provided from a sump, run through heat exchangers, and the extracted heat is circulated through a forced-air heating system.

The Geronimo Springs Museum, site of the original hot springs used by the early cowboys and later the Old State Bathhouse location, is heated by 108 °F geothermal water piped through forced-air heaters in the rooms. A shallow well in front of the building supplies water to the heating system and cascaded over sculptures in front of the buildings (Photo 5). Unfortunately, the well has sanding problems, and cannot supply sufficient heat to the building in the winter. A life-size wax statue of the famous Apache leader along with the history of his exploits, stands in the lobby of the museum.



**Photo 5.** *Geronimo Springs Museum showing the sculpture with cascaded geothermal water.*

A series of eight hot spring pools and spas are located throughout the community. Some provide lodging and massages, and are frequent by many return customers. Both indoor and outdoor soaking tubs are available using the geothermal water direct (Photos. 6, 7, 8 and 9).



**Photo 6.** *Hot Springs Association sign showing the location of the pools and spas.*





**Photo 7.** *River Bend Hot Springs consisting of two soaking pools.*



**Photo 8.** *Itay-Yo-Kay Hot Springs channel with effluent water.*



**Photo 9.** *Marshall Hot Springs Spa and Resort.*

## REFERENCES

- Kelley, V. C. and C. Silver, 1952. "Geology of the Caballo Mountains," University of New Mexico, Publications in Geology 4, 286 p.
- Lozinsky, R. P. and J. W. Hawley, 1986. "Upper Cenozoic Palomas Formation of South-Central New Mexico: Truth or Consequences." *New Mexico Geological Society 37<sup>th</sup> Annual Field Conference Guidebook*, p. 239-247
- Summers, W. K., 1976. "Catalog of Thermal Waters in New Mexico," New Mexico Bureau of Mines and Minerals Resources Hydrologic Report 4, 80 p.
- Theis, C. V.; Taylor, G. C. and C. R. Murray, 1942. "Thermal Waters of the Hot Springs Artesian Basin Sierra County, New Mexico," New Mexico State Engineers 14<sup>th</sup> and 15<sup>th</sup> Biennial Reports, 1938-1942, p. 419-492.
- Wells, S. G. and H. Granzow, 1981. "Hydrogeology of the Thermal Aquifer near Truth or Consequences, New Mexico in State-Coupled Low-Temperature Geothermal Resource Assessment Program, Fiscal Year 1980," p. 3-5 to 3-51.
- Witcher, J. C., 1995. "New Mexico Geothermal Resources Database," New Mexico State University, Southwest Technology Development Institute Report prepared for Geo-Heat Center, Oregon Institute of Technology, 32 p.



# GILA HOT SPRINGS

James C. Witcher  
Southwest Technology Development Institute  
NMSU, Las Cruces, NM

John W. Lund  
Geo-Heat Center

## INTRODUCTION

Gila Hot Springs, is located on the West Fork of the Gila River in the Gila National Forest about 40 miles north of Silver City, center of a major copper mining district in the U.S. in southwestern New Mexico. A popular tourist destination in the area, the Gila Cliff Dwellings National Monument is located four miles northwest of the Gila Hot Springs. The area in the vicinity of the Gila Cliff Dwellings has been occupied by various cultures as far back as 10 to 12,000 years. These various people started with Archaic cultures through Early- and Late-Pit House, and Classic Pueblo Periods to present Apache cultures. Most used the caves as temporary shelters by the nomadic people as indicated by campfire soot on the ceiling; however, from the 1280s through the early-1300s, the Mogollon culture built and lived in rock dwelling in the six caves in the cliffs. Over 100 prehistoric sites are scattered throughout the area of the headwaters of the West Fork and Middle Fork of the Gila River (National Park Service website, 2002). Gila Hot Springs and the Cliff Dwellings Nation Monument are virtually surrounded by the rugged forested canyons and mountains of the Gila Wilderness, the nation's first designated wilderness area.

The Gila Hot Springs are mentioned as "A small army camp established in the late 1800s, where the village of Gila Hot Springs now sits, to guard the settlers from the dreaded Apache." Another historical reference states: "Scattered through out the canyons is the old ranching community of Gila Hot Springs, settled in the 1880s by the Hills brothers. (Geronamo Trail Home Page, 2002). The first permanent adobe houses were built around 1890. In 1929, Doc Campbell moved to the area and ranched and led hunting trips in the area and built Doc Campbell's Post in 1963." The store has grown into the geothermally-heated "Doc Campbell's Post Vacation Center" (Photo 1). The present Gila Hot Springs community consists of about 20 homes and house trailers, and is a recreation area. There are several other hot springs in the area (see Figure 2), including Melanie Hot Springs (Waterfall Hot Springs) on the Gila River below the junction of the West and East Fork of the Gila River, Lyons Lodge Hot Springs on the East Fork of the Gila River, and Jordan Hot Springs and Lightfeather Hot Springs on the Middle Fork of the Gila River, all requiring access by hiking (see Bischoff, 2001 for additional details). An abandoned "Indian" bath surrounded by a low rock wall can still be seen in the community above the east bank of the Middle Fork of the Gila River (Photo 2).



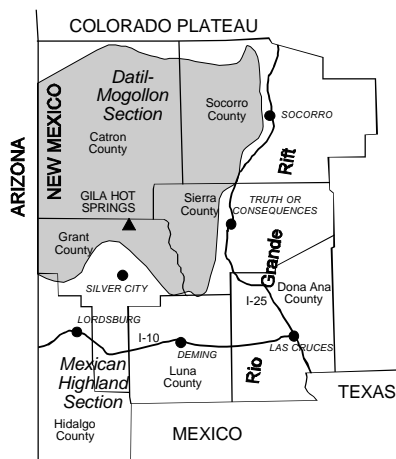
**Photo 1.** *Doc Campbell's Store with geothermal floor heating.*



**Photo 2.** *Gila conglomerate over andesite above the hot springs.*

## GEOLOGY AND HYDRO-GEOLOGY

Gila Hot Springs is situated in a transition zone between the Colorado Plateau and the Mexican Highland section of the southern Basin and Range and Rio Grande rift (Figure 1). This zone is called the Datil-Mogollon section of the Basin and Range Province and is underlain by a thick pile of mid-Tertiary volcanics and volcaniclastic sediments. The Datil-Mogollon country is probably similar to the Transition Zone in Arizona in terms of the Tertiary subcrop. The Tertiary subcrop is probably characterized by Precambrian and Paleozoic rocks with the Mesozoic aquitards of the Colorado



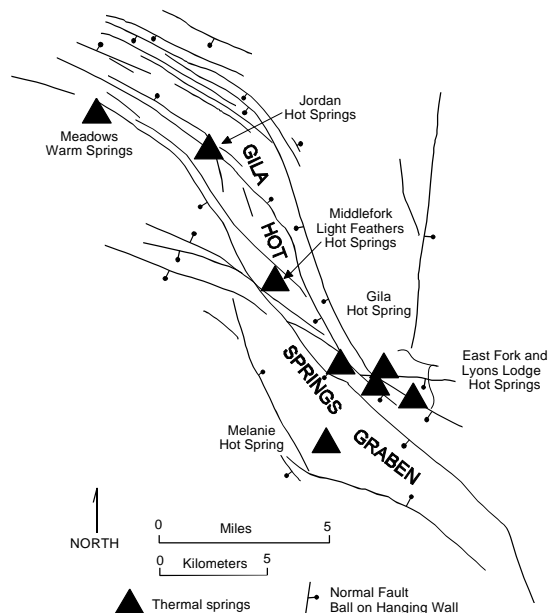
**Figure 1.** *Regional location map of Gila Hot Springs.*

Plateau stripped away. Several large silicic caldera complexes occur in Datil-Mogollon region as well as several large stratovolcano centers of andesite and basaltic andesite (Ratte, et al., 1979). Post volcanism deformation consists of several in echelon northeast and northwest-trending half grabens of Miocene age that were largely backfilled with basin fill sediment (Gila Conglomerate) by late-Miocene and early-Pliocene. Post early-Pliocene erosion and entrenchment of the Gila River and its tributaries have removed much of the graben basin fills, and have created the spectacular landscape the Gila Wilderness of deep rugged forested canyons (Photo 3). Gila Hot Springs and other hot springs in the area all occur within the Gila Hot Springs graben along normal faults (Ratte, et al., 1979) (Figure 2).



**Photo 3.** *The remains of the Indian bath on the east bank of the Gila West Fork.*

A geologic map and cross sections of Gila Hot Springs shows the stratigraphic and structural control on the shallow reservoir (Figures 3 and 4). Well logs and map data are from Summers and Colpitts (1980) and Witcher, unpublished data (fault dips and logs on Campbell 3 and 4 wells and the Doyle well). The shallow geothermal reservoir at Gila Hot Springs is the 600 ft thick Bloodgood Canyon Tuff



**Figure 2.** *Tectonic map of the Gila Hot Springs region.*

(rhyolite ash flow tuff) of Elston (1968). The Bloodgood Canyon (28.05 ma)(McIntosh, et al., 1990) is one of the most extensive units of the Datil Mogollon region and can reach up to 1,000 ft thickness west of Gila Hot Springs and it may represent an outflow ignimbrite from the large Bursum Caldera to the west in the Mogollon Mountains. The Bloodgood Canyon reservoir is confined by the Tertiary andesite. Gila Conglomerate overlies the andesite and represents graben basin fill remnants. Temperature isotherms drawn on the cross section from temperature logs of wells indicates that an east-to-west trending normal "cross" fault between two northwest striking normal faults provides important upflow permeability for the Gila Hot Springs geothermal system.

The Gila Hot Spring thermal waters are excellent quality with total dissolved solids between 620 and 659 mg/L. Chloride ranges from about 100 to 105 mg/L and silica ranges from 65 to 75 mg/L (Summers, 1976; Witcher, 1995). There is not a lot of variability between the wells and springs in terms of chemistry. There is some variability in temperature among the wells and the hot springs. Eight wells have been drilled in the immediate area of Gila Hot Springs. Only one of the wells, Campbell 4, is currently being used for geothermal direct-use heating and bathing. All of these wells have temperature logs and lithology information, and some have chemistry information. A step-pump test and a constant rate (52 gpm) 48-hr pump test of the Campbell 2 well indicates a transmissivity of about 12,000 to 14,000 gpd/ft and a storativity of about 0.05 (Schwab; et al., 1982). These values should be considered provisional as the well did not fully penetrate the reservoir host and the well had also caved back prior to pump testing. Natural total discharge of the Gila Hot Springs system is believed to be about 150 to 200 gpm (Summers, 1976).



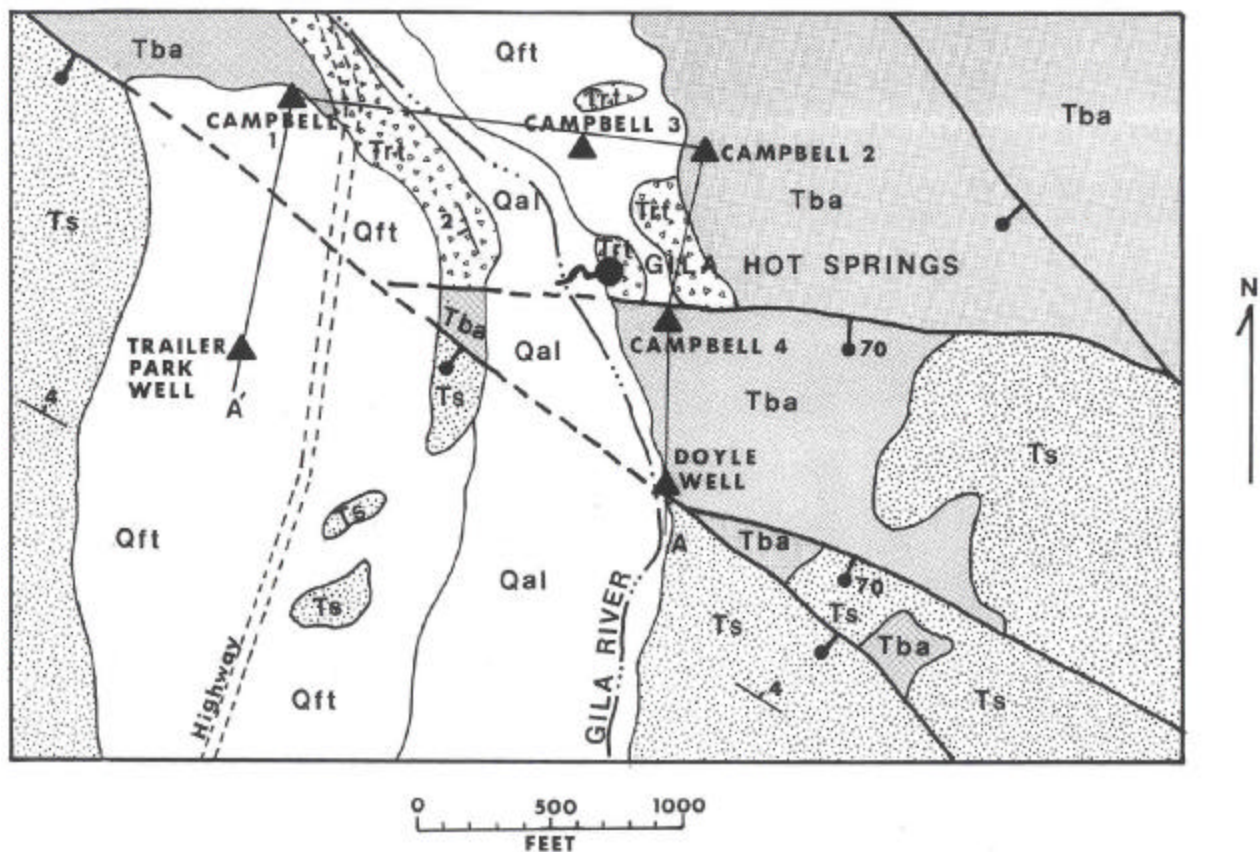


Figure 3. Geologic map of Gila Hot Springs with key well locations.

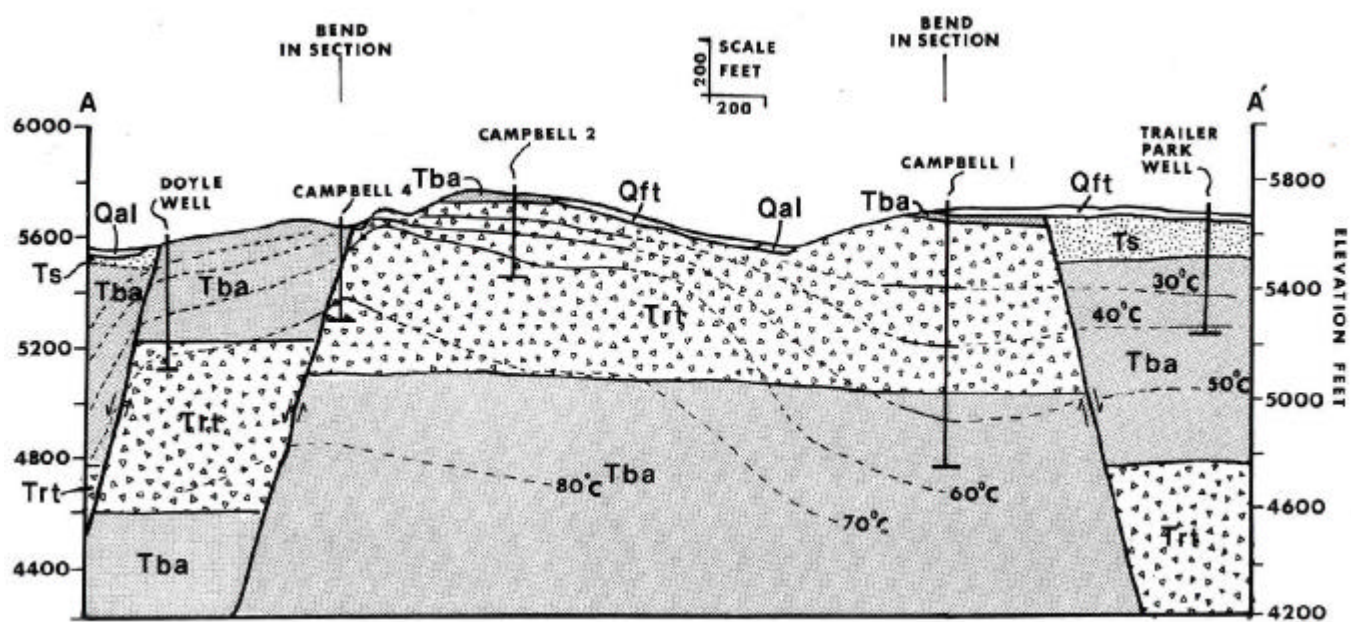


Figure 4. Geologic cross section of the Gila Hot Springs area with actual subsurface temperatures.



## GEOHERMAL USE

The Campbell 4 artesian well on the hill slope above the hot springs on the east bank of the Gila West Fork, provides hot water to the community through a suspended pipeline over the river (Photos 4 and 5). Twenty buildings and two greenhouses are heated from this artesian well which flows water at 165°F. Approximately 40,000 ft<sup>2</sup> of floor space is heated with water at 135°F; 50% by floor radiant systems using copper pipes. The systems, installed 15 years ago, uses an average of 76 gallons per minute. There are four other systems in the community using spring water at 155°F, heating individual homes and two swimming pools. The artesian well also provides geothermal water through a two-pipe system to a home situated on a hill, approximately 200 feet above the well.



**Photo 4.** *The Campbell 4 artesian geothermal well on the east bank of the Gila West Fork.*



**Photo 5.** *The suspended pipeline across the West Fork of the Gila River.*

Allen Campbell, son of Doc Campbell, heats his home with a radiant floor system of copper pipes using one to two gallons per minute, in an open system supplying water at 145°F and rejecting it at 80°F (Photo 6). Allen also supplies hot water to bathing ponds for use in a primitive RV park next to the river (Photo 7).



**Photo 6.** *Allen Campbell's controls for his home heating system.*



**Photo 7.** *Bathing/soaking ponds in the Campbell's Gila Hot Springs RV Park.*

The estimated installed capacity of the systems is 0.4 MWt with an annual energy use of 2.5 billion Btu/year. They estimate their annual savings is \$5,000 to \$10,000 per year, compared to the alternate available energy source of propane and firewood. However, at today's prices for propane, their savings are probably closer to \$25,000 per year.

## REFERENCES

- Bischoff, M., 2001. *Touring New Mexico Hot Springs*. A FalconGuide, The Globe Pequot Press, Guilford, CT.
- Elston, W. E., 1968. "Terminology and Distribution of Ash Flows of the Mogollon-Silver City-Lordsburg Region, New Mexico," *Southern Arizona, Arizona Geological Society Guidebook*, 3, p. 231-240.
- Geronimo Trail Home Page, 2002. "Gila Hot Spirngs." [www.geronimotrail.com](http://www.geronimotrail.com).

- McIntosh, W. C.; Sutter, J. F.; Chapin, C. E. and L. L. Kedzie, 1990. "High-Precision  $^{40}\text{Ar}/^{39}\text{Ar}$  Sanidine Geochronology of Ignimbrites in the Datil-Mogollon Volcanic Field, Southwestern New Mexico., *Bulletin of Volcanology*, v. 52, p. 584-601.
- National Park Service Website, 2002. [www.nps.gov/gicl/adhi/](http://www.nps.gov/gicl/adhi/)
- Ratte, J. C.; Gaskill, D. L.; Eaton, G. P.; Peterson, D. L.; Stotelmeyer, R. B. and H. C. Meeves, 1979. "Mineralresources of the Gila Primitive Area and Gila Wilderness, New Mexico," *U. S. Geological Survey Bulletin 1451*, 229 p.
- Schwab, G. E.; Summers, W. K.; Colpitts, R. M.; Teuten, C. E. and W. E. Young, 1982. "Pumping Tests of Well Campbell 2, Gila Hot Springs, Grant County, New Mexico," *Idaho National Engineering Laboratory Report EGG-2156*, 146 p.
- Summers, W. K., 1976. "Catalog of Thermal Waters in New Mexico," *New Mexico Bureau of Mines and Mineral Resources Hydrologic Report 4*, 80 p.
- Summers, W. K. and R. M. Colpitts, 1980. "Preliminary Appraisal of the Hydrothermal-Resource Potential of the Gila Hot Springs Area, Grant and Catron Counties, New Mexico," W. K. Summers and Associates, Inc. Report prepared for D. A. "Doc" and Ida Campbell, Gila Hot Springs, New Mexico, 102 p.
- Witcher, J. C., 1995. "New Mexico Geothermal Resource Database," New Mexico State University, Southwest Technology Development Institute Report prepared for Geo-Heat Center, Oregon Institute of echnology, 32 p.



# GEOHERMAL ENERGY AT NEW MEXICO STATE UNIVERSITY IN LAS CRUCES

James C. Witcher, Rudi Schoenmackers and Ron Polka  
Southwest Technology Development Institute  
NMSU, Las Cruces, NM

and

Roy A. Cunniff  
Lightning Dock Geothermal Inc.  
Las Cruces, NM

## INTRODUCTION

In 1949, the Clary and Ruther State 1 oil test adjacent the southeast boundary of the NMSU campus encountered hot water and "steam." Later in the mid-to-late 1950s, a couple of shallow domestic wells drilled within a half mile south of the campus east of I-25 in the present day Las Alturas neighborhood encountered "warm and salty" water (Figure 1). Until the 1970s, these reports of geothermal heat in the area were largely treated as a curiosity. Then during a period of five years between 1973 and 1979, New Mexico State University experienced a major increase in the cost of natural

gas that exceeded 400 percent. Through the vision and leadership of Gerald Thomas, former NMSU President and Harold Daw, former NMSU Vice President of Research, campus expertise in renewable energy was mobilized to find a cost effective solution. Because of reports of hot water adjacent to campus, NMSU faculty, staff and students began a campus geothermal exploration program that identified a potential geothermal resource with geologic and geophysical studies including the drilling of shallow heat flow holes (Dicey and Morgan, 1981; Gross and Icerman, 1983; Jiracek and Gerety, 1978; King and Kelley, 1980; Swanberg, 1975). Deeper exploration drilling and testing confirmed that suitable low temperature geothermal resource existed beneath the eastern end of the campus (Chaturvedi, 1979 and 1981; Cunniff, et al., 1981).

An appropriation from the New Mexico Legislature provided funds for the design and construction of the NMSU Campus Geothermal Project (Cunniff, et al., 1983). Additional funds for well drilling, project management and monitoring for one year also became available with a USDOE Cooperative Agreement. The NMSU Campus Geothermal Project under the leadership and engineering design of Roy Cunniff was the first large-scale demonstration of geothermal energy in New Mexico. The system was built by NMSU staff and a large crew of student employees, and assisted by temporarily employed skilled trades construction workers (Cunniff, et al., 1983). Began in 1981 and completed in 1982, the NMSU Campus Geothermal Project provides domestic hot water and space heat to dorms, athletic facilities, and academic buildings on the eastern part of campus.

Geothermal use at NMSU does not end with the district heating system. In 1985 under the leadership of Rudi Schoenmackers, Southwest Technology Development Institute (SWTDI), staff and students built the Geothermal Greenhouse Facility (GGF) with a combination of industry donations and state of New Mexico funding. The project was conceived by Larry Icerman to promote economic development in New Mexico with direct-use geothermal. Finally in 1994, the Geothermal Aquaculture Facility (GAF) was built by SWTDI (Zachritz, et al., 1996).

Today, NMSU has an enrollment of about 24,300 with 15,300 undergraduate and graduate students on the main campus. NMSU is New Mexico's land grant university with



**Figure 1.** Location map of the Tortugas Mountain area on the NMSU campus.



strong and active engineering, agriculture, and geoscience-related programs that have played the major roles in stimulating and forwarding geothermal resource development in New Mexico.

## GEOLOGY AND HYDROGEOLOGY

The NMSU geothermal resource is a part of the larger Las Cruces East Mesa geothermal system that extends from US Highway 70 on the north to Vado and Anthony on the south (Iceman and Lohse, 1983). The Las Cruces East Mesa geothermal system is contained within a fractured horst block of mid-Tertiary volcanics and Paleozoic limestone (Gross and Iceman, 1983). Most of the horst block is buried under ancestral Rio Grande axial fluvial deposits and alluvial fan deposits shed westward from the Organ Mountains to the east (Figure 1). The Tortugas Mountain or 'A' Mountain area is the locus of the geothermal upflow on the NMSU campus. The current production wells on campus and the thermal wells in the Las Alturas neighborhood are completed in Tertiary Santa Fe Group basin fill of the outflow zone adjacent the parent reservoir in fractured Paleozoic limestone beneath and around Tortugas Mountain, a partially alluvium buried inselberg on the horst block (Figure 2).

Four geothermal production wells and one injection well have been drilled and completed on campus (Table 1). Only two of the production wells are in current use. All of the wells are completed across lower Santa Fe basin fill sediments. However, the lower 40 ft of PG-4 may be completed in a fault zone or karst at the Tertiary basin fill–

Paleozoic limestone contact. The production wells PG-1 (Photo 1) and PG-4 are currently rotated for campus district heating and the greenhouse (GGF) and aquaculture facility (GAF).

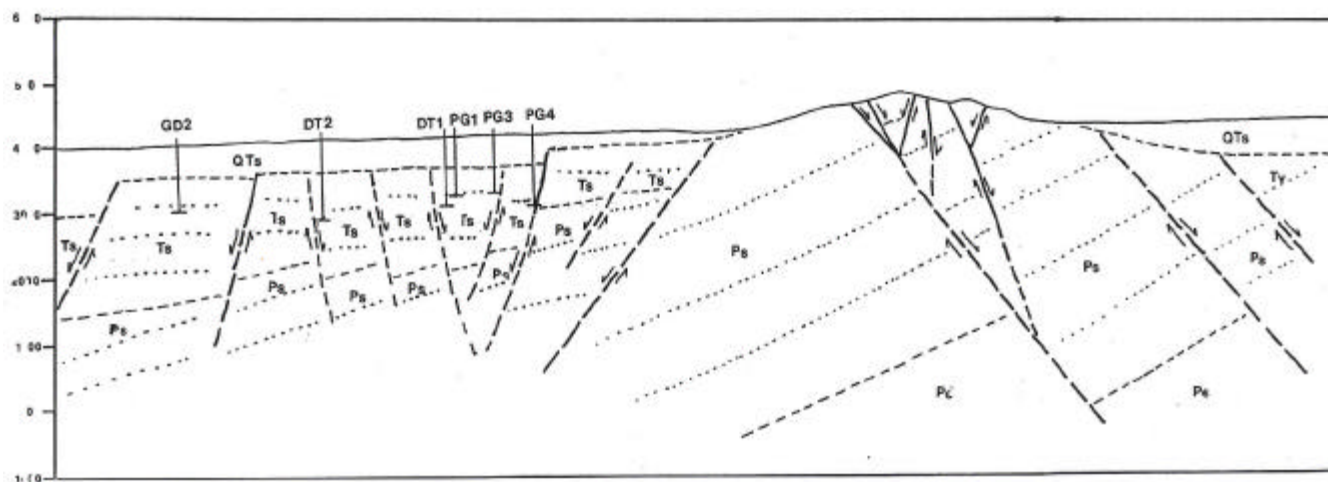
Pump tests of PG-1 and PG-3 indicate much variability in aquifer properties in the Santa Fe Group reservoir with transmissivity ranging from 6,500 to 40,000 gpd/ft. PG-4 has much higher over all transmissivity as a result of the highly productive zone in the lower 40 ft of the well. Specific capacity of about 100 gpm/ft indicates that PG-4 is capable of sustained production in excess of 1,000 gpm at 146 to 148°F.

Overall, chemical quality from the production wells varies slightly with TDS ranging between 1700 to 1900 mg/L. The waters are sodium bicarbonate-chloride composition. Wells PG-1 and PG-3 are associated with very small amounts of hydrogen sulfide that has caused problems with pump columns corrosion.

## GEOHERMAL USE

### Campus District Heating System

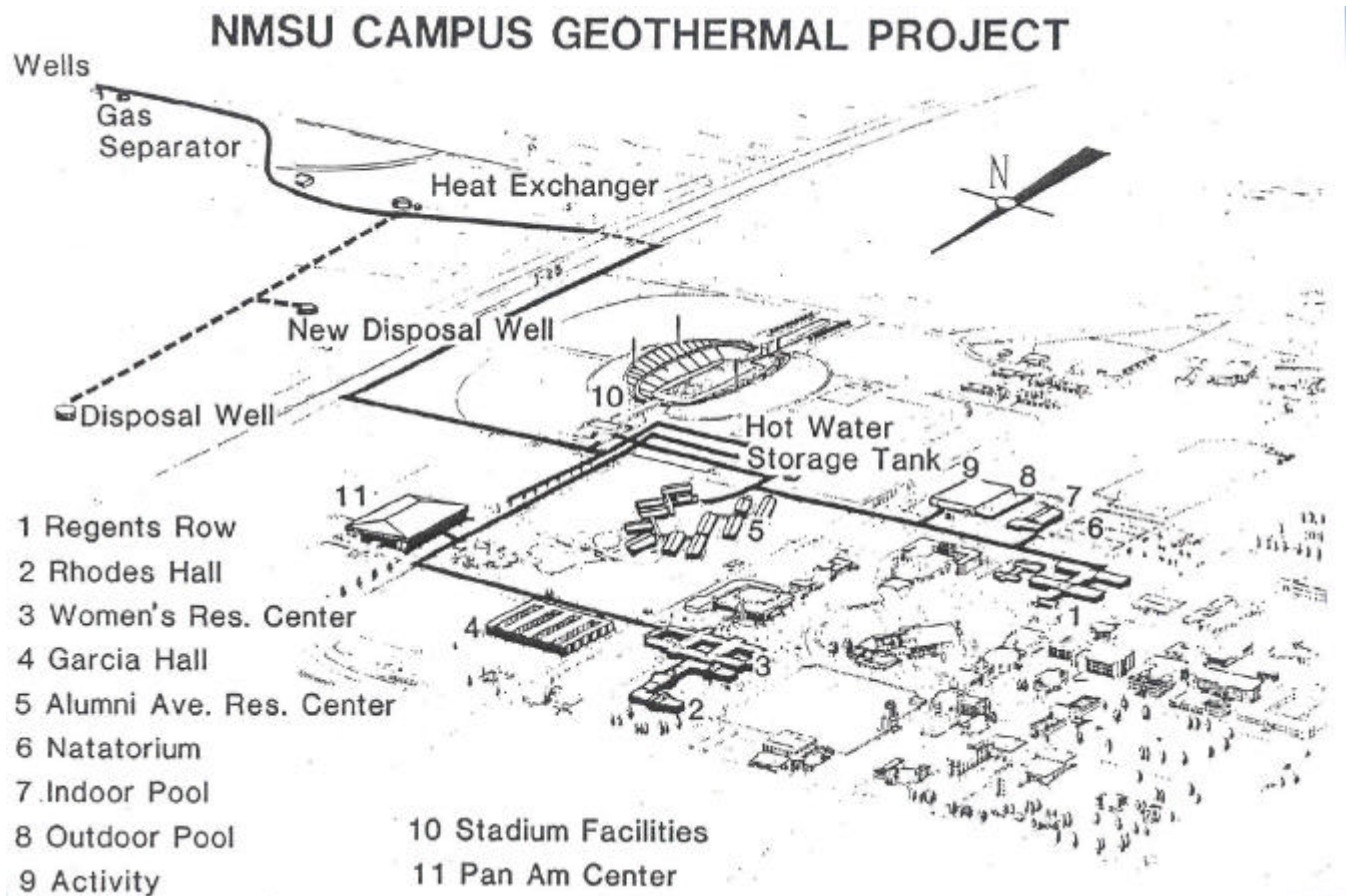
Currently, two wells, PG-1 and PG-4 are outfitted with submersible pumps and are used alternatively to supply 141 to 148°F water at 250 gpm to supply heat to the NMSU campus district heating system, the SWTDI greenhouse (GGF) and the aquaculture facility (GAF). The layout of the district heating system allows for the heating of a total of 30 building and facilities that include dorms and athletic facilities (Figure 3). Hot water from the wells is piped along side Geothermal Drive to a heat exchanger building located adjacent to a



**Figure 2.** *Geologic cross-section of the Tortugas Mountain area. Wells (see Table 1, DT1 & 2 are temperature gradient holes) are projected on the cross-section and sub-surface structure, and lithology is based on wells, various geophysical surveys and surface geologic mapping. Lithology: Qts - Tertiary basin fill (younger Santa Fe Group); Ts - Tertiary basin fill (older Santa Fe Group); Tv- mid-Tertiary volcanics; Ps - Paleozoic limestone and dolomite; Pe - Precambrian granite. Vertical and horizontal scales are the same. Bars on left side of cross-section are in 1,000-ft increments (Witcher, unpublished).*

**Table 1. Geothermal Wells on the New Mexico State University Campus**

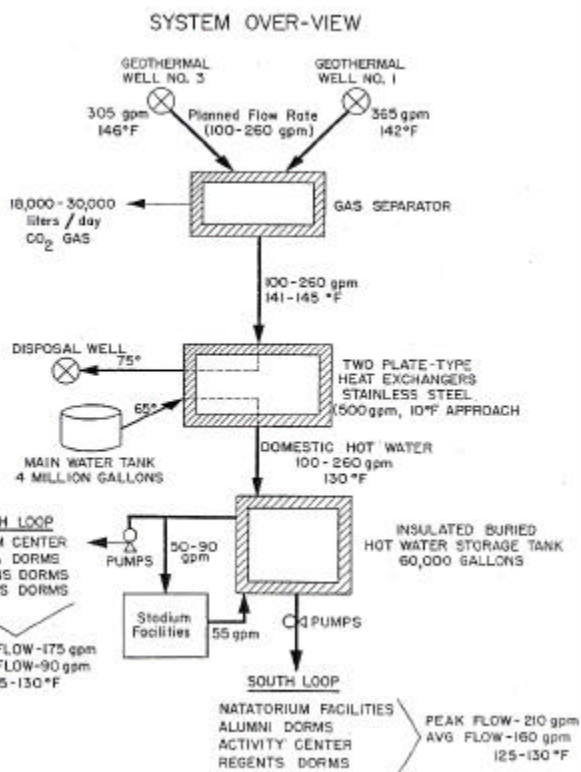
Well	Depth ft	BHT °F	Year Completed	Casing in.	Depths ft	Diameter in.	Depths ft	Remarks
PG-1	860	145	1979	10 ID 10 ID screen	0-750	17	0-860	Produces 142°F T = 6,500 gpd/ft
PG-2	507	122	1979	6	507	9 7/8	507	Produces 18 gpm at 118°F from 451 to 171 ft depth; well currently not in use.
PG-3	870	150.4	1980	18 ID 10 ID 10 ID screen	0-60 0-750 750-860	26 18 18	0-60 26-750 750-860	Produces 146°F T = 40,000 gpd/ft Well currently not in use.
PG-4	1,015	-150	1986	14 8 5/8 8 5/8 screen 5 9/16	0-684 658-744 744-971 972-1,015	17 1/2 12 1/4 12 1/4 7 7/8	0-684 684-733 733-960 982-1,015	Produces 146°F Specific capacity 100 gpm/ft
GD-2	464	-110	1980	8 5/8 cement 8 5/8 Cement plug	0-348 348-464 464-486	14 3/4 14 3/4 14 3/4	0-348 348-464 464-486	Injection well on NMSU Golf Course Slotted screen at 370-380 ft; 390-464 ft T = 9,000 gpd/ft



*Figure 3. Overall layout of the NMSU campus geothermal project (from Cunniff, et al., 1981).*



**Photo 1.** NMSU well (PG-1).



**Figure 4.** The original NMSU geothermal system design overview (Cunniff, et al., 1981).

adjacent to a 4 -million gallon freshwater storage tank along a ridge on the south side of the NMSU Golf Course. At one time, a gas separator near the production wells was used to extract carbon dioxide gas from the hot water stream. However, this was discontinued because the overall system performance was better without the gas separation step. A stainless steel plate-and-frame Tranter heat exchanger takes 141 to 145°F geothermal water and 65°F freshwater from the large freshwater storage tank and heats the freshwater to 130

to 135°F (Figure 4)(Photo 2). The geothermal stream leaves the heat exchanger at about 75°F and is then piped to an injection well at the NMSU Golf Course where the geothermal water is returned to the reservoir margins. The heated freshwater stream is piped underground beneath I-25 to a buried and insulated 60,000 gallon storage tank adjacent to the football practice field. Two district heating loops are used to supply 125 to 130°F hot water from the hot water storage tank on demand for space heating and domestic hot water. With all heat losses included, 115 to 125°F hot water is supplied to final users on campus. In the first year of operation, the system provided  $53 \times 10^9$  Btu in February 1982 through the end of January 1983. In 2001, the system provided approximately  $36 \times 10^9$  Btu. This decrease in use is the result of several changes in the overall campus heating and cooling system since the geothermal district heating system was installed in 1982. Among the major changes include the installation of natural gas turbine co-generation plant to supply 5 MWe of electrical power on campus. As a result, the swimming pool was taken off line from geothermal heating and it is now heated with reject heat from the co-generation plant. While the campus has doubled in size since 1982, the co-generation power has allowed conventional district heating and cooling to increase without additional geothermal direct-use. On the other hand, additional geothermal direct-use is probable as campus is beginning to expand eastward and on to the east side of I-25 on the opposite end of campus from the co-generation plant. The far eastern side of campus is the site of the geothermal reservoir and the SWTDI greenhouses (GGF) and aquaculture facility (GAF).

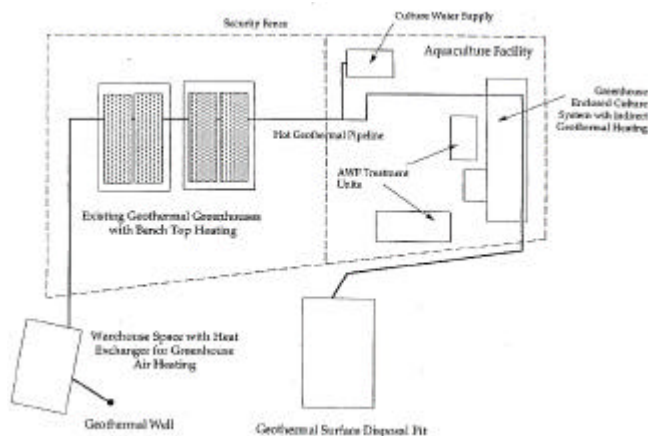


**Photo 2.** NMSU plate heat exchanger with Jim Absher and Leo Valenzuela, campus Physical Plant Department.

#### SWTDI GREENHOUSE FACILITY (GGF)

Two 6,000-ft<sup>2</sup> greenhouses and a 2,400-ft<sup>2</sup> metal storage space, office and work shop comprise the Geothermal Greenhouse Facility (GGF), which has been heated continuously with geothermal since December 1986 (Figure 5) (Photo 3) (Schoenmackers, 1988). A propane boiler provides back up heat in case of geothermal well pump failure. The





**Figure 5.** *Generalized layout of the NMSU/SWTDI Geothermal Greenhouse (GGF) and Geothermal Aquaculture (GAF) Facilities (Zachritz, et al., 1996).*



**Photo 3.** *Interior of SWTDI greenhouse facility.*

GGF is of Dutch design and all structural members are made of galvanized steel that are mounted on 10-inch concrete piers set 24 inches into the ground. A variety of glazing films are used in the doubled glazed panels that contain central dead air spaces. Also, different cooling and ventilation schemes are applied in the two greenhouses that are laid out with the long axes oriented east to west. The south greenhouse has a traditional fan and pad evaporative air cooling system installed

with a typical 75 percent wet bulb depression and a complete air exchange capability of once every minute. GGF temperature increases from the west end pad to the east end fan are about 10 to 12°F when in a cooling mode. The north greenhouse has a fog cooling system that uses 90 fog nozzles that create 10-micron droplets or fine mist to create a distributed evaporative cooling effect without significant lateral temperature gradients. Side and roof vents are used to provide natural ventilation.

The GGF uses between 25 and 60 gpm of 148°F water from well PG-4 for geothermal heating. The maximum flow represents about 25 percent of the currently installed discharge from PG-4. The geothermal water is feed into a Trantor stainless steel (type 316) plate and frame heat exchanger with a designed maximum flow of 80 gpm and an approach temperature of 10°F. The heated freshwater is feed into a closed-loop, hydronic geothermal heating system by 3- inch black iron pipe. Four modine high-efficiency, fan-coil units are outfitted with inflatable 24-inch poly tube with 1-inch holes on 1-ft centers to provide 3,850 cfm of evenly distributed warm air flow (Photo 4). Typical hot water inflow to the four heaters is at 131°F with an exit temperature of 110°F for an installed geothermal heating capacity of about  $525 \times 10^3$  Btu/hr in the closed-loop hydronic system.

An additional bench top heating system taps geothermal water directly with motorized ball valves before passing through the heat exchanger. The bench top system provides soil heating for horticultural cultivation with a 50,000-ft long series of 5/32 inch ID rubber tubing (Photo 5). The bench top heating system uses about 25 gpm and typically shows a temperature loss of 15 to 30°F for an installed geothermal heating capacity of about  $375 \times 10^3$  Btu/hr.

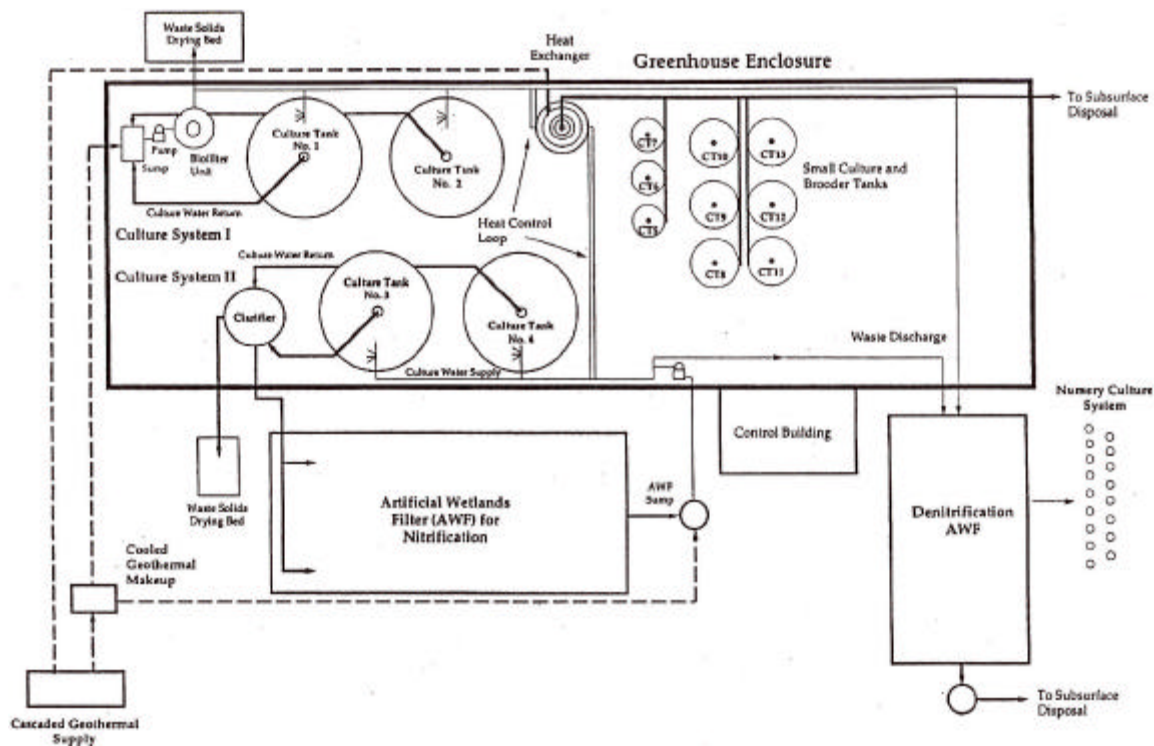


**Photo 4.** *Modine heater with poly tube.*

All heating and cooling in the geothermal greenhouse is monitored and controlled by computer. After exiting the heat exchanger and the bench top heating system, the cooled geothermal water is allowed to flow into a 46-ft by 46-ft by 15-ft permitted disposal pond or is cascaded to the SWTDI Geothermal Aquaculture Facility (GAF).

#### **SWTDI GEOTHERMAL AQUACULTURE FACILITY (GAF)**

The SWTDI Geothermal Aquaculture Facility (GAF) was funded in 1993 by the USDOE with the purpose of demonstrating energy use and energy savings and value enhancement of a cascaded direct-use geothermal aquaculture operation that is coupled to geothermal greenhouse heating (Zachritz, et al., 1996). In addition, the facility also demonstrates the application of several wastewater treatment



**Figure 6.** *Process flow diagram of the Geothermal Aquaculture Facility (GAF)(Zachritz, et al., 1996).*

approaches for aquaculture that include an artificial wet land for denitrification and two different approaches of solids removal. The facility was designed for both research and as a business incubator for lease to potential aquaculturalists. Tilapia and striped bass have been grown in the facility.

The layout of the geothermal aquaculture facility is shown in Figure 6. Two large 6,000-gallon capacity intensive culture systems simulate commercial level production while a number of smaller tanks provide for brood stock maintenance and fry production (Photo 6). The culture systems can use freshwater, cooled geothermal water, or custom mixes for marine applications. Each of the two large culture systems uses different wastewater treatment. Flow through or recirculating flows can also be accommodated by the GAF.

Geothermal heating is done by cascading a maximum 25 gpm of geothermal water from the GGF bench top heating system to the aquaculture facility. Cascaded hot water arrives at the heat exchanger at 90 to 135°F for heating culture water in a closed loop fashion. The GAF is contained in a 3,000-ft<sup>2</sup> double-walled arched greenhouse (Photo 7). Cooling and ventilation is done with cooling pad at one end of the greenhouse and fans at the opposite end of the greenhouse. All heating and cooling is monitored and controlled by computer. The GAF system at 16 to 17 gpm geothermal flow typically shows a temperature loss of 6 to 9°F across the heat exchanger for an installed geothermal heating capacity of about  $76 \times 10^3$  Btu/hr.



**Photo 5.** *Greenhouse bench heating system..*



**Photo 6.** *Large aquaculture tanks.*





**Photo 7. SWTDI aquaculture building.**

## BENEFITS

Geothermal use at NMSU has benefitted New Mexico in several ways. First, the campus geothermal system has an annual energy savings compared to natural gas up to several hundred thousand dollars annually depending upon annual climate, the cost of fossil fuel and maintenance costs for the geothermal system. Since 1986, six clients have leased the GGF and one client has leased the GAF. The GGF has resulted in important rural economic development as five clients have gone on to build successful geothermal and non-geothermal greenhouse business in the state.

## REFERENCES

- Chaturvedi, L., 1979. "Analysis of Geological and Geophysical Logs of Two Geothermal Exploration Wells Drilled on NMSU Land, Las Cruces, NM." NMSU Engineering Experiment Station Report prepared for the U. S. Department of Energy under contract EW-78-0500701717, 25 p.
- Chaturvedi, L., 1981. "New Mexico State University Geothermal Production Well." New Mexico Energy Research and Development Institute Report EMD 77-2218, 47 p.
- Cunniff, R. A.; Chaturvedi, L. and C. Keyes, 1981. "New Mexico State University Campus Geothermal Demonstration Project." New Mexico Energy Research and Development Institute Report EMD 2-68-2207, 223 p.
- Cunniff, R. A.; Houghton, C. and P. Chintawongvanich, 1983. "New Mexico State University Campus Demonstration Project – One Year Later," *Geothermal Resources Council Transactions*, v. 7, pp. 585-587.
- Dacey, T. R. and P. Morgan, 1981. "Magnetic, Gravity, Seismic-Refraction and Seismic-Reflection Profiles Across the Las Alturas Geothermal Anomaly, New Mexico," in Icerman, L., Starkey, A., and Trentman, N., eds., *State-Coupled Low-Temperature Geothermal Resource Assessment Program Fiscal Year 1980, final Technical Report*, pp. 1-1 to 1-55.
- Gross, J. and L. Icerman, 1983, "Subsurface Investigations for the Area Surrounding Tortugas Mountain, Dona Ana County, New Mexico.: typically shows a temperature loss of 6 to 9°F across the heat exchanger for an installed geothermal heating capacity of about  $76 \times 10^3$  Btu/hr." New Mexico Research and Development Institute Report NMERDI 2-67-2238, 70 p.
- Icerman, L. and R. L. Lohse, 1983. "Geothermal Low-Temperature Reservoir Assessment in Dona Ana County, New Mexico.": New Mexico Energy Research and Development Institute Report NMERDI 2-69-2202, 188 p.
- Jiracek, G. R. and M. T. Gerety, 1978. "Comparison of Surface and Downhole Resistivity Mapping of Geothermal Reservoirs in New Mexico," *Geothermal Resources Council Transactions*, v. 2, pp. 335-336.
- King, W. E. and R. E. Kelley, 1980. "Geology and Paleontology of Tortugas Mountain, Dona Ana County, New Mexico," *New Mexico Geology*, v. 2, no. 2, pp. 33-35.
- Schoenmackers, R., 1988. "Design and Construction of the NMSU Geothmally-Heated Greenhouse Research Facility." New Mexico Research and Development Institute Report NMRDI 2-72-4214, 38 p.
- Swanberg, C. A., undated. "Detection of Geothermal Components in Groundwaters of Dona Ana County, Southern Rio Grande Rift, New Mexico," *New Mexico Geological Society 26<sup>th</sup> Annual Field Conference Guidebook*, pp. 175-180.
- Zachritz, W. H.; Polka, R. and R. Schoenmackers, 1996. "Enhancement of Existing Geothermal Resource Utilization by Cascading to Intensive Aquaculture." New Mexico State University, Las Cruces, Southwest Technology Development Institute Technical Report to U. S. Department of Energy under contract DE-FC07-93ID13203, 37 p.



# **LIGHTNING DOCK KGRA NEW MEXICO'S LARGEST GEOTHERMAL GREENHOUSE, LARGEST AQUACULTURE FACILITY, AND FIRST BINARY ELECTRICAL POWER PLANT**

**James C. Witcher<sup>1</sup>, John W. Lund<sup>2</sup> and Damon E. Seawright<sup>3</sup>**

**<sup>1</sup>Southwest Technology Development Institute, New Mexico State University, Las Cruces, NM**

**<sup>2</sup>Geo-Heat Center, Klamath Falls, OR**

**<sup>3</sup>AmeriCulture, Cotton City, NM**



*Aerial photograph of Burgett's Greenhouses (lower) and AmeriCulture (upper)(USGS photograph).*

## **LIGHTNING DOCK KGRA**

The Lightning Dock Known Geothermal Resource Area (KGRA) is located in the Animas Valley of the "boot heel country" of southwest New Mexico about 10 miles south of Interstate 10 off of the Animas-Cotton City exit or about 20 road miles southwest of Lordsburg, New Mexico. The name Lightning Dock comes from a peak in the Pyramid Mountains just east of the geothermal area in the Animas Valley.

The Lightning Dock geothermal system is a blind system with no surface manifestations and the resource was fortuitously discovered during cable tool drilling of an irrigation well in 1948 (Summers, 1976). Since that time, geochemical sampling of fluids, electrical and gravity geophysical surveys, temperature gradient drilling, shallow production well drilling of the resource for direct-use heating for green-housing and aquaculture, and a deep geothermal exploration hole has been done at the site (Cunniff and Bowers, 1988; Dellechiaie, 1977; Elston, et al., 1983; Jiracek,

et al., 1977; Norman and Bernhardt, 1982; Smith, 1978). Information developed by these activities provide the basic geoscience information for the Lightning Dock geothermal system.

The Lightning Dock geothermal system is contained in a small intra graben horst block at the intersection of three major regional tectonic features. A mid-Tertiary caldera ring fracture zone, a major basement structure zone, and a young incipient normal fault tip intersect in the region of the thermal anomaly (Elston, et al., 1983). The late-Pleistocene fault tip may enhance or reopen older fractures. An intra horst fault zone or a mid-Tertiary caldera ring fracture intrusion in the younger horst block probably hosts the upflow zone. The shallow outflow plume flows through highly-silicified and fractured "bedrock" that is overlain by a thin cover of unconsolidated basin fill. A potential deep outflow plume between 1,200 and 1,800 ft depth is hosted in a "problematic unit" that may represent karst at the top of the Paleozoic

carbonate section or possibly one of at least three other tectono-stratigraphic configurations common to the structural setting of the site in the region that could have solution and fracture permeability (Witcher, 2002).

The “tear drop” shape of the heat flow anomaly at Lightning Dock largely outlines the heat loss from the top of the shallow outflow plume reservoir. A north flow is indicated in the shallow outflow plume. The relatively sharp western and eastern boundaries of the anomaly are probably limited to some extent by fault zones that prevent lateral dispersion and mixing. Heat flow and temperature gradient data indicate a total natural heat loss for the system less than 10 MWt (Witcher, 2001). A base reservoir or upflow zone temperature around 310 to 320°F is determined with quartz geothermometer and the temperature profile of the 7,000 ft depth Steam Reserve Animas 55-7 geothermal test well (Dellechiaie, 1977; Elston, et al., 1983; Cunniff and Bowers, 1988).

A 48-hr pump test of a Lightning Dock well indicates reservoir transmissivity in excess of 25,000 gpd/ft and an important hydraulic boundary on the west side of the Lightning Dock heat flow anomaly (Witcher, 2001).

Chemistry of geothermal waters at Lightning Dock are very good quality sodium sulfate-carbonate waters with TDS around 1,100 mg/L. However, fluoride concentrations can exceed 10 mg/L. Most geothermal waters contain elevated arsenic concentrations; however, the Lightning Dock waters show no detectable arsenic (Dellechiaie, 1977; Elston, et al., 1983; Witcher, 2002). Gas concentrations are reported by Norman and Bernhardt (1982) for the Lightning Dock thermal waters and dissolved carbon dioxide and hydrogen sulfide are very low.

Geologic and hydrogeologic information suggests that the system is the discharge of deeply-penetrating regional groundwater flow in bedrock. The heat source is most likely regional background heat flow and not basaltic magma as has been suggested by Elston, et al. (1983). Basaltic magma in the shallow continental crust is generally not sufficiently voluminous in subsurface bodies with the proper geometries favorable for sustained heating of groundwater.

This system is not unlike other higher temperature systems in southeast Arizona and southwest New Mexico (Witcher, 1988). With a location at relative low elevation, it is in a favorable location for “forced” or advective discharge of fluid and heat from a regional bedrock groundwater flow system and a combination of Cretaceous and Tertiary uplift has facilitated non-deposition or erosional stripping of regional aquitards to create a local “geohydrologic discharge window” (Witcher, 1988). Recharge for this system is no doubt from higher terrain, both mountains and valleys, to the south. Oxygen isotopes on the geothermal waters indicate that recharge probably occurred during wet periods during the latest Pleistocene to Recent (Elston, et al., 1983).

All currently producing geothermal wells at Lightning Dock are between 350 and 600 ft depth, and produce from the shallow outflow plume reservoir. Well production ranges from a few hundred gpm to 1,200 gpm, typically at 210 to 235°F.

## BURGETT GEOTHERMAL GREENHOUSES

Burgett Geothermal Greenhouses, Inc., established by Mr. Dale Burgett in 1977 in the Animas Valley south of Lordsburg in southwest New Mexico, is the largest geothermally-heated greenhouse complex in the U.S. The initial structure of wood and fiberglass covered 72,000 square feet (1.65 acres) and was used to grow potted mums and geraniums (“for a quick return on investment”). However, his long range plans were to grow cut roses for the southwest markets. At that time, there were two wells on the property, drilled in 1948. By 1980, a second greenhouse had been erected, increasing the facility to three acres and by this time, the operation was producing only roses. In 1982, Mr. Burgett attempted to generate electric power using a 40-kW and 100-kW binary unit, designed by Wally Minto of Florida (Sun Power Systems - SPS). Unfortunately, neither produced any energy and were abandoned.

In 1984, Mr. Burgett designed and built his own greenhouse and in 1986, he moved two 80-ft by 400-ft Lord and Burnham greenhouses that were originally located in the western mountains at Cloudcroft which were designed with steep roofs to allow snow to slide off easily (Photo 1). This increased the operation to eight acres. Up to this time most of the roses were grown in the ground, but now some were grown hydroponically in a “bucket system.”



**Photo 1.**      **80-ft by 400-ft Lord and Burnham greenhouses.**

By 1990, the operation had grown to 22 acres which included the largest greenhouse at 300,000 square feet (6.9 acres)—on the theory that bigger is better. However, he learned that sometimes it was hard to control the environment from one end to the other. As a result, in 1993 when the last greenhouses were built, Mr. Burgett went back to the 150,000 square foot sized structures. The operation now has nine greenhouses covering 1,400,000 square feet (32 acres) and is still producing cut roses (Photo 2). Some are grown hydroponically and others directly in the ground.

In 1995, three binary power generators were moved in from Lakeview, Oregon – a 350 kW unit and two 400-kW units of ORMAT/SPS design (Photo 3). They were run for two session of approximately eight months each, but cooling



water and the design of the heat exchangers/evaporators became a problem, thus the generators have been shut down. Mr. Burgett is attempting to acquire a cooling tower, as the spray operated cooling ponds are not adequate.



**Photo 2.** *Interior of one of the greenhouses with Mr. Burgett.*



**Photo 3.** *ORMAT/SPS binary power units.*

The operation produces approximately 25 million roses a years, which are shipped to markets from Las Vegas, NV to Houston, TX and as far north as Albuquerque. He presently has 90 employees, including day laborers from Mexico. The geothermal resource consists of one well on state land producing 1200 gpm (Photo 4), and three wells on federal land. State royalties are based upon the square footage of heated greenhouse, while Federal royalties are determined by actual energy use and required the installation of meters that cost nearly as much or more than well construction costs to install, maintain, and monitor. The Federal energy use is monitored by the U S Bureau of Land Management (BLM) from the energy meters (Photo 5). The maximum usage is 2,000 gallons per minute to keep the greenhouses at 60°F at night. The 220 to 235°F geothermal water is circulated directly through finned tube heat exchangers in each greenhouse. The installed capacity is 19 MWt and uses about

184 billion Btus of geothermal energy annually. This amounts to an energy savings of about \$736,000 annually, as compared to using propane.



**Photo 4.** *State well used by Burgett's (Jim Witcher).*



**Photo 5.** *Energy meters at Burgett's Greenhouses.*

The Burgett Greenhouses, as well as other rose growing operations in the U.S. are under pressure from lower cost imports from countries such as Ecuador. Thus, according to Mr. Burgett, the greenhouse business is not for amateurs, you have to know what you are doing to succeed. Geothermal energy helps to cut costs in this competitive market.

#### **AMERICULTURE GEOTHERMAL AQUACULTURE**

AmeriCulture is among largest domestic supplier of tilapia fingerlings and is able to produce between four and seven million fingerlings annually (Photo 6). AmeriCulture raises a genetically improved Nile Tilapia or *Tilapia nilotica* in tanks under greenhouse roof to protect from weather, natural predators such as birds, and from the introduction of pathogens (Photo 7). Great care is taken to optimize rearing conditions for disease free tilapia using strict protocols, standards, and regular inspections by an aquatic disease

diagnostic laboratory. The rural location and use of geothermal heating certainly assists isolating the tilapia from pathogens. AmeriCulture ships male tilapia fingerlings by UPS throughout the country. The fingerlings are graded for size and quality and counted and placed in plastic bags with oxygenated water and boxed just prior to shipping.



**Photo 6.** *Tilapia fingerlings raised by AmeriCulture.*

depth. The interval from 282 to 399 ft is open-hole across competent, but fractured reservoir. Temperatures in the open portion of the hole average around 230°F. With the downhole heat exchanger, 100 gpm of “cold” water is circulated through the closed or isolated heat exchange loop in the well (Photo 9). On average the water is heated 50°F by the time it is



**Photo 8.** *Overview of AmeriCulture’s facility.*



**Photo 7.** *Large Tilapia rearing tanks (Thomas Lund).*

In 1995, AmeriCulture began geothermal aquaculture operations at the site of greenhouses that first formerly housed the 0.5 acre Beall geothermal greenhouse operation and then later on the McCants geothermal greenhouse at Lightning Dock prior to acquisition by AmeriCulture (Photo 8). Both Beall and McCants grew roses. AmeriCulture added about 0.2 acre of additional greenhouse space and drilled a new geothermal well on a state lease adjacent to the aquaculture operations and installed a downhole heat exchanger. The new well, AmeriCulture State 1, is 399 ft deep and cased to 282 ft



**Photo 9.** *Downhole heat exchanger system with Manager/Owner Damon Seawright.*

returned to the surface. The heated water is then fed to a 10,000-gallon insulated storage tank at the aquaculture facility by an insulated surface pipeline that is laid out on wooden pallets to allow movement for thermal expansion. The black iron pipeline is insulated with a wrap consisting of fiberglass insulation that is covered by tar paper that is held in place by chicken wire. This insulation lasts about three years and costs less than a \$0.40/lineal foot. Temperature loss between the well downhole heat exchanger and the storage tank is generally about 3°F, except during rain on older tar paper



where temporary heat loss can be as high as 20°F. Hot water in the storage tank is then used for geothermal heating of the facility that consists of six breeding tanks and about 200 smaller rearing tanks for the fingerlings. The installed geothermal heating capacity of the facility is  $2.5 \times 10^6$  Btu/hr (0.7 MWt) and annual energy use of  $11 \times 10^9$  Btu. The AmeriCulture website is: [www.americulture.com](http://www.americulture.com).

## CONCLUSION

Geothermal use by Burgett Geothermal Greenhouse and the AmeriCulture aquaculture facility represents one of the largest sectors, if not the largest, of the economy in Hidalgo County, New Mexico. Small-scale electrical power generation at the site and further expansion of both operations will only add to the importance of geothermal in rural economic development in New Mexico.

## REFERENCES

- Cunniff, R. A. and R. L. Bowers, 1988. "Temperature, Water Chemistry, and Lithological Data for the Lightning Dock Known Geothermal Resources Area, Animas Valley, New Mexico," in Icerman, L. and Parker, S. K., eds, New Mexico Statewide Geothermal Program: New Mexico Research and Development Institute, pp. 3-1 to 3-37.
- Dellechiaie, F., 1977. "A Geological and Hydro-Chemical Study of the Animas Geothermal Area, Hidalgo County, New Mexico," *Geothermal Resources Council Transactions*, v. 1, pp. 73-75.
- Elston, W. E.; Deal, E. G. and M. J. Logsdon, 1983. "Geology and Geothermal Waters of Lightning Dock Region, Animas Valley and Pyramid Mountains, Hidalgo County, New Mexico." New Mexico Bureau of Mines and Mineral Resources Circular 177, 44 p.
- Jiracek, G. R.; Smith, C.; Ander, M. E.; Holcombe, H. T. and M. T. Gerety, 1977. "Geophysical Studies at Lightning Dock KGRA, Hidalgo County, New Mexico," *Geothermal Resources Council Transactions*, v. 1, pp. 157-158.
- Norman, D. E. and Bernhardt, 1982. "Assessment of Geothermal Reservoirs by Analysis of Gases in Thermal Waters." New Mexico Research and Development Institute Report EMD 2-68-2305, 130 p.
- Smith, C., 1978. "Geophysics, Geology and Geothermal Leasing Status of the Lightning Dock KGRA, Animas Valley, New Mexico," *New Mexico Geological Society 29th Field Conference Guidebook*, pp. 343-348.
- Summers, W. K., 1976. "Catalog of Thermal Waters in New Mexico." New Mexico Bureau of Mines and Mineral Resources Hydrologic Report 4, 80 p.
- Witcher, J. C., 1988. "Geothermal Resources of Southwestern New Mexico and Southeastern Arizona," *New Mexico Geological Society 39th Field Conference Guidebook*, pp. 191-197.
- Witcher, J. C., 2001. "A Preliminary Analysis of the Shallow Reservoir Characteristics of the Lightning Dock Geothermal System as Determined from Pump Test of AmeriCulture 1 State Production Well." Unpublished technical report submitted to AmeriCulture, 39 p.
- Witcher, J. C., 2002. "AmeriCulture EGS-1 Characterization Well Geologic Log and Preliminary Geologic Analysis of the Lightning Dock Geothermal System." Unpublished technical report submitted to AmeriCulture, 37 p.

# MASSON RADIUM SPRINGS FARM

James C. Witcher  
Southwest Technology Development Institute  
New Mexico State University  
Las Cruces, NM

John W. Lund  
Geo-Heat Center



*Figure 1. Location map of the Masson Greenhouses (Witcher, 2001).*

## INTRODUCTION

The Masson Radium Springs Farm geothermal greenhouses are located on private land in southern New Mexico 15 miles north of Las Cruces and just west of Interstate 25 near the east bank of the Rio Grande adjacent the Federal Radium Springs KGRA (Figure 1). The operation started in 1987 with four acres of geothermally-heated greenhouses (Whittier, et al., 1991). Prior to startup at Radium Springs, Masson was one of the first clients in the SWTDI/NMSU business incubator and research Geothermal Facility. Masson selected New Mexico and the Radium Springs area to take advantage of the sunshine, ease of climate control because of the dry desert air, a willing and trainable work force, and geothermal heat. Today, the greenhouses employ 110 people, and cover 16 acres in two major modules, each with shipping and warehousing buildings attached (Photo 1). The Masson Radium Springs Farm is the production facility for Alex R. Masson, Inc. of Linwood, Kansas which handles distribution, marketing, and sales of wholesale potted

flowering and tropical plants. The markets cover southern Arizona, New Mexico, west Texas, and the mid-west, and the products are sold under the registered trade name of Sunflower Sue (<http://www.sunflowersue.com/>). The Masson Radium Springs Farm geothermal greenhouses are used to produce more than 30 groups of potted plant products including season products such as poinsettias.

## GEOLOGY AND HYDROGEOLOGY

The Radium Springs geothermal system is one the largest in the southern Rio Grande rift and the main thermal anomaly extends northward from Radium Springs nearly 10 miles over a 3-mile wide swath. The Radium Springs geothermal system is confined to a late-Tertiary horst block bound on the east by a major Pleistocene normal fault, and on the west by several smaller late Tertiary and Quaternary faults (Seager, 1975). However, the pre-Tertiary bedrock or reservoir host in the horst is dominated by large-scale Laramide reverse faults and associated folds, and minor thrust





**Photo 1. Two views of the greenhouses.**

faults in Precambrian granite and Paleozoic limestones. These deformed rocks are part of the frontal convergence zone of a very large basement-cored and northwest-trending Laramide uplift that has since been sliced apart by north-striking Tertiary rift normal faults (Seager, et al., 1986). The Laramide compressional deformation of Precambrian and Paleozoic rocks with an overprinting of extensional faults forms a favorable host for the deep or parent reservoir at Radium Springs and northward in the subsurface to San Diego Mountain. The deep reservoir is confined by up to 1,000 feet of altered andesitic volcanic mud flows (lahars), and muddy gravely sand and muddy andesitic boulder conglomerate of Eocene age called the Palm Park Formation (Seager, 1975).

At Radium Hot Springs, a low angle, north-dipping rhyolite dike acts as the conduit or “hydrogeologic discharge window” out of the deep Precambrian-Paleozoic reservoir for thermal water flow to the surface across the Palm Park aquitard (Witcher, 1988 and 2001). Because the shallow rhyolite dike of probable Oligocene age is also highly fractured, it forms a shallow outflow plume reservoir at Radium Springs that ultimately discharges thermal water into the near surface river gravels and sands of the Rio Grande.

The geothermal water at Radium Springs is a sodium chloride type with total dissolved solids (TDS) between 3,600 and 3,700 mg/L (Witcher, 1995 and 2001). Because of the high chloride content between 1,500 and 1,700 mg/L, chemical corrosion becomes an issue, requiring titanium alloys to be used in the heat exchangers.

Currently, three wells, drilled on private land, are online for production purposes. A fourth well, Masson 36 well, is on a Federal BLM lease held by Masson and has not gone into production due in part to the costly requirements of installing and maintaining energy meters for production monitoring to determine royalties. The Masson 36 well is probably capable of producing more than 1,500 gpm of 210°F (Witcher, 2001) (see vol. 22, no. 4 - December 2001 - issue of the *GHC Quarterly Bulletin* for details on this latter well).

Pump and recovery tests of a shallow (<250 ft depth) Masson geothermal well in the fractured rhyolite dike reservoir indicates a transmissivity of about 45,000 gpd/ft (Gross, 1986). Pump testing also shows that the shallow

reservoir has some hydraulic connection to the near surface cold fresh water aquifer. Quantitative properties of the deep reservoir are not known at this time. However, this reservoir is isolated from near surface cold aquifers by up to 1,000 ft of clayey aquitard (Palm Park Formation) and probably has significant solution permeability in addition to fracture permeability.

Besides the geothermal resource, the site also has a cold near surface aquifer that is used for irrigation. This aquifer is recharged from the nearby Rio Grande and consists of fluvial sands and gravels. Because of the requirements of irrigation with many crops grown in the greenhouses, a reverse osmosis unit is used to tailor the freshwater quality to specific needs.

## **GREENHOUSE GEOTHERMAL HEATING**

The Masson greenhouse facility consists of 16 acres of single wall fiberglass sides with double-poly roofs. Daytime and summer cooling is provided with evaporative pads and fans. The heating and cooling of the greenhouse environment is monitored and controlled by computer.

The greenhouse space is heated by geothermal energy from three wells that are located on private land. Masson 32 and 33 are shallow wells less than 350 ft depth in the rhyolite dike reservoir and produce 165°F water. Masson 36 was drilled during the last year to 800 ft depth and produces at 199°F water from the deep reservoir. Flows vary from 430 gpm in summer to 720 gpm in winter for Masson 32 and 33, and 750 gpm in winter for Masson 36. The water is stored in a newly construct 167,000 gallon storage tank that is used mainly for night-time heating (Photo 2), and then fed thru two large titanium plate heat exchangers (Photos 3 and 4). The geothermal water that is cooled to 110 to 130°F is then injected back into the shallow rhyolite reservoir with three shallow (<250 ft depth) injection wells at a location on the outflow plume down hydraulic gradient from the production wells.

In general, two types of heating arrangements are done in the greenhouses. In the older greenhouses, plotted plants are placed on benches underlain with finned tubing, black plastic and iron pipe for heating. In the older greenhouses, the finned tubing and piping is also run along the



**Photo 2.** *The 167,000-gallon storage tank.*



**Photo 3.** *The two new plate heat exchangers.*



**Photo 4.** *The existing plate heat exchanger (Jim Witcher).*

base of the greenhouse walls for heating. The most of the newer greenhouses use floor heating and the potted plants are placed directly on the concrete floor. In addition to heating, this arrangement conserves irrigation water and fertilizers by avoiding runoff and promoting recycling. Polybutylene tubing is embedded in the concrete floor for heating.

Maximum installed geothermal heating capacity is  $44.1 \times 10^6$  Btu/hr (12.9 MWt). Maximum annual energy use is probably around  $76.8 \times 10^9$  Btu for a minimum capacity factor of about 0.20. Annual energy use per acre is assumed to be between  $4.2$  and  $4.8 \times 10^9$  Btu/acre/yr based upon the energy use of the SWTDI/NMSU Geothermal Greenhouse Facility in Las Cruces.

## CONCLUSION

In addition to lowering overall energy costs, the Radium Springs geothermal resource gives Masson several advantages in production that has enabled the company to be less dependent upon other growers. For example, the company is able to grow its own stock plants that would normally be purchased from a plant specialist. Because of the economical geothermal heat, the company is able to be its own supplier for starter plant material, such as unrooted chrysanthemum cuttings, for final grow out at Radium Springs. With this approach, plants are more readily adapted to the environment and production schedules can be reduced and product quality improved.

## REFERENCES

- Gross, J., 1986. "Results of Groundwater Monitoring and Pump Testing in the Radium Springs Geothermal Area, New Mexico." Malcolm Pirnie, Inc. (Phoenix, AZ) Report prepared for the New Mexico State Engineer's Office and Alex R. Masson, Inc., 41 p.
- Seager, W. R., 1975. "Geologic Map and Sections of South Half San Diego Mountain Quadrangle, New Mexico." New Mexico Bureau of Mines and Mineral Resources Geologic Map 35, 1:24,000 scale.
- Seager, W. R.; Mack, G. H.; Raimonde, M. S. and R. G. Ryan, 1986. "Laramide Basement-Cored Uplift and Basins in South-Central New Mexico," *New Mexico Geological Society 37<sup>th</sup> Annual Fall Field Conference Guidebook*, p. 120-130.
- Whittier, J.; Schoenmackers, R. and J. C. Witcher, 1991. "Geothermal Direct-Use – A Successful Example of Greenhouse Heating in New Mexico," *Geothermal Resources Council Transactions*, v. 15, pp. 73-76.
- Witcher, J. C., 1988. "Geothermal Resources in Southwestern New Mexico and Southeastern Arizona," *New Mexico Geological Society 39<sup>th</sup> Annual Fall Field Conference Guidebook*, pp. 191-197.
- Witcher, J. C., 2001. "Geothermal Direct-Use Well for Commercial Greenhouses Radium Springs, New Mexico," *Geo-Heat Center Quarterly Bulletin*, v. 22, no. 4, pp. 1-7.



# J & K GROWERS LAS CRUCES, NEW MEXICO

John W. Lund  
Geo-Heat Center



J & K Growers are located adjacent to the New Mexico State University (NMSU) campus in Las Cruces. They use geothermal energy to heat 1.6 acres of 18 poly-covered greenhouses and cold frames. At first the owners, Kerry and John Krumrine, grew all potted plants and bedding crops on the ground to limit costs, especially with the use of in-ground heat. However, later they decided to put the crops on benches and further, from the buried heating source to increase air circulation, lower soil temperature and thus, decrease disease and pest problems. Also, this limited the stress of working at ground level. They initially produced potted crops, mostly cyclamen, exacum, and geraniums; however, they have changed to bedding plants as they have proven to be less work and more profitable. They also grow some poinsettias.

The Krumrines got their start in 1988 by leasing the 6,000-ft<sup>2</sup> “incubator” greenhouse on NMSU administered by the Southwest Technology Development Institute (STDI). This greenhouse is provided to potential commercial growers to get their feet wet and to see if the client really wants to have a “green thumb.” After a year successfully growing poinsettias, they moved to their present location on land owned by a gravel pit business. The landowner drilled the geothermal well by accident, but did not need the hot water to wash his sand and gravel. Thus, the Krumrines uses only the heat and return the water to a pond for the landowners use. A 50-gpm pump draws water from the well at 148°F into a 30,000-gallon tank adjacent to the greenhouses.

The geothermal water is used directly from the tank in the green-house heating systems which consists of 3-inch black poly-butylene pipe main supply and return lines with simple thermostats connected to spa pumps to push water

through the system. Each greenhouse of approximately 3,000-ft<sup>2</sup> in area, has 2-inch branch lines that run at about bench height (2-feet off the ground), and then 3/4-inch branch lines from these pipes run underground at four to six inches beneath the gravel greenhouse floor and buried in sand. These underground loops are each about 1,000 feet in length. An additional line heats 15,000 ft<sup>2</sup> of cold frames to keep the crops from freezing.

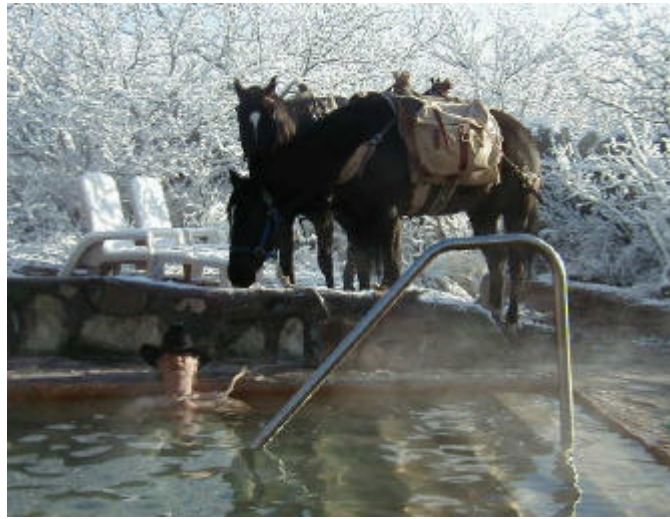
The geothermal system proved its value when strong winds collapsed one of the greenhouses. The below bench and underground heating system kept the plants warm, even though the Krumrine’s had to crawl on their hands and knees to service the crops. An overhead system would have been destroyed. They also have installed kerosene back-up heaters, but only have had to use them once--which created an unpleasant odor in the greenhouses.

The cost to operate the heating system is about 60 percent of natural gas heat costs. The hot water bill at the peak (about four weeks out of the year) is around \$500 per month (1992 figures), and considerably less the rest of the year. The only drawback is that since the geothermal water is used directly in the heating system, calcite deposits have built up inside the pipes reducing the flow and heat output. The well is on federal land; thus, a royalty is paid based on an annual average energy use per acre.

This material was summarized and edited from an article in *Greenhouse Manager* magazine (June, 1992) by Sami Harman Thomas title: “Geothermal Energy Fuels Success - New Mexico Couple Find Down-to-Earth Heat Supply,” pp. 56-60, and from the Editor/Author’s visit to the site (see page 30, Figure 1, for location map).

# FAYWOOD HOT SPRINGS

James C. Witcher  
Southwest Technology Development Institute  
NMSU, Las Cruces, NM



Faywood Hot Springs is a lush oasis in the high desert of southwestern New Mexico about halfway between Silver City and Deming. For centuries, the hot springs have lured prehistoric and native American peoples, such as the Mimbres Culture and Apaches, Spanish explorers, stage coach travelers, “buffalo soldiers,” health seekers, miners, and even a professional baseball team near the beginning of the last century. Many circular “mortar” holes in the spring tufa mound attest to early use by prehistoric peoples. Today, the hot springs are commercially developed as a year round natural hot spring resort on a 1,200-acre ranch with activities that include bathing, massage, camping, horseback riding, bird watching, and star gazing (<http://www.faywood.com/>). About three road miles distance is the popular City of Rocks New Mexico State Park. The City of Rocks are rows of large rock spires and towers that are shaped by chemical weathering and mechanical erosion from a welded ash flow tuff unit or ignimbrite that was erupted during Oligocene volcanism in the region. The hot springs water, report at 125 to 130°F, has sodium bicarbonate chemistry with a total dissolved solids (TDS) of about 500 mg/L and are associated with a calcium carbonate tuffa mound that is more than 30 ft in height and more than 600 ft in circumference. The spring temperature and natural flow rate has apparently declined since the 1899 when natural flow rates of 100 gpm and temperatures of 142°F were recorded (Summers, 1976). By 1957, the flow had decreased to 50 gpm and the temperature was measured at 128°F (Summers, 1976). It recently increased to 137°F due to cleaning of the spring. The decrease in flow may be related to water development in the region during the last century. Other historic thermal springs, located northwest of Faywood Hot Springs, such as Apache Tejo Warm Springs and Warm Springs, no longer flow. Geologically, Faywood Hot Springs is located on a

horst block that is separated from the San Vicente half graben to the southwest by a large normal fault (Elston, 1957; Seager, 1995). About one mile east of the hot springs, a large felsic intrusion or dome is exposed in highway cuts along the highway to City of Rocks State Park. The margins of the intrusive body may act as a “discharge hydrogeologic window” to allow hot water to flow vertically across the Rubio Peak Formation, a regional aquitard that caps a thermal Pennsylvanian carbonate aquifer in the area (Witcher, 1988). Heat for the springs comes from background, but elevated, crustal heat flow for the region and results from deeply circulating (3,500 to 4,500 ft depth) water flowing relatively fast back to the surface and retaining higher temperatures.

## REFERENCES

- Elston, W. E., 1957. “Geology and Mineral Resources of Dwyer Quadrangle, Grant, Luna, and Sierra Counties, New Mexico.” New Mexico Bureau of Mines and Mineral Resources Bulletin 38, 86 p.
- Seager, W. R., 1995. “Geologic Map of the Southwest Part of Las Cruces and Northwest Part of El Paso 1 X 2 Degree Sheets, New Mexico.” New Mexico Bureau of Mines and Mineral Resources Geologic Map GM-60, 1:125,000 scale.
- Summers, W. K., 1976. “Catalog of Thermal Waters in New Mexico.” New Mexico Bureau of Mines and Mineral Resources Hydrologic Report 4, 80 p.
- Witcher, J. C., 1988. “Geothermal Resources of Southwestern New Mexico and Southeastern Arizona,” *New Mexico Geological Society 39th Field Conference Guidebook*, pp. 191-197.



# OJO CALIENTE – AMERICA’S OLDEST SPA?

James C. Witcher  
Southwest Technology Development Institute  
NMSU, Las Cruces, NM



Ojo Caliente (“Hot Springs”), New Mexico may be one of the oldest health resorts in North America. The following history is given in the website for the Ojo Caliente Spa which is located west of Taos along U.S. Highway 285 between Santa Fe, New Mexico and Alamosa, Colorado (<http://www.ojocalientespa.com/>):

“Through the years, Ojo Caliente has been steeped in myth and legend. Long before the Spaniards described the “hot eye” of a subterranean volcanic aquifer and even before the early native peoples gathered at these ancient springs, the waters have been steadily flowing to the surface. These ancient people, believed to be the ancestors of today’s Tewa tribes, built large pueblos and terraced gardens overlooking the springs. Posi or Poseuinge, “village at the place of the green bubbling hot springs” was home to thousands of people.

The Spaniards, in their quest for gold and the fountain of youth also discovered the springs. In 1535, explorer Cabeza de Vaca wrote “The greatest treasure that I found these strange people to possess are some hot springs which burst out at the foot of a mountain... so powerful are the chemicals contained in this water that the inhabitants have a belief that they were given to them by their gods. These springs, I have named Ojo Caliente.”

Explorer Zebulon Pike, while under arrest in 1807 for exploring New Spain without permission, was marched to Santa Fe and passing through Ojo

Caliente he observed “the greatest natural curiosity is the warm springs.”

In 1880, Antonio Joseph, New Mexico's first territorial representative to congress opened the first health spa with overnight lodging. Joseph's Ojo included a post office and general store and was a center of activity. Historical ledgers show that Kit Carson purchased supplies at the store.

The thermal waters at Ojo Caliente discharge along the northeast-trending Ojo Caliente fault zone that juxtaposes the Precambrian metarhyolite footwall to the west against Tertiary basin-fill deposits in the hanging wall to the east (Stix and others, 1982). The Precambrian metarhyolite is cut by pegmatite dikes dipping 45° west and the metarhyolite is broken by a prominent joint set of N45°E,60°E and N70°W,80°N orientation (May, 1980). Five different developed springs that go by the names “Iron,” “Sodium Sulfate,” “Soda,” “Arsenic,” and “Lithia” are found on the Ojo Caliente Spa location (Summers, 1976). The hot springs at Ojo Caliente are associated with calcium carbonate deposits of tufa or travertine. The Ojo Caliente fault zone has many tuffa deposits along its trace in the region from Ojo Caliente to La Madera as well as some warm springs. A shallow, 87 ft deep, hot well produces 128 to 132°F water. The Ojo Caliente springs range in temperature from 95 to 111°F. The well and spring waters have total dissolved solids (TDS) between 3,600 and 3,700 mg/L. Total natural flow of the developed springs was 97 gpm in 1965 (Summers, 1976). The spring waters probably gain their heat by deep (about 4,500 to 6,000 ft depth) circulation in fractures of the Precambrian metarhyolite after recharge from rain and snow in the highlands to the north. Background, but elevated, regional temperature gradients of the Rio Grande rift allow heating with deep circulation of groundwater.

## REFERENCES

- May, S. J., 1980. “Neogene Geology of the Ojo Caliente-Rio Chama Area, Espanola Basin, New Mexico.” unpub Ph.D. Dissertation, University of New Mexico, Albuquerque, 204 p.
- Stix, J.; Pearson, C.; Vuataz, F.; Goff, F.; East, J. and B. Hoffers, 1982. “Geology, Resistivity and Hydro-Geochemistry of the Ojo Caliente Hot Springs Area, Northern, New Mexico,” *Geothermal Resources Council Transactions*, v. 6 p. 55-58.
- Summers, W. K., 1976. “Catalog of Thermal Waters in New Mexico.” New Mexico Bureau of Mines and Mineral Resources Hydrologic Report 4, 80 p.

# RADIUM HOT SPRINGS

John W. Lund  
Geo-Heat Center

Radium Hots Springs is located about 16 miles north of Los Cruces, NM, just west of Interstate I25. It originally issued from a small rhyolite hill just north of the Radium Hot Springs Resort and is between the Rio Grande River and the Santa Fe Railroad. The original highway between Albuquerque and El Paso ran adjacent to the project with traces of it still seen today. According to the brochure from the Resort:

“The history of Radium Springs, the hottest, strongest natural radium springs in the world, dates back to the time when Indian tribes made pilgrimages here. The Springs became a sacred place, and no horseman was allowed to ride within a mile of the steaming waters. Even Geronimo, the famous Apache Chief, used to make his camp nearby, so he and his warriors could bathe in the revitalizing waters. Early Spanish settlers also used the Springs to rejuvenate themselves from the rigors of the New World, and later, soldiers from Fort Selden once again “discovered” the beneficial powers of the Radium Springs.”

“At the turn of the century a Harvey House was built near the Springs, and it became a favorite resting place for travelers on the Santa Fe Railway. Weekend trainloads of El Pasoans would also come, spending their day in the baths before catching the southbound for home. In 1931 Harry Bailey, one a friend of Pat Garrett and Billy the Kid, built the hotel and bathhouse so that visitors might have more comfortable access to the healing waters.” This building still stands today (Figure 1).



**Figure 1.** *Radium Hot Springs Resort with Jim Witcher and the owner Jeff Gocher.*

Across the railroad to the east from the Radium Hot Springs Resort is the remains of Bailey’s Bath House (Figure 2). This was the hot spring bath that the “Buffalo Soldiers” from nearby old Fort Selden used. Fort Selden was established in 1865, and between 1866 and 1881, four regiments of Black soldiers were stationed there. The 9<sup>th</sup> Cavalry and the 21<sup>st</sup>, 38<sup>th</sup> and 125<sup>th</sup> Infantry were referred to as “Buffalo Soldiers” by the Indians because of their short, curly hair and fighting spirit - two attributes shared with the buffalo. General Douglas McArthur spent several years at the Fort during his childhood, when his father was commanding officer. The post was abandoned in 1891. The well was a dug well about 8 ft by 8 ft and 20 ft deep. The water discharged through a small pressure tank and was used in the bath and for domestic supply.

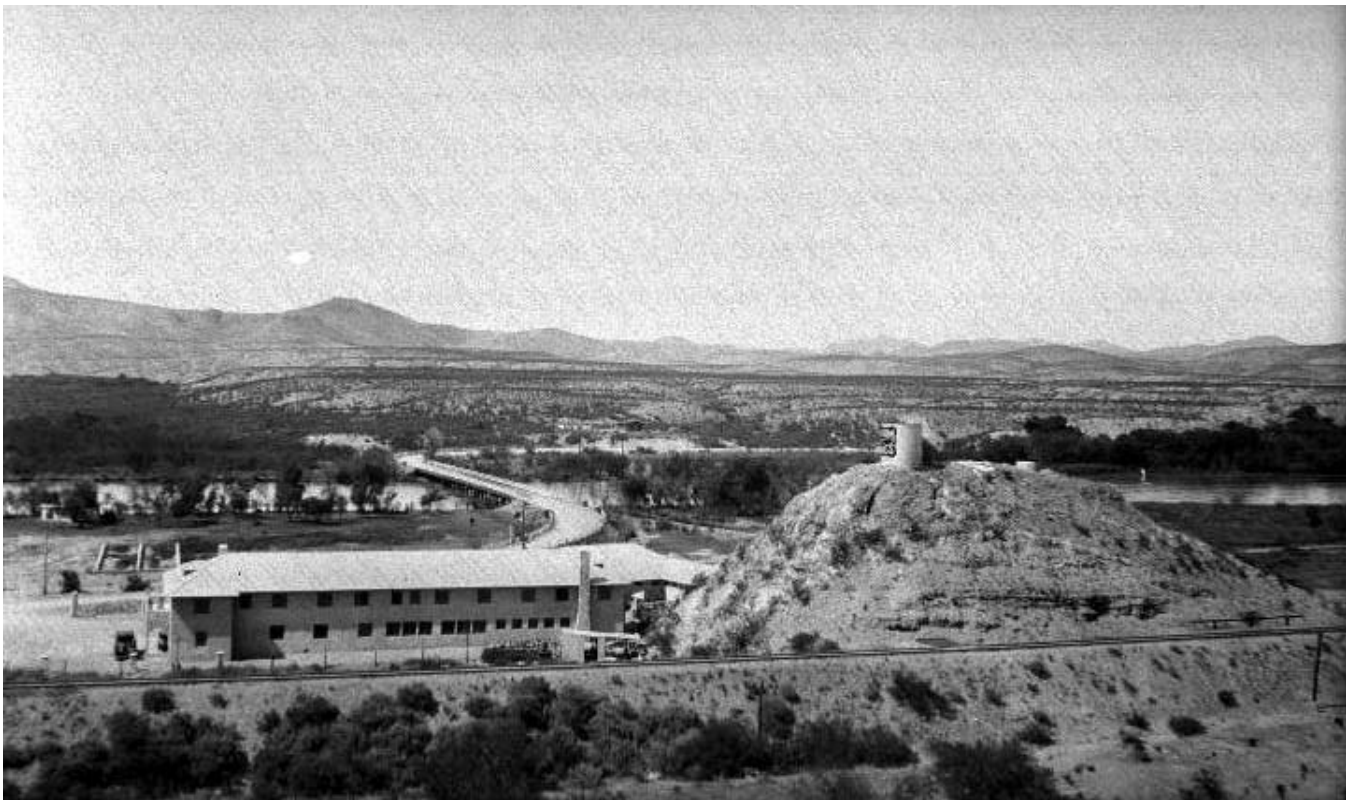
The spring and wells at both locations are sodium-chloride types with TDS of about 3700. The temperatures varied from 43 to 85°C (109° to 185°F) and all are under 100 m (330 feet) in depth. The present well at the Resort is 44°C (112°F) and 55 m (180 feet) deep. The 9000 square foot resort uses the mineral water in bath tubs. In addition they have a large dug well, about five feet across inside the building. One analysis reportedly made by the University of New Mexico gave the radium concentration of 2.57 picocuries/liter ( $\mu\text{Ci/L}$ ). Another sample from 1954 reported beta-gamma activity, 170 picocuries/liter; radium, 0.6 picocuries/liter, and uranium 1.8  $\mu\text{g/L}$ . It is reported from 1899, that the spring was then called Selden Hot Springs and that “These springs.... are patronized by those afflicted with rheumatism.” (W. K. Summers, *Catalog of Thermal Waters in New Mexico*, New Mexico Bureau of Mines and Mineral Resources, Socorro, NM, 1976.) The Resort is presently being renovated and can be contacted at (505-524-4093).



**Figure 2.** *Remains of Bailey's Bath House.*



**Figure 3.** *Radium Hot Springs Resort in the 1930s looking north. Note the rhyolite dome in the background—source of the original hot springs. Courtesy of New Mexico State University Archives, Rio Grande Historical Collection, Louis B. Bentley photo (Jim Witcher’s great-grandfather).*



**Figure 4.** *Radium Hot Springs Resort in the 1930s looking west. Note the Rio Grande River and old state highway to Albuquerque in background. Courtesy of New Mexico State University Archives, Rio Grande Historical Collection, Louis B. Bentley photo (Jim Witcher’s great-grandfather).*

# **GEOHERMAL RESOURCES COUNCIL**

## **2003 ANNUAL MEETING**

### **MORELIA, MEXICO**

### **OCTOBER 12-15, 2003**

“International Collaboration for Geothermal Energy in the Americas” is the theme of the GRC’s first annual meeting outside the United States. The meeting is cosponsored by Mexico’s Comisión Federal de Electricidad (CFE) and the U.S. Department of Energy (USDOE), and will provide an ideal opportunity for developers, suppliers and support organizations to exhibit their equipment and services to the world geothermal community. Morelia is located about halfway between Mexico City and Guadalajara.

Interested persons are invited to present their latest technical work in geothermal research, exploration, development and utilization at the Centro de Convenciones y ExpoCentro in the beautiful and historic City of Morelia, Mexico. The draft paper of two hard copies and disk or CD in Microsoft Word or Rich Text Format (with submission form) must be received by the GRC by May 9, 2003.

The “Americas” emphasis of the meeting recognizes the importance of geothermal resources development in Mexico and Latin America. The 2003 Annual Meeting will feature distinguished international keynote speakers at its Opening Sessions; Technical and Poster Sessions on a broad range of timely geothermal resources and development topics; Technical Workshops; Field Trips to nearby geothermal fields and features; a unique Guest Program; and the popular Annual Golf Tournament and GRC Banquet; and the U.S. Geothermal Energy Association Geothermal Energy Trade Show.

Additional information can be obtained from the GRC office in Davis, CA; phone: (503) 758-2360 or email: [grc@geothermal.org](mailto:grc@geothermal.org). Also, visit their website: [www.geothermal.org](http://www.geothermal.org) for the complete First Announcement and Call for Papers brochure.