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**Utah State Prison Space Heating
With Geothermal Heat**

**RESOURCE ASSESSMENT REPORT
CRYSTAL HOT SPRINGS GEOTHERMAL AREA**

DECEMBER 1981

Work performed under DOE Cooperative Agreement
No. DE-FC07-79ET27027

Utah Energy Office
3266 State Office Bldg.
Salt Lake City, Utah 84114

**U. S. DEPARTMENT OF ENERGY
Geothermal Energy**

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ABSTRACT

Reported herein is a summary of work conducted under the Resource Assessment Program - Task 2, for the Utah State Prison Geothermal Space Heating Project at Crystal Hot Springs, Draper, Utah. Assessment of the geothermal resource in and around the Utah State Prison property began in October of 1979 with an areomagnetic and gravity survey. These tasks were designed to provide detailed subsurface structural information in the vicinity of the thermal springs so that an informed decision as to the locations of test and production holes could be made.

The geophysical reconnaissance program provided the structural details needed to focus the test drilling program on the most promising production targets available to the State Prison. The subsequent drilling and well testing program was conducted to provide information to aid in the siting and design of a production well and preliminary design activites.

As part of the resource assessment portion of the Utah State Prison Geothermal Project, a program for periodic geophysical monitoring of the Crystal Hot Springs resource was developed. The program was designed to enable determination of baseline thermal, hydraulic, and chemical characteristics in the vicinity of Crystal Hot Springs prior to production and to provide a history of these characteristics during resource development.

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1.0 INTRODUCTION

1.1 PROJECT BACKGROUND

In July, 1978 the Utah Energy Office, on behalf of the State of Utah, submitted a successful proposal to the Department of Energy (DOE) in response to a Program Opportunity Notice (PON) for Direct Utilization of Geothermal Energy Resources.

The Utah Energy Office PON proposal proposed to develop the Crystal Hot Springs geothermal resource located on private property adjacent to the Utah State Prison at the southern end of the Salt Lake Valley. The objective of the PON was to demonstrate the economic and technical feasibility of providing sufficient geothermal water for use in a variety of direct applications at suitable sites within the Utah State Prison complex. A geothermal well, heat exchange system, and injection disposal well were proposed to form the initial demonstration of providing geothermal water for space heating and domestic water heating for the minimum security facility at the Prison.

Consisting of dorms, offices, a gymnasium, and a cafeteria, the 72,000 square foot minimum security facility was considered a good candidate for retrofit to geothermal energy for three reasons.

1. Due to its size and function, the facility consumed a large portion of the energy used at the Prison,
2. The minimum security facility's location as the nearest major prison building to the Crystal Hot Springs resource; a distance of only 400 meters, and
3. The existing building's space heating system was a hot water system and was considered to be a relatively easy retrofit for a geothermal heating system.

The initial demonstration of providing the minimum security facility with space and hot water heating was intended to form the nucleus of a system which potentially could be expanded to provide the bulk of the heating requirements for the entire Prison.

In order to meet the objectives of the PON proposal, the Utah Energy Office programmed the project into three phases consisting of:

Phase I - Resource Assessment

- ° Additional geophysical reconnaissance comprised of aeromagnetic and gravity surveys of the Crystal Hot Springs resource area.
- ° Resource monitoring program to establish baseline thermal, hydraulic, and chemical characteristics of the Crystal Hot Springs resource area.
- ° Selection of a drilling site on Prison property for a deep test well.

- Short term artesian flow testing program to assist in fixing a production well design and to provide information needed for completion of a preliminary heating system design.

Phase II - Resource Development

- Selection of a site on Prison property for drilling a production well.
- Detailed evaluation of well and reservoir characteristics.
- Investigation of disposal alternatives.
- Preliminary system design and economic and technical feasibility assessment.

Phase III - Construction and Inspection of Demonstration

- Final system design.
- System construction.
- Commissioning and initiation of monitoring and performance verification program.

Work on the project was to begin in March, 1979, with the writing of the environmental report and culminate with the startup of the heating system in September of 1981.

The total estimated cost for the project is \$637,326 with a cost share arrangement assigning \$458,704 to DOE and \$178,622 to the State of Utah.

1.2 PROJECT DESCRIPTION

Resource

Development is focused on the Crystal Hot Springs geothermal resource, the surface expression of which is located on private property adjacent to Prison property.

The Crystal Hot Springs geothermal system is a deep convective system located at the eastern margin of the Basin and Range physiographic province. The thermal springs are located north of an east-northeast trending horst that is perpendicular to the structural trend of Wasatch Front grabens. The horst, known as the Traverse Range, consists of highly fractured mid-Paleozoic quartzites and tertiary volcanics. Meteoric water enters the system in the adjacent ranges, circulates to depths of 3 Km, and is heated. The thermal fluids return to the surface along steeply dipping range front faults that bound the northern flank of the range. The thermal springs issue between two such faults that are buried beneath Tertiary and Quaternary age valley fill deposits. Highly fractured quartzite beneath the valley fill act as a near-surface reservoir for the thermal water that is being targeted for development.

The surface expression is defined by several hot water spring discharges contained within a 70 acre area. At the center of the Crystal Hot springs resource area springs issue to the surface through alluvium that is approximately 80 feet thick.

The maximum measured temperature at Crystal Hot Springs is 98° C, recorded in the bottom of the 410 foot Utah Roses well. The chemical quality of the thermal waters are excellent. The total dissolved solids content is between 1,500 - 1,700 ppm.

System Design

In the minimum security facility's existing system, heat from steam supplied by the natural gas fired central boiler plant, is exchanged onto fresh water which is circulated through the building. This system will be modified by the addition of geothermal water/fresh water heat exchangers in series with steam/water units for both space and culinary water heating. Apart from supplementary pumping capacity, the rest of the system will be left essentially in tact.

To produce the necessary flows from USP/TH-1, the well will be pumped. A 50 hp vertical turbine pump, set at approximately 500 feet, capable of producing flows up to 288 gpm, is proposed. The pump discharge will connect to a 6-inch diameter epoxy-lined insulated asbestos-cement transmission pipeline, buried at a safe depth. The transmission pipeline will be routed as directly as possible to the two mechanical rooms in the minimum security facility.

Heat Exchangers

Located either within these mechanical rooms or just outside in their areaways, plate-type heat exchangers will transfer heat from the 175° F geothermal water into the existing space heating and domestic hot water systems that serve minimum security. The heat transfer would be accomplished through stainless steel plates that separate and completely isolate the hotter geothermal water from the space heating water and from the domestic hot water.

Control

Control of the geothermal flow would be regulated by two-way control valves that modulate in response to actual heating loads. Such a control system could minimize the geothermal flow, thereby conserving the resource and minimizing the geothermal discharge to the receiving stream.

Disposal Pipeline

After leaving the heat exchangers, the spent geothermal water, now 40° F to 50° F cooler, would be handled by a 6-inch diameter epoxy-lined asbestos-cement disposal pipeline, buried along the same route as the transmission pipeline. The buried disposal pipeline will continue past the production well through the Prison farm to a cooling pond located approximately 5,000 feet to the northwest.

Cooling Pond and Outfall

At the fully lined cooling pond, incoming spent geothermal water will be sprayed through the air into the pond to further cool the water to a temperature suitable for discharge. From the cooling pond, the cooled geothermal water would flow by gravity through a buried pipeline to a diffuser in the receiving stream.

1.3 SUMMARY AND FINDINGS OF THE RESOURCE ASSESSMENT PROGRAM

The Resource Assessment phase of the Utah State Prison Field Demonstration Project was designed to supplement existing resource data and provide the data base needed to make an informed decision as how best to develop the geothermal resource on Utah Prison property.

The gravity and areomagnetic data were gathered to provide detailed structural and geologic information of the subsurface conditions beneath Crystal Hot Springs and the Utah State Prison. The results of the detailed gravity survey revealed a complex faulted bedrock surface buried beneath the unconsolidated materials that are present at the surface. Interpretation of the gravity data identified an area north of the springs in the vicinity of the State Prison farm where the fractured quartzite was present at approximately 250 and 300 feet in depth. Because of the known association between the thermal springs and the near surface presence of quartzite, the intermediate depth bedrock was selected as a target for the test hole drilling program.

The test hole drilling program confirmed the bedrock model and confirmed the presence of significant quantities of thermal water within the fractured quartzite. An existing thermal gradient monitoring well, (SF-1), was deepened from 270 feet to 500 feet. SF-1 penetrated 140 feet of quartzite, and upon completion flowed artesian at 300 gpm. A new test hole referred to as USP/TH-1 was drilled to a total depth of 1,000 feet. USP/TH-1 penetrated 640 feet of quartzite, and when completed flowed artesian at 600 gpm.

Results of the drilling program suggested that the quartzite is not homogeneously fractured and that the upper portion of the quartzite is relatively impermeable. Production from SF-1 originates from below 330 feet, while production from USP/TH-1 is primarily from below 600 feet.

The resource monitoring program was designed to enable determination of baseline thermal, hydraulic, and chemical characteristics in the vicinity of Crystal Hot Springs and to provide a history of these characteristics during resource development. Results from the thermal monitoring of gradient holes in the vicinity of Crystal Hot Springs have yielded results similar to those of earlier investigations. Development activities that have occurred to date have not caused a change in the thermal characteristics of the resource. The limited chemical monitoring conducted early in the program did not yield significant conclusions regarding the chemical characteristics of the Crystal Hot Springs resource except to verify the excellent quality of the geothermal resource. Monthly hydraulic measurements of the Crystal Hot Springs KGRA suggests that Utah Roses' Inc. production has had a noticeable effect upon the resources' hydraulic characteristics.

A program for testing well USP/TH-1 was conducted to provide information required to aide in siting and design of a production well and to provide information for preliminary system design activites.

Noncondensable gas concentrations at wellhead conditions were found to range from 0.08 to 0.22 weight percent. Using soluability relationships and measured gas concentrations, noncondensable gas flashpoints in the wellbore were calculated to range from 140 feet to 270 feet from the well-head under hydrostatic wellbore conditions.

The production characteristics of well USP/TH-1 were determined from a controlled 48 hour artesian flow test. Analysis of surface and drawdown/recovery data indicated a highly permeable reservoir of somewhat limited area. Long term production characteristics of well USP/TH-1 were estimated to be limited due to reservoir boundary effects. The well is capable of sustaining a flow rate of 100 gpm for 8 months with a drawdown of 275 feet. Production temperature at the wellhead averaged 179 degrees F during testing.

Due to the limited scope of the test program and short duration of time under which the artesian flow testing was conducted, definitive statements about long-term reservoir productivity cannot be made. Therefore, Terra Tek, Inc., has made the following recommendations in regards to future resource assessment efforts:

1. Due to the limited long term production potential predicted for the prison portion of the resource, drilling of an additional well for production is not warranted at this time.
2. A long term pump test of well USP/TH-1 should be conducted during a period when Utah Roses is not producing its well. This test is necessary to verify the predicted long term drawdown characteristics and to assess any system recharge effects.
3. A test of the Utah Roses Well (or perhaps just careful monitoring) should be conducted to determine the effect of Utah Roses Production upon well USP/TH-1.
4. Seasonal system flow requirements for heating the Minimum Security Building should be established during preliminary system design activites.
5. Current and future production requirements for Utah Roses should be established.

Following completion of the above, the ability of the Crystal Hot Springs resource to supply the anticipted development activities of both the Utah State Prison and Utah Roses, Inc. can be more accurately assessed.

2.0 ENVIRONMENTAL IMPACT

Studies were conducted to determine potential adverse environmental effects resulting from implementation of the Utah State Prison Geothermal Project. The completed study indicated that only minor, temporary environmental effects will result. The drilling and development will occur entirely on prison property; project efforts will be integrated into planned prison facilities construction and rehabilitation activities. Direct use of land will be approximately one acre (for wells, equipment buildings, and pipelines). Because the development is small and will be integrated with prison construction plans, the aesthetic quality of the area will not be diminished.

Temporary disruption of surface soil will occur during drilling of the wells and installation of pipelines. The surface impact is considered small compared to other prison construction activities that will be conducted concurrently with the geothermal development. With property excavation, the short-term effects to the prison's environment will be minimal.

Slight impact to flora and fauna will result from clearing of land for roads, drill sites, and piping. These activities will require only minimal removal of vegetation or displacement of fauna. The area anticipated for drilling and for pipeline routes is essentially void of vegetation and wildlife.

At this time, the means of disposal of spent geothermal fluids have not been selected. Adequate investigations will be made prior to implementation of any disposal alternative to ensure that no adverse environmental impacts will occur.

3.0 GEOPHYSICAL RECONNAISSANCE

The geophysical reconnaissance task was designed to provide detailed subsurface structural information in the vicinity of thermal springs so that an informed decision as to the locations of test and production holes could be made. In the original proposal the reconnaissance task consisted of detailed gravity and ground magnetic surveys in the immediate vicinity of the prison, but at the time the surveys were to be conducted, significant changes were made. The detailed gravity survey was maintained, but was tied to a more regional survey conducted under the DOE/DGE State Coupled Geothermal Resource Assessment program. The ground magnetics survey was dropped in favor of a detailed aeromagnetics survey being conducted under the same state coupled program. These changes resulted in a superior geophysical survey at reduced cost to the PON and without significantly increasing the cost to the state coupled program. The results of these surveys, in particular the gravity survey, were a significant contribution to the data needed to select test hole sites for Task 2.2.

Prior to the investigations conducted in conjunction with the field demonstration project, considerable resource data had been gathered in the vicinity of Crystal Hot Springs under the DOE state-coupled geothermal resource assessment program. These previous investigations are described in detail by Murphy and Gwynn (1979). Initial models of the resource constructed using this early data were further developed during the geophysical reconnaissance investigations. A summary of drill hole data available as of the writing of this report is included as Table 1. Locations of the wells are shown on Figures 1 and 2.

TABLE 1 - SUMMARY OF DRILL HOLE DATA IN THE VICINITY OF CRYSTAL HOT SPRINGS

Salt Lake County, Utah

HOLE	IDENT.	DATE DRILLED	TYPE DRILL ₁	DEPTH FT.	MAX TEMP C°	ARTESIAN FLOW	TEMP DEPTH FT.	STATUS ₂	COMPLETION
UGMS Gradient	A	2/78	R/M	220	68.5	175 gpm	TD	M	Tertiary Seds
	B	2/78	R/M	245	35.5	NO	TD	M, G	Tertiary Seds
	C	2/78	R/M	280	76.0	NO	TD	G	Tertiary Seds
	D	3/78	R/M	237	74.2	NO	65	M	Paleozoic Qtz
	E	3/78	R/M	200	85.5	5-10 gpm	TD	M	Paleozoic Qtz
	F	3/78	R/M	250	33.0	NO	TD	M, G	Tertiary Seds
ASARCO		6/55	R, C/M	940	34.3	NO	150	A	Tertiary Volc
LEE			CT	825	24.5	NO	215	A	Tertiary Volc (?)
HALL		12/75	CT	290	45.0	NO	TD	W	Paleozoic Qtz (?)
STATE FORESTRY-1		4/78	R/M	280	80.4	12 gpm	TD		
		10/80	R/W	505	80.4	300 gpm	0	T	Paleozoic Qtz
* UTAH ROSES	-1	11/79	R/W	410	98.4	150 gpm	TD	P	Paleozoic Qtz
	-2	11/79	R/W	210	16	NONE	0	W	Tertiary Seds
	-3	10/80	R/W	175	14	NONE	0	W	Tertiary Seds
	-4	10/80	R/W	950	82	7100 gpm	0	I	Tertiary Seds
USP/TH-1		10/80	R/W	1005		800 gpm		T	Paleozoic Qtz

1. Method/Fluid
 R = Rotary
 C = Core
 M = Bentonite
 W = Water
 CT = Cable Tool

2. M = Monitor
 G = Gradient
 A = Abandoned
 W = Producing Water Well
 T = Test

P = Geothermal Production
 I = Geothermal Injection

Well locations are shown on
 Figures 1 and 2

3.1 AEROMAGNETIC SURVEY

The aeromagnetic survey was flown by Aerial Surveys of Salt Lake City, Utah, under subcontract to Applied Geophysics, Inc., of Salt Lake City, Utah, in November 1979. Instrumentation for the survey was a Geometrics proton precession magnetometer model G 803 having a sampling rate of 0.8 sec. with plus or minus 0.25 gamma sensitivity. The area surveyed was 9.5 miles long in the north-south direction, 6 miles wide in the east-west direction and centered on the Crystal Hot Springs system. Flight lines were oriented north-south and were spaced one-eighth mile apart. A mean terrain clearance of 500 feet was maintained.

The aerial survey detailed the complex magnetic surface and was a significant improvement over the existing aeromagnetic data. The main feature identified by the survey is an east-west trending zone of magnetic highs, the most intense of which is immediately north of the Crystal Hot Springs system. The eastern end of the zone is adjacent to the Cottonwood Stock. North and south of the zone the magnetic surface is relatively flat, but not featureless.

Preliminary modeling of the magnetic data by Christian Smith of ESLD/UURI resulted in an acceptable model of the bodies responsible for the observed magnetic surface. According to Smith (1980), the magnetic anomaly results from a series of magnetically susceptible intrusive and extrusive bodies that trend east-northeast. These bodies extend from a minimum depth of 7500 feet to within 350 feet of the surface. The lower portions of the bodies are believed to be intrusives, while the upper levels may be either intrusive dikes and sills, or extrusive flows. The ASARCO hole shown in Figure 1 was a mineral test hole drilled by the American Smelting and Refining Company in May of 1955. A log of the hole compiled by an ASARCO geologist describes the bedrock of this hole as "reddish andesite porphyry flow rock showing calcite along seams and in vugs and containing hematite. The geologist also notes that no mineralization was seen in any of the core.

Of most interest to the objectives of the Utah State Prison Field Demonstration Project was the structural relationship of the andesite porphyry to the quartzite. Smith (1980) noted the presence of deep seated faults that juxtapose non-magnetic quartzite against magnetically susceptible andesite. This hypothesis is supported by the known stratigraphic and structural relationships of the area.

The fault along which the volcanics and quartzite have been brought into contact is located immediately north of the hot springs (Figure 1). The andesite may be an important hydrologic feature that directly influences the location of the thermal springs. If the andesite is of significantly lower permeability than the quartzite, then the andesite may act as an impermeable barrier interrupting the lateral flow of deeply circulating water and directing the water upward towards the surface along the permeable zone associated with the fault between the andesite and quartzite.

- EXPLANATION**
- Spring associated lakes
 - Aeromagnetic contours (100 gamma interval)
Zero value : 54,600 gammas
 - Inferred fault
 - Water well
 - Gradient hole

0 5000 Feet
0 1000 Meters

Observed Aeromagnetic Map of the Crystal Hot Springs Area ,
Salt Lake County, Utah

FIGURE 1
OBSERVED AEROMAGNETIC MAP OF THE CRYSTAL
HOT SPRINGS AREA, SALT LAKE COUNTY.UTAH

3.2 GRAVITY SURVEY

Gravity surveys in the vicinity of the Utah State Prison were conducted during the Fall and early Winter by Applied Geophysics, Inc. Area-wide coverage was obtained by using profiles that began on the Traverse Range to the south and ended on the valley floor to the north of the prison facility. Most of these profiles were straight lines oriented perpendicularly to the range fronts of the Eastern Traverse and Wasatch Ranges. Profiles were spaced approximately one-half mile apart and stations were spaced at approximately 1000 foot intervals along the profiles. This area-wide survey defined the major features of the gravity surface, providing a regional setting into which the more detailed gravity grid could be placed.

The gravity grid was centered on the prison and adjacent thermal springs, and was designed to provide a detailed gravity surface for the area most likely to be targeted for drilling by the Utah State Prison Field Demonstration Project. The grid consisted of 290 stations spaced 350 feet apart, and covered an area 8,500 feet long by 5,300 feet wide (approximately 1.5 mi²). The long axis of the grid strikes northeast, paralleling the strike of the Eastern Traverse Range.

The gravity data gathered added much detail to a previously available gravity map by Cook and Berg (1961) and provided detailed structural and geologic information of the subsurface conditions beneath Crystal Hot Springs and the Utah State Prison.

The detailed gravity survey revealed a complex faulted bedrock surface buried beneath the unconsolidated materials that are present at the surface. Normal range-front faults strike east-west through the area breaking the bedrock into blocks. From south to north the depth to the top of the blocks generally increases. In addition, these fault blocks are internally faulted by north-northeast striking faults resulting in structural and topographic complexity of the bedrock in the vicinity of the thermal springs. Immediately beneath the springs the bedrock is fractured quartzite that approaches to within 80 feet of the surface. To the west, north and east of the springs, bedrock is encountered at depths on the order of 500 to 700 feet. North of the springs, in the vicinity of the State Prison farm, the fractured quartzite is present at approximately 250 to 300 feet in depth.

Figure 2 is a representation of the structural conditions present beneath the thermal springs and the Utah State Prison as interpreted from gravity and drill hole data. Both the springs and the prison complex are located between two range front faults that roughly parallel the strike of the Eastern Traverse Range. A third range front fault is known from drill hole data to exist between the ASARCO and Lee holes. The dip of all three of these faults is believed to be north and northwest, however, the gravity data yields no direct measurement of fault dip. The structure between the two range front faults is complex, consisting of a number of tilted blocks that are faulted to various depths. For ease of discussion, these blocks have been lettered in Figure 2.

FIGURE 2

FAULTS IN THE VICINITY OF THE UTAH STATE PRISON AS INTERPRETED FROM THE RESIDUAL GRAVITY ANOMALY.

Block A is bound on north and south by the range front faults described above, and bound on the east by the northwest striking fault just east of the Utah Roses production hole. The surface of the block appears to be tilted westward. Bedrock is present at a depth of approximately 80-90 feet in gradient hole E and in Utah Roses - 1, and although no drill holes encounter bedrock to the west, the relatively uniform slope of the residual gravity surface can be interpreted as a sloping bedrock surface.

Block B is a relatively small, triangular shaped block adjacent to block A. Block B appears to be displaced downward approximately 200 feet relative to block A and the surface may dip south or southwestward. This block is bound on the east by a north-northeast striking fault that has a displacement of approximately 700 feet. This fault appears to strike parallel or sub-parallel to the strike of the eastern pond.

Block C is bound on the west by two faults. The first is the fault on the eastern edge of block B. The second fault is the southward extension of the fault bounding the western edge of block B. This northwest striking fault is one of the most prominent features on the residual gravity surface and is represented by a very steep gravity gradient. The Paleologic bedrock surface is displaced at least 500 feet in the vicinity of the steep gravity gradient. It is important to note that the thermal data (Figure 3) reported by Murphy and Gwynn (1979) suggests the presence of elevated temperatures in blocks A and B. It should also be noted, however, that this data does not exclude the possibility that thermal water might be present within the remaining blocks at depths beyond those penetrated by the drill holes shown in Figure 3.

Block D has not been modeled, but appears to be a southeast tilted block that rises to within about 500 feet of the surface.

3.3 TEST HOLE SITE SELECTION

The geophysical investigations together with available drill hole data provided a reasonably detailed description of the subsurface structural conditions in the vicinity of Crystal Hot Springs. On the basis of this description a zone was defined in which test holes would be drilled into the geothermal reservoir. This zone was identified as the area under Block B located beneath Utah State Prison property. The zone was chosen for the following reasons:

1. the block consisted of the quartzite thought to be a reservoir rock and known to be present beneath the thermal springs.
2. the top of the block was present at a depth of less than 300 feet and was accessible to shallow drilling.
3. the block was adjacent to an area known to contain thermal water.
4. the property in question was owned by the State of Utah.

FIGURE 3

TEMPERATURES IN °C AT A DEPTH OF 61m (200 feet)
AND LOCATIONS OF GEOLOGIC CROSS-SECTIONS AT
CRYSTAL HOT SPRINGS, SALT LAKE COUNTY, UTAH

It should be noted that additional potential targets at some distance from the known thermal springs and at greater depth were identified. These sites lie south of the northern range-front fault in the vicinity of the eastern gravity high, beneath the prison's maximum security facilities. (Figure 1 Appendix 1).

The actual locations of the test holes were primarily chosen on the basis of practical considerations. SF-1 an existing hole, could be deepened into the quartzite at minimum cost. USP/TH-1, the new hole, would test the eastern edge of the target, but would be sited to avoid power lines and proposed roadways.

4.0 TEST HOLE DRILLING PROGRAM

The geophysical reconnaissance program provided the structural details needed to focus the exploration program on the most promising production targets available to the State Prison. The objective of the subsequent test hole drilling program was to establish the presence of significant quantities of thermal water and to provide holes that could be used for preliminary reservoir testing. These objectives were markedly different from the simple gradient hole drilling program envisioned in the original proposal, and represented an evolution of project scope that was influenced by: 1) the findings of the geophysical reconnaissance program, and 2) changes in the disposition of the land status in the vicinity of the springs adjacent to the Prison.

UGMS began a search for a drilling contractor to carry out the test hole drilling program during September of 1980. Billings Drilling Company of Salt Lake City, Utah was eventually selected, and a contract was signed in September 1980. The equipment used for drilling was a 1978 Chicago Pneumatic RT-1800 equipped with a 30 foot mast and a compressor rated for 825 CFM at 250 PSI. Equipped in this fashion the drill rig was rated to 18000 feet with 4½ inch drill steel. The contractor also supplied a water truck and back hoe. The driller, Paul B. Billings, had considerable experience in drilling private and municipal water wells, as well as mineral exploration holes.

4.1 DEEPENING SF-1

SF-1 was drilled in April 1978 for the State Division of Forestry by Burt Drilling, Inc. The eight-inch hole was drilled with bentonite mud through the unconsolidated materials and continued into the quartzite for a distance of 10 feet. A six inch slotted casing was installed over the bottom 110 feet and then grouted from the surface. After several hours of development, the hole flowed artesian at 12 to 14 gpm. A 4 inch diameter gate valve was attached to the casing to control the artesian flow. A subsequent pump test of SF-1 revealed that only 25 to 30 gpm could be pumped from the hole (Smith 1978). The hole remained unused until the deepening operation began in October 1980.

In order to deepen SF-1 the 4 inch diameter gate valve was replaced with a six-inch diameter gate valve and the T assembly shown in Figure 4. Drilling was accomplished through the valve, and the T assembly diverted the drilling returns away from the well head. The well head modification work was completed by the drilling contractor on October 3.

Drilling began at approximately 3:00 p.m., October 8. The driller was able to occupy the hole to a depth of 279 feet, at which point he began drilling with a mill tooth bit. Water was selected as a drilling fluid to minimize potential impairment of the fractured production zone by conventional mud based drilling fluids. The mill bit wore quickly necessitating a change of bit and termination of drilling activities for the day after only reaching 290 feet at 6:30 p.m.

FIGURE 4
WELLHEAD T ASSEMBLY WELL SF-1

Drilling resumed at 7:45 a.m. the following day, October 9. Initial drilling rates were relatively slow, averaging approximately 0.5 ft/min to a depth of approximately 380 feet. From 380 feet to 450 feet rates increased rapidly from 1 to 2 ft/min. At depths greater than 450 feet drilling rates were consistently greater than 2 ft/min and occasionally exceeded 3 ft/min. These penetration rates are averages of the time required to drill 5, 10, or 15 foot intervals. Drilling was accomplished by applying draw down pressure on the drill string. The draw down applied remained constant below approximately 350 feet. The targeted total depth of 500 feet was reached by 1:00 p.m. on October 9, 1981.

4.2 DRILLING USP/TH-1

Drilling at the USP/TH-1 site began on the morning of October 13. A 14 inch hole was drilled to a depth of 40 feet, and a 12 inch casing was installed. The casing was grouted into place by the following method: 1) 1½ yards of grout were dumped directly into the casing; 2) water was used to fill the remainder of the casing volume; 3) an inflatable packer attached to the drill steel was installed at the top of the casing; and 4) water was forced into the casing until grout was returned to the surface around the outside of the casing. The grout was left to cure for 39 hours.

At 7:30 a.m. on October 15, the driller penetrated approximately 3 feet of grout as drilling continued.

A 10 inch diameter hole was drilled from the bottom of the 12 inch casing to the top of the bedrock surface. Water was used as a drilling fluid until the hole began to cave and the cuttings could not be cleaned from the hole. This problem began to occur at a depth of approximately 95 feet. After reaching 120 feet, the driller chose to use an inorganic polymer to increase the viscosity of the drilling fluid. Circulation of this fluid quickly cleaned the hole and drilling proceeded without major difficulty. The bedrock surface was intersected at a depth of 268 feet and drilling continued to 278 feet. An eight inch schedule 40, standard wall casing was installed from the surface to a total depth of 272 feet. The casing was grouted using techniques similar to those described above. Grout was implaced on the morning of October 20 and was allowed to cure for approximately 44 hours. Only three feet of grout remained to be drilled out on the morning of October 22. After grouting, an eight inch diameter gate valve was installed on the eight inch casing, and a T assembly was fastened to the valve (Figure 5).

With the well-head assembly in place and approximately 90 feet of drill collars behind the bit, drilling continued to a total depth of 1000 feet. Water was used as a drilling fluid. While evidence of fluid loss was noticed in drilling the upper portions of USP/TH-1, major losses did not occur until a depth of approximately 625 feet. Large water losses continued to total depth.

Drilling fluid was lost while drilling through the most permeable zones in the reservoir. At the conclusion of drilling the geothermal fluid began to warm and decreased in density. After approximately 4 days the cool fluid had warmed sufficiently enough so that the hole began to flow at rates of 600 to 1,000 gpm. The liner could not be installed while the well

FIGURE 5
WELLHEAD ASSEMBLY WELL USP/TH-1

flowed at these rates, so the flow was controlled with cold water. A reducer was fabricated to allow a fire hose line to be coupled to the eight inch flange on the horizontal leg of the T assembly. The vertical leg of the hole was blocked with a blind flange. After preparing the well head in this manner, the gate valve was opened and cold water from a nearby fire hydrant was forced into the hole. The flow of cold water was controlled by a two-inch valve installed between the fire hose and the reducer. After flowing cold water into the hole for approximately 2 to 3 hours, the hole was chilled. The blind flange on the vertical leg of the hole could be removed and the liner installed. As installation of the liner proceeded, additional cold water was allowed to flow by gravity into the hole. The method of well control described above worked well because the wellhead pressures were on the order of only 5 to 10 psi.

The hole was completed with a six inch diameter slotted liner (Figure 6). As this liner was being installed, a tool failed, allowing 245 feet of the liner to drop into the hole. Two days of fishing were required to retrieve the liner. However, all indications suggested that the string was intact. After retrieving the dropped liner the driller resumed welding the remaining liner to the liner already installed in the hole. The completed liner string was lowered into place with the drill steel by using a K-packer.

4.3 RESULTS AND INTERPRETATION OF TEST HOLE DRILLING

State Forestry - 1

Drilled in April of 1978, SF-1 penetrated the overlying unconsolidated materials and continued only 10 feet into the quartzite. The upper 85 feet of the hole primarily consists of Bonneville Lake clay. From depths of 65 to 85 feet this clay contains quantities of sand. From approximately 85 feet to 261 the material changes markedly to sand and gravel derived from quartzite and andesite source rocks. Those sand and gravel units also contain appreciable quantities of silt, clay and very fine sand. The quartzite encountered at the bottom of the hole was dark gray in color and was interpreted to be fractured from the uneven, jerky manner in which the material was drilled.

Drilling of SF-1 was originally terminated at a depth of 280 feet. At the time this hole was drilled the model of the resource consisted of selected fracture zones in the relatively impermeable quartzite leaking thermal water into the overlying unconsolidated sediments. The sediments, not the quartzite, were thought to be the better target because of the limited area in which drilling might encounter the appropriate fractures. It was not until SF-1 was tested and the transmissivities (T) of the sediments were found to be exceptionally low ($T=18.7$ to 34.4 ft.²/day), that this model was discarded, and the quartzite was thought of as a possible reservoir. The successful completion of Utah Roses production well in the quartzite proved that the large quantities of thermal water could be pulled from the quartzite, and suggested the possibility that the Prison's best target might be the quartzite beneath the unconsolidated materials. Thus, deepening SF-1 was seen as a relatively inexpensive method of determining whether or not the quartzite beneath State-owned land would yield thermal water.

FIGURE 6

COMPLETION SCHEMATIC - WELL USP/TH-1

The cuttings retrieved during the deepening of SF-1 contained few surprises. The material being penetrated was predominantly dark to light gray, fine grained quartzite. Occasionally small quantities of stiff clay-like materials were found mixed with the quartzite. These materials were predominantly white or green in color or noncalcareous and although the materials have not been positively identified, they are believed to be alteration products of impurities within the quartzite. At a depth of approximately 410 feet a black substance was noticed floating on the surface of the mud pit. Shortly thereafter the cuttings became darker in color, and changed significantly in composition suggesting the quartzite cuttings were mixed with varying percentages of carbonaceous shale.

During the drilling of SF-1 the hole appeared to be very stable. Cuttings were rapidly cleaned from the hole, and after adding new drill steel only small quantities of fill were ever found in the bottom of the hole. This apparent stability was misleading. Two hours after completion a temperature log (Figure 7) was run to total depth. The following day, the temperature logging tool could not be lowered past approximately 460 feet. Several days later the probe stopped at 440 feet. Approximately 60 feet of hole had apparently been lost due to slumping of the hole walls.

The log in Figure 7 graphically illustrates the cooling effect of the drilling fluid lost during the drilling operation. The temperature log indirectly provides data as to location of the potential production zone. The most noticeable feature of the profile in Figure 7 is the sharp temperature decrease that occurs at a depth of 330 feet. This depth corresponds well with the first report by the driller of major drilling fluid losses at 340 feet and a noticeable increase in the drilling rate. Also of interest is the fact that the temperature reversal does not occur at the bedrock surface, but occurs approximately 70 feet into the quartzite. This occurrence suggests the possibility that the upper portion of the quartzite is relatively impermeable.

USP/TH-1

The lithologies encountered during the drilling of USP/TH-1 (Figure 8) were very similar to those encountered in SF-1. However, because USP/TH-1 was drilled using only water and inorganic polymers, the samples of the unconsolidated materials were much cleaner than those from SF-1. The cleaner samples allowed for more positive identification of returns, resulting in an improved understanding of subsurface materials. A 10 foot thickness of green and pink colored clay on top of the quartzite surface was not seen in SF-1 but was observed in USP/TH-1.

The quartzite in USP/TH-1 was very similar to that in SF-1. Cuttings were commonly very light gray to medium gray in color, and varied in size from 1/16 to 1/2 inches in diameter. The white clay-like substance described above was generally less than 5% of the total sample. When the bailer used to locate the liner was dropped into USP/TH-1, a number of relatively large fragments of the quartzite were retrieved. Although there is no way of determining from what depths the samples were derived, the samples have proved useful. Inspection of the samples revealed that the degree of metamorphism varies within the section penetrated. Most of the large samples were coarsely crystalline and individual sand grains were no longer identifiable. In the remaining samples individual grains were visible, and in one sample the metamorphism was only slight.

FIGURE 7

TEMPERATURE LOG TAKEN DURING AN ARTESIAN
FLOW TEST OF THE WELL TWO HOURS
FOLLOWING COMPLETION

FIGURE 8
 STATIC TEMPERATURE LOG, USP/TH-1, 6 HOURS
 FOLLOWING COLD WATER INJECTION

The drilling rates in USP/TH-1 on the average were significantly lower than rates in SF-1. Within the unconsolidated materials the drilling rates were inconsistent and varied unlike the quartzite bedrock. In the quartzite there were three distinct segments to the drilling rate curve: 270 to 480; 480 to 615; and 615 to 1000 feet. At a depth of approximately 480 feet, drilling rates began to increase rapidly to maximum rates of approximately 1.5 ft./min., then gradually decreased to rates approaching those in the 270 to 480 segment. Beginning at a depth of approximately 615 feet and continuing to total depth, the rates generally reached a maximum of approximately 2.2 ft./min. but normally ranged from 1.0 to 1.5 ft./min.

The three drilling rate zones described above appear to be related to production zones as defined by the temperature profile (Figure 8) run in USP/TH-1 after installation of the liner and injection of cold water. The temperature profile within the quartzite has three segments that correspond to the breaks in the drilling rate. From 270 to 480 feet temperatures remained relatively high. In this zone the permeability of the quartzite is low and the rock was cooled by conduction only. The temperatures in this zone remained relatively high as temperatures were only decreased for a short distance away from the hole. In the interval between 615 and 1000 feet the thermal profile indicates a significantly greater cooling of the rock which is interpreted as indicating heat loss by both conduction and convection. In this zone water migrated into the permeable rock extracting significantly more heat from the reservoir rock at greater distances from the hole. The zone between 480 and 615 feet was also cooled by convection but to a lesser degree than the deepest zone. The degree of cooling appears to be related to the permeability of the surrounding rock. This interpretation is supported by the drillers report of significant drilling fluid losses beginning at 625 feet.

The results of the test hole drilling program suggest the possibility that a relatively impermeable zone is present at the top of the quartzite. In both SF-1 and USP/TH-1 drilling rates were relatively slow, and permeabilities were limited in the upper portion of quartzite. There are, however, significant differences between the drilling results in each hole. Based on the SF-1 drilling rates and thermal profiles, the impermeable zone appears to extend from the top of the quartzite at 270 feet to approximately 330 feet; a thickness of 60 feet. In USP/TH-1 the same types of data are interpreted as indicating that the impermeable zone extends from 270 feet to 600 feet; a thickness of 330 feet. As discussed above, there is an indication that the quartzite is slightly permeable between 450 and 600 feet in USP/TH-1, but the magnitude for the chilling effect in this zone is interpreted as indicating lower-permeability than the reservoir encountered in SF-1 below 330 feet.

There are two explanations for the upper impermeable zone that appears most appropriate in light of the known facts. In both explanations the quartzite is assumed to have no primary permeability and therefore water can only be transported through fractures within the quartzite. First, the impermeable zone or cap may simply be less fractured than the permeable rock below. Variations in the degree of fracturing have been noted by those who have mapped the Traverse ranges. Second, a uniformly fractured body of rock may be undergoing a process of cementation or self-sealing at

the bedrock sediment interface. The process of self-sealing by deposition of soluble materials such as CaCO_3 and SiO_2 in fractures has been documented at a number of other thermal systems including Roosevelt Hot Springs near Milford, Utah. The water of the Crystal Hot Springs thermal system contains a high percentage of non-condensable gas that is primarily CO_2 . The loss of CO_2 from solution in response to decreases in pressure decreases the solubility CaCO_3 within the fractures of the quartzite. This would decrease the fracture permeability of the rock body, thereby inhibiting the movement of water.

Although the self-sealing hypothesis is a viable explanation of the impermeable zone, the following observations should be noted. First, deposition of calcium carbonate within the fractures would tend to decrease the permeability of the quartzite but would not necessarily imply that the quartzite would be more difficult to penetrate. Second, significant quantities of calcium carbonate have not been observed in the cuttings from the impermeable zone. Third, the large difference in the apparent thickness of this zone is not easily explained in terms of the self-sealing hypothesis.

5.0 RESOURCE MONITORING AND RESERVOIR TESTING PROGRAM

5.1 RESOURCE MONITORING PROGRAM

As a part of the resource assessment portion of the Utah State Prison Geothermal Project, a program for periodic monitoring of the Crystal Hot Springs resource was formulated. The program was designed to enable determination of baseline thermal, hydraulic, and chemical characteristics in the vicinity of Crystal Hot Springs prior to production and also to provide a history of these characteristics during resource development. A program such as this was necessary to aid in evolving a strategy for effectively utilizing the resource.

Resource monitoring conducted to date has consisted of periodically making thermal and hydraulic measurements and analyzing the water chemistry of the wells and springs in the area. Presented in Figure 9 is a map of the current configuration of the Crystal Hot Springs region. The locations of water wells, temperature gradient holes, and surface waters (formed from spring discharges) included within the monitoring program are shown on the map.

The monitoring program as originally formulated is presented in the following section of the report. Modifications to the originally outlined program, dictated by project budget constraints, are described in the discussion of Results to Date and the Monitoring Program.

Thermal Monitoring

Temperature measurements were made in the following wells:

- Gradient Holes B, C, D, E, and F
- State Forestry Well SF-1
- Test Well USP/TH-1
- ASARCO
- Lee

Temperatures were measured from the surface to total depth at 10 foot intervals using a downhole temperature measurement probe. Wells SF-1 and USP/TH-1 flow artesian. Static and flowing temperature logs of these wells were obtained. Well temperature measurements were made at four month intervals.

In addition to the outlined well temperature measurements, the discharge temperature of the eastern springs (CR-1, CR-2, and CR-3) were measured monthly.

In the originally outlined program, a temperature survey of the western pond (and associated submerged springs) was to have been made on a yearly basis. The discharge temperature of four shallow culinary water supply wells were also to have been measured at one year intervals. These measurements were eliminated from the program to decrease program costs.

FIGURE 9

Hydraulic Monitoring

Hydraulic measurements were made on a monthly basis in the following:

Gradient Holes A, B, D, E, and F
State Forestry Well SF-1
Test Well USP/TH-1
ASARCO
Lee

Gradient Hole A, State Forestry Well SF-1, and Test Well UPS/TH-1 flow artesian. Wellhead pressures in these wells were measured with a pressure gauge or manometer of appropriate range following shut-in for a period of time sufficient to ensure that equilibrium conditions exist. The remaining gradient holes and wells have static water levels which are below the surface of the ground. Water levels in these wells were measured with an electrical conductivity probe.

The discharge rates from the eastern springs were measured monthly. Two of the eastern cumulative discharges (SR-2 and SR3) were measured using Parshal Metering Flumes. It was not possible to install a metering flume to measure discharge of CR-1 due to the physical configuration of the spring discharge.

Items originally outlined for monitoring but later dropped from the program include measurement of static water levels in domestic wells Lear, Peterson, Fitzgerald, and Prison on a semi-yearly basis and measurement of the discharge from the western pond on a monthly basis.

Chemical Monitoring

The entire chemical portion of the monitoring program was deleted shortly after the first series of field samples had been obtained and field measurements had been made. The program as originally outlined was as follows:

Samples for chemical analysis were to have been obtained on a periodic basis from the following:

Thermal Wells

State Forestry Well SF-1
Test Well USP/TH-1
Gradient Hole A

Water Wells

Prison
Peterson
Lear
Fitzgerald
ASARCO
LEE

Springs and Ponds

Eastern Springs (CR-1, CR-2 and CR-3)
Western Pond (CR-4)

The thermal wells were to have been sampled every six months. Water wells, springs, and ponds were to have been sampled on a yearly basis.

Samples from the artesian thermal wells were to be obtained at the wellheads from the discharge flows. Prior to sampling, the wells were to be produced for a period of time sufficient to provide equilibrium temperatures at the wellhead. Samples from domestic wells having static water levels below the surface (Peterson, Lear, and Fitzgerald) were to be obtained at the points of discharge from the well pumps. Currently unused water wells having static water levels below the surface (ASARCO and Lee) were to have been sampled via use of a submersible point sampler.

The flow from the eastern series of springs currently discharges into three drainage ditches. Samples were to be obtained from those ditches as close to the point of spring discharge as possible. The springs associated with the western pond were to be sampled via use of a submersible point sampler.

Results of the thermal monitoring program to date are summarized in Figures 10 to 13 and in Table II. Results from hydraulic monitoring are presented in Figures 14 to 17. The results of chemical monitoring are outlined in Tables III - V.

Findings and Summary of Resource Monitoring Program

Thermal monitoring of the gradient holes in the vicinity of Crystal Hot Springs conducted to date has yielded results very similar to those of an earlier investigation by the Utah Geological Survey (Reference 2).

TABLE II
TEMPERATURE DATA (OF) - HOT SPRINGS DISCHARGE

Spring No.	Monitoring Date				
	10/1/80	10/21/80	10/24/80	10/28/80	2/20/81
CR-1	135	136	131	--	192
CR-2	113	97	93	97	91
CR-3	85	75	68	64	50

Briefly summarizing these results, temperatures in excess of 160 degrees F were present in portions of radiant Holes C, D, and E (indicating that these holes penetrate the producing formation). Water wells ASARCO and Lee

FIGURE 10

STATIC TEMPERATURE PROFILE FOR
WELL USP/TH-1 (DEC. 1980)

FIGURE 11

FLOWING WELL TEMPERATURE PROFILE
FOR WELL USP/TH-1 (FEB. 1981)

FIGURE 12
STATIC TEMPERATURE PROFILE
FOR WELL SF-1 (DEC. 1980)

FIGURE 13

TEMPERATURE PROFILES FOR GRADIENT HOLES
AND CULINARY WELLS (NOV.-DEC. 1980)

and Gradient Holes B and F exhibit anomalous thermal characteristics (gradients on the order of 180 degrees F per 1,000 feet) suggesting that these wells are influenced by, but are not completed, within the producing formation. The consistency of the results obtained during the current project and during the previous investigation indicate that the development activities that have occurred to date have not caused a change in the thermal characteristics of the resource.

Monitoring of the test wells drilling during the project indicate that the producing formation in the vicinity of the prison is essentially isothermal from a depth of 300 feet to 700 feet at 175 degrees F. A temperature inversion was observed in Well USP/TH-1 below a depth of 700 feet. At this time it has not been determined whether or not the observed temperature profile in USP/TH-1 is indicative of resource characteristics. The inversion could be a resource thermal transient caused by a cold water quenching operation conducted during drilling. The increase in bottom hole temperature versus time in the well (December, 1980 data in Figure 10 and February, 1982 data in Figure 11) indicate that the information at depth has not reached thermal equilibrium following the quenching operation.

Results of hydraulic monitoring activities for gradient Holes B and F and water wells Lee and ASARCO, indicate these wells that were not completed within the producing formation, do not appear to have been influenced by production activities conducted to date at the Crystal Hot Springs. Although completed within the quartzite formation, Gradient Hole E was found to have highly variant water levels with no discernible trends over the monitoring period. The behavior of Gradient Hole E is perhaps indicative that the well is not in good hydraulic connection with the quartzite formation.

Utah Roses' production appears to have had a noticeable effect upon resource hydraulic characteristics. The significant drop in wellhead pressures of Wells SF-1 and USP/TH-1 (Figure 17), static water level in Gradient Hole D (Figure 14), and flow rate from Springs CR-2 and CR-3 (Figure 16) during October of 1980 coincide with the initiation of Utah Roses' production.

The chemical quality of the geothermal water of Crystal Hot Springs is excellent by comparison to other low temperature geothermal waters along the Wasatch Front. The total dissolved solids content has been used to rank the general water quality of Wasatch Front springs as presented in Table III.

MONITORING PROGRAM - GRADIENT HOLE WATER LEVELS VS. TIME

FIGURE 14

FIGURE 15

STATIC WATER LEVELS IN WELLS LEE AND ASARCO

THERMAL SPRINGS CR-2 AND CR-3 FLOW RATES

FIGURE 16

FIGURE 17

STATIC WELLHEAD PRESSURES IN WELLS SF-1 AND USP/TH-1

TABLE III
WASATCH FRONT THERMAL SPRINGS

Spring	Approximate TDS (mg/l)*	Maximum Reported Temperature
Crystal	1,500	187°F
Saratoga	1,500	111°F
Udy	7,900	121°F
Wasatch	8,600	103°F
Beck	13,700	132°F
Utah	29,200	144°F
Crystal (Madsen)	42,900	135°F

*From Mundorff (1970)

The factors contributing to the anomalously good quality of the thermal waters at Crystal Hot Springs are not fully understood, however, a number of factors could possibly contribute to the observed water chemistry. First, the water recharging the system is know melt and low in total dissolved solids. Second, the water may move rapidly through the system thereby decreasing the time available for the dissolution of soluble components along the flow path. Third, the material through which the water flows is not readily soluble. Fourth, the thermal water has not been contaminated with nonthermal brines.

The preliminary chemical monitoring conducted early within the program was not sufficient to yield any significant conclusions regarding the chemical characteristics of the Crystal Hot Springs Resource. (Table IV) However, the State Department of Health took samples of water from USP/TH-1 and performed a water qualify analysis on the geothermal fluid. CH2M Hill under subcontract to the Utah Energy Office subsequently compiled additional chemical data for the resource under Task 4 Investigation of disposal alternatives.

An analysis of the geothermal water from USP/TH-1 is presented in Table V. To help illustrate the high quality of the geothermal water, a comparison to drinking water standards is included. The parameters were determined by the State Health Department laboratory on a sample taken in February, 1981.

A gas sample from USP/TH-1 was not analyzed, but the noncondensable gas is believed to be mostly CO₂. Noncondensable gas concentrations at wellhead conditions comprise from 0.08 to 0.22 percent by weight of the geothermal fluid. A complete noncondensable gas analysis is available for the primary production well supplying Utah Roses' greenhouse complex with hot water. Data is also available for this well. This data summarized in Table VI. Based on this data, it can be concluded that noncondensable gas emissions at Crystal Hot Springs will not represent a problem.

TABLE IV
CHEMICAL MONITORING DATA

Date	Location	pH	Conductivity MMHO/cm	Sampling Temp. (°C)	TDS
10/1/80	Gradient Hole A	5.75	--	45	--
10/24/80	Gradient Hole A	5.49	2.6×10^3	32	--
10/24/80	Spring CR-1	5.79	3.4×10^3	55	--
10/24/80	Spring CR-2	6.44	2.9×10^3	34	--
10/24/80	Spring CR-3	6.75	2.6×10^3	20	--
10/28/80	Well SF-1	6.5	4.3×10^3	77	--
11/6/80	Spring CR-4	7.03	2.5×10^3	25	2009
11/6/80	Western Pond	6.77	2.3×10^3	23	1336

TABLE V
WATER ANALYSIS
UTAH STATE PRISON GEOTHERMAL WELL (USP/TH-1)

	Units	Geothermal Well ^a	Comparison to Drinking Water Standards	
			Primary Drinking Water Standards Maximum Levels ^b	Secondary Drinking Water Standards Recommended Limits ^b
Temperature	°F	179	2,000 ^c	
TDS	ppm	1,754.		
Sp. cond.	umhos/cm	3,130.		
pH		7.0		6.5 - 8.5
NO ₂ + NO ₃ as N	mg/l	0.07		
T.K.N. ^d	mg/l	0.07		
T.O.C. ^e	mg/l	1.0		
C.O.D.	mg/l	15.		
Phenolic	mg/l	0.003		
-----CATIONS-----				
Ammonia as N(ionized)	mg/l	0.7		
Boron	ug/l	1,555.0		
Calcium	mg/l	154.		
Chromium, Hex.as Cr	ug/l	5.0		
Magnesium	mg/l	30.		
Potassium	mg/l	78.		
Sodium	mg/l	495.0		
(Total Cations 757)				
-----ANIONS-----				
Bicarbonate	mg/l	416.		
Carbon Dioxide	mg/l	67.		
Carbonate	mg/l	0.		
Chloride	mg/l	750.		250
CO ₃ Solids	mg/l	205.		
Fluoride	mg/l	2.05	1.6 - 2.0 ^f	
Hydroxide	mg/l	0.00		
Nitrate as N	mg/l	0.07	10.	
Nitrate as N	mg/l	0.05		
Phosphorus,Ortho as P	mg/l	0.02		
Silica, Dissolved				
as SiO ₂	mg/l	40.		
Sulfate	mg/l	71.	500	
(Total Anions 1,066)				
(Grand Total 1,823)				

TABLE V -- CONTINUED

Comparison to Drinking Water Standards				
			Primary Drinking Water Standards Maximum Levels ^b	Secondary Drinking Water Standards Recommended Limits ^b
	Units	Geothermal Well ^a		
-----TOTAL METALS ANALYSIS-----				
Arsenic	ug/l	200.0	50.	
Barium	mg/l	0.41	1.	
Cadmium	ug/l	1.	10.	
Chromium	ug/l	5.	50.	
Copper	ug/l	10.		1,000
Iron	mg/l	0.63		0.3
Lead	ug/l	7.	50.	
Manganese	ug/l	560.		50
Mercury	ug/l	0.1	2.	
Nickel	ug/l	10.		
Selenium	ug/l	1.	10.	
Silver	ug/l	2.	50.	5,000
Zinc	ug/l	5.		
-----OTHER-----				
Total Phosphorus	mg/l	0.05		
Total Alk.as CaCO ₃	mg/l	341.		
Total Hdns.as CaCO ₃	mg/l	508.0		
Turbidity,as NTU		8.5	5.0	
-----RADIOLOGICS-----				
Alpha, gross	pCi/l	183	15 (combined)	
226 Radium	pCi/l	20		

^aUtah State Department of Health Environmental Health Laboratory, February 27, 1981. Analysis covers only those constituents normally tested for by the Department.

^bUtah Safe Drinking Water Committee.

^cIf TDS is greater than 1,000 mg/l, the supplier shall show to the Committee that no better water is available.

^dTotal Kjeldahl Nitrogen.

^eTotal Organic Carbon.

^fDepends on ambient air temperature.

^gBecause of the level of TDS, the accuracy of the radiologics may have been affected.

NOTE: denotes constituent level was below detectable limit of the approved method.

5.2 WELL USP/TH-1 TESTING PROGRAM

A program for testing of Well USP/TH-1 was conducted to provide information required to aid in siting and design of the production well to be drilled during the project and to provide information required for preliminary system design activities. The specific goals of the testing program were as follows:

1. To determine the point within the wellbore at which noncondensable gases dissolved within the production fluid begin to evolve as free gas.
2. To determine the flow/pressure drawdown characteristics of the well and the production fluid temperature versus time.
3. To quantitatively determine the effect of production of USP/TH-1 upon other features and wells of the Crystal Hot Springs Resource.
4. To obtain data required to estimate reservoir parameters, production potential, and production lifetime.

Noncondensable Gases

Well USP/TH-1 was flowed at a rate of approximately 7 gmp into a 55 gallon separator. The separator was operated in a steady-state mode such that water inlet and outlet flows, separator level, and the noncondensable gas outlet flow rate remained constant. The separator was operated at essentially atmospheric pressure.

The water flow rate from the separator was determined by measuring the time required to fill a calibrated volume. Noncondensable gas flow rates were measured via two techniques--using a rotameter and by filling a tank of known volume. Water and gas discharge temperatures were measured with a mercury thermometer. The apparatus used in testing is schematically depicted in Figure 18.

Using the data obtained via the outlined procedures, the noncondensable gas flashpoint within the wellbore was calculated based upon pressure/solubility relationships.

A third method was also used to determine the noncondensable gas flashpoint. During artesian flow testing, a downhole pressure gauge was suspended within the well by a wireline. During retraction of the wireline from the well at the conclusion of testing, definite calcium carbonate scale deposition horizons, indicative of the noncondensable gas flashpoint, were observed and recorded.

METHOD 2 CALIBRATED COLLECTION TANK

FIGURE 18

APPARATUS FOR MEASURING NON-CONDENSIBLE GAS CONTENT

TABLE VI
Noncondensable Gas Data for the Utah Roses
Production Well - Crystal Hot Springs
December 31, 1979

<u>Noncondensable Gases</u>	<u>Percent by Volume</u>
Hydrogen Sulfide As H ₂ S	4.14
Carbon Monoxide as CO	6.86
Total Hydrocarbon as CH ₄	-
Ammonia as NH ₃	0.35
Nitrogen Dioxide	26.79
Carbon Dioxide as CO ₂	51.09
Sulfur Dioxide as SO ₂	6.62
Nitrous Oxide as NO _x	4.14

Artesian Flow Testing

The production characteristics of well USP/TH-1 were determined from a controlled artesian flow test. Testing was conducted over a 72 hour period. For the first 15 hours of testing, the well was flowed at an essentially constant rate of 575 gpm. For the next 33 hours of testing, the well was flowed at a rate of 400 gpm. After 48 hours, the well was shut-in and allowed to recover. Pressure drawdown (during the first 48 hours) and pressure recovery (following shut-in) were monitored regularly during the test. The temperature of the flow from the well was also measured frequently.

In addition to monitoring well USP/TH-1, periodic measurements were made at other wells and springs associated with the Crystal Hot Springs resource. Measurement locations are shown in Figure 19. Pressures (or static water elevations) were monitored in well SF-1 and in Gradient Holes B, D, E, and F. Flow rates from springs CR-2 and CR-3 were also measured. Utah Roses' production rate during the test was also measured.

The configuration of the wellhead apparatus is depicted in Figure 20. Within the vertical run of the well was an 8 inch gate valve. A standard 8 inch tee was situated directly above the valve. An 8 inch diameter by 4 foot long discharge pipe was attached to the branch leg of the tee. Following the 8 inch pipe was a 14 foot section of 6 inch pipe containing a flow measurement device. A six inch gate valve was positioned at the end of the discharge line for flow control.

Access to the well for the downhole pressure probe and cable was provided by a standpipe situated on the run leg of the wellhead tee. A packing was located at the top of the standpipe for sealing of the cable.

During the test formation pressures were measured using a Lynes RES-300 downhole reservoir evaluation system. This system consists of a digital surface recorder, a single conductor cable, and a downhole probe. Downhole pressure measurements were necessitated due to the effect of noncondensable gases upon wellhead pressure measurements. This system was also used to measure downhole temperatures during the test.

To provide redundancy information for pressure measurement, additional pressure data was obtained at the wellhead. A dial pressure gauge and manometers (mercury and water) were plumbed to a sampling port on the 8 inch diameter discharge pipe for this purpose.

Well flow rates were measured by two independent methods. A Dieterich Standard Type 73 Annubar (differential pressure flow sensor) installed in the 6 inch diameter discharge pipe provided one means of flow measurement. Differential pressures generated by this sensor were measured with an air over water U-tube manometer. A standard 9 inch Parshall Flume installed in the discharge channel downstream of the wellhead assembly provided a second means of measuring the well discharge flow.

Wellhead temperatures were measured with a Type K thermocouple which was connected to a digital readout instrument.

ARTESIAN FLOW TESTING MONITORING STATIONS

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FIGURE 19

FIGURE 20

Pressure drawdown and recovery in well SF-1 was measured with a dial pressure guage and a mercury manometer. Static water levels in Gradient Holes B, D, E, and F were measured using a conductivity-type depth sensor.

Three inch Parshall Measuring Flumes were previously installed to measure the discharge from Springs CR-2 and CR-3 as a part of the monitoring program. These flumes were used to measure the flow rate of these springs during the test. A 6 inch Parshall Measuring Flume installed within a drainage ditch was used to measure Utah Roses' production rate.

5.3 RESERVOIR TEST RESULTS AND CONCLUSIONS

Noncondensable Gases

Using the previously outlined separation technique, noncondensable gas concentrations at wellhead conditions were found to range from 0.08 to 0.22 weight percent. The noncondensable gas was assumed to be primarily carbon dioxide because no odor of hydrogen sulfide was detected during the well test. Using solubility relationships and the above gas concentrations, noncondensable gas flashpoints in the wellbore were calculated to range from 140 feet to 270 feet from the wellhead under hydrostatic wellbore conditions.

In the above results, the lower figures (0.08 weight percent noncondensable gas with corresponding 140 feet flashpoint) were obtained using a volumetric displacement technique. This technique is probably the more reliable of the two methods used in the testing.

Visual inspection of the pressure gauge wireline cable during removal from the well yielded the following:

1. A distinct scale deposit was present on the first 160 feet of cable extracted from the well.
2. The next 60 feet of cable had decreasing amounts of deposition.
3. No deposit was noticeable on the cable beyond the 220 foot mark.

In view of the above results, the noncondensable gas flashpoint within the wellbore should be considered to be at least 220 feet when considering pump setting depth requirements. Details of the noncondensable gas flashpoint analysis are included as Appendix 2.

Artesian Flow Tests

Analysis of surface and downhole drawdown data from well USP/TH-1, downhole recovery data from well USP/TH-1, and drawdown/recovery data from well SF-1 yielded the following values for important well and reservoir parameters:

1. Permeability = 1570 - 4340 millidarcy
2. Porosity/Compressibility Product = 1.59×10^{-5} psi⁻¹
3. Well Skin Factor = -1.51

4. Reservoir Area = $4.5 \times 10^6 \text{ ft}^2$
5. Impermeable Boundary Location = 730 ft. from well
6. Well/Reservoir Shape Factor 0.101

The above parameters indicate a highly permeable reservoir (similar to that of a fine medium sand) of somewhat limited area. The determined area corresponds closely to that predicted via the gravity modeling work (Murphy and Gwynn, 1979). The well/reservoir shape factor as well as the inferred impermeable boundary location indicate that test well USP/TH-1 is completed within the periphery of the reservoir. This proximity of USP/TH-1 to reservoir boundaries was evidenced by the rapid transition from an infinite-acting to a pseudo-steady-state flow regime observed in the drawdown data.

It should be noted that the above parameters were based upon the actual response of the test and monitor wells during the test. Concurrent with the testing program, Utah Roses was producing at a constant rate of 260 gpm from its well located approximately 1,000 feet from well USP/TH-1. This production could have had a significant effect upon the results obtained. Unfortunately, it was not possible to precisely define this effect. An estimate of the order of magnitude of this effect is included in Appendix 3.

To rigorously conduct a multiple well test in a developed reservoir such as that at Crystal Hot Springs, it would be necessary to have a record of the influence of the producing well upon the well to be tested prior to conducting the test. Although proposed earlier in the program, funding limitations and difficulties in reaching an agreement with Utah Roses precluded compilation of this record.

Details of the test data analysis including an analysis of the effect of production of the Utah Roses well upon test results are provided in Appendix 4.

Drawdown Characteristics/Production Potential

Based on the determined reservoir parameters, long term production characteristics of well USP/TH-1 were estimated. Estimates of predicted pressure drawdown versus time for several different flow rates are included as Figure 21. As shown in the figure, long term delivery of the well is somewhat limited due to reservoir boundary effect. For a continuous flow rate of 100 gpm, a drawdown of 275 feet of water is predicted over an 8 month heating season. This amount of drawdown is probably near to the limit which would be tolerable due to the current well configuration and due to pump setting considerations. The well should be capable of sustaining short term flows in excess of 100 gpm to meet peak load requirements, however. Further refinement of these predictions can be made after seasonal system flow requirements are determined during preliminary design activities.

Production temperature at the wellhead averaged 179 degrees F during testing with little variation. It is believed that the well will maintain this temperature during long term production.

FIGURE 21
PREDICTED LONG-TERM PRESSURE DRAWDOWN
CHARACTERISTICS FOR WELL USP/TH-1

Again, it must be emphasized that these predictions are based upon the performance of well USP/TH-1 observed during testing (which was affected by Utah Roses' production). Refinements of these predictions should be made after the effect of Utah Roses' production is better established and after future Utah Roses' flow requirements are defined.

In addition, testing was not conducted for a period of time sufficient to assess the effect of system recharge upon the performance of well USP/TH-1. Any significant recharge effects would cause the pressure draw-down in the well to be less than predicted. A long term (30 days) pumped flow test of USP/TH-1 will be carried.

6.0 DISPOSAL ALTERNATIVES

The combined production of USP/TH-1 and the Utah Roses well during the test significantly affected the springs associated with the resources. The discharge from Spring CR-2 decreased from 49 to 40 gpm during the test. The flow from spring CR-3, initially 10 gpm, completely stopped during the test.

Of the gradient holes monitored, only Hole D appeared to be in good hydraulic connection with the quartzite formation. The static water level in this well decreased by 2.3 feet during the test. Other gradient holes were either unaffected or yielded inconsistent results (the water level in Hole E increased by over 5 feet during the test).

The response of well SF-1 indicated that it was in good hydraulic communication with well USP/TH-1. Drawdowns observed in both wells were very consistent.

The surface expression of the Crystal Hot Springs Resource is characterized by a cumulative discharge of 650 to 1000 gpm of geothermal waters via a series of hot springs. The total natural discharge flows eventually to the Jordan River. Thus, the baseline condition is discharge of up to 1000 gpm of geothermal water, via surface drainage paths, to the Jordan River.

Existence of geothermal resource at Crystal Hot Springs is based on upwelling of deeply circulating meteoritic waters along Wasatch Front faults into a capped, highly fractured metaquartzite. The primary permeability of the metaquartzite is extremely low. However, extensively developed secondary permeability due to fracturing accounts for high measured fluid conductivities which exceed 1 darcy. The quartzite is capped by impermeable lacustrine and glacial deposits which prevent migration of geothermal fluids to the surface except via penetrating faults. The surface expression of the faults are the hot spring discharges referred to previously.

Subsurface disposal of spent geothermal fluids is only practical by using deep injection wells completed within the metaquartzite reservoir formation. Subsurface injection into overlying sediments is not feasible due to low permeabilities. Wells completed in andesite in adjacent areas bounding the northern portion of the geothermal resource also indicate very low permeability.

Technical difficulties with deep injection arise due to the potential for thermal contamination of production fluids by relatively cold injected fluids. Thermal breakthrough is a definite potential problem due to the very high fracture conductivities of the metaquartzite. Injection wells could be completed at much greater depths than production wells in an attempt to prevent thermal breakthrough. However, the cost of such wells would be prohibitively high and no guarantee could be made that a through going fracture would not be intersected.

Observations of surface thermal spring discharge rates during periods of significant production by Utah State and Utah Roses indicates that

spring discharge rates undergo substantial reductions. Thus, it can be argued that surface disposal of geothermal fluid would simply offset the decline in natural hot spring discharge rates due to operation of production wells. The chemical characteristics of hot spring fluids and production well fluids (less than 2000 ppm total dissolved solids) are essentially identical with the exception that production fluids, after passage through heat exchangers, would be somewhat cooler than the natural hot spring discharge.

In November of 1981, the Utah Energy Office was granted a surface disposal permit by the Utah Water Quality Board. This permit will allow for the surface disposal of spent geothermal waters from the Crystal Hot Springs to the Jordan River via a pipeline.

ACKNOWLEDGEMENTS

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APPENDIX 1

Modeling and Interpretation of the Gravity Survey Data

MODELING AND INTERPRETATION OF THE GRAVITY SURVEY DATA

The Crystal Hot Spring geothermal system is located in a structurally complex area in which normal faults extend to depths sufficiently great as to interest temperature on the order of 100 degrees C. Because thermal water is present, the assumption is made that these fault zones must be sufficiently permeable to allow the rapid transport of water to the surface. These same faults vertically displace permeable and impermeable rocks into contact with one another, creating a complex subsurface structural and geological setting in which the thermal water is non-uniformly dispersed. The entire structure is covered by a variable thickness of impermeable sediments that cap the thermal system and effectively mask the subsurface structure from direct observation.

An understanding of the geological and structural setting of the Crystal Hot Springs geothermal system is of primary importance to an orderly development of the resource. Because the subsurface structure was effectively masked from direct observation, the geophysical reconnaissance program included an element for the collection and analysis of aeromagnetic and gravity data.

The following discussion describes the data collection, reduction and modeling of the aeromagnetic and gravity surveys conducted under UEO/DOE Cooperative Agreement No. DE-FC07-79ET2707.

Data Collection

Gravity surveys in the vicinity of the Utah State Prison were conducted during the fall and early winter 1980 by Applied Geophysics, Inc. Area-wide coverage was obtained by using profiles that began on the Traverse Range to the south and ended on the valley floor to the north of the prison facility. Most of these profiles were straight lines oriented perpendicularly to the range fronts of the Eastern Traverse and Wasatch Ranges. Profiles were spaced approximately one-half mile apart and stations were spaced at approximately 1,000 foot intervals along the profiles. This area-wide survey defines the major features of the gravity surface, providing a regional setting in which the more detailed gravity grid can be placed. The gravity grid was centered on the prison and adjacent thermal springs, and was designed to provide a detailed gravity surface for the area most likely to be targeted for drilling by the Utah State Prison Field Demonstration Project. The grid consisted of 290 stations spaced 350 feet apart, and covered an area 8,500 feet long by 5,300 feet wide (approximately 1.5 mi²) as shown on Figure A1-1. The long axis of the grid strikes northeast, paralleling the strike of the Eastern Traverse Range.

The gravity surveys were conducted using standard gravity methods. Elevations were surveyed to the nearest 0.1 foot and the observed gravity values were read with a LaCoste and Romberg Model G gravimeter. Complete Bouguer gravity values were obtained by applying appropriate latitude, elevation and terrain corrections. A density of 2.67 gm/cc was assumed in making both elevation and terrain corrections.

FIGURE A1-1
REGIONAL GRAVITY SURFACE IN THE VICINITY OF THE UTAH
STATE PRISON DRAPER, UTAH
STATION LOCATIONS INDICATED.

Principle facts and complete Bouguer gravity contour maps were prepared by the contractor and submitted to UGMS. The regional gravity surface was compiled and submitted at a scale of 1:24,000. The detailed gravity surface was prepared at a scale of 12,400 and submitted at a scale of 1:6,000. A portion of the regional map is presented in Figure A1-2.

Description of Complete Bouguer Gravity Surfaces

Regional

The complete regional Bouguer gravity surface was well defined by the gravity profiles, and added much detail to a previously available gravity map by Cook and Berg (1961). In general, the surface strikes northeastward and dips to the northwest. The surface is primarily a result of the bedrock ranges to the south and east and the sediment filled basin, or graben, of the Jordan Valley to the northwest. The value decreases with the increasing thickness of low density sediments in the graben.

Viewed in more detail, the regional gravity surface reveals the presence of normal range-front fault segments that bond the edges of the Wasatch and Traverse Ranges. In the vicinity of the thermal spring system, these range front faults trend almost east-west (parallel to the gravity contours), and abruptly terminate a gravity high that is present south of the springs. In other areas gravity contours trend northeast and indicate the presence of northeast trending faults.

The regional surface presented in Figure A1-2 incorporated data from the detailed grid and as a result, the complexity of the hot springs area is apparent. However, had only the gravity profiles been used, many important details in the vicinity of the springs would not have been apparent.

Detailed Grid

Several important features of the detailed gravity surface can be observed in Figure A1-2. First, a distinct change in trend can be seen on the gravity surface. In the eastern two-thirds of the area the trend is east-west, while in the western one-third the trend is noticeably more northeasterly. Second, the southern one-half of the area dips steeply to the north, while the northern one-half is relatively flat. On the broadly curved, steeply dipping regional surface appear two major gravity highs that push the contours northward. One of these features is directly beneath the Crystal Springs, while the other is at the eastern end of the Utah State Prison facility.

Data Reduction

In order to view the true gravity anomalies free from the influence of the steep regional gradient, the regional gradient was removed by constructing a smooth set of curves through the area, and subtracting the milligal values of the curves from the values of the contours. The regional curves used are presented in Figure A1-3. The resulting residual anomaly is presented in Figure A1-4.

FIGURE A1-2

UTAH GEOLOGICAL AND MINERAL SURVEY BOUGUER
GRAVITY (DENSITY - 2.67 g/cc) CRYSTAL HOT SPRINGS

FIGURE A1-3

REGIONAL GRAVITY GRADIENT REMOVED FROM THE COMPLETE
BOUGUER GRAVITY SURFACE

The residual anomaly consists of two gravity highs separated by a gravity low. The total relief on the anomaly is approximately 1.75 milligals. The western gravity high is centered beneath the eastern one-half of the hot springs property, and rises to approximately 1.2 milligals above zero. The eastern gravity high is centered beneath the maximum security section of the prison and rises approximately 0.75 milligals above zero. The highs are separated by a north-south striking through having an magnitude of about 0 milligals. Both of the gravity highs are somewhat rectangular in shape and both are bound on the north by relatively steep gravity gradients. Both appear to be bound on the south also. However, this trend is not as well defined. The western gravity high appears to dip relatively gently to the west, but is abruptly terminated by the steepest gravity gradient of the residual along its eastern edge. The eastern high is more complex, but appears to be terminated on its eastern flank by a modestly steep gradient.

The residual anomaly in Figure A1-4 was modeled on the ESLD/UURI PRIME computer. The GM30 program used to model the anomaly is a right-rectangular prism model capable of modeling both gravity and magnetic data in three dimensions. To use the gravity modeling portion of the program the user constructs a model of prisms and assigns the appropriate density contrasts. The program calculates the gravity anomaly that would result from the model and displays a contour map of the anomaly. The calculated anomaly is visually compared with the observed anomaly and the user makes appropriate changes in the model to produce the desired results in the calculated anomaly. This iterative process allows the user to produce progressively better fits (size, shape and amplitude) between the observed and calculated anomalies by changing the parameters (number of prisms, size of prisms, and density of contrast) of the model. The desired result is a model, reasonable in terms of the known geologic and structural setting that produces a calculated anomaly similar to the observed anomaly. The model generated by this process is not unique.

There are four distinct types of geologic materials present within the area shown in Figure A1-4. Beneath the springs is Paleozoic quartzite. North of the springs are Tertiary volcanics. Blanketing both of these materials is a variable thickness (0-900 feet) of Tertiary Fanglomerate. The Fanglomerate is in turn overlaid with a relatively constant thickness (80 to 90 feet) of Lake Bonneville sediments. The gravity anomaly is a result of the contrasts in density between these materials. When density measurements of the various materials are not available (such as is the case at the Utah State Prison), a known thickness of the material in question as defined by drill hole data can be used to place limits on the required density contrast.

Early modeling efforts (such as those reported in the First Semi-annual Report by Blair (1980) assumed that the quartzite and andesite or bedrock were the same density, and that the Bonneville sediments and Tertiary Fanglomerate of alluvium were of the same density. The contrast between the bedrock and alluvium thus defined was judged responsible for the observed residual anomaly (Figure A1-4). Based on these assumptions and the thickness of alluvium as determined from existing gradient holes, a density contrast of 0.50 gm/cm^3 was found appropriate. The models

FIGURE A1-4

RESIDUAL GRAVITY ANOMALY OF THE DETAILED GRAVITY GRID IN THE VICINITY OF THE UTAH STATE PRISON

generated using this density contrast appeared to successfully account for all known depths to bedrock (or thicknesses of alluvium) except that measured in the ASARCO hole.

When the Utah Roses injection well (UR-4) was drilled to a depth of 950 feet without encountering the bedrock predicted to be present at a depth of 600 feet, the model was re-examined. The assumption that the andesite was of the same density as the quartzite was not correct. Instead, the upper portion of the andesite appears to be approximately the same density as the Tertiary alluvium, and does not appear as a major feature on the gravity surface (Figure A1-1). Thus, a simple model of the residual anomaly can ignore the presence of the relatively low density andesites north of the springs. Given the new interpretation of the information, a density contrast of only 0.20 gm/cc is required to generate a computed anomaly similar in amplitude to the observed residual anomaly. The net effect of this change in density contrast is the lowering of the modeled bedrock surface by a factor of approximately 2. However, the positions of faults as interpreted from the gravity data were not directly affected by this change in the density contrast.

APPENDIX 2

Noncondensable Gas Concentration Calculations

NONCONDENSABLE GAS CONCENTRATION MEASUREMENTS - USP/TH-1

Procedure

Well USP/TH-1 was flowed at a rate of approximately 7 gal/min, into a 55 gallon separator. The separator was operated in a steady-state mode such that water inlet and outlet flows, separator water level, and the noncondensable gas outlet flow rate remained constant. The water flow rate from the separator was determined by measuring the time required to fill a calibrated volume. Noncondensable gas flow rates were measured via two techniques -- using a rotameter and by filling a tank of known volume. Water and gas discharge temperatures were measured with a mercury thermometer. The separator was maintained at essentially atmospheric pressure.

Data

Method 1:

Rotameter Reading $\cong$ 60 (some fluctuation, water entrained with gas)
Separator Pressure = 1-3/4 inches H₂O
Inlet Gas Temp. to Rotameter = 50°C
Water Exit Temp. = 59°C
Water Flow Rate = 7.1 gal/min

Method 2, Run 1:

Water Flow Rate = 7.1 gal/min
Water Exit Temp. = 63°C
Collected Gas Vol. = 42,000 ml
Collection Time = 144.87 sec
Gas Temp. = 48°C
Gas Pressure = 2 inches H₂O

METHOD 1 ROTAMETER

METHOD 2 CALIBRATED COLLECTION TANK

A 2-1

APPARATUS FOR MEASURING NON-CONDENSIBLE GAS CONTENT

Method 2, Run 2:

Water Flow Rate = 7.1 gal/min
Water Exit Temp. = 65°C
Collected Gas Vol. = 42,000 ml
Collection Time = 141.88 sec
Gas Temp. = 50°C
Gas Pressure = 2 inches H₂O

Note: In the data analysis, the following are assumed:

- 1) Local atmospheric pressure is 12.5 psia.
- 2) The noncondensable gas is CO₂.
- 3) The noncondensable gas samples are saturated with water vapor at 50°C.

Water Saturation of CO₂

$$P_{\text{tot.}} = 12.5 \text{ psia}$$

$$y = \text{mass fraction of water in CO}_2 = \frac{M_w}{M_{\text{CO}_2}}$$

Utilizing perfect gas law and Dalton's Rule for partial pressures:

$$P_w V_T = M_w R_w T$$

$$P_{\text{CO}_2} V_T = M_{\text{CO}_2} R_{\text{CO}_2} T$$

$$M_w = \frac{P_w V}{R_w T}$$

$$M_{\text{CO}_2} = \frac{P_{\text{CO}_2} V}{R_{\text{CO}_2} T}$$

$$\frac{M_w}{M_{CO_2}} = \frac{P_w}{\frac{P_{CO_2}}{R_{CO_2}}} = \frac{P_w/R_w}{P_{CO_2}/R_{CO_2}}$$

$$R_w = .1099 \text{ btu/lbm}^\circ\text{R}$$

$$R_{CO_2} = .0451 \text{ btu/lbm}^\circ\text{R}$$

$$\frac{M_w}{M_{CO_2}} = \left(\frac{.0451}{.1099} \right) \frac{P_w}{P_{CO_2}} = .41 \frac{P_w}{P_{CO_2}}$$

$$P_w = P_{\text{sat}_{50^\circ\text{C}}} = 1.79 \text{ psi}$$

$$P_T = 12.5 \text{ psi} \Rightarrow P_{CO_2} = 12.5 - 1.79$$

$$= 10.7 \text{ psi}$$

$$= \frac{M_w}{M_{CO_2}} = (.410) \left(\frac{1.79}{10.7} \right) = \boxed{.069}$$

Mass Fraction:

$$M_w + M_{CO_2} = M_T$$

For A 1 lb. total

$$M_w + 14.99 M_w = 1 \text{ lb}$$

$$\Rightarrow \frac{M_w}{M_T} = .065$$

$$\frac{M_{CO_2}}{M_T} = .935$$

Properties:

$$\rho_{CO_2} = .104 \frac{\text{lbm}}{\text{ft}^3}$$

50°C, 1atm

$$\times \frac{12.5}{14.7} = .089 \frac{\text{lbm}}{\text{ft}^3} @ 12.5 \text{ psia}$$

$$\mu_{\text{CO}_2} = 1.09 \times 10^{-5} \text{ lbm/ft}\cdot\text{sec}$$

50°C

$$\rho_{\text{H}_2\text{O}} = .00519 \frac{\text{lbm}}{\text{ft}^3}$$

50°C, 1atm

$$\times \frac{12.5}{14.7} = .0044 \text{ @ } 12.5 \text{ psia}$$

$$\mu_{\text{H}_2\text{O}} = .87 \times 10^{-5} \text{ lbm/ft}\cdot\text{sec}$$

50°C

$$\rho_{\text{mix}} = (.935)(.089) + (.065)(.0044)$$

$$= .084 \text{ lbm/ft}^3$$

$$\mu_{\text{mix}} = (.935)(1.09 \times 10^{-5}) + (.065)(.87 \times 10^{-5})$$

$$= 1.076 \times 10^{-5} \text{ lbm/ft}\cdot\text{sec}$$

Data Reduction, Method 1:

$$\dot{M}_{\text{H}_2\text{O}} = 7.1 \text{ gal/min @ } 59^\circ\text{C}$$

$$\rho_{59^\circ\text{C}} = 61.4 \text{ lb/ft}^3$$

$$\Rightarrow \dot{M}_{\text{H}_2\text{O}} = 7.1 \text{ gal/min} \times .13368 \frac{\text{ft}^3}{\text{gal}} \times 61.4 \text{ lb/ft}^3$$

$$= \boxed{58.3 \text{ lb/min}}$$

Gas Flow Rate:

Rotameter = Gilmont No. F-1500

Scale Reading = 60

Temp. = 50°C

R@60 = 16.8 (Calib. Curve)

$$W_f = 2.715 \text{ gm} \quad D_f = .5''$$

$$\rho_f = 2.53 \text{ gm/ml}$$

$$\rho_{\text{mix}} = .084 \text{ lb/ft}^3 \times \frac{1 \text{ gm}}{2.205 \times 10^{-3}} \times \frac{1 \text{ ft}^3}{28.32 \text{ l}} \times \frac{1 \text{ l}}{1 \times 10^3 \text{ ml}}$$

$$= 1.35 \times 10^{-3} \text{ gm/ml}$$

$$\mu_{\text{mix}} = 1.076 \times 10^{-5} \text{ lbm/ft}\cdot\text{sec} \times \frac{1 \text{ cp}}{.000672}$$

$$= 1.601 \times 10^{-2}$$

$$S_t = 1.042 \frac{W_f (\rho_f - \rho) p R^3}{\mu^2 \rho_f}$$

$$= \frac{(1.042)(2.715)(2.53 - 1.35 \times 10^{-3})(1.35 \times 10^{-3})(16.8)^3}{(1.601 \times 10^{-2})^2 (2.53)}$$

$$= 7.06 \times 10^4$$

$$\Rightarrow C_R = .97$$

$$q(\text{ml/min}) = (59.8) D_f C_R \sqrt{\frac{W_f (\rho_f - \rho)}{\rho_f \rho}} R \left[\frac{R}{100} + 2 \right]$$

$$= (59.8)(.5)(.97) \sqrt{\frac{(2.715)(2.53 - 1.35 \times 10^{-3})}{(2.53)(1.35 \times 10^{-3})}} 16.8 \left[\frac{16.8}{100} + 2 \right]$$

$$= 4.74 \times 10^4 \frac{\text{ml}}{\text{min}} \times 1.35 \times 10^{-3} \text{ gm/ml} \times 2.205 \times 10^{-3} \text{ lbm/gm}$$

$$= \boxed{.14 \text{ lb/min}}$$

$$.14 \frac{\text{lb}}{\text{min}} \times .935 \frac{\text{lb}_{\text{CO}_2}}{\text{lb}_{\text{mix}}} = .13 \frac{\text{lb}_{\text{CO}_2}}{\text{min}}$$

$$\frac{\dot{M}_{\text{CO}_2}}{\dot{M}_{\text{H}_2\text{O}}} = \frac{.13}{58.3} = .0022 = \boxed{.22 \text{ wt \%}}$$

Data Reduction, Method 2:

Run 1:

$$\dot{M}_{\text{H}_2\text{O}} = 7.1 \text{ gal/min} = 58.3 \text{ lb/min}$$

$$\text{Gas Flow} = 42,000 \text{ ml/144.87 sec} \times 1.35 \times 10^{-3} \text{ gm/ml}$$

$$\times 2.205 \times 10^{-3} \text{ lb/gm} \times 60 \text{ sec/min} = .052 \text{ lb/min}$$

$$.052 \text{ lb/min} \times .935 \frac{\text{LB}_{\text{CO}_2}}{\text{LB}_{\text{mix}}} = \boxed{.048 \text{ LB}_{\text{CO}_2}/\text{min}}$$

$$\frac{\dot{M}_{\text{CO}_2}}{\dot{M}_{\text{H}_2\text{O}}} = \frac{.048}{58.3} = .000823 = \boxed{.08 \text{ Wt \%}}$$

Run 2:

$$\dot{M}_{\text{H}_2\text{O}} = 58.3 \text{ lb/min}$$

$$\text{Gas Flow} = 42,000 \text{ ml}/141.88 \text{ sec} \times 1.35 \times 10^{-3} \text{ gm/ml}$$

$$\times 2.205 \times 10^{-3} \text{ lb/gm} \times 60 \text{ sec/min} = \boxed{.053 \text{ LBCO}_2/\text{min}}$$

$$.053 \text{ lb/min} \times .935 \frac{\text{LBCO}_2}{\text{LBmix}} \times .050 \text{ LBCO}_2/\text{min}$$

$$\frac{\dot{M}_{\text{CO}_2}}{\dot{M}_{\text{H}_2\text{O}}} = \frac{.050}{58.3} = .000850 = \boxed{.085 \text{ wt \%}}$$

EFFECT OF NONCONDENSABLE GASES

CO₂ Solubility Equilibrium Constant:

$$-\log K^{\circ} = -3178.6/T + 56.0537 - 7.6776 \ln T \\ + 0.229 \times 10^{-3} T - 0.225 \times 10^5/T^2$$

Where:

K° = solubility equilibrium constant for CO₂ in water, moles per kg H₂O per bar

T = Temp. in °K

(Reference: L.W. Ross, "Solubility of Gases in Fluids under Geothermal Conditions. Estimation Methods and Example Calculations," Geothermal Resources Council, Transactions, Vol. 1, May, 1977)

For T = 80°C = 353°K

$$-\log K^{\circ} = 2.0896$$

$$K^{\circ} = .00814$$

For T = 50°C = 323°K

$$-\log K^{\circ} = 1.7126$$

$$K^{\circ} = .01938$$

At test conditions, CO₂ remaining in water equals:

$$.01938 \frac{\text{Moles CO}_2}{(\text{Kg H}_2\text{O})(\text{bar})} \times \frac{1 \text{ bar}}{14.7 \text{ psi}} \times 12.5 \text{ psi} \times 44.01 \frac{\text{gm CO}_2}{\text{Mole}} \\ \times \frac{1 \text{ Kg CO}_2}{1000 \text{ gm}} = 7.25 \times 10^{-4} \frac{\text{Kg CO}_2}{\text{Kg H}_2\text{O}} \text{ in discharge}$$

Total gas content equals:

$$\text{Method 1} - .0022 \frac{\text{LB CO}_2}{\text{LB H}_2\text{O}} + 7.25 \times 10^{-4} \frac{\text{LB CO}_2}{\text{LB H}_2\text{O}} = .0029 \frac{\text{LB CO}_2}{\text{LB H}_2\text{O}}$$

$$\text{Method 2} - .00084 + 7.25 \times 10^{-4} = .00157 \frac{\text{LB CO}_2}{\text{LB H}_2\text{O}}$$

Pressure Required to Maintain Gas in Solution:

$$K^o = .00814 \text{ @ } 80^{\circ}\text{C}$$

$$K^o \times \hat{M}_{\text{CO}_2} \times \text{Pressure} = \text{Wt. Concentration CO}_2$$

$$\text{Pressure} = \frac{\text{Wt. Concentration CO}_2}{K^o \hat{M}_{\text{CO}_2}}$$

Method 1:

$$\begin{aligned} \text{Pressure} &= \frac{.0029}{(.00814) \times (44.01 \text{ CO}_2) \times \frac{1}{1000}} \\ &= 8.1 \text{ bars} = 119.0 \text{ psi} \times \frac{144 \text{ in}^2}{\text{ft}^2} \times \frac{1 \text{ ft H}_2\text{O}}{62.43 \text{ lb/ft}^3} = \boxed{274 \text{ ft H}_2\text{O}} \end{aligned}$$

Method 2:

$$\begin{aligned} \text{Pressure} &= \frac{.00157 \text{ LB CO}_2/\text{LB H}_2\text{O}}{(.00814)(44.01) \frac{1}{1000}} \\ &= 4.38 \text{ bars} = 64.4 \text{ psi} = \boxed{149 \text{ ft. H}_2\text{O}} \end{aligned}$$

Conclusion

Under hydrostatic conditions, the following noncondensable gas flashpoints were determined:

274 ft. - Method 1 (Rotameter)
149 ft. - Method 2 (Collection Drum)

Method 2 probably yields more precise results due to water entrainment problems with the rotameter system.

APPENDIX 3

Test Data - Artesion Flow Test

ARTESIAN FLOW TEST USP/TH-1 FLOW RATE VS. TIME

FIGURE A3-1

FIGURE A3-2

FIGURE A3-3

FIGURE A3-4

FIGURE A3-5

APPENDIX 4

Data Analysis - Artesian Flow Test

USP/TH-1 ARTESIAN FLOW TEST - ANALYSIS OF RESULTS

Estimation of Formation Properties From Well SF-1 Interference Data:

Note: The following assumes the Utah Roses well to have negligible influence upon early-time test data. The validity of this assumption will be verified following determination of reservoir properties.

Type curve matching of SF-1 response is used to determine formation permeability and porosity-compressibility product.

Data:	Elapsed Time	ΔP
	0.7	0.13
	1.23	0.25
	2.18	0.56
	2.63	0.62
	3.17	0.68
	3.90	0.80
	4.75	0.86
	5.48	0.92
	6.27	1.11
	6.87	1.13
	7.38	1.21
	8.25	1.25
	8.90	1.31
	9.52	1.33
	10.95	1.46
	11.98	1.41
	12.92	1.51
	13.92	1.61

(Reference: R.C. Earlougher, Advances In Well Test Analysis, Society of Petroleum Engineers of AIME, Dallas, 1977.)

Match point with Figure C.2 of Reference is:

$$t_m = 10.0, (t_D/r_D^2)_m = 4.8$$

$$\Delta P_m = 0.1, (P_D)_m = 0.097$$

Permeability is estimated from the match point values as follows:

$$K = 141.2 \frac{qB\mu}{h} \frac{(P_D)_m}{\Delta P_m} \quad (\text{Ref., Eq. 9.2})$$

where: K = permeability (md)

q = flow rate (bbl/day)

B = formation volume factor

μ = viscosity (cp)

h = formation thickness (ft)

$(P_D)_m$ = dimensionless pressure at the match point

ΔP_m = pressure change from transient test data at the match point

$$q = 575 \text{ gpm} \times \frac{1 \text{ bbl}}{42 \text{ gal}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}} = 19,700 \text{ bbl/day}$$

$$B = 1.027 \quad (\text{Ref., Fig. D.8})$$

$$\mu = 0.34 \text{ cp} \quad (\text{Ref., Fig. D.35})$$

$$h = 600 \text{ ft.} \quad (\text{approximation based on drilling experience})$$

$$\Rightarrow K = \frac{(141.2)(19,700)(1.027)(0.34)}{600} \left(\frac{0.097}{0.1} \right) = 1570 \text{ md}$$

The porosity-compressibility product is estimated as follows:

$$\phi C_t = \frac{0.0002637}{r^2} \frac{K}{\mu} \frac{t_m}{(t_D/r_D^2)_m}$$

where: ϕ = porosity (fraction)

C_t = system total compressibility (psi^{-1})

r = distance between wells (ft)

t_m = time value at the match point (hours)

$(t_D/r_D^2)_m$ = dimensionless time parameter at the match point

Distance R between forestry well and USP/TH-1 is approximately 400 feet.

$$\phi C_t = \frac{0.0002637}{(400)^2} \left(\frac{1570}{0.34} \right) \left(\frac{10.0}{4.8} \right) = \boxed{1.586 \times 10^{-5} \text{ psi}^{-1}}$$

The above properties can be expressed in typical groundwater units as follows:

$$\text{Hydraulic conductivity } K = K_i \left(\frac{\rho g}{\mu} \right)$$

where K_i = permeability

$$K = 1.586 \times 9.87 \times 10^{-9} \times (.03281 \text{ ft})^2 \times 60.57 \frac{\text{lb}}{\text{ft}^3} \times \frac{32.2 \text{ ft/sec}^2}{.34 \text{ cp}}$$

$$\times \frac{1 \text{ cp}}{.000672 \text{ lbm/sec ft}} \times \frac{60 \text{ sec}}{\text{min}} \times \frac{60 \text{ min}}{\text{hr}} \times \frac{24 \text{ hr}}{\text{day}}$$

$$= \boxed{12.42 \text{ ft/day}} \quad (\text{typical of a fine to medium sand})$$

$$\text{Coefficient of storage } S = \phi C t h \left(\frac{\rho g}{\gamma_c} \right)$$

$$= 1.586 \times 10^{-5} \times 600 \times (60.57) \frac{32.2}{32.2} \times \frac{1}{144}$$

$$= .0040$$

$$\frac{S}{h} = 6.67 \times 10^{-6}$$

ANALYSIS OF USP/TH-1 DRAWDOWN DATA

Wellbore Storage

Following is a log-log plot of downhole pressure vs. time. From the curve, the slope of the plot (one cycle in ΔP per cycle in t) indicates that wellbore storage dominates the test data up until .03 hours into the test.

$$C = \frac{q B \Delta t}{24 \Delta P} \quad (\text{Eq. 2.20, Ref.})$$

where C = wellbore storage coefficient

ΔP = pressure change (psi)

Δt = running testing time (hours)

$$= \frac{(19,700)(1.027)}{24} \left(\frac{.019}{2.5} \right) = 6.4$$

Skin Factor:

$$S = 1.1513 \left[\frac{P_{1hr} - P_i}{M} - \log \left(\frac{K}{\phi \mu C r_w^2} \right) + 3.2275 \right] \quad (\text{Eq. 3.10, Ref.})$$

where: P_{1hr} = pressure on straight line portion of semilog plot 1 hr after beginning a transient test (psi)

P_i = initial pressure (psi)

M = slope of linear portion of semilog plot of pressure transient data (psi/cycle)

r_w = wellbore radius (ft)

$$S = 1.1513 \left[\frac{307.0 - 309.96}{-0.6 \text{ psi/cycle}} - \log \left(\frac{1570}{(1.586 \times 10^{-5})(.34)(.25)^2} \right) + 3.2275 \right]$$

$$= \boxed{-1.51}$$

Note: This skin factor is indicative of an efficient well with some permeability improvement in the vicinity of the wellbore.

Formation Permeability From Production Well Data:

$$K = -162.6 \frac{\text{B}\mu\text{g}}{\text{Mh}} \quad (\text{Eq. 3.9, Ref.})$$

FIGURE A4-1
TYPE CURVE MATCH SF-1 DRAWDOWN
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FIGURE A4-2

DIMENSIONLESS PRESSURE FOR A SINGLE WELL IN AN INFINITE SYSTEM,
NO WELLBORE STORAGE, NO SKIN, EXPONENTIAL-INTEGRAL SOLUTION.

Downhole Data - M = -.6 psi/cycle

Surface Data - M = -.43 psi/cycle

For an assumed H of 600 ft.

$$\Rightarrow K = \frac{(-162.6)(1.027)(.34)(19,700)}{(-.6)(600)} = \boxed{3106 \text{ md (downhole data)}}$$
$$= \frac{(-162.6)(1.027)(.34)(19,700)}{(-.43)(600)} = \boxed{4335 \text{ md (surface data)}}$$

Reservoir Limit Analysis:

Note: Both downhole and surface drawdown data indicate the influence of a system boundary upon the drawdown characteristics of the well after approximately one hour of testing.

A cartesian plot of wellhead pressure vs. time indicates that pseudo-steady-state flow exists in the formation after 9 hours of testing (as evidenced by linear pressure decline versus time). The rate of pressure decline in this flow regime is .11 psi/hr.

$$\phi h A = \frac{-0.23395 q B}{C_t M^*} \quad (\text{Eq. 3.35, Ref.})$$

$$A = \frac{-.23395 q B}{\phi h C_t M^*}$$

where A = reservoir area (ft²)

M* = slope of linear pressure decline (psi/hr)

$$A = \frac{(-.23395)(19,700)(1.027)}{(1.586 \times 10^{-5})(600)(-.11)}$$

$$A = \boxed{4.52 \times 10^6 \text{ ft}^2} \quad \text{Reservoir drainage area}$$

Note: This area corresponds closely to that predicted by UGMS gravity modelling.

Reservoir Shape (Based upon wellhead pressure decline data)

$$C_A = 5.456 \frac{M}{M^*} \text{ Exp } [2.303 (P_{1hr} - P_{Int})/M] \quad (\text{Eq. 3.36, Ref.})$$

FIGURE A4-3

ARTESIAN FLOW TEST USP/TH-1 DOWNHOLE PRESSURE
DRAWDOWN VS. TIME

FIGURE A4-4

ARTESIAN FLOW TEST USP/TH-1 WELLHEAD PRESSURE VS. TIME

where: C_A = shape factor

P_{int} = pressure at intercept of cartesian pressure vs. time curve (psi/hr)

$$C = 5.456 \frac{(-.43)}{(-.11)} \text{Exp} [2.303 (4.0 - 3.0)/(-.43)] = .1007$$

From Table C.1 of the Reference, this shape factor corresponds to a well located very near to a boundary in a bounded reservoir.

APPENDIX 5
Influence of Utah Roses Well Upon Test Data

Discussion

To rigorously conduct a multiple well test in a developed reservoir such as that at Crystal Hot Springs, it would be necessary to have a long term record of the influence of the producing well upon the well to be tested. The scope of the current testing program did not allow this record to be compiled.

During the 2-3 day period preceding the test, unseasonably warm weather minimized production from the Utah Roses well. Continuous discharge from the well was not initiated until the morning of the USP/TH-1 test. To facilitate analysis, both wells were assumed to initiate flow simultaneously. The reservoir was assumed to be at equilibrium prior to initiation of the flow.

Model as follows:

$$q_{\text{USP/TH-1}} = 575 \text{ gpm} \\ (19,700 \text{ bbl/day})$$

$$q_{\text{Utah Roses}} = 260 \text{ gpm} \\ (8,910 \text{ bbl/day})$$

This model is based upon the resource configuration predicted by gravity modeling and upon reservoir area determined from analysis of flow test results.

Response of Utah Roses well at USP/TH-1:

Nondimensional pressures: (Table C.2, Ref.)

$$X_D = Y_D = .75$$

t_{DA}	$P_D (\sqrt{A}/r_w = 2000)$	$P_D (\sqrt{A}/r_w = 6375)$
.0010	.0000	1.159
.0020	.0000	1.159
.0030	.0000	1.159
.0050	.0000	1.159
.0070	.0000	1.159
.0090	.0000	1.159
.0150	.0008	1.160
.0250	.0091	1.168
.0400	.0437	1.203
.0600	.1241	1.283
.0800	.2279	1.387
.1000	.3433	1.503
.2000	.9632	2.122
.3000	1.5913	2.751
.5000	2.8479	4.007
.7000	4.1046	5.264
.9000	5.3612	6.520
2.0000	12.2727	13.432
4.0000	24.8391	25.998
8.0000	49.9717	51.131
10.0000	62.5381	63.697

$$\Delta P_t = 141.2 \frac{q B \mu}{Kh} \left(P_D(t_D) \right)$$

$$t_{DA} = \frac{0.0002637 Kt}{\phi \mu Ct A}$$

$$q = 8,910 \text{ bbl/day}$$

$$B = 1.027$$

$$\mu = .34 \text{ cp}$$

$$K = 3106 \text{ md}$$

$$A = 4.52 \times 10^6 \text{ ft}^2$$

$$Ct \phi = 1.586 \times 10^{-5} \text{ psi}^{-1}$$

FIGURE A5-2
ARTESIAN FLOW TEST USP/TH-1 DRAWDOWN VS. TIME
DUE TO ROSES WELL

t (hrs)	ΔP (psi)
.030	.273
.060	.273
.089	.273
.149	.273
.208	.273
.268	.273
.446	.273
.744	.275
1.190	.284
1.786	.302
2.38	.327
2.976	.354
5.95	.500
8.93	.648
14.88	.945
20.83	1.24
26.78	1.54
59.52	3.17
119.0	6.13
238.1	12.05
297.58	15.02

Discussion

From the preceding figure, it can be observed that the observed drawdown in Well USP/TH-1 could have been significantly influenced by the Utah Roses well. However, due to the uncertainty in the reservoir configuration, recharge characteristics, and physical properties, correction of the observed data is not warranted.

ANALYSIS OF RECOVERY DATA

Horner Plot

P_{wf} vs. $(t_p + \Delta t)/\Delta t$

where: P_{wf} = downhole pressure (psi)

t_p = equivalent time well was on production before shut-in (hrs)

Δt = time since shut-in (hrs)

$$t_p = \frac{24 V_p}{q} \quad (\text{Eq. 5.9, Ref.})$$

V_p = cumulative volume produced (bbls)

Production History

575 gpm 0-15 hrs (19,700 bbl/day)

400 gpm 15-50 hrs (13,700 bbl/day)

$$\Rightarrow V_p = 19,700 \times \left(\frac{15}{24}\right) + 13,700 \times \frac{35}{24} = 32,292 \text{ bbl}$$

$$t_p = \frac{24 \times 32,292}{13,700} = 56.57$$

Test Data

Elapsed Time (hrs)	Downhole Pressure (psi)	$(t_p + \Delta t)/\Delta t$
.568	308.09	100.60
.901	308.03	63.79
1.234	307.96	46.84
1.851	308.34	31.56
2.851	308.58	20.84
3.851	308.61	15.69
4.851	308.49	12.66
5.851	308.36	10.67
6.851	308.45	9.26
7.851	308.55	8.21
8.851	308.82	7.39
9.851	308.67	6.74
10.851	308.90	6.21
11.851	308.73	5.75

Elapsed Time (hrs)	Downhole Pressure (psi)	$(t_p + \Delta t)/\Delta t$
12.851	308.71	5.40
13.851	308.96	5.08
14.851	308.86	4.81
15.851	308.63	4.57
16.851	309.12	4.36
17.851	309.09	4.17
18.851	308.75	4.00
19.851	309.08	3.85
20.851	309.25	3.71
21.851	309.24	3.59
22.851	309.345	3.48
.734	308.215	78.07
1.068	308.097	53.97
1.3519	307.886	42.84
2.351	308.573	25.06
3.351	308.147	17.88
4.351	308.344	14.00
5.351	308.265	11.57
.651	308.091	87.90
.984	308.25	58.49
1.318	308.115	43.92
2.1008	308.254	27.93

$$K = 162.6 \frac{q B \mu}{Mh} \quad (\text{Ref., Eq. 5.6})$$

m = slope of Horner plot

$$= .52 \text{ psi/cycle}$$

$$K = \frac{(162.6)(13,700)(1.027)(.34)}{(.52)(600)}$$

$$= \boxed{2493 \text{ md}}$$

Distance to Boundary

$$P_D[t_D/(2L/r_w)^2] = \frac{1}{2} \ln\left(\frac{t_p + \Delta t}{\Delta t}\right) x \quad (\text{Eq. 10.6, Ref.})$$

where L = distance to boundary (ft)

x = intersection point of lines on Horner plot

$$P_D[t_D/(2L/r_w)^2] = \frac{1}{2} \ln 7.6 = 1.014$$

$$t_D/(2L/r_w)^2 = 3.2 \quad (\text{Fig. C.2, Ref.})$$

$$L = \sqrt{\frac{.0002637 K t_p}{4 \phi \mu C_t [t_D/(2L/r_w)^2]}} \quad (\text{Eq. 10.7, Ref.})$$

$$= \sqrt{\frac{(.0002637)(2493)(56.57)}{(4)(1.586 \times 10^{-5})(.34)(3.2)}}$$

$$= \boxed{734 \text{ ft}}$$

PREDICTION OF LONG TERM PERFORMANCE

Note: The following predictions are based upon drawdown characteristics of Well USP/TH-1 observed during testing. These results were influenced by Utah Roses production. However, it was not possible to quantify the effect of Utah Roses due to previously outlined constraints. Thus, the following predictions should be taken as approximations.

$$C_A = .1007$$

For pseudosteady-state reservoir conditions:

$$P_D = 2\pi t_{DA} + \frac{1}{2} \ln\left(\frac{A}{r_w^2}\right) + \frac{1}{2} \ln\left(\frac{2.2458}{C_A}\right) \quad (\text{Eq. C.18, Ref.})$$

$$\Delta P_f = 141.2 \frac{q B \mu}{Kh} \left[P_{D t_{DA}} \right] \quad (\text{Eq. C.18, Ref.})$$

(Skin Effects Neglected)

$$t_{DA} = \frac{0.0002637 K t}{\phi \mu C_t A} \quad (\text{Eq. 2.36, Ref.})$$

Reservoir Properties

$$B = 1.027$$

$$\phi C_t = 1.586 \times 10^{-5}$$

$$\mu = .34 \text{ cp}$$

$$A = 4.52 \times 10^6 \text{ ft}^2$$

$$h = 600 \text{ ft}$$

$$r_w = .25 \text{ ft}$$

$$K = 2876 \text{ md (average of all determinations)}$$

$$\Rightarrow \Delta P_f = (141.2) q \frac{(1.027)(.34)}{(2876)(600)} \left[2\pi t_{DA} + \frac{1}{2} \ln\left(\frac{4.52 \times 10^6}{.25^2}\right) + \frac{1}{2} \ln\left(\frac{2.2458}{.1007}\right) \right]$$

$$= 2.857 \times 10^{-5} q [2\pi t_{DA} + 10.601]$$

$$t_{DA} = \frac{(0.0002637)(2876) t}{(1.586 \times 10^{-5})(.34)(4.52 \times 10^6)}$$

$$= 3.11 \times 10^{-2} t$$

Flow Rate		Production Time (hrs)				
(gpm)	(bbl/day)	10	100	1,000	10,000	100,000
25	857	.71	1.70	11.62	110.78	1102.44
50	1,714	1.42	3.40	23.24	221.57	2204.89
75	2,571	2.13	5.10	34.85	332.35	3307.33
100	3,429	2.84	6.81	46.47	443.14	4409.78
200	6,857	5.68	13.61	92.95	886.27	8819.56
300	10,286	8.52	20.42	139.42	1329.41	13,229
400	13,714	11.36	27.22	185.89	1772.5	17,639
500	17,143	14.20	34.03	232.36	2215.7	22,049
600	20,572	17.04	40.84	278.84	2658.8	26,459

STATIC TEMPERATURE PROFILE FOLLOWING TEST

Depth (ft)	Temp. (°F)/(°C)
50	138.76/59.3
100	152.53/67.0
150	162.16/72.3
200	169.02/76.1
250	176.81/80.5
300	180.52/82.5
350	180.75/82.6
400	180.91/82.7
450	181.20/82.9
500	181.31/83.0
550	181.35/83.3
600	181.41/83.0
650	181.31/83.0
700	180.43/82.5
750	176.60/80.3
800	172.36/78.0
850	171.34/77.4
900	170.08/76.7
950	165.94/74.4

A5-4

PREDICTED LONG-TERM PRESSURE DRAWDOWN
CHARACTERISTICS FOR WELL USP/TH-1

A5-5

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