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PHILLIPS PETROLEUM COMPANY, GEOTHERMAL OPERATIONS

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ABSTRACT

The Roosevelt geothermal field, located in southwestern Utah, has been the focus of a high level of activity by both private industry and the academic community. Phillips Petroleum Company has drilled seven and Thermal Power Company two, of nine exploration wells to depths ranging between 370 and 2300 meters into a late Tertiary granitic igneous complex which intruded Precambrian (?) metamorphic rocks. The reservoir is confined to fractures within the granitic and metamorphic rocks. The nature of the reservoir is such that all wells drilled are wildcats.

The geothermal field lies along the west side of the central Mineral Range. Young rhyolite domes, with associated flows, pierce the late Tertiary granitic complex a few kilometers to the east and south of the producing wells. The heat at Roosevelt is probably supplied by the parent magma for the rhyolite domes.

Phillips' integrated exploration program combining geology, geochemistry and geophysics culminated in the drilling of the discovery well in April of 1975. The resource is a water dominated geothermal system with a maximum temperature in excess of 265°C. The water is a sodium chloride water with salinity less than 8000 mg/l. Recent activities include the formation of the Roosevelt Hot Springs Unit, applications to appropriate water from the state, the establishment of a groundwater monitoring system in the valley, and preparation for additional reservoir testing.

INTRODUCTION

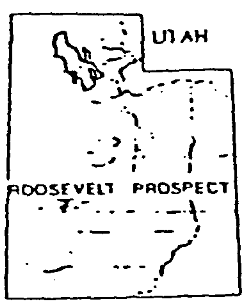


Fig. 1
Utah Index
Map

The Roosevelt geothermal field is situated in the western foothills of the Mineral Range in eastern Beaver County, Utah, near the eastern edge of the Basin and Range physiographic province (Fig. 1). The field named for a now dry-hot springs is about 12 miles northeast of the city of Milford and about 18 miles northwest of Beaver, the county seat. Among previous investigations are water studies by Lee (1908), Mundorff (1970) and Mower and Cordova (1974). Earll (1957) geologically mapped portions of the Mineral Range. Condie (1960) investigated the petrogenesis of the Mineral Range Pluton. Recently, Petersen (1974) focused attention on the geology and geothermal potential of the Roosevelt Hot Springs area. In 1975 the University of Utah researchers launched an in-depth program and have published many reports, too numerous to be mentioned here.

Phillips Petroleum Company's exploration activities in Utah began in late 1972 and a chronological listing of the activities at Roosevelt are given in Table 1. As shown, many exploration surveys were completed in the 1-1/2 years preceding the Roosevelt KGRA lease sale. An evaluation of these surveys led to the conclusion that the Roosevelt area showed exceptional promise. The lease sale in July 1974, was the first KGRA put up for bid in the state. The original eight sections in the KGRA had grown to 36.5 sections as a result of the competitive interest shown in the January 1974 noncompetitive acreage filing period. Of twelve tracts offered in the July sale, Phillips acquired nine tracts totaling 18,871 acres at a cost of $798,860. The location of the tracts, the successful bidder, cost of each tract, and cost per acre are shown in Fig. 2. After the leases issued in October 1974, exploration activity shifted to drilling the acquired acreage. During 1975 six exploratory wells and two stratigraphic tests were drilled. The discovery well (3-1), the second well drilled, came in at the end of April. During 1976, efforts focused toward furthering the knowledge of the geothermal system through resevoir tests and a variety of geophysical and geochemical surveys.

MAY	[illegible]	LITERATURE SURVEY & FIELD RECONNAISSANCE
FEB	[illegible]	RECONNAISSANCE GEOCHEMICAL SURVEY
MAR	[illegible]	GRAVITY SURVEY
MAY	[illegible]	GEOCHEMICAL SURVEY (CONTINUING)
MAY	[illegible]	EARLY LEASING ACTIVITIES (CONTINUING)
JUNE	[illegible]	DIPOLE - DIPOLE SURVEY
JUNE	[illegible]	GROUNDNOISE SURVEY
JULY	[illegible]	TEMPERATURE GRADIENT SURVEY (CONTINUING)
OCT	[illegible]	MAGNETOTELLURIC SURVEY
JULY	[illegible]	COMPETITIVE LEASE SALE (~ 38,000 ACRES)
OCT	[illegible]	LEASES ISSUE
DEC	[illegible]	REFLECTION SEISMIC SURVEY
FEB	[illegible]	SPUDDED OBSERVATION HOLE #[illegible]
MAR	[illegible]	SPUDDED OBSERVATION HOLE #[illegible]
MAR	[illegible]	SPUDDED ROOSEVELT KGRA #[illegible]
APR	[illegible]	SPUDDED ROOSEVELT KGRA #3-1 - DISCOVERY WELL
APR	[illegible]	GROUND LEVEL MAGNETIC SURVEY
MAY	[illegible]	MAGNETOTELLURIC SURVEY
JUNE	[illegible]	PETROLOGIC STUDIES
JULY	[illegible]	SPUDDED ROOSEVELT KGRA #54-3
AUG	[illegible]	SPUDDED ROOSEVELT KGRA #12-35
OCT	[illegible]	SPUDDED ROOSEVELT KGRA #13-16
NOV	[illegible]	SPUDDED ROOSEVELT KGRA #82-33
JAN	[illegible]	WATER OBSERVATION SYSTEM
FEB	[illegible]	MAGNETOTELLURIC SURVEY
FEB	[illegible]	MOST SIGNIFICANT FLOW TEST (#54-3)
MAR	[illegible]	ISOTOPIC STUDIES
APR	[illegible]	WATER APPROPRIATION HEARING
APR	[illegible]	UNIT APPROVED
MAY	[illegible]	HELIUM SURVEY
AUG	[illegible]	SPUDDED ROOSEVELT HOT SPRINGS UNIT #25-15
OCT	[illegible]	MICROEARTHQUAKE AND GROUNDNOISE SURVEYS
OCT	[illegible]	SPONTANEOUS POTENTIAL SURVEY
NOV	[illegible]	HIGH RESOLUTION SEISMIC SURVEY
DEC	[illegible]	LANDSAT IMAGERY STUDY

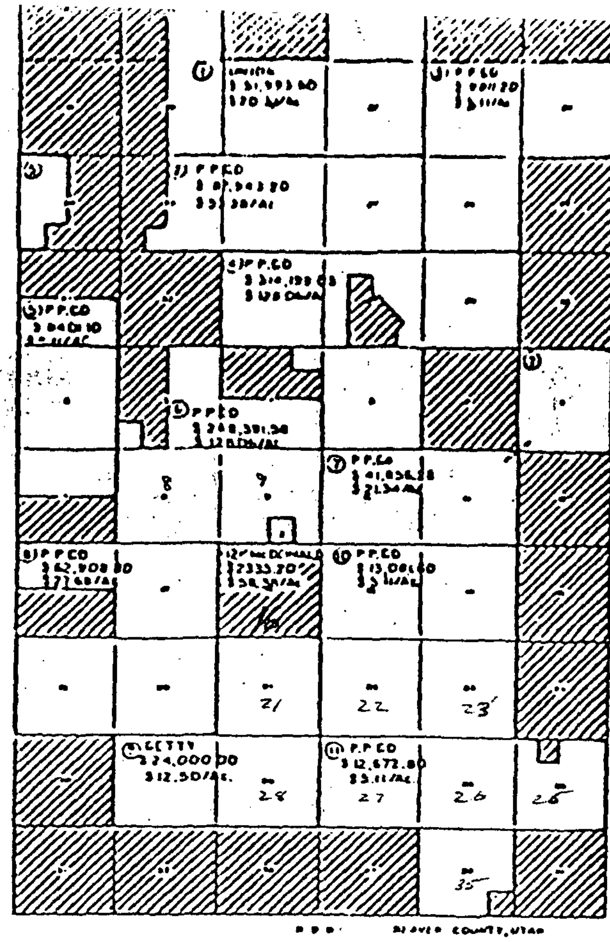


Fig. 2. The Roosevelt Hot Springs KGRA showing the location of 12 tracts offered at the July 1974 lease sale.

GEOLOGY

The Roosevelt geothermal field is located at the junction between Escalante Valley, a north-south trending graben, and the Mineral Range, a horst block paralleling the east side of the valley (Fig. 3). The valley is flanked on the west by a horst forming a number of smaller mountain ranges. The graben is filled with upwards of 5,000 feet of poorly consolidated sediments, volcanics and alluvium resting on more dense consolidated rocks. The valley fill is thickest immediately northeast of Milford.

The Mineral Range is about thirty miles long and six to ten miles wide. Topography is rugged, with steep slopes and high relief. The southern third of the range is composed of folded and faulted Paleozoic and Mesozoic sediments and Tertiary volcanic rocks which have been intruded by small acidic igneous stocks. The central Mineral Range has a granitic central core which is recognized as Utah's largest pluton. The granite has intruded and metamorphosed Palezoic sedimentary rocks now cropping out along the southeast edge of the Range. To the west, granite intruded Precambrian schists and gneisses (Fig. 4). The granite-metamorphic rock contact is gradational with a zone about one-mile wide consisting of metamorphic inclusions within the granite forming the granite-metamorphic rock contact (Earll, 1957). North of Roosevelt Springs, granite is in gradational contact with a granodiorite intrusive which in turn intruded a sequence of upper Precambrian and lower Paleozoic sedimentary rocks at the north end of the range (Liese, 1957). Late Cenozoic acidic ash flow tuffs and lava flows partly fill older erosional valleys cut in the granite and partly cap portions of the granite in the central Mineral Range. These volcanics appear to be younger than the basin-range faulting which exhumed and permitted dissection of the granite pluton. Age dates of 400,000 years to 0.8 m.y. are reported by W. P. Nash (1976) for the volcanics. Bearskin Mountain has been identified as one of perhaps several volcanoes supplying the tuffs and lavas (Earll, 1957). Other possible sources are North and South Twin Flat Mountain and a small siliceous stock [illegible] Section 31, T26S, R8W.

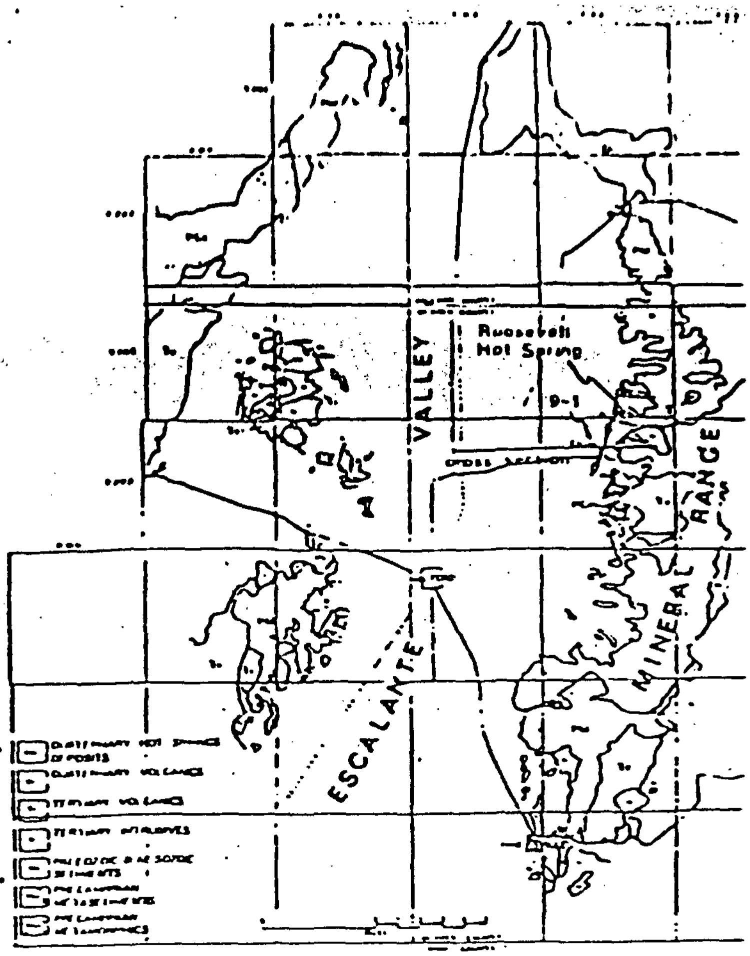


Fig. 3. Geologic Map of Northern Escalante Valley. Modified after Petersen, 1974; Liese, 1957; Earll, 1957; Hintze, 1963.

Faulting is ubiquitous throughout the area. Several faults within the Roosevelt KGRA apparently have a significant influence on the hydrology. These are the Dome Fault, striking NNE through the center of the KGRA, and the east-west striking Negro Mag Wash fault.

The Phillips exploration program has been discussed elsewhere by Berge et. al. (1976) and Lenzer et. al. (1976) and only the results of temperature gradient surveys will be repeated here. In addition, the University of Utah investigating team led by Dr. Ward have published many reports on the Roosevelt area, which will not be discussed. The temperature gradient map (Fig. 5) is based on a total of thirty-nine holes and combines Phillips' results with data from Petersen (1975) and Whelan (University of Utah, personal communication). Depths of gradient holes vary from 60 to 610 m (200 to 2,000 ft). Gradients in five holes in the center of the thermal anomaly exceed 40°C/100m. The anomaly is elongate north-south with a change in trend to the northwest in the northern third of the anomaly. The north-south trace of the Dome Fault centers on the anomaly, and the east-west Negro Mag Wash fault is coincident with the zone of the change in trend. All exploration wells presently drilled fall in areas having gradients exceeding 30°C/100 m. Drilling activity to date totals nine geothermal wells and four stratigraphic test holes (Table 2 and Fig. 7). Seven of the nine wells encountered geothermal resources. Two wells (54-3 & 72-16) are reported to be capable of producing 1 x 10^6 pounds per hour or more total mass flow. One of the seven, (3-1), cannot be produced due to safety considerations.

The rocks encountered in drilling beneath the thin veneer of alluvium, are either igneous intrusive rocks of the Tertiary Mineral Range granitic complex or metamorphic rocks of the Precambrian Wildhorse Canyon series (Fig. 6). These rocks have almost no intergranular porosity or permeability. The geothermal reservoir is associated with interconnected fracture zones and faults lending local high effective permeability to the crystalline rocks. The reservoir is confined beneath a cap varying from 300 to several thousand feet in thickness—the cap apparently formed by precipitated silica sealing the fractures. All the wells drilled to date are considered wildcats since the targets sought are fracture systems whose attitudes are poorly known and are not related to any particular lithology or formation. Using the classification of White and Williams (1975), the geothermal resource is identified as a high temperature, low salinity, liquid dominated type. Geothermal reservoir water is classified as sodium chloride water containing 6000 to 8000 mg/l T.D.S. (Table 3). These waters contain anomalously high amounts of Si, Na, K, Cl, F, B, Li, NH_3 and salinity relative to other basin waters. The Na-K-Ca emperical geothermometer of Fournier and Truesdell (1973) has been applied to the reservoir water from geothermal wells 54-3 and 3-1, Roosevelt Hot Springs water, and present surface water discharging near the old hot springs (Table 3). There is close agreement (within 10%) between the calculated reservoir temperatures and the reservoir temperatures measured in the wells.

ROOSEVELT HOT SPRINGS UNIT AGREEMENT

Efforts to unitize the Roosevelt Hot Springs reservoir have been successful. The

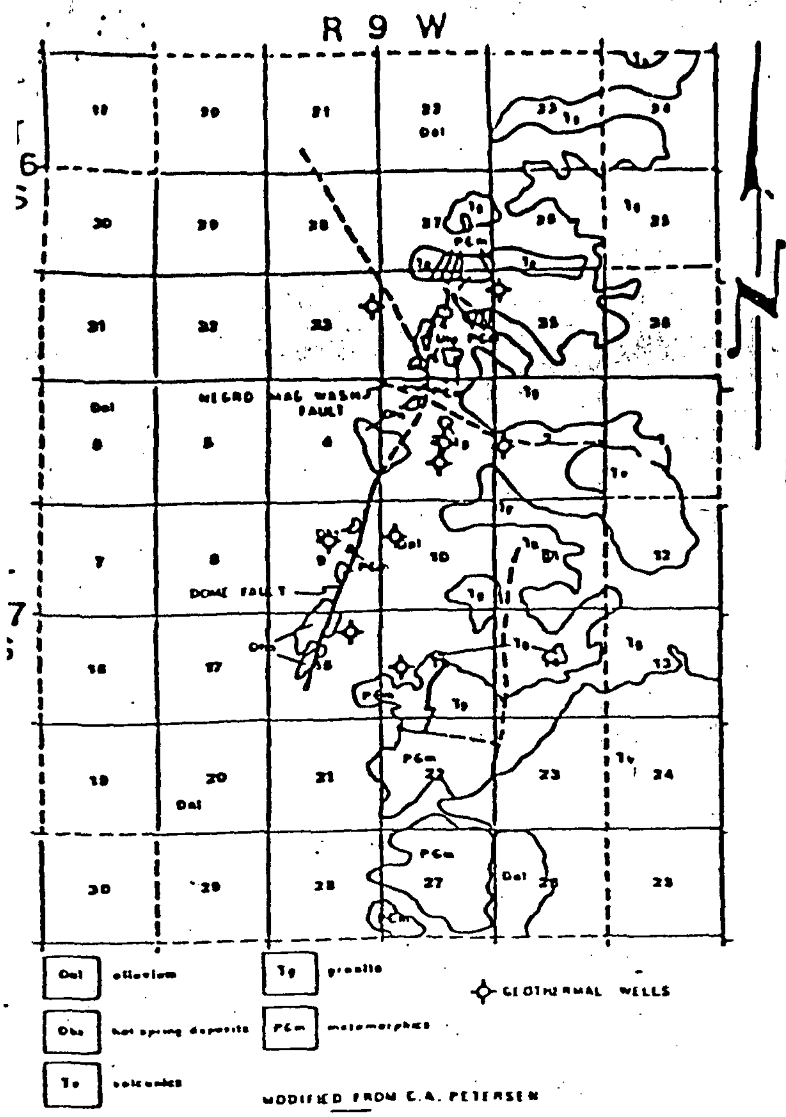


Fig. 4. Geologic Map of the Roosevelt Hot Springs area. Modified after Petersen, 1974.

purpose of forming a geothermal unit is for the same purposes as unitization in oil and gas exploration, and that is the efficient and economic development of the resource. A unit accomplishes this by eliminating lease lines, allowing the field to be developed in the most prudent manner; offset situations are thereby avoided.

The Roosevelt Hot Springs Unit is the first approved Federal geothermal unit in the United States. The unit area is shown in Fig. 7. The formation of any unit can be an extremely involved process, and the Roosevelt Unit, being the first of its kind, took well over a year to write and to receive final approval. The Federal geothermal unit agreement, which states the regulations regarding unit operation, was derived from the basic Federal oil and gas unit agreement. If more than one party holds land in the area to be unitized, as is the case at Roosevelt, a Unit Operating Agreement setting forth the operating conditions must be agreed upon by the different parties.

The fact that the geothermal reservoir at Roosevelt is contained in fractures and the distribution of fractures can be highly erratic led to the adoption of a divided type unit on a tract basis. Under this system, costs and production are apportioned to each party based on the amount of their acreage included within a participating area, and entrance into a participating area is gained by drilling a production well. Each well drilled is credited with a certain amount of acreage which, if the well is a producer, is then included within the participating area. Dry holes do not count and acreage credited to them is not included in a participating area.

WATER APPROPRIATION PROCEEDING

Everyone desiring to develop geothermal resources in Utah is faced with the same problem and that is the appropriation of water necessary to run the power plant. This holds true even if the resource to be developed is on Federal lands, for in the state of Utah, all waters within the state are public property. The basis for granting a water right in Utah is that the water shall be put to beneficial use. Phillips has taken steps to appropriate the necessary water by submitting applications to the State Engineer. The notices of application were published, protests were filed, and a public hearing before the State Engineer was held in Beaver, Utah, in April 1976 to consider the applications. For the State Engineer to approve any application, the following requirements must be met: (1) There is unappropriate water in the proposed source. (2) The proposed use will not impare existing rights, or interfere with more beneficial use of the water. (3) The proposed plan is physically and economically feasible and would not prove detrimental to the public welfare. (4) The applicant has the financial ability to complete the proposed works and the application has been filed in good faith and not for purposes of speculation or monopoly. At the hearing specific testimony was present to meet each of these specific requirements.

As a result of the geothermal discovery and the concern of existing water users in

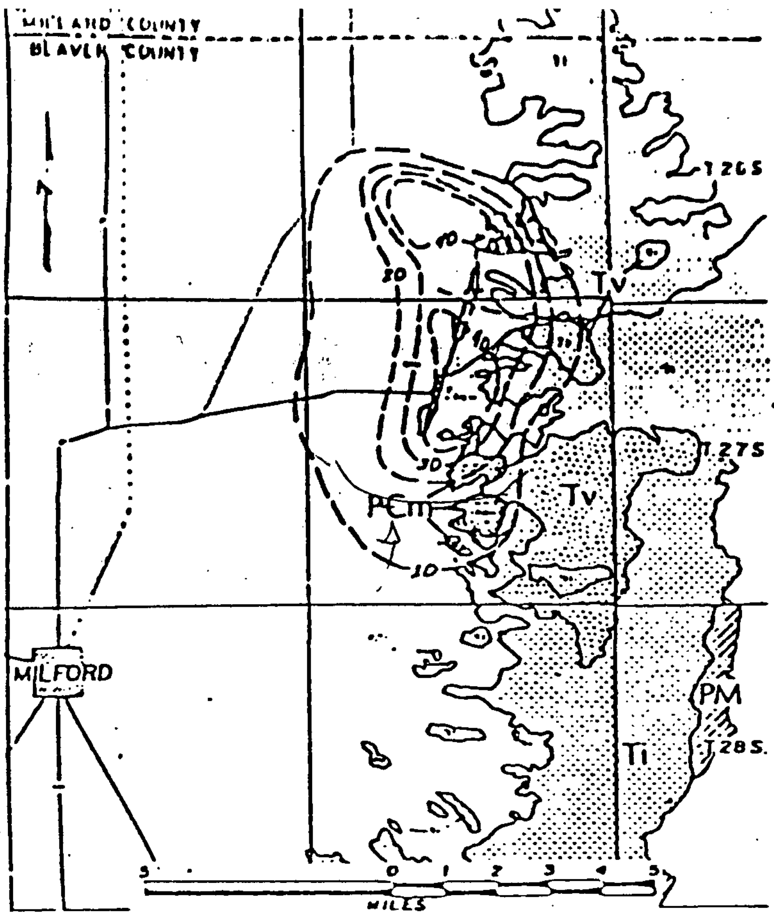


Fig. 5. Temperature gradients in the Roosevelt Hot Springs area. Contour Interval is 10°C/100m (Includes data from Petersen, 1975 and Whelan, 1976, personal communication).

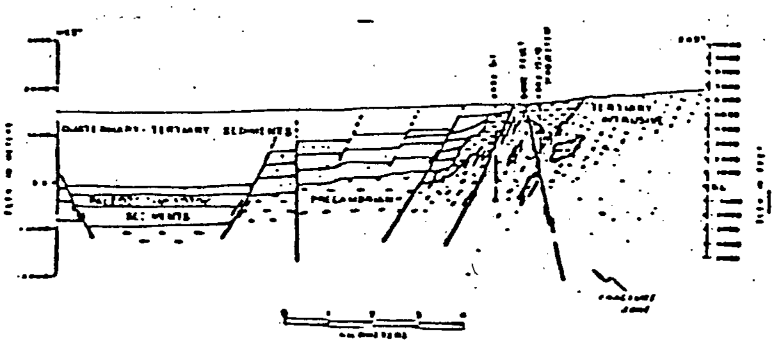


Fig. 6. Generalized Structure section through Well No. 9-1.

cation with the USGS Water Resources Division. At present, the system includes six stock wells, the Roosevelt seep, four water observation wells specifically drilled by Phillips for monitoring purposes, and one stratigraphic test hole modified to act as a water observation well (Fig. 8). The Phillips' wells are located between the geothermal wells and the existing water users points of diversion and penetrate the same reservoir utilized by the ranchers and farmers in the valley. The well sites were located far from existing irrigation wells to minimize or eliminate the effect that present pumping in the irrigation district might have on the water table at the monitoring sites.

The system is an early warning system designed to detect any effect that testing or production would have on existing water users source of supply. Additional monitoring points will be added to the system as necessary.

EXPLORATION ACTIVITY

Most recently, exploration activity at Roosevelt has consisted of drilling several 2000 foot observation holes or deep temperature gradient holes. These have been drilled to test certain ideas concerning the Roosevelt geothermal system. This intermediate depth drilling step has proven extremely valuable in evaluating other prospects.

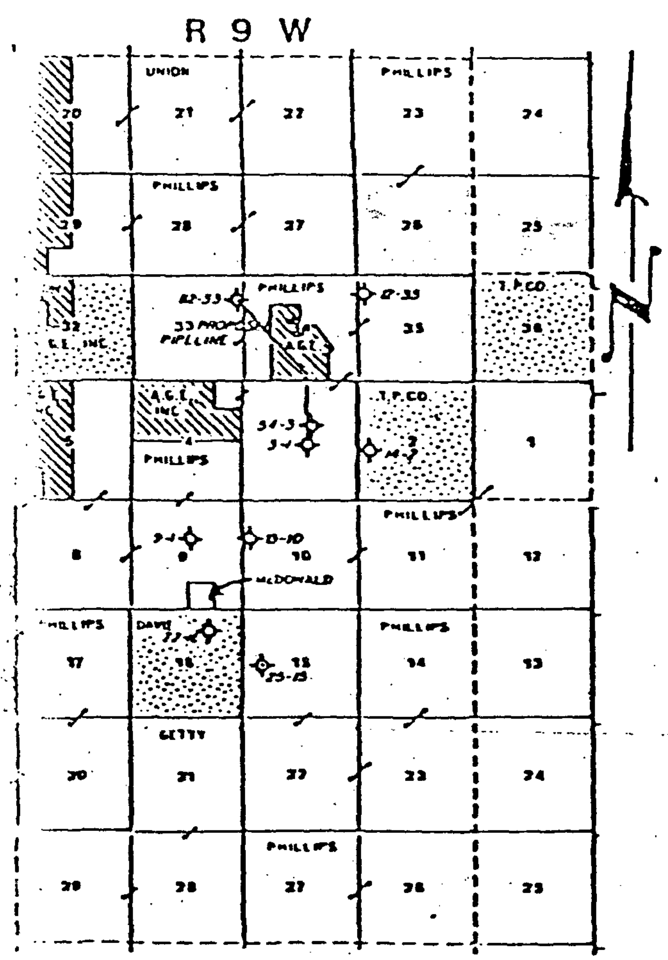
The chief benefit of drilling a 2000 foot observation hole is the large quantity of information obtained for a relatively low cost. Our average drilling cost is less than $50,000, which is 1/10 that of drilling an exploration well to 6000 feet. Information generated by drilling these holes includes the following: temperature gradients, stratigraphy, hydrology, alteration, drilling problems and structure. These holes are particularly useful in minimizing the risk in picking the proper spot to drill an exploration well. Such a hole might be drilled if it were suspected that the thermal anomaly might be caused by lateral movement of warm waters below depths reached by shallow temperature gradient holes.

ENGINEERING

The engineering program at Roosevelt is a multipurpose program designed (1) to gain experience, (2) to determine the production capabilities of each well drilled, and (3) to characterize the reservoir. Testing has been limited to short term flow tests of about two days duration on the production wells. The longest test was a 3.9 day flow of Well 54-3. With tests of such short duration, we have not reached all our objectives. We have gained invaluable experience and confidence in operating equipment and in interpreting the results and we have been successful in determining each well's capabilities. Two systems have been used for testing. The initial testing at Well 54-3 used

Table 2. Exploratory Geothermal Wells & Stratigraphic Test Holes, Roosevelt KGRA Utah.

Location	Operator	Well	Status	Depth
NW Sec. 10, T.27S., R.9W.	Phillips Petroleum Co.	O.H. 2	Abandoned 1975	2250'
SE NE Sec. 17, T.27S., R.9W.	Phillips Petroleum Co.	O.H. 1	Idle-Strat Test	—
NE NW Sec. 9, T.27S., R.9W.	Phillips Petroleum Co.	Roosevelt KGRA 9-1	Idle Dry Hole	6885'
NE Sec. 3, T.27S., R.9W.	Phillips Petroleum Co.	Roosevelt KGRA 3-1	Idle	2724'
NE Sec. 3, T.27S., R.9W.	Phillips Petroleum Co.	Roosevelt KGRA 54-3	Idle	2882'
NW Sec. 35, T.26S., R.9W.	Phillips Petroleum Co.	Roosevelt KGRA 12-35	Idle	—
NW Sec. 10, T.27S., R.5W.	Phillips Petroleum Co.	Roosevelt KGRA 13-10	Idle	—
NE NE Sec. 33, T.26S., R.9W.	Phillips Petroleum Co.	Roosevelt KGRA 82-33	Idle Disposal	—
SW NW Sec. 2, T.27S., R.9W.	Thermal Power-Natomas	Utah State 14-2	Idle	6108'
NW SW Sec. 15, T.27S., R.9W.	Phillips Petroleum Co.	Roosevelt HSU 25-15	Idle	—
NW NE Sec. 16, T.27S., R.9W.	Thermal Power-Natomas-O'Brien	Utah State 72-16	Testing	1254'
NE NW Sec. 33, T.26S., R.9W.	Phillips Petroleum Co.	O.H. 4	Idle-Strat Test	—
SE NE Sec. 28, T.26S., R.9W.	Phillips Petroleum Co.	O.H. 5	Drilling Strat-Test	—



...sevelt Hot Springs Unit Area.

for testing. The initial testing at Well 54-3 used a separator to separate liquid and vapor phases so they could each be measured separately. The separator has a capacity of 1 million pounds per hour of total mass flow and it proved to be inadequate to handle the maximum well flow. At the other production wells, flow has been measured using Russell James (1966) method of steam-water measurement employing an orifice plate and a lip critical pressure measuring device.

The limiting factor on the duration of the flow tests is the disposal of the produced liquids. At present the reserve pits adjacent to the wells are used to contain the test fluids. During the 3.5 day flow test of Well 54-3, the liquids produced were discharged into the natural drainage system. It was an experiment designed to measure the effect that reservoir fluids would have on the native vegetation, and was allowed to proceed because the shallow groundwater in the area is similar in quality to the reservoir fluids. The discharge pipe was buried beneath riprap in the center of a large wash. After the test gullying was noted below the outlet pipe for several 100 feet downstream. A second result was the death of trees immediately adjacent to the channel, but not all

TABLE 3.

SELICTED WATCH ANALYSES of ROOSLVLLT KGHA

	[illegible]	[illegible]	[illegible]	[illegible]	54-3	3-1
Date	11-4-50	9-11-57	5-9-73	8-15-75	8-26-75	5-25-75
Temperature (°C)	85	56	17	28	1 760	1 205
Silica (ppm)	405	343	76	107	560+	560?
Calcium (ppm)	10	22	113	107	101	80
Magnesium (ppm)	33	0	17	236	074	001
Sodium (ppm)	2080	2300	2400	1800	2000	2437
Potassium (ppm)	472	488	378	280	410	448
Bicarbonate (ppm)	150	150	536	300	200	180
Sulfate (ppm)	65	73	147	70	54	59
Chloride (ppm)	3850	4240	3400	3200	3400	4090
Fluoride (ppm)	71	75	52	53	50	50
Nitrate (ppm)	19	11	TR	TR	TR	01
Boron (ppm)	–	38	37	29	29	25
Lithium (ppm)	–	027	–	17	190	200
TDS (ppm)	7040	7800	7506	5948	6442	7067
pH	–	7.9	8.2	6.43	6.5	6.3
T Na-K-Ca	295	285	247	239	294	273
T SiO2	307	282	250	248	290	294

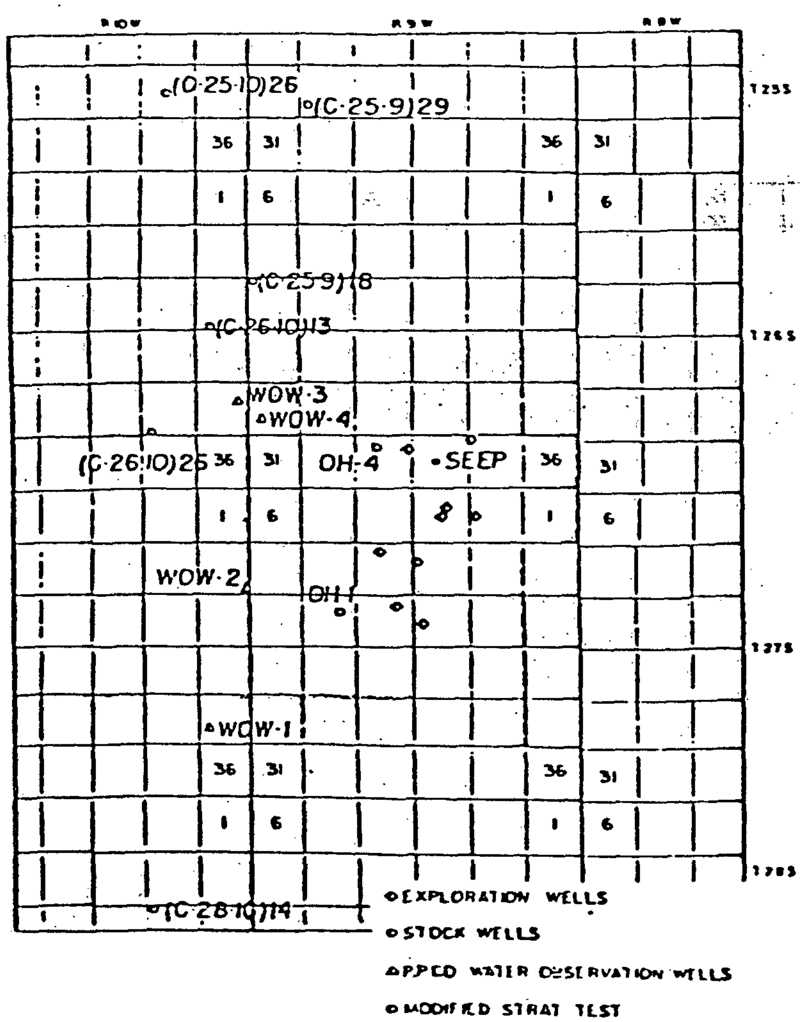


Fig. 8. Water Observation Well System in the area of the Roosevelt Hot Springs Unit.

check indicates that dead trees are juniper trees, but healthy pine trees are found next to dead junipers. A detailed study of the effect which this test has had on the environment has not yet been made, and until it is, it is unlikely that any further surface disposal will be permitted.

In order to acquire needed reservoir data, there is in preparation a plan for a long term flow test. The proposal calls for flow-testing Well 54-3 for a sustained period of up to six months to determine reservoir size and production characteristics.

The fluids produced at Well 54-3 will be piped through a centrifugal steam/water separator at the well site where the steam portion will be vented in the pit through an existing muffler. It will be necessary to construct approximately 1.4 miles of 10" pipe to connect Well 54-3 to Well 82-33 (Fig. 7). Well 82-33 will function as an injection well during the reservoir tests. The liquid portion from Well 54-3 will be piped to Well 82-33 using the produced pressure for injection into the well.

ACKNOWLEDGMENTS

The writers wish to acknowledge the contributions of Stuart Johnson, Robert Wright and Joe Beall in all phases of the exploration at Roosevelt. Permission to publish the paper has been generously granted by Phillips Petroleum Company.

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