3202

Geoscience Interpretations of the Raft River Resource

by
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In 1973, at the peak of the Arab oil embargo, the United States began to take a serious look at alternative energy sources. One area of investigation was a study by the U.S. Geological Survey (USGS) of a geothermal resource in southern Idaho near the northeastern extreme of the Basin and Range Province. Here they observed two artesian water wells in the southern Raft River valley with water temperatures of 194° and 199.4°F. The aquifer temperature, inferred from silica and Na-K-Ca geothermometers, ranged from 275°-293°F.

A cooperative program was initiated in 1973 by the USGS and the Energy Research and Development Administration (ERDA, now the Department of Energy, DOE), to evaluate the feasibility of using the Raft River resource to demonstrate the production of electricity from moderate-temperature water. Over the next few years, the USGS made a series of geological, hydrological, and geophysical studies, supported by shallow and intermediate-depth drilling (up to 1475 ft) to evaluate the resource. As these studies (documented in numerous USGS open-file reports) progressed, it became clear that the geology of the southern Raft River valley is quite complex. The purpose of this paper is to discuss this geology and the wellfield development that followed.

Geological Setting

The geothermal resource is located in a downdropped and downwarped basin bordered on east, west, and south by mountain ranges that vary in both stratigraphy and structure. The stratigraphy in the basin consists of sediments derived from the surrounding ranges, overlying a series of Precambrian metasediments and the Adamellite basement rock. The upper sediments consist of the Quaternary Raft Formation, fluvial and alluvial sediments up to 985 ft thick; and the Tertiary Salt Lake Formation, a lacustrine deposit of tuffaceous sand, silt, and conglomerate, approximately 5250 ft thick. The Precambrian metasediments, primarily quartzites and schists, and the Precambrian Adamellite basement rock are found in the Raft River Range where the metasediments form allochthonous sheets thrusted along low angle faults overlying the Adamellite core.

The eastern boundary of the basin is formed by the downwarped flank of the Black Pine Mountains with secondary normal faulting. The western boundary of the basin is downdropped along a series of listric normal faults called the Horse Well Fault and the Bridge Fault. The Bridge Fault strikes north-south and extends from the south end of the Jim Sage Mountains, northward to the east side of Sheep Mountain (Figure 1). The fault plane has a 60-80° dip at the surface, flattening to parallel the metasediments at depth (Figure 2). Numerous vertical fractures extend into the basin sediments from these faults (Covington, 1980).

A poorly understood structural lineament, called the Narrows Zone, extends through the Narrows at the south end of the Jim Sage Mountains and strikes to the northeast (Figure 1). This feature is identified by geophysical surveys, and is thought to be a basement shear possibly related to the Humboldt Zone of northern Nevada (Mabey, 1978). The

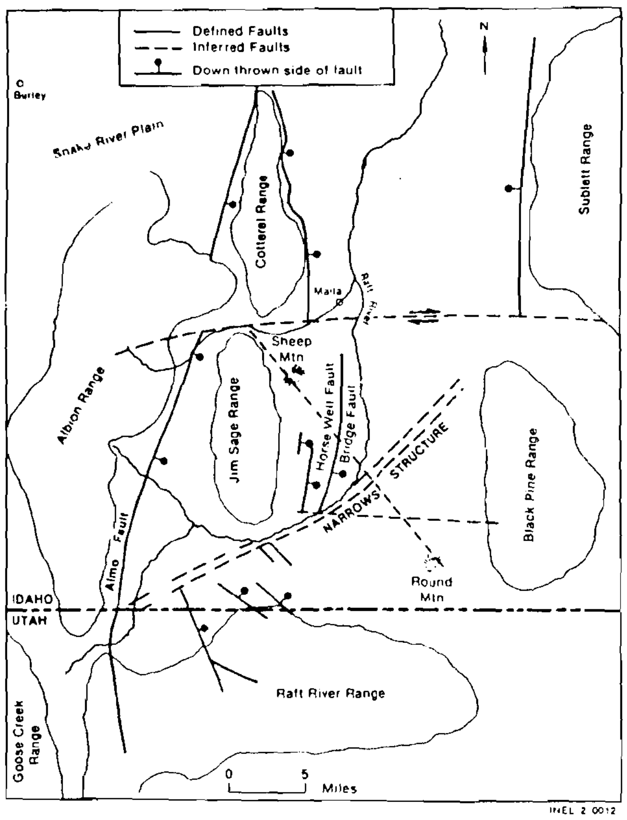

Figure 1. Major structural features of the southern Raft River Valley.

Vol. 11, no. 2

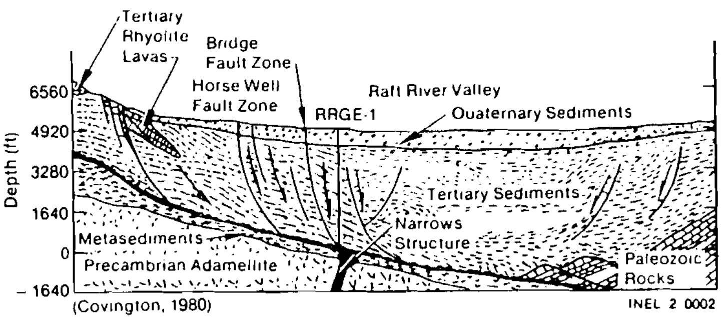

Figure 2. Cross-sectional view of major structures across the Raft River KGRA.

southernmost end of the Bridge and Horse Well faults terminate against the Narrows Zone.

Although the intersection of the Bridge Fault and the Narrows Zone is the locus of the geothermal reservoir, there are other inferred structural lineaments within the basin. One lineament (Figure 1) extends to the northwest through Round Mountain (on the southeast) and Sheep Mountain (on the northwest). Both Round Mountain and Sheep Mountain are rhyolite domes age-dated at 8.3 ± 1.7 and 8.42 ± 0.2 m.y., respectively. Several smaller rhyolite bodies have been mapped to the northwest of Sheep Mountain.

A second lineament strikes east-west across the basin extending into Kelsaw Canyon in the Black Pine Mountains (Figure 1). This lineament is identified by anomalies found in chemical modeling (Overton et al., 1978) and on the SP survey (Williams et al., 1974), both oriented east-west, by the east-west orientation of the vertical fractures produced during stimulation of Raft River Geothermal Production - 4 (RRGP-4), and by a distinct lineament observed on aerial photographs extending to the east through the Black Pine Mountains.

It is inferred that the geothermal resource at Raft River occurs where hydrothermal water rises at the intersection of and along the Narrows Zone and the Bridge Fault. The hydrothermal water spreads laterally into the Salt Lake Formation along porous zones in the sediments, and along soft-sediment fractures. Upward leakage of the resource provides hydrothermal water to the shallow wells in the valley.

Well Field Development

Three exploration wells, two development wells, and two injection wells were drilled at Raft River between 1974 and 1978. The basic strategy of field development was to drill deep production wells on the faulted northwest side of the field and injection wells to an intermediate depth on the southeast side of the field (see Figure 3). The following is a summarized history of well development.

The Raft River Geothermal Exploration No. 1 well (RRGE-1) was designed to confirm the existence of the geothermal reservoir. It was spudded between the two shallow boiling wells to intersect the Bridge Fault at depth (Figure 3). The well was completed on April 1, 1975 to a total depth (TD) of 4989 ft, open-

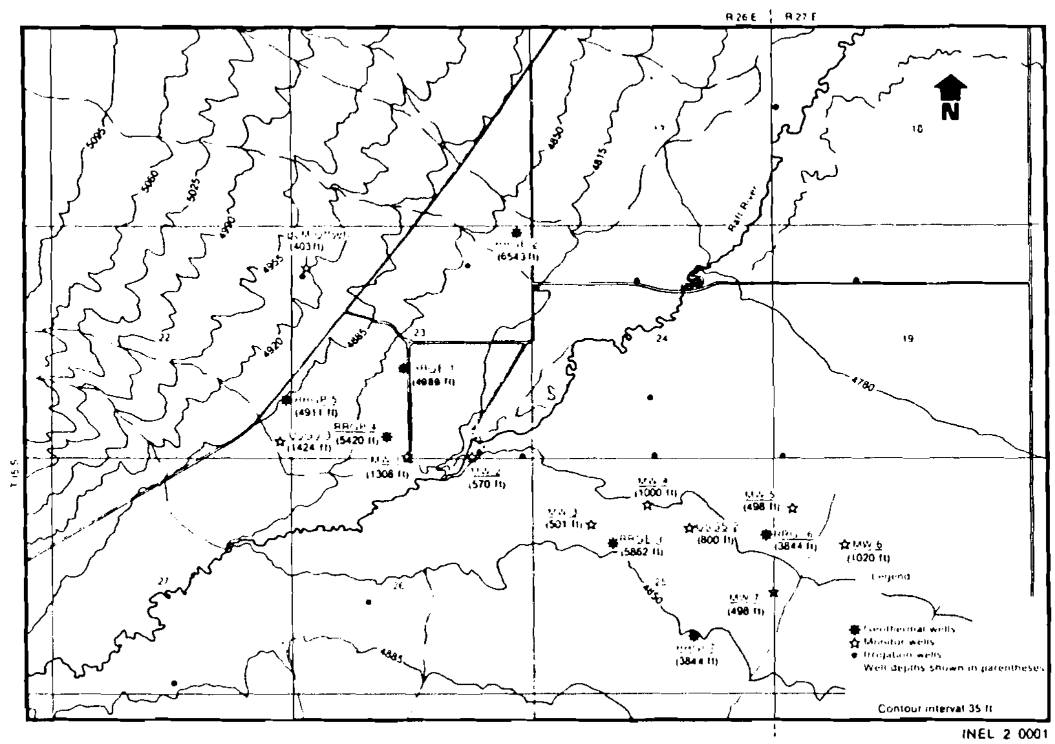

Figure 3. Raft River Well Field.

hole from 3621 ft to TD. The well intersected 4578 ft of the Raft River and Salt Lake Formations, 116 ft of the Precambrian metasediments, and bottomed in the basement Adamellite. A bottomhole temperature of 291°F verified the existence of a moderate-temperature hydrothermal resource of low-salinity fluid. The major artesian production zone in this well (3700 to 4500 ft) is near the base of the Salt Lake Formation in highly fractured rock (Dolenc et al., 1981).

Well RRGE-2 was spudded to the northeast of RRGE-1 on April 26, 1975 (Figure 3), also to intersect the Bridge Fault at depth. It was completed June 26, 1975 to a depth of 6006 ft, over 1000 ft into the Precambrian Adamellite. The well was cased to 4224 ft, and left open-hole through the production zone (4250 to 4800 ft). After testing both deep wells, RRGE-2 was deepened (on the recommendation of the USGS) in March 1976 to a TD of 6543 ft. No major fractured intervals were observed in the Adamellite basement rock during the deepening operation. The major production zone is in fractured rocks at the base of the Salt Lake Formation and the top of the metasediments (Dolenc et al., 1981).

Upon completion of RRGE-2, the rig was moved to a location 9000 ft to the southeast. This exploratory well location was recommended by the USGS to determine if the resource extended outside the known fault zones into the center of the valley. At this location, RRGE-3 was spudded on March 28, 1976 with plans to drill a three-legged well (Figure 3). This well was cased to 4234 ft, and left open-hole in all three legs. The deepest leg, drilled to the north to a depth of 5919 ft, encountered the highest flow rate. The maximum bottomhole temperature was 302°F. The well was completed on June 7, 1976.

RRGI-4 was spudded to the south of RRGE-1 April 8, 1977 (Figure 3). It was drilled for use as an experimental injection well to a depth of 2840 ft in the Salt Lake Formation. Near the bottom of the well, two joints of casing, the casing shoe and float collar, parted and could not be recovered. The bit and drill string were capable of passing through the parted casing, and the well was completed (with the fish in the hole) on May 4, 1977. Injection testing of this well resulted in a pressure response in nearby monitor wells which suggested that long-term injection into RRGI-4 might result in a major impact on near-surface aquifers.

RRGI-6, designed for injection into the intermediate zone, was spudded April 12, 1978 and completed May 3, 1978 to a TD of 3844 ft (Figure 3). The well was cased to 1685 ft and left open-hole from there to total depth in the Salt Lake Formation (Dolenc et al., 1981).

RRGP-5 was spudded on the northwest edge of the well field, near the surface exposures of the Bridge Fault, on May 7, 1978 (Figure 3). On June 17, drilling reached a depth of 4911 ft, where the drill pipe twisted off. Fishing attempts required the use of a salt "kill" fluid to control the artesian flow. Upon recovery of the drill pipe, salt was flushed from the wellbore to avoid contamination of near-surface aquifers. The rig was moved to drill RRGI-7 while this flush was in progress.

RRGI-7, designed for injection, was spudded 2300 ft southwest of RRGI-6 on July 14, 1978 (Figure 3). The well was drilled to a TD of 3844 ft and completed on August 3, 1978. The well is cased to a depth of 2030 ft and is open-hole from there to TD (Dolenc et al., 1981). Both RRGI-6 and RRGI-7 were drilled in this area to avoid short-circuiting the production zone on the north side of the field.

Upon completion of RRGI-7, the rig was moved back to RRGP-5 to case and complete the well. Difficulty in drilling through a cement plug resulted in a deviated hole near the bottom of the wellbore. The well was cased to a depth of 3408 ft, and drilled to a TD of 4910 ft. Disappointing flows from the deviated wellbore suggested that cement had penetrated into the fractured zones of the original hole.

Deep drilling activity at Raft River was concluded in late 1978 with the deepening of RRGI-4 into a production well, hereafter referred to as RRGP-4. Spudded September 21, 1978, RRGP-4 was cased to 3457 ft and drilled as a two-legged well. Total depth of the deepest leg was 5420 ft. The well was completed on November 15, 1978.

Stimulation

Due to very disappointing flows in RRGP-4 and RRGP-5, discussions were initiated in the spring of 1979 with DOE officials and Republic Geothermal, Inc. (RGI, Santa Fe Springs, CA) to consider these two wells in the DOE National Geothermal Well Stimulation Program (BULLETIN, Vol. 8, No. 8, August 1979). Because of the relatively low-temperature environment of these wells, they provided an excellent starting point for the program. As a result, in August 1979 Leg B of RRGP-4 was selected as the first candidate for a massive hydraulic fracture. A four-stage "Kiel" dendritic treatment was used on this stimulation, the first known stimulation of a geothermal well in the United States. A liner was set to 4705 ft, and the hole sanded off from 4900 ft to TD. The pump job, performed on August 20, 1979, employed 7900 barrels of a light polymer gel (guar) pumped at a rate of 50 BPM. The treatment included 50,400 lbs of 100-mesh sand and 58,000 lbs of 20-40 mesh proppant. Post-treatment, the USGS, using a borehole televiewer, observed a near vertical, east-west oriented fracture. Although a flow test indicated a five-fold increase over the pre-stimulation flow rate (Campbell et al., 1981), the well remains subcommercial and is not currently used for production.

RRGP-5 was stimulated on November 11, 1979, using a conventional planar massive hydraulic fracture. Pretreatment isolation of the fracture zone involved the setting of a 7-in liner to 4586 ft and sanding off the well from 4800 ft to TD. The massive hydraulic fracture employed 7600 barrels of guar with 84,000 lbs of 100-mesh sand and 347,000 lbs of 20-40 mesh proppant. A borehole televiewer analysis by the USGS showed a near-vertical, northeast-southwest oriented fracture. The flow rate increased only slightly (Campbell et al., 1981).

Conclusions

The Raft River resource has been developed to supply geothermal fluids to the Raft River 5 MW(e) Power Plant. Four wells, RRGE-1, RRGE-2, RRGE-3, and RRGP-5, are employed as production wells. RRGI-6 and RRGI-7 are used to inject the spent fluids. RRGP-4 has never been connected to the nearly three miles of interconnected production pipelines because of low artesian flow rates.

This section was designed to describe the early history of developing the resource and well field. Additional material on the power plant, the well productivities, and the injection system will be described in other papers appearing in this BULLETIN.

References

1. D.A. Campbell et al., "A Review of the Geothermal Reservoir Well Stimulation Program, in Proceedings of the International Conference on Geothermal Drilling and Completion Technology," Albuquerque, New Mexico, Jan. 21-23, 1981.
2. H.R. Covington, "Subsurface Geology of the Raft River Geothermal Area, Idaho, in Geothermal Resources Council, Transactions," Vol. 4, September 1980.
3. M.R. Dolenc et al., "Raft River Geoscience Case Study," EG&G-2125, 1981.
4. D.R. Mabey et al., "Reconnaissance Geophysical Studies of the Geothermal System in Southern Raft River Valley, Idaho," Geophysics, Vol. 43, No. 7, December 1978.

5 MW(e) Raft River Pilot Plant Description and Operation

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Introduction

The Idaho National Engineering Laboratory geothermal programs have been focused toward the utilization of low- and moderate-temperature hydrothermal resources. A major portion of this work has been the design and construction of a binary cycle pilot plant with a nominal rating of 5 MW(e) located in the Raft River valley of southern Idaho. This plant utilizes state-of-the-art components, but employs a dual-boiling power cycle using isobutane as the working fluid. The plant is designed to take advantage of the low average ambient temperature. In addition to normal process instrumentation, some of the large heat exchangers contain special instrumentation to obtain performance data. Treated geothermal water is used for plant heat rejection in the cooling towers.

Three pumped production wells supply the geothermal fluid to the plant. Two injection wells are used to dispose of this fluid. The first startup of the pilot plant occurred during the week of October 20, 1981, at which time it was brought up to its full thermal power of 45 MW(t). The generator was synchronized with the system and run at about 1 MW(e) output on October 31, 1981. The plant is now shut down until spring when a complete series of engineering tests will be performed.

This paper provides a review of the pilot plant and the supply and injection systems, as well as a "quick look" at the startup results.

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Project Objective

The principal objective of the pilot plant is to demonstrate the technical feasibility of generating electric power from a moderate-temperature (285°F) geothermal resource in an environmentally acceptable manner. Specific technical objectives of the project are: (1) establish the actual performance of an organic Rankine cycle using state-of-the-art components, (2) obtain realistic cost data from which commercial conversion costs can be predicted, (3) gather data on reservoir productivity and longevity, (4) identify operating problems so that solutions can be addressed, (5) evaluate hardware performance, (6) determine maintenance requirements and procedures, and (7) ensure that there are no unacceptable environmental impacts from using geothermal fluids for power generation.

Review of Plant Design

The original design was for a thermal loop with a thermal rating of 45 MW(t). The design was later modified to include a turbine generator with a nominal electrical rating of 5 MW(e). The following gives a brief review of the plant.

Power Cycle Selection and Description

A variety of working fluids and cycles were initially studied for moderate-temperature power generating applications. These initial performance studies have shown that in the moderate-temperature range, the dual-boiling cycle results in better geofluid utilization than the