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Acord 1-26 Hot, Dry Well, Roosevelt Hot Springs Hot Dry Rock Prospect, Utah

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DISCLAIMER

ACORD 1-26 HOT, DRY WELL, ROOSEVELT HOT SPRINGS HOT DRY ROCK PROSPECT, UTAH

by

Spencer S. Shannon, Jr., Roland Pettitt, John Rowley, Fraser Goff, Mark Mathews, and Jimmy J. Jacobson

ABSTRACT

The Acord 1-26 well is a hot, dry well peripheral to the Roosevelt Hot Springs known geothermal resource area (KGRA) in southwestern Utah. The bottom-hole temperature in this 3854-m-deep well is 230°C, and the thermal gradient is 54°C/km. The basal 685 m, comprised of biotite monzonite and quartz schist and gneiss, is a likely hot, dry rock (HDR) prospect. The hole was drilled in a structural low within the Milford Valley graben and is separated from the Roosevelt KGRA to the east by the Opal Mound Fault and other basin faults. An interpretation of seismic data approximates the subsurface structure around the well using the lithology in the Acord 1-26 well. The hole was drilled with a minimum of difficulty, and casing was set to 2411 m. From drilling and geophysical logs, it is deduced that the subsurface blocks of crystalline rock in the vicinity of the Acord 1-26 well are tight, dry, shallow, impermeable, and very hot. A hydraulic fracture test of the crystalline rocks below 3170 m is recommended. Various downhole tools and techniques could be tested in promising HDR regimes within the Acord 1-26 well.

I. INTRODUCTION

This report documents a hot, dry well near the margin of a known geothermal resource area (KGRA) in southwestern Utah. The intent is stimulation of interest in the development of additional sites for the generation of electricity from hot, dry rock (HDR).

The Acord 1-26 well is one of four hot, dry wells drilled around the western periphery of the production zone of the Roosevelt Hot Springs geothermal unit, Utah (Fig. 1). Because the Roosevelt Hot Springs area is

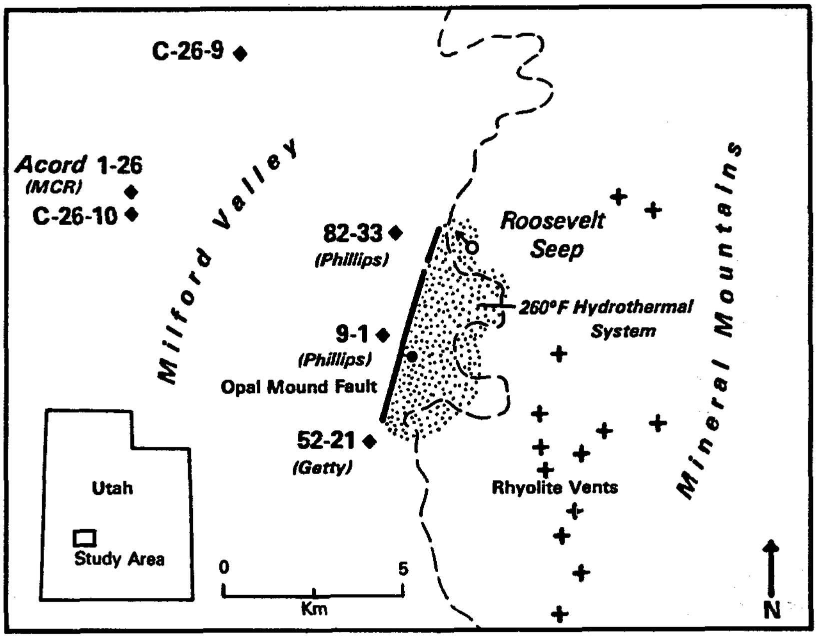


Fig. 1.
Location map of Roosevelt Hot Springs area, Utah, showing Opal Mound Fault, geothermal production zone, four hot, dry wells, and shallow, stock wells.

known to have high temperatures in impermeable crystalline basement rocks at relatively shallow depths, it has been the subject of several Los Alamos investigations on HDR (East 1981; Goff and Decker 1983; F. D. Vuataz and F. Goff, unpub. data, 1983).

II. SETTING

The Acord 1-26 hot, dry well was drilled in spring 1979 by McCullough Geothermal Corporation in C, SW 1/4 sec. 26, T. 26 S., R. 10 W., Salt Lake Meridian. This site is in Beaver County, Utah, approximately 15 km north-northeast of Milford and 8 km west-northwest of the Roosevelt Hot Springs geothermal field. The well site is 3.6 km east of a paved highway and 3.2 km east of a main line of the Union Pacific Railroad. Local relief is low where the well is collared in lake sediments in Milford Valley. The well has a depth of 3.85 km and a recorded bottom-hole temperature of 230°C.

East (1981) has prepared a detailed discussion of the regional geological and geophysical setting of the Roosevelt Hot Springs area including the Acord 1-26 well, which is on the periphery of this KGRA. The following generalizations are derived from her paper.

The Milford Valley and adjoining Roosevelt Hot Springs are in the transition zone between the Basin and Range and Colorado Plateau provinces. Within this zone the crust is only 25 km thick and the P_n velocity is only 7.5 km/s. The depth of the crustal low-velocity layer in the transition zone varies from 8 to 15 km. The area of interest is near the western edge of the Intermountain seismic belt where its trend turns from northeast to north.

Typically, heat flow averages 2.2 heat-flow units (HFU) in the Basin and Range province and only 1.2 HFU in the Colorado Plateau province. However, the high heat-flow characteristic of the Basin and Range province extends eastward beyond the provincial boundary. Futhermore, the Acord 1-26 well and the Roosevelt Hot Springs area are along the margin of the southern region of elevated heat flow where values typically are 2.5 HFU.

The Roosevelt Hot Springs hydrothermal system circulates in a faulted graben east of the Opal Mound (Dome) Fault (Fig. 1) at temperatures of 260 to 320°C. Although the regional heat flow is high, local heat sources as indicated by basaltic cinder cones north of Roosevelt Hot Springs, are also present as young as 0.1 Myr. Also 0.8-to-0.5-Myr rhyolitic magma erupted from a chain of vents along the axis of the Mineral Mountains to the east. Thus, the thermal anomaly and hydrothermal system may be driven partially by Quaternary volcanic processes.

III. GEOLOGY

In stratigraphic succession, the geology of the Acord well includes 30 m of metamorphic rocks, 655 m of plutonic rocks, 700 m of coarse sedimentary rocks, 315 m of volcanic rocks, and 2155 m of sedimentary rocks and sediments (Fig. 2).

The bottom 30 m comprise white to dark-gray migmatitic quartz schist and gneiss containing abundant potassium feldspar, plagioclase, biotite, and muscovite. Locally the rock is altered to chlorite or epidote. This could be a major inclusion in the monzonite pluton described next.

Above the schist and gneiss are 655 m of white to green propylitized biotite monzonite. Some fragments of biotite-chlorite schist remain 6 to 9 m above the base of the plutonic rock and a residual block of light-orange quartzite is 18 to 20 m higher in the section. Also, a 4-m-thick bed of light orange-pink quartzite occurs 90 m above the base of the plutonic rock.

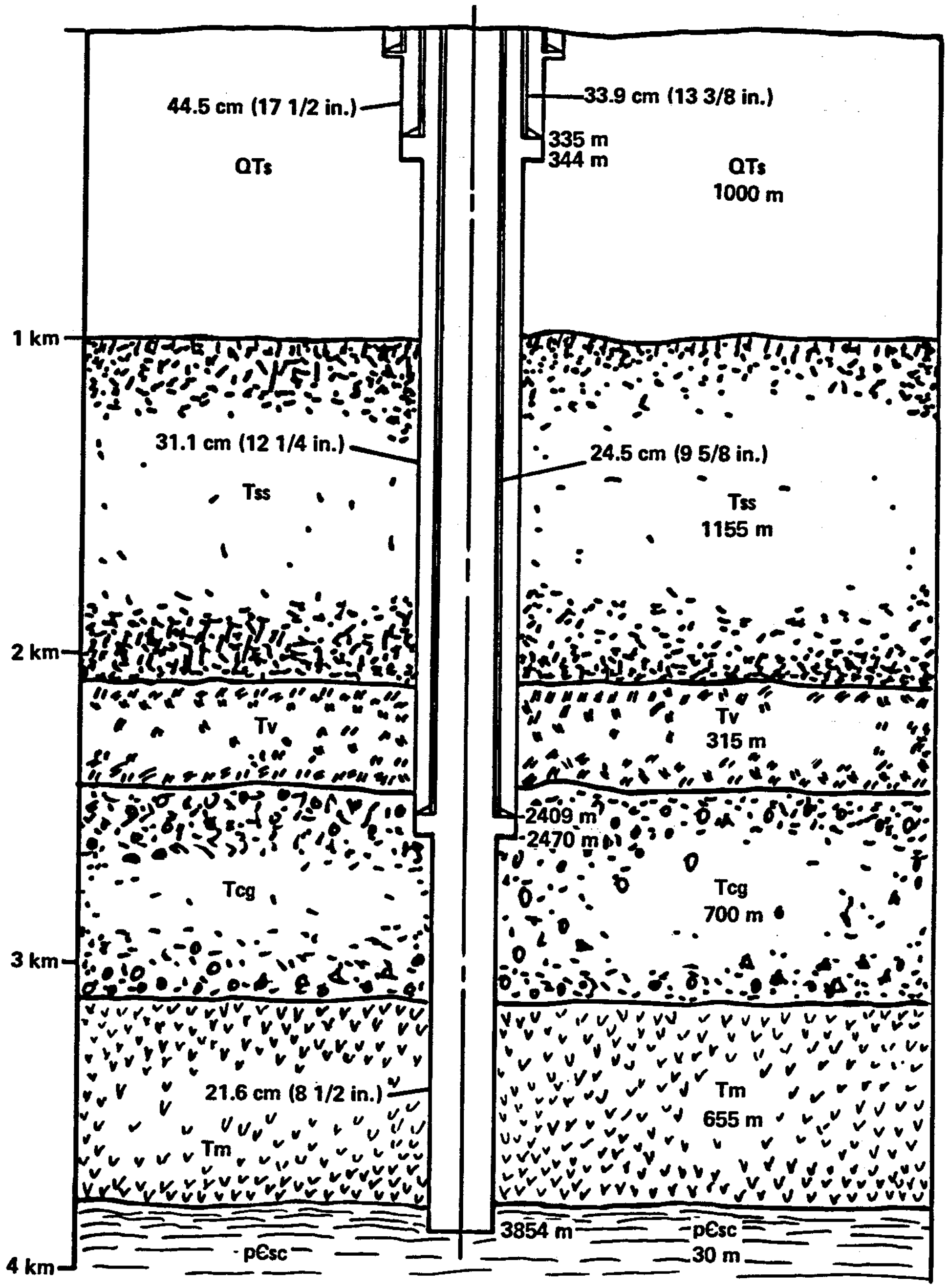


Fig. 2.
Generalized stratigraphy of an east-west section through the Milford Valley.

The 700-m interval above the quartz monzonite pluton is made up of conglomerate and some sandstone. The clasts in the basal 135 m of the conglomerate are composed chiefly of chloritized white to green volcanic rock and gray-brown siltstone. The remainder of this section contains clasts of light-green sandstone, reddish-brown volcanic rock (chiefly altered basalt), and a small amount of light-brown dolomite.

A suite of volcanic rocks follow, which has a total thickness of 315 m. The basal unit is 73 m of basalt containing amygdaloidal epidote. Above this, in turn, are 58 m of light-pink porphyritic rhyolite, 150 m of medium-gray to reddish-brown dacite, and 34 m of dark-gray andesite.

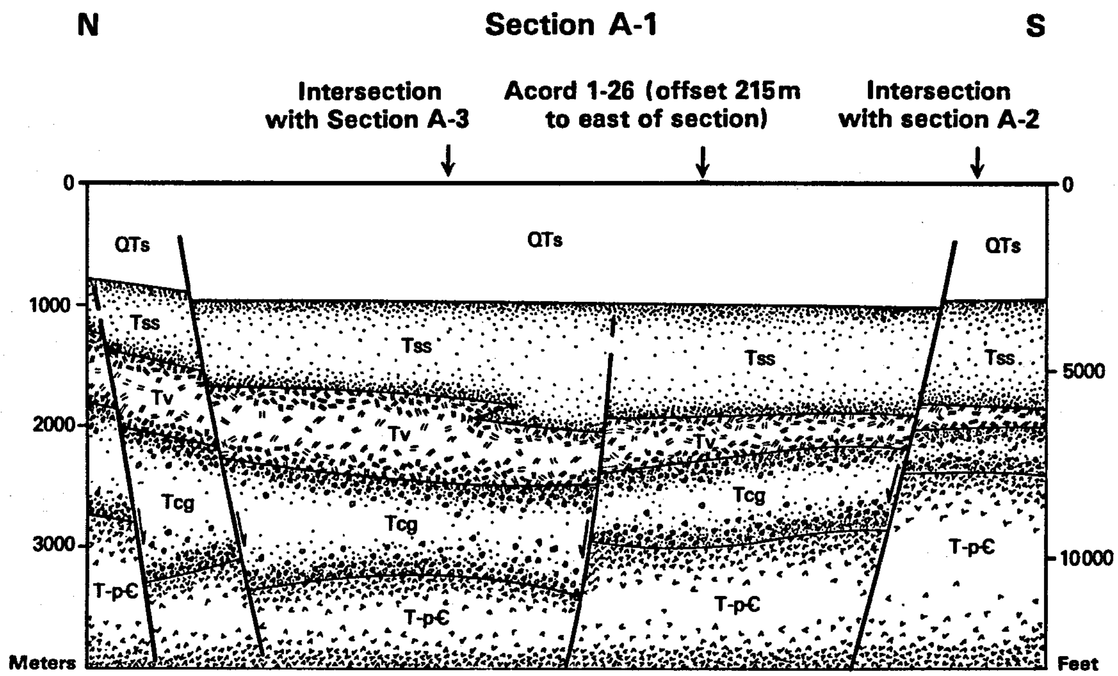
Overlying the volcanic rocks are 390 m of white, brown, and green sandstone that chiefly has a volcanic provenance, 135 m of light- to reddish-brown siltstone, and 320 m of varicolored, poorly sorted arkosic sandstone and conglomerate containing granules and pebbles mostly composed of andesite and basalt.

Next in the sequence is 190 m of reddish-brown sandy claystone containing some pebbles of quartz monzonite. This is overlain by a 120-m wedge of clastic strata, namely, 37 m of sandstone and conglomerate, 56 m of reddish-brown siltstone and silty claystone, and 27 m of light-brown silty sandstone.

The uppermost kilometer of sediments in the Acord well is composed predominantly of lacustrine clay. About 363 m of light-brown claystone are overlain by 565 m of light bluish-gray calcareous claystone, which contains abundant selenite crystals. Several thin (10- to 25-m) light-brown locally gypsiferous sandstones are intercalated at and near the lower and upper limits of the bluish-gray claystone sequence.

The Milford Valley is a complex graben bounded by normal faults. An elongated north-trending gravity low centered northeast of Milford is evidence that the graben may be filled with alluvium (Group Seven 1978). Intrusive rock of Tertiary age underlies most of the Milford Valley (East 1981). The channel of the Beaver River in the vicinity of the Acord 1-26 well is entrenched 6 m because of local uplift (Mower and Cordoba 1974).

According to Davis (1980), the Acord 1-26 well was drilled in a structural low or synform (Fig. 3). The well site may be along the northwestern projection of the Hot Springs Fault from the Roosevelt Hot Springs area. In the vicinity of the Acord 1-26 well, the dominant north-northeast trending faults extend into the basement. There is a local zone of faulting within the basin immediately east and northeast of the Acord 1-26 well. Approximately 1 km of movement along the major northeast-trending fault, which is less than 400 m east of the Acord 1-26 well, may have caused the fracture zones below 3.6 km in the basement rock intersected by the well. Motion along several



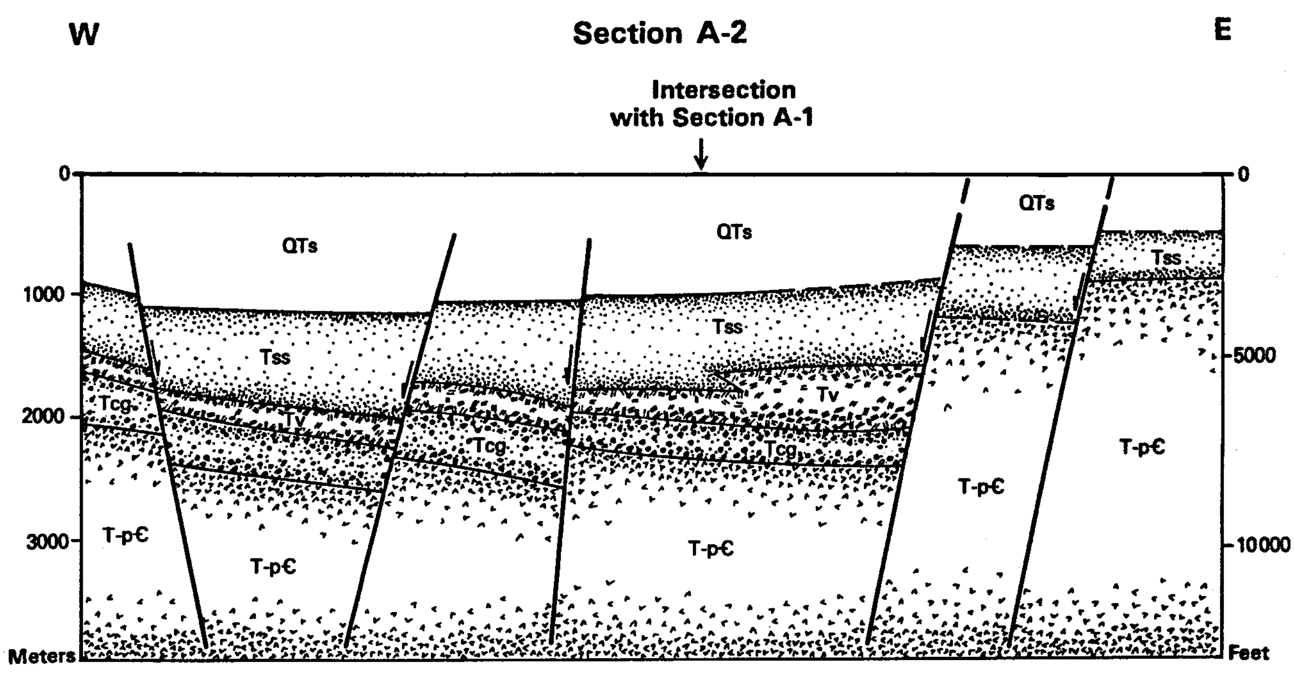
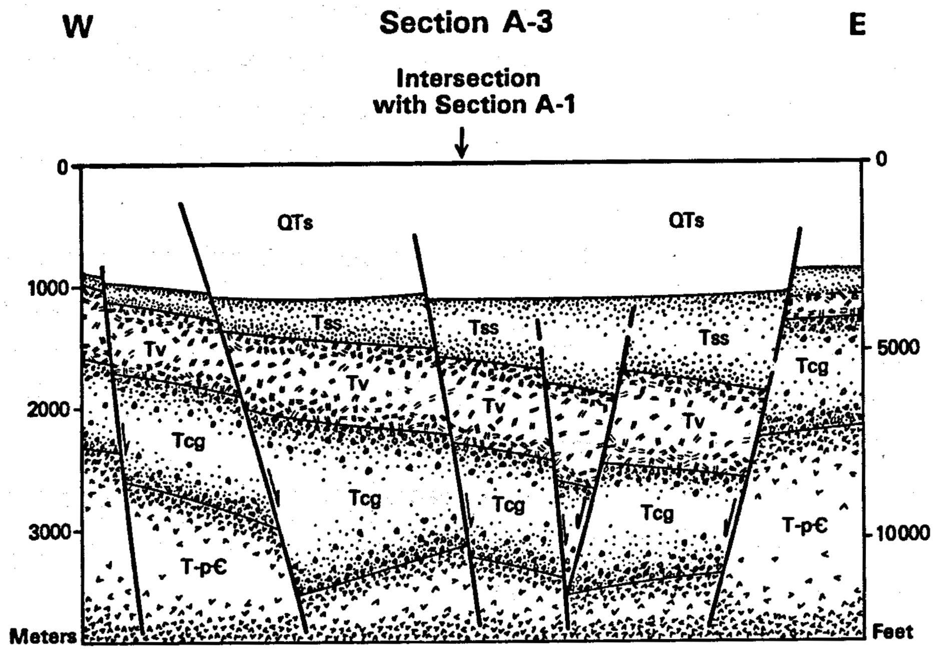
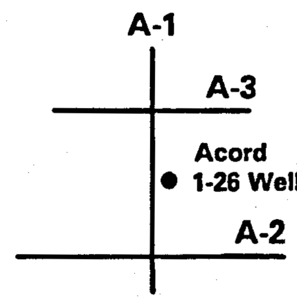


Fig. 3.
Interpretation of three seismic reflection traverses (courtesy of MCR Geothermal Corporation) based on model of Davis (1980) and stratigraphy of Acord 1-26 well.



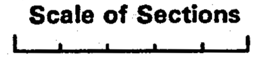
Generalized Stratigraphy

Quaternary-late Tertiary	QTs	Lacustrine deposits and gypsiferous sandstone overlying claystone, siltstone, sandstone, and conglomerate.
Late Tertiary	Tss	Volcaniclastic siltstone, sandstone, and conglomerate.
	Tv	Amygdaloidal basalt overlain by rhyolite, dacite and andesite.
	Tcg	Volcaniclastic conglomerate and sandstone, altered basalt and rare dolomite.
Basement Complex	T-p€	Tertiary biotite monzonite intruded into Precambrian mica schist, gneiss, and minor quartzite.



Approximate location and bearing of seismic sections.

Scale of Sections



5 Kilometers

Fig. 3. (cont)

major faults approximately 1.2 km north-northeast of the Acord well along the northern boundary of section 26 may have caused extensive fracturing and faulting of basement rocks. Another possible fault zone is in the extreme southeastern corner of the township approximately 3 km southeast of the Acord 1-26 well.

The structural interpretation of Davis shows the late Tertiary volcanic sequence thickens to the north and west of the Acord well. Because the volcanics are very thin or absent above the basement high to the east, much of the offset along the major fault east of the Acord well is inferred to have taken place before or contemporaneously with volcanism.

If hydrothermal fluids occur in sedimentary and volcanic rocks above basement, they probably have limited volume and are trapped adjacent to the major fault zone east of the Acord well.

IV. HYDROLOGY

Both surface and subsurface water in Utah are allocated by the Utah Department of Natural Resources. MCR Geothermal Corporation has no surface water rights in or near sec. 26, T. 26 S., R. 10 W. Most of the ground water in the Milford, Utah area is in coarse, poorly consolidated basinal sediments within 150 m of the surface corresponding to the upper sandstones in the geologic log of the Acord 1-26 well. The L. Kant Anderson water well (C-26-10) 26 had a measured water level 25 m deep in May 1982. A second Anderson water well (C-26-9)13, 5 km northeast of the Acord 1-26, also had a measured water level 25 m deep in May 1982. Both water wells had yields exceeding 1500 ℓ/min during spring 1983. A Los Alamos National Laboratory pumping test will be made on one of the two wells to determine if enough water is available for circulation in an HDR energy extraction system of 50 MW(e) (information provided by F. D. Vuataz, Los Alamos National Laboratory, 1983).

The decline in water-table level in this part of the basin was less than 3 m during the period from 1950 to 1972. The Beaver River commonly is dry in proximity to the Acord 1-26 well because its water has been diverted upstream for irrigation. A stream that heads 0.7 km northwest of the Acord 1-26 well is ephemeral. It trends northwestward from the Acord 1-26 well, but terminates in sand dunes before reaching the intermittent Beaver River 6 km away.

Some water was intersected within 1 km of the surface in poorly consolidated alluvial sediments of Quaternary age. Essentially no water was found deeper in the Acord 1-26 well; even the fracture zones were dry.

V. GEOPHYSICS

Using seismic data, Davis estimated the top of the basement in the Acord 1-26 well to be at a depth of 2.83 to 2.9 km, which is 10% too shallow. The estimated depth to the crystalline basement based on magnetic data is about 1.5 km (Group Seven 1979), but the contact in the well is twice as deep. Our revised cross-sections (Fig. 3) are based on contact relations and depths observed in the Acord well as well as on the seismic interpretation of Davis.

In Beaver Bottoms, 6 km northwest of the Acord 1-26 well, aeromagnetic data have been used to postulate a depth of 2.5 to 5 km to basement. However, a large magnetotelluric anomaly, no magnetization, and low resistivity there could be because of temperature effects or clays. The depth to basement is greatest along the north-trending Milford Valley axis. The valley fill is deeper both north and south of a hingeline in T27S, R10W, which is 8 km south of the Acord 1-26 well. In contrast, along an east-west aeromagnetic profile through the Acord 1-26 well, the depth of the basement contact is estimated to be 300 to 1500 m (East 1981).

VI. DRILLING HISTORY

A. Drilling

The well was spudded on March 30, 1979, and drilling proceeded largely without incident to the total depth of 3854 m (12 645 ft) on June 5, 1979. The drilling contractor was Republic Drilling Company; the rig consisted of a GB-800 EMSCO draw works, an IDECO Full View 40.5 m (133 ft) mast, powered by two D-379 Caterpillar engines.

Drilling began with a 44.5-cm-diam Smith DST milled-tooth bit and proceeded at an average penetration rate of 11 m/h to a depth of 344 m (1129 ft). (See Table I for a summary of the drilling record.) After the 33.9-cm casing was set to 335 m (1100 ft), drilling continued with 31.1-cm Smith DT bit at an average penetration rate of 15 m/h. During the next bit run, the penetration rate decreased by about one-third, even though the load on the bit was increased to 9 t and the rotational speed was held at 74 rpm. During bit run No. 4, the bit load was increased to 14 t and the rotational speed decreased

TABLE I

SUMMARY OF DRILLING RECORD FOR ACORD WELL I-26

Bit No.	Size (in)	Make	Type	Depth Out (ft)	Footage (ft)	Hours (hr)	Pen. Rate (ft/hr)	Max. Bit Wt (1000 lbs)	lb/in dia	RPM	Pump Pressure (psi)	Mud Weight (lb/gal)	VIS	PV	Remarks
1	17 1/2	Smith	DSJ	1129	1084	29.5	37	5-10	571	50-62	750	8.8	43	5	13 3/8" Casing set to 1100 ft.
2	12 1/4	Smith	DT	3433	2304	46.75	49	10-12	980	50-74	1600	8.6	33	6	Losing ~20 bbl/hr
3	12 1/4	Smith	DGT	3999	566	32.5	17	15-20	1633	74	1800	8.8	33	7	Losing ~10 bbl/hr
4	12 1/4	Smith	F3	5271	1272	65.75	19	30	2450	40-46	1225	9.2	34	4	Reduced RPM
5	12 1/4	Smith	F3	5484	213	28.0	8	30	2450	40	1200	9.4	38	9	
6	12 1/4	smith	DTJ	5980	496	28.25	18	35	2857	66	1350	9.1	36	--	40 ft of fill
7	12 1/4	Smith	DTJ	6250	270	14.25	19	30	2450	63	1200	--	--	--	Losing ~15 bbl/hr
8	12 1/4	Smith	F3	6716	466	25.75	18	30-32	2612	48	1200	9.2	34	4	
RR8	12 1/4	Smith	F3	7288	569	28.25	20	35	2857	46	1300	9.2	34	7	Losing 10 bbl/hr
9	12 1/4	Smith	F4	7919	631	36.0	18	25-30	2450	45	1250	9.1	36	6	9 5/8" Casing set to 7904 ft
10	8 1/2	Smith	DGH	8115	196	11.25	17	25-30	3530	45	--	--	--	--	
11	8 1/2	Hughes	J44	9001	886	81.5	11	30	3530	56-60	900	8.8	35	3	
12	8 1/2	Smith	F4	9228	228	21.5	11	30	3530	56-60	900	--	--	--	No mud loss
13	8 1/2	Hughes	J44	9563	334	34.25	10	30	3530	50	1000	9.0	35	4	Twist-off at 9230 ft
14	8 1/2	Smith	F3	9988	425	52.0	8	20	2350	66	1050	9.0	36	3	No mud loss
15	8 1/2	Smith	F3	10414	426	49.5	9	20	2350	66	1050	9.1	36	5	Lost 3-10 bbls/hr from 10,260 to 10,350 ft
16	8 1/2	Smith	F4	10659	245	24.0	10	20	2350	59	1000	9.2	36	7	
17	8 1/2	Smith	F4	10897	238	23	10	20	2350	60	1000	9.2	36	7	
18	8 1/2	Hughes	J44	11111	214	23.75	9	25	2940	40	1000	9.2	45	5	
19	8 1/2	Smith	F5	11321	210	28.0	8	25	2940	40	1000	--	--	--	
20	8 1/2	Smith	4JS	11451	130	15.5	8	25	2940	40	1000	--	--	--	
21	8 1/2	Smith	4JS	11681	230	24.0	10	25	2940	40	1000	9.1	35	7	
22	8 1/2	Smith	4JS	11916	235	25.0	9	25	2940	40	1000	--	--	--	
23	8 1/2	Smith	4JS	12143	227	26.0	9	25	2940	52	1100	9.1	38	10	CO_2 Content in mud = 8,000 to 38,000 ppm
24	8 1/2	Smith	F4	12336	193	24.25	8	25	2940	52	1000	--	--	--	
25	8 1/2	Hughes	J44	12561	225	26.5	9	--	--	--	--	--	--	--	
26	8 1/2	Smith	F7	12645	84	12	7	--	--	--	--	--	--	--	CO_2 content = 40,000 ppm

to 40-46 rpm, resulting in a greatly increased time on bottom. Drilling of the 31.1-cm hole continued through mixed strata of conglomerate, claystone, and partly consolidated sands to a depth of 2155 m (7100 ft) where the volcanic rocks begin; on to a depth of 2414 m (7919 ft), where the 24.5-cm casing was set.

Drilling below 2414 m (7919 ft) was done with 21.6-cm bits, mostly Smith F3 and F4, plus a few Hughes J44 bits. The average penetration rate through the predominately conglomerate and monzonite sequence in the lower section of the hole was 2.8 m/h at a bit load of 9 to 11 t, at 40 to 60 rpm. The only trouble occurred at 2813-m (9230-ft) depth, where the drill pipe twisted off leaving 17 drill collars in the hole. These were retrieved, however, on the first fishing attempt. In general, the drilling progressed very smoothly, taking 68 days and averaging 56.7 m (186 ft) per day.

B. Drilling Fluids

The initial mud mixture, to a depth of 2536 m (8320 ft), was bentonite and water. In the upper 2195 m (7200 ft) of the hole, mud losses were often 1.6 to 4.8 kℓ/h, with mica and nut plug being added as lost-circulation materials. Below 2536 m (8320 ft), a Geo-Gel (sepiolite) mud was used.

Throughout the drilling, the mud weight was kept between 1080 and 1100 g/ℓ, at a viscosity of 34 to 38/s.

C. Casing

Casing data for the well are summarized as follows:

Casing Size cm(in.)	Weight kg/m	Weight (lbs/ft)	Type	Thread	Length m (ft)	Set Depth m (ft)
33.9 (13-3/8)	81	54.5	K-55	Buttress	335 (1100)	335 (1100)
24.5 (9-5/8)	70	47.0	N-80	Buttress	397 (1300)	
	70	43.5	N-80	Buttress	465 (1526)	
	60	40.0	L-80	Buttress	770 (2524)	
	60	40.0	K-55	Buttress	779 (2554)	2411 (7904)

D. Cementing

Both the 33.9-cm and 24.5-cm casing strings were cemented full length, from the casing shoe to the ground surface. The cement slurry was composed of Class G cement, containing 40% silica flour and 1:1 perlite.

VII. LOG INTERPRETATION

Figure 4 records the mud log and geophysical logs run in the Acord 1-26 well. The depth intervals, data, and comments on data are included. The logs and primary interpretation results are described below.

A temperature log was run on April 21, 1979, 36 h after the last mud circulation. The zone from 2400 to 3701 m has an essentially linear temperature profile and little sign of even slight lost circulation zones or fluid entry points. This indicated gradient implies a 150 MW/m^2 conductive heat flow (East 1981). On May 29, 1979, another temperature log was run 26.5 h after circulation. It confirms the earlier log and shows a bottom-hole static temperature of at least 230°C. Logging depths were 2408 to 3701 m. Differential temperature and temperature logs were run on May 21, 1979. Two logging runs from 1220 to 3475 m have a constant and essentially featureless differential temperature profile. On the mud log, monzonite begins at 3170 m and goes to a total depth of 3854 m.

The velocity or acoustic log was run from 3170 to 3487 m. Over the bottom 30 to 45 m there is a possible temperature problem with the logging tool. The caliper log shows a washout from 3456 to 3459 m. This caliper log was recorded with the temperature log; therefore the log obtained going down

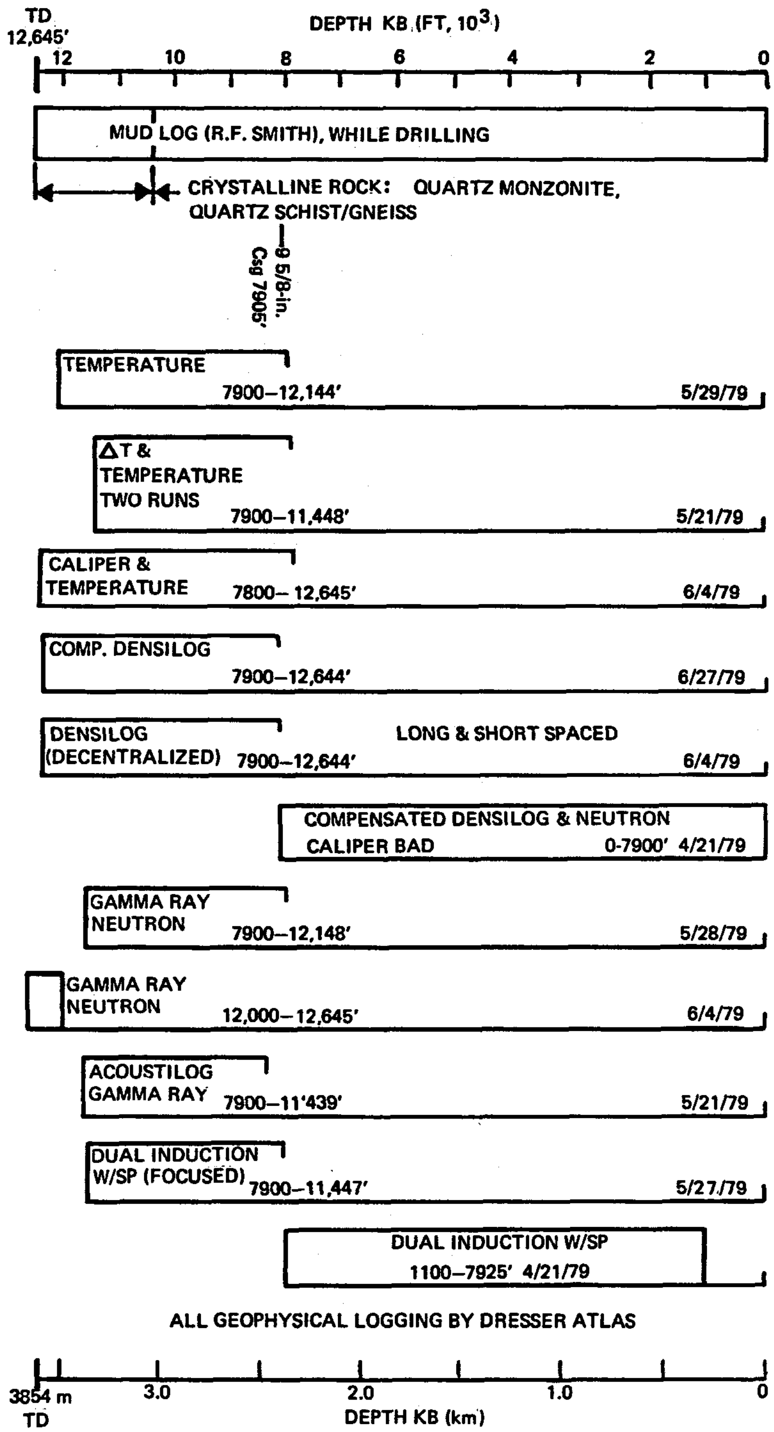


Fig. 4.
Summary of well logs, Acord 1-26 well, Roosevelt Hot Springs area, Utah.

the well is in error. The washout seen on the velocity or acoustic log is from 3162 to 3165 m. The Δt ranges from 17 to 18 μs/m (5.60 to 5.09 km/s) in the depth interval from 3170 to 3487 m. The mostly competent rock has a few Δt spikes, which may indicate fractures or tool decentralization.

The log recorded with the gamma-ray tool has a zone of high count rate. One explanation is that the amount of potassic granitic rock increases where a sill or dike was injected into the country rock. Another is that old fractures were healed with uraniferous material. The Δt spikes seen with the gamma-ray highs indicate weak zones. The gamma-ray log recorded with the neutron log shows the following zones of high gamma intensity: 3216 m, 3277 m, 3414 m, 3453 m, 3640 m, 3679 to 3694 m, and 3746 to 3847 m. The neutron log shows large values (high API units) associated with high gamma-intensity zones. This indicates that these zones have little or no porosity and differ from the surrounding rock.

The density log shows spikes of low density from 3170 to 3854 m. The acoustic log extends only to 3487 m. It also shows acoustic spikes (decrease in velocity or increase in Δt). These indicate weak zones, fractures, and possibly lithologic changes. The caliper log acquired with the temperature log indicates a reasonable diameter and smooth borehole that should not cause any problems for interpreting the density or neutron logs. The density ranges in the 2.80 to 2.55 g/cm^3 are satisfactory, but zones of 2.5 (at 3383 to 3414 m) and 2.4 to 2.5 (at 3571 to 3603 m) are weak zones representing old healed fractures or changes in lithology. This hole intersects both weak fractured zones and strong zones having little or no porosity.

In summary, the crystalline rock from 3170 m to a total depth of 3854 m (an interval of 684 m) is a very interesting target for HDR investigations. Although there are some weak or fracture zones in this portion of the hole, there are no indications of any significant fracture permeability from the drilling record or temperature surveys. The bottom-hole static temperature of 230°C, a gradient of 54°C/km, and a contact with crystalline rock at 3170 m indicate that drilling another kilometer deeper should be considered. The log data affirm that the deep crystalline rock at the Acord 1-26 well near Roosevelt Hot Springs, Utah, is an excellent candidate for further HDR investigations.

VIII. OTHER PERTINENT FACTORS

The section including the Acord 1-26 well is fee land leased by MCR Geothermal Corporation. The lease on the surrounding sections has been released to the Roosevelt Hot Springs Corporation. Because the drilling and potential HDR energy-production facilities are on privately owned desert land, major environmental objections to its utilization are not anticipated. Utah Power and Light Company (UP&L) is constructing a 20-MW plant in the vicinity of Roosevelt Hot Springs, 8 km away, to use the hydrothermal system production (Rasband 1982). Hence it would be feasible to tie any electrical output from an HDR installation at the Acord 1-26 well to transmittal lines emanating from the Roosevelt Hot Springs power plant. Because the contract between UP&L and the Bonneville Power Company terminates in 1983, UP&L is seeking additional inexpensive firm power and supplemental power during peak loads.

IX. CONCLUSIONS

It can be inferred from seismic data that there are large faulted blocks of crystalline rock at depth that can be penetrated for HDR purposes. Drilling records and geophysical logs indicate that the rock within these blocks is especially tight and dry. The best location for a new HDR well would be east of Acord 1-26 and west of Phillips 9-1. In this intervening area, the depth to crystalline rock is shallow, but the rocks are still impermeable and very hot. A hydrofracture test in a large zone of this rock would be extremely valuable. The fracture gradient, instantaneous shut-in pressure, and fracture density could be determined and various tools and techniques could be tested in these promising HDR regimes.

ACKNOWLEDGMENTS

George R. Keller of the Colorado School of Mines provided valuable insight concerning the local and regional setting of the Acord 1-26 well. MCR Geothermal Corporation was most helpful in supplying logs and other data from this well.

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