Alpine 1/Federal
Final Report
Executive Summary

James C. Witcher[1]

April 1994

ARIZONA GEOLOGICAL SURVEY
CONTRIBUTED REPORT CR-94-D

Prepared for the
Arizona Department of Commerce
Energy Office
Phoenix, Arizona

[1]Geologist, Southwest Technology Development Institute, New Mexico State University, Las Cruces, NM

TABLE OF CONTENTS

LIST OF FIGURES

figure **page**

LIST OF TABLES

ACKNOWLEDGMENTS

The community of Alpine, Arizona is thanked for their friendliness, hospitality, and assistance to the drillers and geologists. The fax machines, good mail service, good meals, hardware and other vendors, and friendly smiles in Alpine all contributed to a successful drilling project. Personnel at the U. S. Forest Service (USFS), Apache-Sitgreaves Forest, Alpine District Office, provided valuable assistance by providing gate keys, locating an acceptable and nearby site to place drilling fluids, and suggesting a very good access from the highway to the drill site. Bob Dyson of the Alpine District Office is especially thanked. John Sass of the U. S. Geological Survey (USGS) is thanked for providing preliminary heat-flow data and discussions on the thermal regime of the area. Chuck Chapin, Director, and Richard Chavez of the New Mexico Bureau of Mines and Mineral Resources (NMBMMR) are thanked for sending a loading crew and a truck to Alpine to pickup the Tertiary core on loan from Larry Fellows, Director, Arizona Geological Survey (AGS). Informal discussions on the geology of the region with Wes Peirce (AGS-Emeritus), Steve Rauzi (AGS), Andre Potochnik (ASU), Steve Cather (NMBMMR), Richard Chamberlin (NMBMMR), and Clay Conway (USGS) are greatly appreciated. Geological consultants to SWTDI/NMSU for the Alpine project, Chan Swanberg and Dick Hahman, are thanked for their hard work, valuable assistance, and suggestions. Tonto's outstanding drillers and helpers formed a highly proficient and enthusiastic drilling crew. Mike LaOrange, Tonto Drill Forman, and Larry Pisto, Tonto Core Division Manager, are especially thanked for their close coordination and good communications which assisted the geologists tremendously. The staff, secretaries, and students at SWTDI/NMSU are also thanked for their assistance in various phases of this project. Funding for drilling the Alpine 1/Federal corehole was the Arizona Department of Commerce, Energy Office and the U. S. Department of Energy, Geothermal Division.

BACKGROUND

This summary report overviews a State of Arizona and U. S. Department of Energy funded drilling project to determine if near-term hot dry rock (HDR) geothermal potential exists in the eastern portion of the White Mountains region of Arizona. A 4,505 feet deep slim-hole exploratory well, Alpine1/Federal, was drilled within the Apache-Sitgreaves National Forest at Alpine Divide near the Alpine Divide camp ground about 5 miles north of Alpine, Arizona in Apache County (Figure 1). A comprehensive technical report, in two parts, details the results of the project. Part 1, Alpine1/Federal, Drilling Report, discusses the drilling operations, logging program, permitting and site selection for the hole. Part 2, Temperature Gradients, Geothermal Potential, and Geology, summarizes the temperature gradients, heat flow, geothermal potential, and subsurface geology.

HOT DRY ROCK (HDR) GEOTHERMAL

Hot dry rock (HDR) geothermal energy is a method of mining or extracting the natural heat energy within the earth (Tester and others, 1989). As originally conceived by scientists and engineers at Los Alamos National Laboratory, heat is extracted from relatively impermeable rock by artificially fracturing a hot volume of rock and introducing water into the man-made fracture system with an injection well (Potter and others, 1974). A second well removes or produces the heated water from the fracture reservoir for use at the surface. As currently field tested, the concept requires a relatively impermeable rock volume with predictable fracturing characteristics. A volumetrically-large, structurally-simple rock body with high temperatures is desired.

OBJECTIVES

The main objectives of the Alpine1/Federal drilling project were to drill 100 feet into crystalline Precambrian basement, determine subsurface temperatures, temperature gradients, and heat flow. Based upon sparse regional geologic information, the target depth was selected at 4,500 feet below the surface.

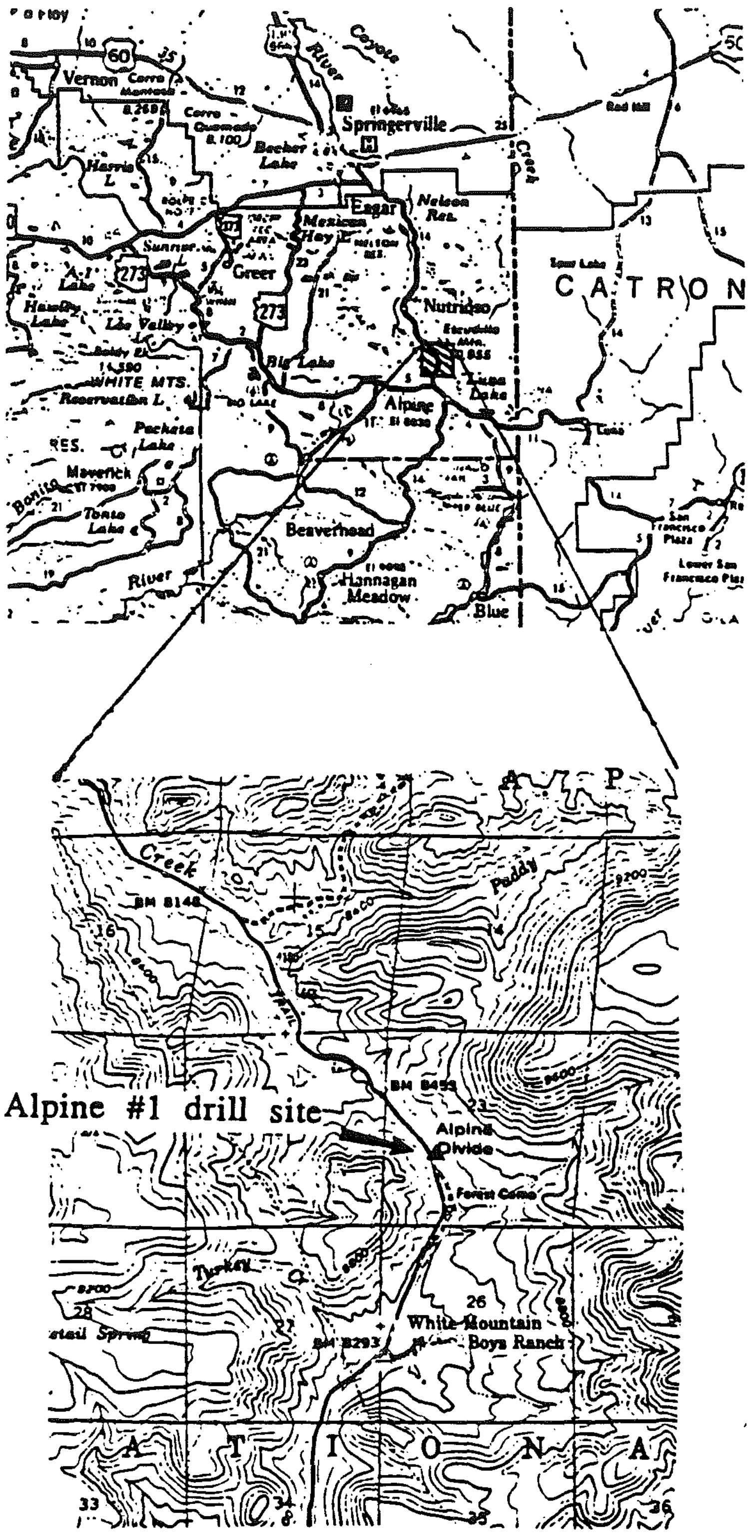

Figure 1. Location map of the Alpine 1/Federal drill site.

Overall, the primary mission of the drilling project was to obtain the data necessary to estimate subsurface temperatures deep into the Precambrian basement and assess the HDR geothermal energy potential of the eastern White Mountains region.

SITE SELECTION

Topography and regional geology indicated that the depth to Precambrian basement at Alpine Divide was greater than at potential sites near Springerville, Nutrioso, and Alpine. Therefore, the sediments that act as thermal blankets have greater thickness. With the same heat flow, this translates into higher temperatures because intervals with low thermal conductivity sediments have higher temperature gradients than high thermal conductivity Precambrian rocks. Second, the site was known to have the highest shallow heat flow in the area (115 mWm^{-2}) (Stone, 1980).

PARTICIPANTS

The project was administered by the State of Arizona Department of Commerce, Energy Office, Phoenix with procurement through the Arizona Procurement Office, Phoenix. Funding was a grant from the U. S. Department of Energy, Geothermal Division, Washington, D. C. to the State of Arizona with a matching contribution from Arizona's share of the Petroleum Violation Escrow Funds. U. S. Department of Energy oversight of the project was through the DOE Albuquerque Field Office. In addition, the State of Arizona Department of Commerce, Energy Office, formed a Geothermal Evaluation Committee to provide assistance in project direction and procurement. Prime contractor to the State of Arizona for the Alpine Geothermal Project was Tonto Drilling Services, Inc., Salt Lake City, Utah. Well site geotechnical services, permit coordination, and reporting were subcontracted by Tonto to the Southwest Technology Development Institute (SWTDI/NMSU) at New Mexico State University. The U. S. Geological Survey (USGS), Geothermal Division, an invited participant, contributed equipment and personnel toward heat-flow studies.

PERMITS

All operations conformed to the regulations, permitting and operational procedures administered by the U. S. Forest Service (USFS), the U. S. Bureau of Land Management (BLM) and the Arizona Geological Survey (AGS), Oil and Gas Administrator. All access and surface issues were closely coordinated with the USFS. All drilling was in compliance with federal Geothermal Resources Operational Orders (GROO's), directives of the USFS, BLM, AGS, and stipulations of the permits. Prior to commencing any operations, specific details were submitted to the USFS, BLM, AGS through the Applications for Permits to Drill (APD's) or Sundry Notices. Access to the drill site road from the highway was permitted with the Arizona Department of Transportation (ADOT). As operator, Tonto Drilling Services posted a Plugging Bond with the AGS and a Compliance Bond with the USFS/BLM.

DRILLING METHOD

The Alpine 1/Federal hole was drilled with an UDR1500 rig, designed for deep continuous wireline diamond core drilling and shallow rotary drilling. The rig was mounted on a 12 feet tall steel substructure to allow clearance of blow out prevention (BOP) equipment and to provide a stable drilling platform. The BOP stack, consisting of a double-gate ram and an annular preventer, was installed on a well head with flow and kill line ports. Continuous hydrogen sulfide detectors with alarms were operated for the duration of core drilling. The hole was drilled with mud rotary to 500 feet and continuous wireline cored from 500 to 4,505 feet. Continuous wireline coring had several advantages over rotary drilling. Drilling was continued even with lost lost circulation. Lost circulation, if not successfuly controlled with expensive remediation measures, would have stopped rotary drilling. Reduction of borehole size to solve a drilling problem was done through the drill string without an expensive intermediate casing job. Also, better geological information was obtained with core than with small drill chips of rotary tools.

DRILLING HISTORY

Figure 2 is a diagram showing depth in feet versus time in days since moblization on to the site began on 1 July, 1993. After the suface casing was run and cemented and the BOP stack was nippled-up and tested, the daily footage rate averaged over 137 feet per day from 500 to 2,700 feet depth. Below 2,700 feet depth the daily footage rate decreased to less than 74 feet per day. Depth of drilling played some role in the rate decrease; however, the nature of the lower Mogollon Rim formation was the primary cause of penetration rate reduction. Starting at 2,700 feet depth, maintenance of proper drilling mud became increasingly difficult and penetration rates slowed. The sandy clay and clayey sand in matrix-supported conglomerate in the basal Mogollon Rim formation were easily eroded from the borehole walls. As a result, the drilling fluids became more viscous and sandy. Formation washouts also left loose gravel behind that fell into the hole and contributed to drill string sticking. The sticking and wedging resulted in bent drill rods on two occasions. Rather than reduce from HQ to NQ coring at the base of the Mogollon Rim formation and place the bad formation behind cement and the HQ drill string, Tonto decided to continue carefuly and slowly coring HQ to insure against premature drill string reduction to NQ size drill string. Prior to actual drilling, the Permian San Andres and Glorieta Formations were identified as potential problem zones for drilling that could require reduction from HQ to NQ core. In the top of the San Andres Formation, a reduction from HQ to NQ core was forced because the drill string became differential stuck at 3,369 feet depth. Differential or hydraulic stuck is a term used to describe a condition where the drill string is unable to be turned and/or be withdrawn or advanced without snapping the rods. This results when differential hydraulic pressures push the drill string into the hole wall and friction prevents rod movement.

Drilling rates increased dramatically below 3,369 feet depth after the NQ reduction and the bad formation in the lower Mogollon Rim formation was cemented behind the HQ rods. NQ core rates for the lower 750 feet of the Alpine 1/Federal averaged about 100 feet per day. A 100 feet per day rate of coring at depths below 3,500 feet is generally regarded as excellent. Overall, core recovery exceeded 99 percent and the target depth of 4,505 feet was reached on the 29th of August.

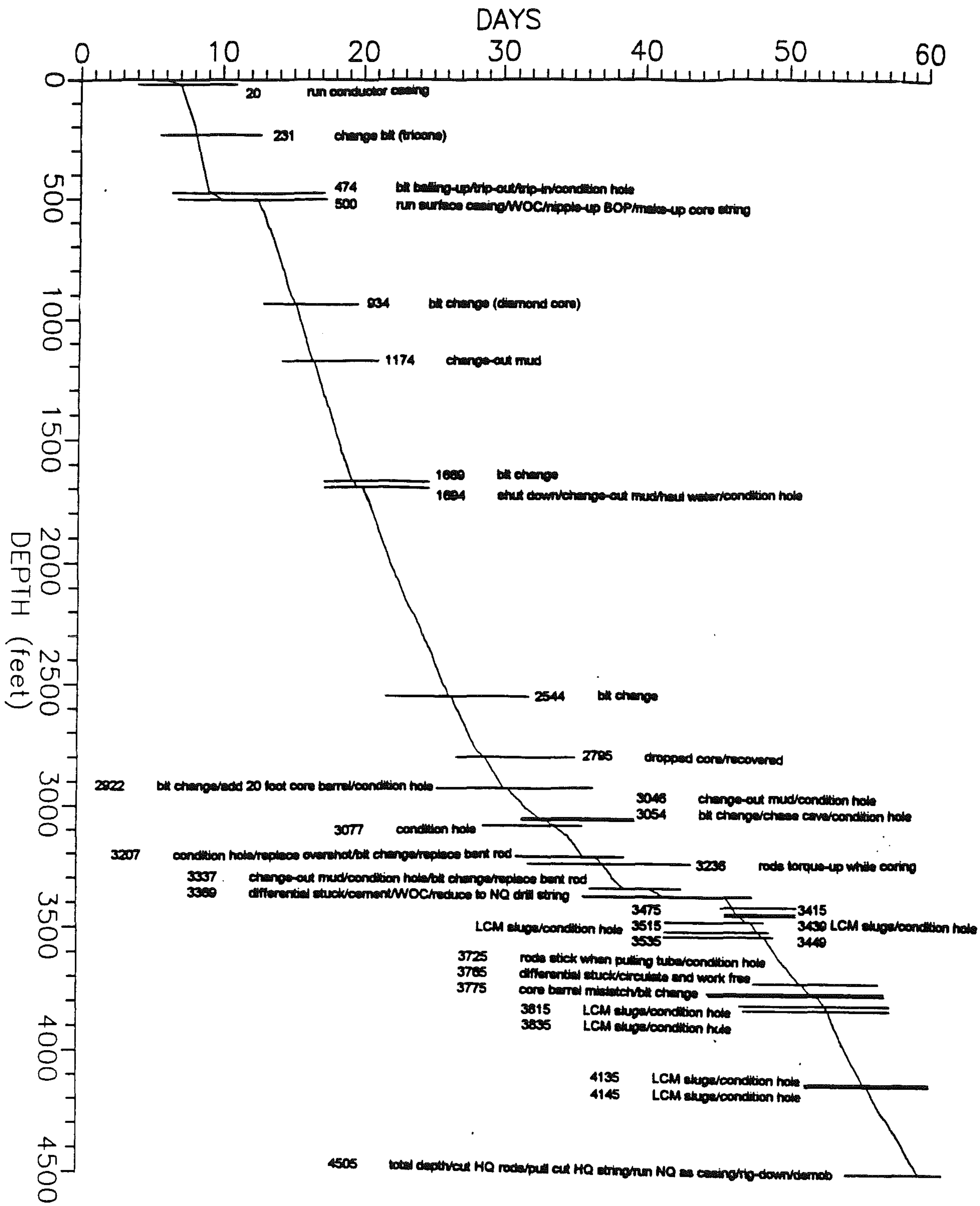

Figure 2. Drilling history of the Alpine 1/Federal borehole.

OBSERVATION WELL COMPLETION

Because Precambrian basement was not reached, the well completion was changed to provide a contigency for re-entering the hole. Instead of a steel pipe liner, the hole was completed with the NQ drill rods after retrieving the HQ rods from 2,510 feet depth to the surface. The remaining 850 feet of HQ rods were left in place to hold back the bad formation in that interval (Figure 3 and Table1). The NQ rods were capped at the bottom and filled with water to allow formation temperature measurements. The completion will allow for later drilling to continue with a NQ drill string if the NQ rods in the hole can be retrieved or with a BQ drill string if the NQ rods cannot be retrieved. A BQ drill string may be inserted in the NQ rods and the bottom cap drilled-out for continued coring to Precambrian.

Table 1 Alpine1/Federal temporary observation completion.

item	hole size	top	bottom	OD	ID	weight	cement
	inches	ft	ft	inches	inches	lbs/ft	sacks
well head flange	0	0		7.0625			
conductor casing	7.875	0	20	6.625	5.796	24	5
surface casing	5.875	20	502	4.5	3.875	11.6	44
HQ hole	3.850	500	3,369				
HQ casing	3.782	2,510	3,360	3.5	3.0625	7.7	22
NQ hole	3.040	3,369	4,505				
NQ casing	2.98	3,369	4,505	2.75	2.375	5.2	0

PREVIOUS STUDIES

A variety of regional geological, geophysical, and geochemical data indirectly infer geothermal potential. The Stone (1980) heat-flow study is the only "hard" data available to reliably predict subsurface temperature. Stone concluded that the heat flow was somewhat elevated; but did not project temperatures to greater depth. Some proponents of HDR in the area have relied heavily on indirect indicators to infer 200 C (400 F) temperatures at 10,000 feet depth or less.

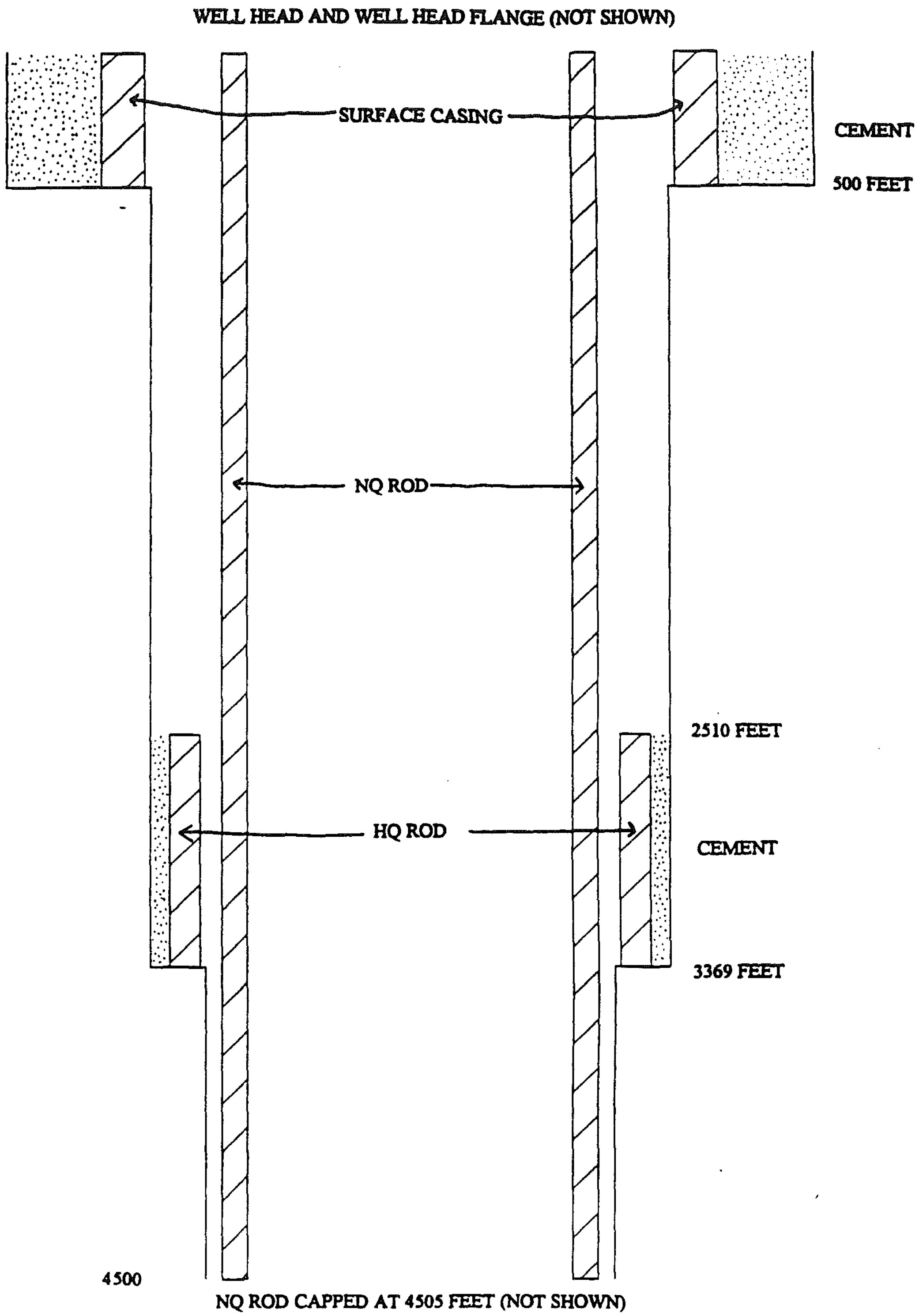

Figure 3. Observation well completion diagram.

GEOLOGY

Table 2 is a summary of formations encountered in the core hole. Figure 4 shows a pre-drilling estimate of geology that is based upon the Belcher 1/State well (Foster, 1964), located 21 miles north-northeast from Alpine Divide, and projection of major regional unconformities into the subsurface of the area. No pre-Tertiary information is available for 60 miles to the south and east. The nearest pre-Tertiary well and outcrop data to the northwest and west is over 40 miles distance. Several reasonable assumptions, given the amount and quality of data available, were used to make the pre-drilling estimate. First, no major structures (faults) were assumed between the Belcher well and Alpine Divide. Existing geologic maps for the area show no faults. Structurally, the area north of the Belcher well is relatively flat with minor folds and the Precambrian is generally at higher elevation toward the south. Second, Tertiary sediments and volcanics were assumed to be inset against paleotopography, resulting from major regional unconformities. Inset Tertiary sediments and volcanics along the Mogollon Rim, a mostly Mesozoic to earliest Tertiary erosional scarp, is common in the region to the west in the Transition Zone between the Colorado Plateau and Basin and Range Provinces. The subsurface model was tested by comparing it with Tertiary subcrops in the Whiteriver area approximately 50 miles to the west. In the Whiteriver area, the Tertiary Mogollon Rim formation, was observed resting unconformably on Permian Supai equivalent rocks at elevations similar to the pre-drilling model.

Figure 5 shows the actual geology to 4,505 feet depth at Alpine Divide. All of the Triassic Chinle, most of the Permian San Andres, and most of the Cretaceous Dakota sandstone were removed by erosion beneath the two major regional unconformities. However, more than 600 feet of Tertiary sediments were cored than predicted by the pre-drilling model. Also, the unconformity at the top of the Cretaceous Dakota Sandstone is approximately 1,600 feet lower in elevation above sea level in the Alpine 1/Federal than in the Belcher 1/State well. At least of 1,600 feet of structural displacement, faulting (?) down to the south, has occurred after deposition of the LaOrange formation, a probable new formation identified by this project. The LaOrange was deposited on the low topographic relief Dakota Sandstone erosional surface.

Table 2 Formation Summary of the Alpine1/Federal corehole.

Tertiary Pueblo Creek Formation and Mogollon Rim formation
    0 to 3,139 feet (0 to 957 m)
    thickness 3,139 feet (957 m)
Tertiary (?)/Cretaceous(?) LaOrange formation
    3,139 to 3,246 feet (957 to 989 m)
    thickness 107 feet (32 m)
Cretaceous Dakota (?) Sandstone
    3,246 to 3,362 feet (989 to 1,025 m)
    thickness 116 feet (36 m)
Permian San Andres Formation
    3,362 to 3,436 feet (1,025 to 1,047 m)
    thickness 74 feet (22 m)
Permian Glorieta Sandstone
    3,436 to 3,639 feet (1,047 to 1,109 m)
    thickness 203 feet (62 m)
Quaternary(?)/Tertiary (?) basaltic intrusion
    3,639 to 3,751 feet (1,109 to 1,143 m)
    thickness 112 feet (34 m)
Permian Corduroy member "Supai Formation"
    3,751 to 4,266 feet (1,143 to 1,298 m)
    thickness 515 feet (157 m)
Quaternary(?)/Tertiary (?) basaltic intrusion
    4,260 to 4,322 feet (1,298 to 1,317 m)
    thickness 62 feet (19 m)
Permian Fort Apache Limestone member "Supai Formation"
    4,322 to 4,327 feet (1,317 to 1,319 m)
    thickness 5 feet (2 m)
Quaternary(?)/Tertiary (?) basaltic intrusion
    4,327 to 4,362 feet (1,319 to 1,330 m)
    thickness 35 feet (11 m)
Permian Fort Apache Limestone member "Supai Formation"
    4,362 to 4,405 feet (1,330 to 1,343 m)
    thickness 43 feet (13 m)
Permian Big A Butte member "Supai Formation"
    4,405 to 4,454 feet (1,343 to 1,358 m)
    thickness 49 feet (15 m)
Quaternary(?)/Tertiary (?) basaltic intrusion
    4,454 to 4,505 feet (1,358 to 1,373 m)
    thickness 51 feet (15 m)

Qal	Quaternary alluvium
Qb	Quaternary basalt
T	Tertiary Pueblo Creek and Mogollon Rim
T/K	Tertiary (?)/Cretaceous (?) LaOrange
K	Cretaceous Dakota Sandstone
TRch	Triassic Chinle
Psa	Permian San Andres
Pg	Permian Glorieta
Psu	Permian Supai
P∊	Precambrian

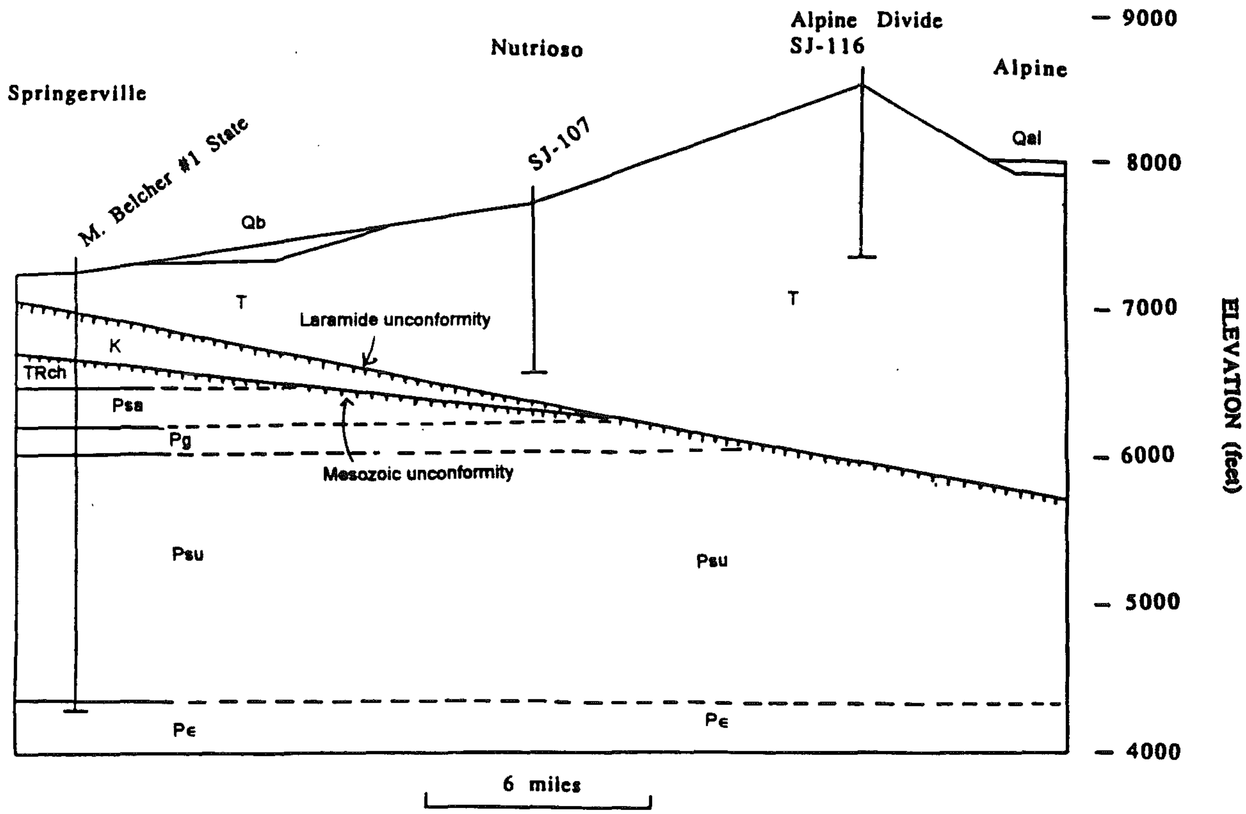

Figure 4. Pre-drilling geologic model of subsurface geology.

Qal	Quaternary alluvium
Qb	Quaternary basalt
T	Tertiary Pueblo Creek and Mogollon Rim
T/K	Tertiary (?)/Cretaceous (?) LaOrange
K	Cretaceous Dakota Sandstone
TRch	Triassic Chinle
Psa	Permian San Andres
Pg	Permian Glorieta
Psu	Permian Supai
P€	Precambrian

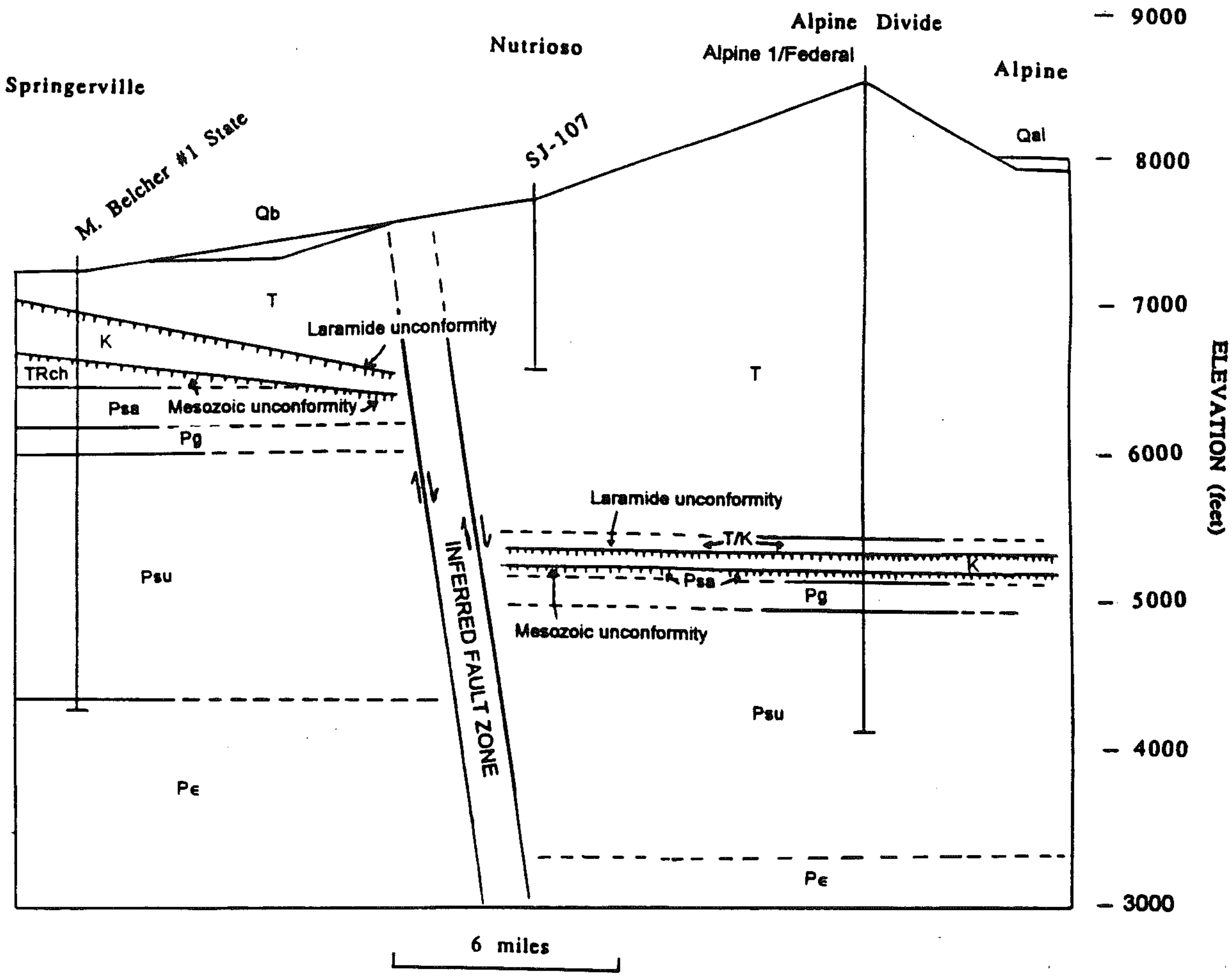

Figure 5. Post-drilling geologic model of subsurface geology.

The Precambrian is at least another 800 to 1,000 feet below the Alpine Divide site or 5,400 feet depth, assuming no additional basaltic intrusions and no Pennslyvanian to Devonian sediments. With additional basaltic intrusions and Pennslyvanian to Devonian sediments, Precambrian may be at least 2,000 feet below the total depth of the Alpine 1/Federal borehole or more than 6,500 feet depth. The type of Precambrian rock beneath the Alpine Divide is unknown without drilling. The nearest available subsurface and outcrop information suggests that the top of the Precambrian will either be schist or Apache Group sandstones and limestones rather than granite.

THERMAL REGIME

Temperature gradients in the earth are the result of several heat transfer processes and properties. In the shallow crust, conduction and convection are primary processes. The magnitude of a temperature gradient in a conductive temperature regime is regulated mostly by rock thermal conductivity and local heat flow from the earth's interior. Heat flow is the product of the rock thermal conductivity and the temperature gradient. A preliminary heat-flow estimate is 96 mWm^{-2} (personnel communication, John Sass, USGS/Flagstaff). The Alpine 1/Federal heat flow is practically the same as the SJ-116 measurement of Stone (1980) ($115 mWm^{-2}$) if thermal conductivity measurement errors are considered for both sets of data.

Figure 6 is an equilibrium temperature versus depth plot for the Alpine 1/Federal borehole. Overall, temperature gradients decrease with depth in this borehole (Table 3). A moderately high temperature gradient (72 C/km) in the upper 300 to 800 feet depth interval changes to a relatively normal temperature gradient (33 C/km) in the lower 700 feet of the hole. Thermal conductivity variation accounts for the temperature gradient differences. Clay-rich sandstones and volcanoclastic sediments in the upper portion of the hole have relatively low thermal conductivity. Quartzose sandstones and carbonate rocks in the lower portion of the hole typically have high thermal conductivity. Similar high thermal conductivity rocks will occur downward, deep, into the Precambrian basement.

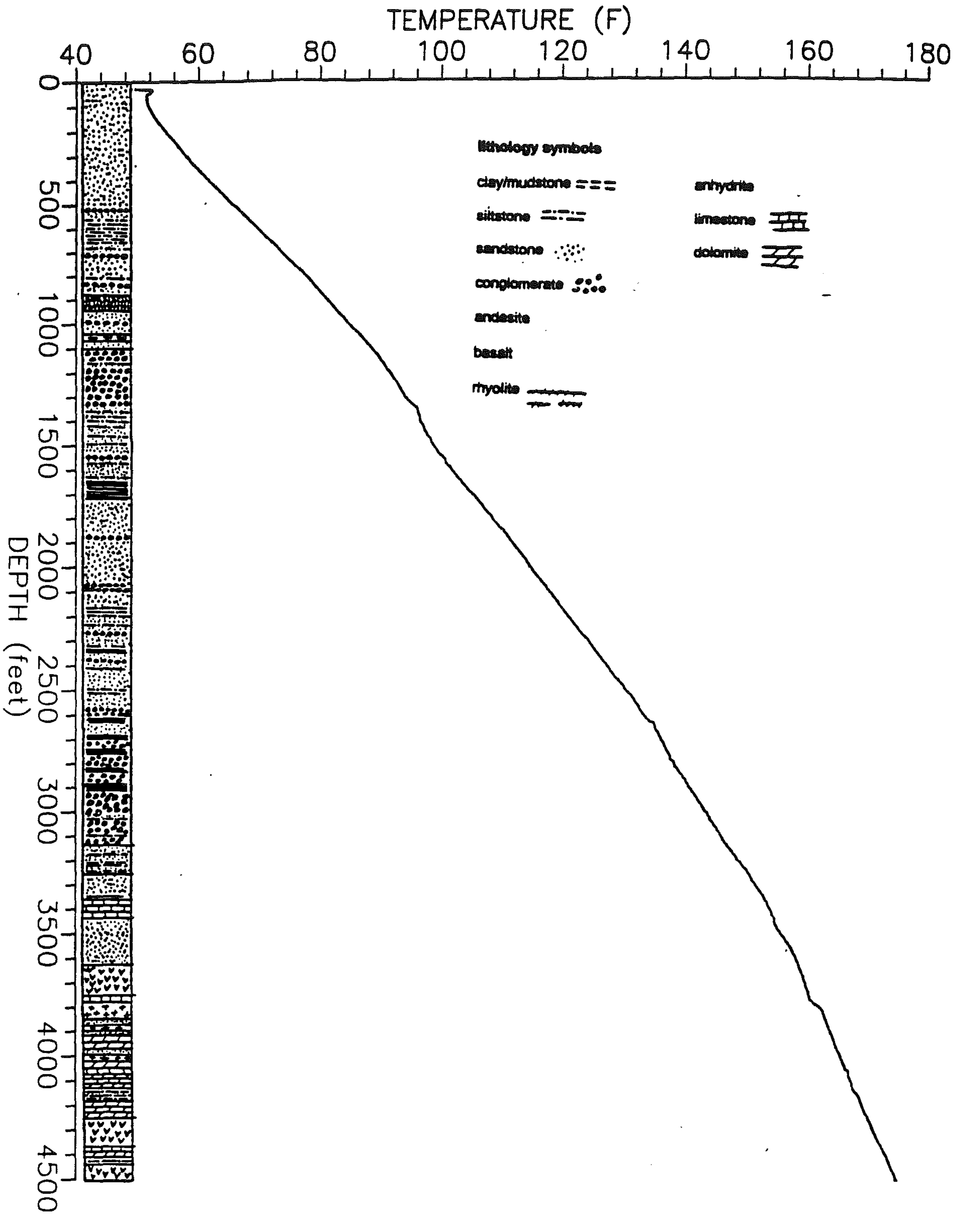

Figure 6. Equilibrium temperature versus depth for the Alpine 1/Federal borehole.

Table 3 **Temperature gradients in the Alpine 1/Federal borehole.**

depth (ft)	temperature gradient (C/km)	intercept temperature (C)	correlation	formation
300 to 800	72.1	7.7	0.99970	Pueblo Creek
800 to 1100	64.1	9.7	0.99938	Pueblo Creek
1500 to 2600	57.2	10.8	0.99978	Mogollon Rim
2800 to 3400	47.8	17.8	0.99931	Dakota/San Andres
3800 to 4500	32.8	33.6	0.99920	Corduroy/Ft Apache

Detailed rock thermal conductivity measurements and heat-flow analysis for the Alpine 1/Federal borehole will be reported by John Sass, U. S. Geological Survey (USGS), an invited participant of the State of Arizona, in a forthcoming USGS Open-File Report.

Figure 7 is a pre-drilling temperature versus depth projection (solid line) that was based on heat-flow information reported by Stone (1980) for the SJ-116 well at Alpine Divide. Thermal conductivity estimates, used in the temperature projection at depth, were typical generic values for rock types expected at depth. Actual temperatures measured in the Alpine 1/Federal borehole are shown at 1,000 feet intervals with the "X" symbol. Predicted temperature at 4,500 feet was 76 C and very close to the actual measured temperature of 78.6 C. An average temperature gradient in the Precambrian will range between 30 and 40 C/km. Heat flow and thermal conductivity constraints indicate that a gradient over 40 C/km will not occur.

GEOTHERMAL POTENTIAL

The Alpine 1/Federal borehole is not situated over a convective hydrothermal geothermal system. Convective geothermal systems are generally associated with shallow temperature gradients that greatly exceed 150 C/km. Therefore, any geothermal resource potential in the Alpine-Nutrioso area is conductive hydrothermal (deep confined aquifer) and hot dry rock (HDR).

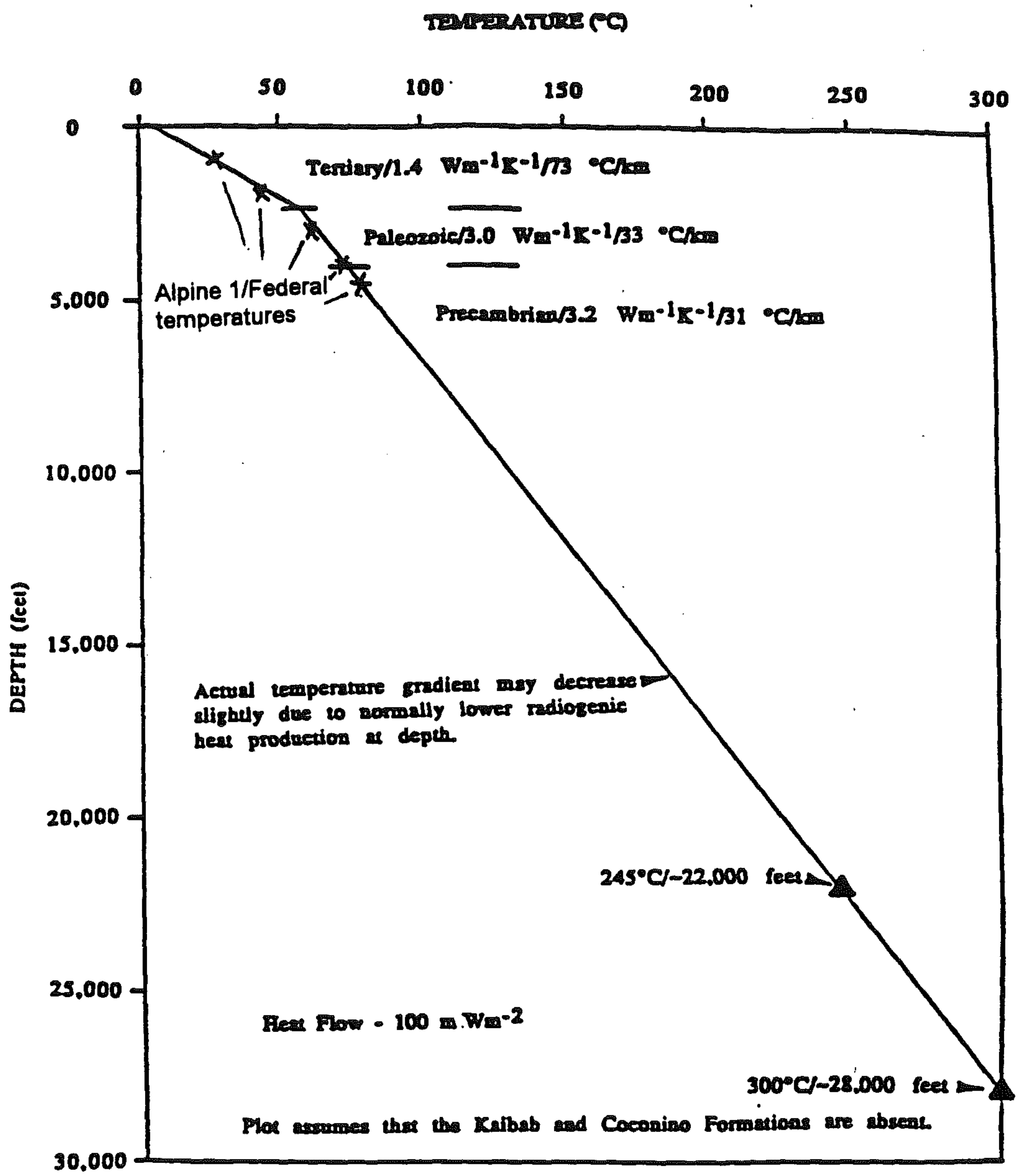

Figure 7. Pre-drilling temperature-depth projection based on heat flow data for Alpine Divide (SJ-116).

Hot dry rock (HDR) is a technology under development. The concept and a degree of technical feasibility has been demonstrated at Fenton Hill, New Mexico. On the other hand, commercial feasibility has not been demonstrated for the general use of HDR beyond the Federal research effort at Los Alamos National Laboratory. Electrical power production and direct-use geothermal applications are possible end uses of a productive HDR geothermal reservoir. Each will have unique requirements and economics aside from the costs and requirements of the HDR reservoir. Considering current and projected fossil fuel cost, assuming no major unforeseen overseas oil crises, a site with near-term HDR potential should be located in an area with currently high electrical and/or other high utility fuel costs and high demand. In other words, the site should be in a good marketable position. Also, a near-term HDR site should have relatively high resource quality for lower end drill costs and for fewer problems in creating the man-made reservoir that connects the injection and production wells.

Because of drilling costs, which currently increase non-linearly with depth, the quality and near-term feasibility of a site will largely depend upon the basement (Precambrian) temperature gradient. This is because the temperature gradient will dictate the depth necessary to drill for temperatures required for economic thermal energy extraction from the HDR reservoir.

Tester and Herzog (1990) define three grades of HDR resources for the purpose of investigating economic feasibility. A high-grade resource has a gradient above 80 C/km; a mid-grade resource has a gradient of 50 C/km; and a low-grade resource has a gradient of 30 C/km. Within the Tester and Herzog (1990) framework, the Alpine-Nutrioso area falls into the low- to mid-grade category. In other words, wells depths of 10,000 to over 20,000 feet are required to obtain usable heat, depending upon whether direct-use or electrical power production is done.

Table 4 summarizes the breakeven cost of electricity with current technology. The Tester and Herzog (1990) model calculates cost on a per KWe installed basis. With a 40 C/km gradient, costs for electricity are 12 to 18 cents per kilowatt-hour. These costs are unlikely to be economically attractive to a utility or its customers. The consumers actual costs would be even higher.

Table 5 summarizes the break even costs for direct-use HDR geothermal utilization with the Tester and Herzog (1990) model. Costs are based upon a supply rate of heat at one million Btu per hour (MMBTU). Costs for direct-use are a little more attractive for HDR in the Alpine area. This is especially true for space heating, using lower temperature fluids. The key parameters involved with direct-use geothermal in the Alpine-Nutrioso area are heating loads and natural gas availibility. Climate in the area requires space heating for much of the year so that potentially large heating loads may exist in the area. Inexpensive natural gas is not available. Direct-use space heating in the Alpine -Nutrioso area, using the 40 C/km gradient model of Tester and Herzog (1990) indicates a $4 to $7 per MMBTU break even cost. This cost may be marginally economic for specific types of large space heating requirements. With natural gas costs in the $3 to $5 MMBTU ($5 to $7 MMBTU with boiler inefficiencies accounted), it is unlikely that commercial enterprises would relocate to the area for industrial process heat or space heat from geothermal resources.

Table 4 Economic model costs for HDR electrical power.

temperature gradient (C/km)	electricity breakeven cost ($/w/hr) with current technology
30	0.375 to 0.235
40	0.184 to 0.119
50	0.121 to 0.082

Table 5 Economic model costs for HDR direct-use geothermal.

temperature gradient (C/km)	cost high-temp (> 80 C) direct-use for industrial applications ($/MMBTU)	cost low-temp (<80 C) direct-use for space heating ($/MMBTU)
30	16.6 to 9.7	10.6 to 6.3
40	9.7 to 5.7	7.2 to 4.3
50	6.9 to 4.1	5.5 to 3.3

The best potential direct-use HDR geothermal application is likely to be a district heating system for homes, schools, businesses, and government buildings at Alpine. Costs per MMBTU will be higher than model costs because additional costs would be encurred for distribution lines. For HDR geothermal energy to compete with current propane use in Alpine, the system would have to operate as a utility and probably have initial capital costs subsidized with government aid and matching grants.

OIL AND GAS POTENTIAL

A qualitative petroleum potential exists in the area (Fellows, 1994; Rauzi, 1994a; and Rauzi, 1994b). The organic-rich Dakota Sandstone and fetid and petroliferous dolomites and limestones in the San Andres Formation, Corduroy member, and Fort Apache Limestone member indicate potential as source rocks for petroleum maturation. Oil shows, first noted on site by project geologists, in the Alpine 1/ Federal may be from local maturation, resulting from the heat of basaltic intrusions in the Paleozoic section. Detailed petrographic analysis and facies studies of core, hydrocarbon maturation studies, delineation of the burial and thermal history of the Cretaceous and Permian rocks, assessment of the hydrodynamic history of the area, and analysis of potential structural and stratigraphic traps and potential reservoir rocks is required before the true oil and gas potential of the area is known. The Alpine 1/Federal core and logs do provide important information toward an assessment.

CONCLUSIONS AND RECOMMENDATIONS

The Alpine 1/Federal drilling project provided valuable new information on the geology of the region. Except for drilling into Precambrian rocks, the objectives of the project were accomplished. Sufficient temperature and heat-flow information were obtained to assess the near-term HDR geothermal potential of the eastern White Mountains region. Therefore, the primary mission of the project was successful.

The HDR potential for near-term electrical power production is not economic. Potential for HDR direct-use space heating is marginal at best and should realistically be considered uneconomic.

The Alpine 1/Federal hole should be deepened to Precambrian basement to provide definitive subsurface geological information for this region. Deeper drilling will determine Precambrian lithology and assess if older Paleozoic rock units are present. The hole may be deepened with a BQ drill string. Depth to Precambrian is likely to be between 800 and 2,000 feet below the current 4,505 feet total depth. The failure to reach Precambrian basement due to major structural offset highlights the need for detailed surface geological mapping in this poorly understood region.

REFERENCES

Fellows, L. D. 1994, Oil show in geothermal test: Arizona Geology, v. 24, no. 1, p. 1.

Foster, R. W., 1964, Stratigraphy and petroleum possibilities of Catron County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 85, 55p.

Potter, R. M., Robinson, E. S., and Smith, M. C., 1974, Method of extracting heat from dry geothermal reservoirs: U. S. Patent #3,786,858.

Rauzi, S. L., 1994a, Geothermal test hints at oil potential in eastern Arizona volcanic field: Oil and Gas Journal, Jan 3, 1994, p. 52-54.

Rauzi, S. L., 1994b, Implications of live oil shows in eastern Arizona geothermal test: Arizona Geological Survey Open-File Report 94-1, 16 p.

Stone, C., 1980, Springerville-Alpine geothermal project, results of heat flow drilling: Arizona Bureau of Geology and Mineral Technology Open-File Report 79-17, 21 p.

Tester, J. W., Brown, D. W., and Potter, 1989, Hot Dry Rock geothermal energy - a new energy agenda for the 21st century: Los Alamos National Laboratory Report LA-11514-MS, 30 p.

Tester, J. W., and Herzog, H. J., 1990, Economic predictions for heat mining: A review and analysis of Hot Dry Rock (HDR) geothermal energy technology: Massachusetts Institute of Technology, Energy Laboratory, Report MIT-EL 80-001, prepared for U. S. Department of Energy, Geothermal Technology Division, 180 p.