GL00821

REPORT
EVALUATION OF GEOTHERMAL POTENTIAL
WHITE ARROW RANCH VICINITY
BLISS, IDAHO:
TASKS D, E AND F

AUGUST, 1981

HOWARD • DONLEY ASSOCIATES, INC.

CONSULTING ENGINEERS AND GEOLOGISTS

IDAHO WYOMING CALIFORNIA

HOWARD • DONLEY ASSOCIATES, INC.

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Job No. 1029-05-02
August 6, 1981

University of Utah Research Institute
420 Chipeta Way
Salt Lake City, Utah 84108

Attention: Mr. Jon Zeisloft

Re: REPORT
Evaluation of Geothermal Potential
White Arrow Ranch Vicinity
Bliss, Idaho
Tasks D, E and F

Dear Mr. Zeisloft:

Please find enclosed copies of our final report for the evaluation of geothermal potential in the White Arrow Ranch Vicinity, Bliss, Idaho. This final report covers Tasks D, E and F as were outlined in our proposal to you last year. The report also includes Appendix A, which is the report that we prepared in December of 1980 for Tasks A, B and C.

If you have questions concerning the contents of the report(s) or our work to date, please contact us. We have enjoyed working with UURI and DOE on this project and look forward to working with you again.

Yours very truly,
Howard · Donley Associates, Inc.

H. Robert Howard, P.E.

Enclosures
cc: Mr. Robert Erkins

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REPORT
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BLISS, IDAHO:
TASKS D, E AND F

by

Howard · Donley Associates, Inc.

(Dale R. Ralston, Principal Investigator)

Moscow, Idaho

August, 1981

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INTRODUCTION

Statement of the Problem

The report is the second of two publications describing the geothermal resources in the vicinity of the White Arrow Ranch located in Gooding County in southern Idaho (Figure 1). The first report, entitled "Evaluation of Geothermal Potential, White Arrow Ranch Vicinity, Bliss, Idaho: Tasks A, B and C" (Ralston and Prager, 1980), described the hydrogeologic setting of the area and delineated a target site for a geothermal gradient test hole. This report presents the results of the test drilling and an analysis of the geothermal flow systems in the area.

The work described within this document was undertaken under funding from the U. S. Department of Energy administered through the University of Utah Research Institute. Although the research results are directed to the resource development at White Arrow Ranch, the results are applicable to geothermal development throughout the lower Clover Creek area.

Purpose and Objectives

The purpose of this project is to evaluate the geologic and the hydrologic controls and the extent of the shallow geothermal systems in the vicinity of the White Arrow Ranch near Bliss, Idaho. The project consists of geologic and hydrologic investigations including the construction of a shallow (less than 1,000-foot) geothermal gradient test hole.

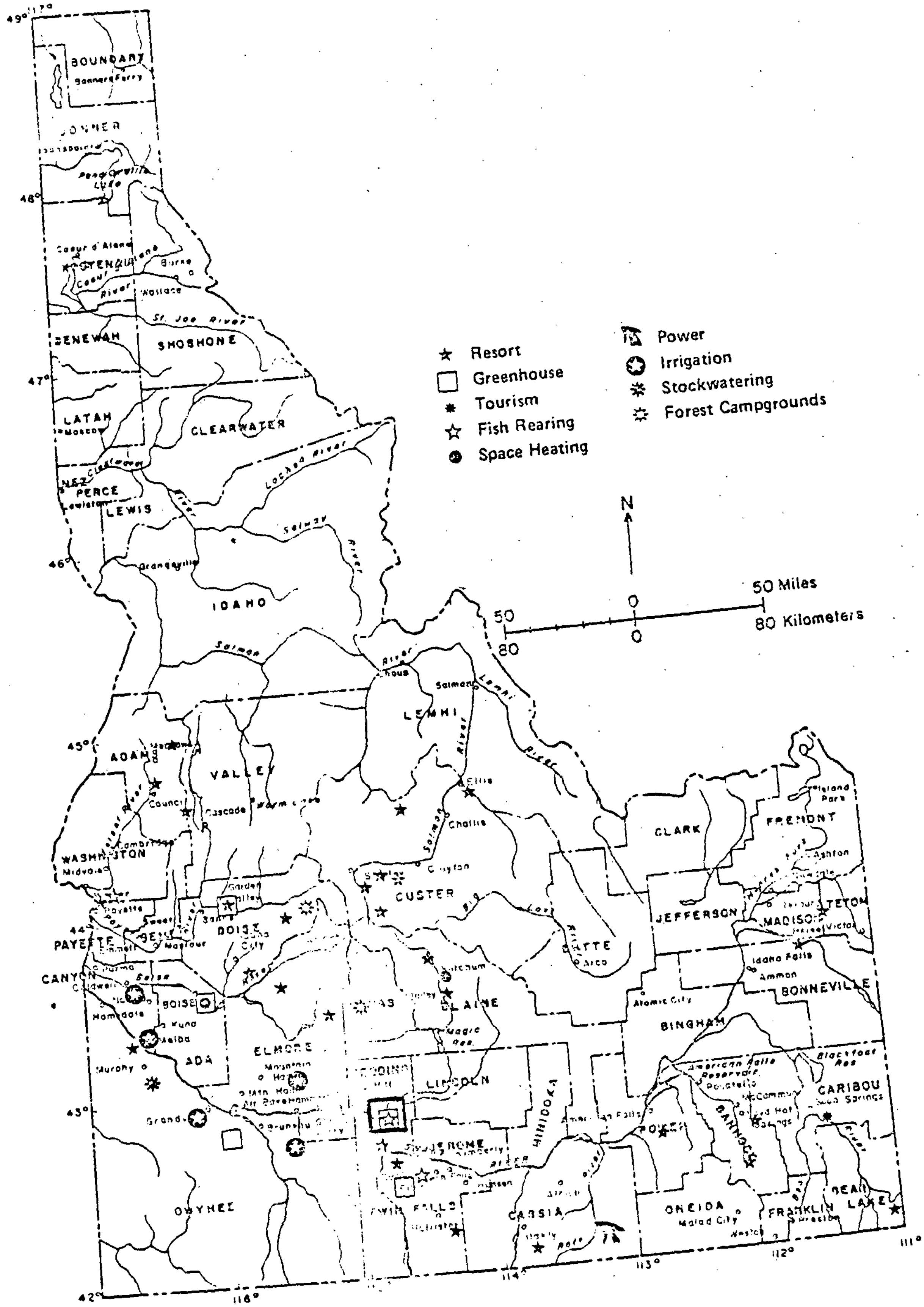


Figure 1. Location map of White Arrow Hot Springs in Idaho.

The objectives of the work are listed as a series of six tasks.

Task A - Summarize geologic knowledge and obtain field data where necessary to formulate a preliminary geologic framework for geothermal flow systems in the general study area.

Task B - Summarize hydrogeologic knowledge and obtain field data where necessary to formulate a preliminary conceptual model of the geothermal flow system in the general study area.

Task C - Utilize geologic and hydrologic interpretations, possibly supplemented by surface geophysical investigations to locate a target site for a 700-800-foot geothermal gradient test hole.

Task D - Construct a small diameter test hole to a target depth of 700-800 feet for the purpose of obtaining hydrogeologic and heat-flow data.

Task E - Utilize standard borehole geophysical techniques to obtain a temperature log of the test hole.

Task F - Administer the project and combine the results of investigations described in tasks A-E into a report of findings.

Method of Study

This report is presented as fulfillment of tasks D, E and F as noted in the previous section. As such, the method of study involved five steps.

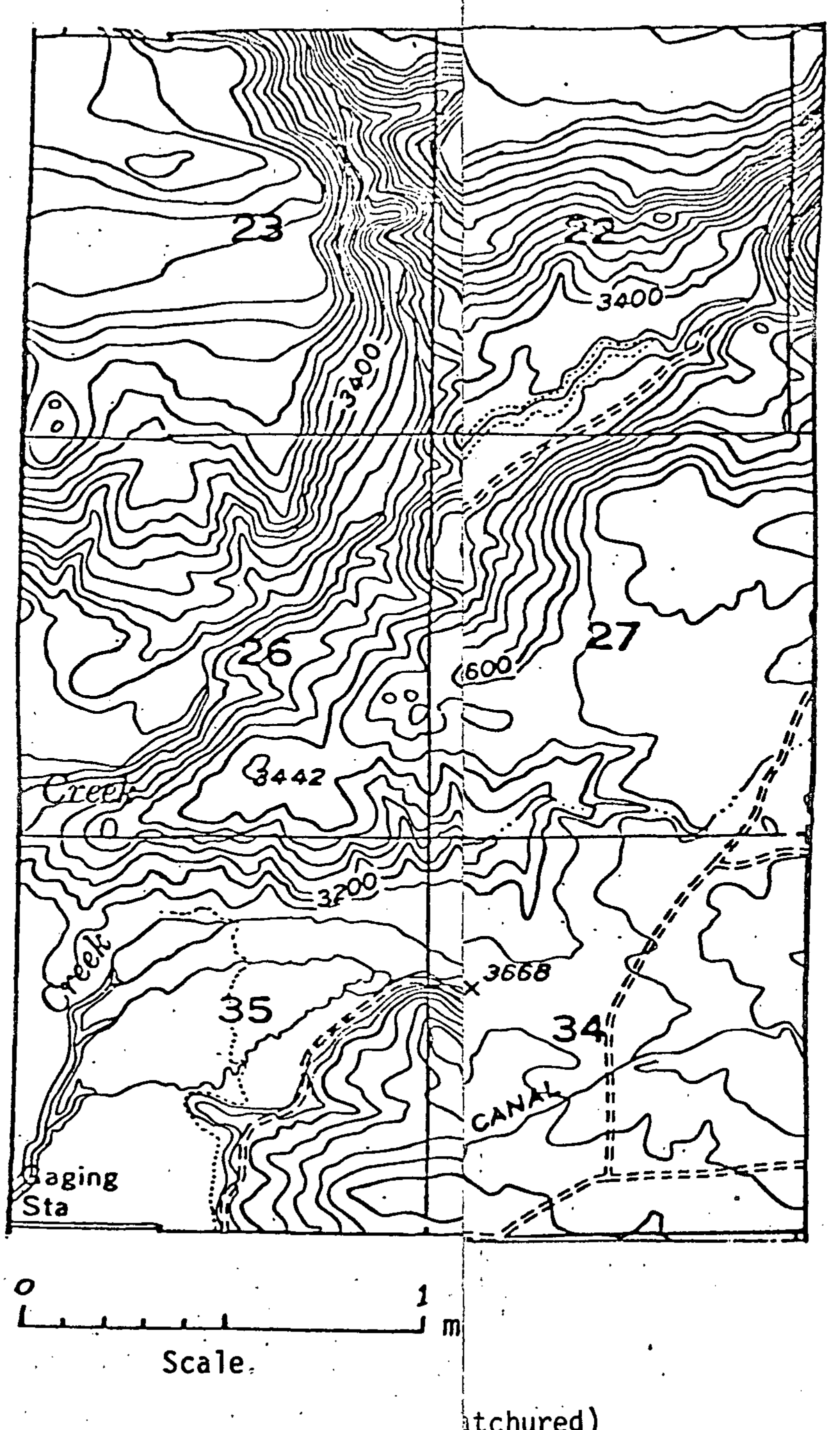
1. Supervise and monitor construction of a small diameter test hole.
2. Obtain selected geophysical logs of the test hole.
3. Analyze the hydrogeologic and geophysical logs of the test hole to describe the geothermal flow systems.
4. Use site specific and published data to estimate heat flow at the site.
5. Prepare a report of findings.

HYDROGEOLOGIC LOG OF THE TEST HOLE

Location and Construction of the Test Hole

A test hole location near the section corner of sections 19, 20, 29 and 30, T.4S., R.13E., B.M., was selected in consultation with individuals from U.U.R.I. (University of Utah Research Institute) (Figure 2). The site was selected away from known faults and at an elevation such that the well would not flow at land surface. The test well was constructed on public lands administered by the U. S. Bureau of Land Management. Considerable time and effort was required to obtain the required permits and approval of both state and federal agencies.

The drilling firm of Walker Water Systems, Inc. was contracted to construct the test well using an air rotary rig capable of conversion to mud circulation. Drilling was initiated on May 11, 1981, and stopped at a total depth of 805.5 feet on June 1, 1981. A 9-7/8-inch hole was drilled to 21 feet; eight-inch diameter casing was placed to 20 feet. The hole was completed to 250 feet at 7-7/8-inch diameter to allow placement of 6-3/8-inch casing to 248 feet. This length of casing was required



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location)

because of problems of lost circulation and no return of cuttings in the interval of 50-250 feet. The hole was drilled to 500 feet at six inches in diameter. A 5-7/8-inch tungston-carbide bit was used to complete the hole to 805.5 feet. Drilling was stopped at 805.5 feet because too much water was entering the hole to allow drilling by air. A suitable mud pump was not available. The hole was completed by installing three-inch plastic casing the full depth as recommended by U.U.R.I.

Geologic Log of the Test Hole

A geologic log of the hole was compiled by on-site geologists based upon analysis of drill cuttings. The field compiled log is presented as Table 1. Basalts (andesites?) of the Banbury formation predominated in the interval of 250-710 feet. Sands of the Banbury formation predominated from 710 feet to the bottom of the hole at 805.5 feet. Layering within the basalt-sand sequence is identified on the log.

The "no returns" interval from 50 to 250 feet probably has highly fractured zones in basalt. These zones could either represent depositional associated fracturing or later faulting. The basalt (andesite?) in the interval of 250 to 653 feet appeared to be mostly hard with limited fracturing. The basalt (andesite?) from 653 to 710 feet appeared to be more fractured than the sequence above. The quartz sand that predominates in the interval of 710 to 805 feet is fairly typical within the Banbury formation. The sand is probably partially cemented.

?

Table 1. Geologic log of White Arrow test hole.

Consultant: Howard · Donley Associates, Inc.
Driller: Walker Water Systems

Location: T.4S., R.13E., 30aad
Elevation: 3560 Topo.?

why not quantified

Depth (feet)	Lithology	Cuttings Size and Shape	Drilling Action and Rate	Water Temperature	Amount of Water Being Blown	Water Level	Comments
0-5½	Sandy-silty clay -weathered and oxidized -50% clays, sand grains of potassium feldspar and quartz.	Cuttings range from clay size to 1/8". Grain size increases @5'	Fast and smooth	---	None	---	Started hole with 9-7/8" tri-cone
5½-19	Sandy-gravel, grey to black basalts -some olivine basalts	1/8" to 2" size rounded cobbles	Jumpy and fast	---	None	---	
19-21	Clay, some cobbles of what	Clay size, cobbles are 1" in diameter	Very fast	---	None	---	Hole caved in to 12' - we drilled out and set 20' of 8" casing
21-25	Sand, small amounts of gravels, basalts, feldspars, volcanics, greens, pinks and blacks	Rounded 1/16" to 1/8"	Fast	---	None	---	Switched to 7-7/8" tri-cone
25-39	Basalt, gravel, vesicular, gray to black	Angular chips 1/16" to 1/8"	Fast	---	None	---	
39-41	Basalt, vesicular gray to black, few white crystals of what	Angular chips 1/8" to 1/2"	Drilling has slowed	---	None	---	Appears to be a competent flow
41-43	Clay -tan to brown -several basalt chip detected	Clay size	Fast	---	None	---	
43-47	Basalt, gray to black vesicular under 10X	Fine to medium	Slowed	---	None	---	
47-49	Clay -Appears baked? -Red, brown, green - ½ basalt chips	1/32" to 1/8"	Fast	---	None	---	
49-51	Clay, very soft		Very fast		None	---	

Table 1. Cont'd.

Depth (feet)	Lithology	Cuttings Size and Shape	Drilling Action and Rate	Water Temperature	Amount of Water Being Blown	Water Level	Comments
51-78	"No Returns" lost circulation. Rig appears to be drilling through an extensive broken and fractured thieving zone	No returns	Very jumpy and jerky, 1.83 min/ft	---	Loss of circulation prevented the usual detection of air lifted ground water		@73' very jumpy
78-85	"No Returns", lost circulation, rock appears harder	No returns	Very slow	---	Loss of circulation prevented the usual detection of air lifted ground water	---	
85-119	"No Returns" lost circulation. It appears we are drilling through a sequence of highly competent zones bedded with broken zones	No returns	Alternating fast and slow	---	Loss of circulation prevented the usual detection of air lifted ground water	---	@90' drill steel dropped 1 ft., must be open fracture
119-214	"No Returns" lost circulation. Driller thinks we are drilling through clay	No returns	Fast	---	Loss of circulation prevented the usual detection of air lifted ground water	---	
214-242½	"No Returns" lost circulation, broken zones or gravels?	No returns	-Several spots rough drilling -very jumpy	---	Loss of circulation prevented the usual detection of air lifted ground water	---	
242½-250	"No Returns" lost circulation, appears to be hard rock	No returns	Drilled a little rough and then smoothed out	---	Loss of circulation prevented the usual detection of air lifted ground water	SWL=220.67' depth=250' 5/11/81 17:35	
				Attempted down hole temperature - broken thermometer		SWL=120.35' depth=250' 5/12/81	Set 248' of 6-3/8" casing to seal off thieving zone

Table 1. Cont'd.

Depth (feet)	Lithology	Cuttings Size and Shape	Drilling Action and Rate	Water Temperature	Amount of Water Being Blown	Water Level	Comments
250-291½	Andesite? -light gray, vesicular -white specks of plagioclase -several quartz grain detected -several fragments of green clay - thinly laminated	Very small	Hard and smooth, appears nonfractured, drilling rate is approx. 20 ft/hr	---	≈5-10 gpm, only water being blown is from rigs injection of drilling fluids and foam		@260' green clay disappears
291½-308	"Same as above" -frequent layering of green-blue clay -50% clay, clay is nonplastic -clay exhibits no platey texture -concoidal fractures in clay when broken -clay laminated	@305'-308', clay and andesite chunks are 1" in diameter @308', less clays, mostly andesites		23°C, drilling water supply is 19.5°C	"Same as above" @310 had driller blow hole to see if we are picking up water, essentially blowing none		
308-328	"Same as above" -very little clay in this zone -thin clay zones in ½' interval at 322', 324' and 326'		Real slow 20-25 ft/hr	@318', 23.5°C	@310' and 320' blowing very little water		
328-335	"Same as above" -much more clay, 70%-80%	1/16-1/4", seam @331.5, has 1" chunks		@328', 25°C	@335', blew very little water water after recovery period		
335-350	"Same as above", white crystals appear to be plagioclase. @343' - more green clay	Very fine to 1/8"	-Very hard drilling, 15 ft/hr -Possibly jumpy drilling results from breaking in and out of the clay lenses	Measurements taken @335', 345' and 350' were a consistent, 30°C	@350' -had driller blow hole for 20 min. maybe 1 gpm -Rock yielding no water	@350', could not measure, tape hung up at 170'. Water level must be below 170'	

i.e. - badly mixed cuttings

Table 1. Cont'd.

Depth (feet)	Lithology	Cuttings Size and Shape	Drilling Action and Rate	Water Temperature	Amount of Water Being Blown	Water Level	Comments
350-453	"Same as above" -porphoritic -vesicular, white specks of plagioclaste are abundant -Abundant intervals of clay, laminated, non-plastic -Small black minerals are either pyronise or amphibole	Cuttings are all angular and ≈very fine to 1/8"	Drillings picked up, 25 ft/hr @400' rate slowed back to 20 ft/hr	Measurements taken @360', 370', 380', 400', 430' and 450', all ≈25°C	-No more than 1-8 gpm. -Most fluid being blown is from rig -Rock still yielding little water		
453-500	"Same as above", small brownish-red specks observed, more clay in thin lenses. @461' brown specks pick up	Very fine to 1/16", cuttings get very fine from 490' to 500' -driller through bit may be worn. -tripped out and bit was in fair condition, bearings appear worn	-Drilling action picks up and gets jumpy whenever brown specks are larger. -drilling action slowed down from 490'-500', 27 to 30 ft/hr	23.5°C @480' and 500', at end of day we blew hole but there wasn't enough water to measure temperature with	Blew hole for 20 min. at end of day. No apparent water. Rock mass still yielding no water	Lowered probe to 450', could not detect water. Must have evacuated borehole of water, rock mass still yielding very little water	
NOTE: Different Field Geologist for remainder of hole.							
500-508	Basalt, dark grayish green, little or no quartz. Chlorite?, light softness of 1, waxy	Medium to coarse (1/32"-1/8") angular, Large fragments up to 3/4" diameter, massive, subangular to subrounded				204-3/4' 5/18/81 a.m.	Changed to 5-7/8" tungsten-carbide bit what type
508-517	Basalt, grayish-brown, some quartz Chlorite, light green, softness of 1, waxy less cuttings than before	Medium to coarse (1/32" -1/8") angular Fragments up to 1/2" diameter, massive, subangular to subrounded					
517-518	Basalt, dark gray, some quartz Chlorite, grayish-green, only change	Medium (1/32"-1/16") angular More smaller fragments (1/32"-1/2")					

Table 1. Cont'd.

Depth (feet)	Lithology	Cuttings Size and Shape	Drilling Action and Rate	Water Temperature	Amount of Water Being Blown	Water Level	Comments
518-522	Basalt, dark gray	Fine grain size ≤1/64", angular	Hard				
522-524	Basalt, dark gray to black, no quartz	1/32"-1/16", angular					
	Chlorite, greenish gray	1/16"-3/4"					
524-528	Basalt, dark gray to black, no quartz	<1/32", angular	Hard to drill				
528-546	Basalt, grayish black to black, some sanidine? 542'-546'	1/32"-1/8", angular					
	Andesite or Diabase? brown w/plagioclase phenocrysts, 528'-542'	1/16"-1/8", angular					
546-558	Basalt, grayish black to black	1/32"-1/16", angular					
	Anesite or Diabase? gray with plagioclse phenocrysts	fragments to 1/2" diameter					
	Chlorite, grayish green, waxy, softness ≈1	fragments to 1" diameter					
558-563	Basalt, dark gray	<1/64", angular	Hard to drill				
563-653	Basalt, grayish black to black, reddish-brown fragments from 573' to 583', 633' to 643'	1/32"-1/8", angular	Steady rate ≈30 ft/hr, drilling rate increases to 40 ft/hr, 643' to 653'				
	Chlorite, 563' to 573'	1/8"-3/4"					
653-655	Chlorite, grayish green, waxy, softness ≈1	1/16"-1", subangular with rounded edges	Steady rate ≈30 ft/hr, drilling rate increases to 40 ft/hr, 643' to 653'		30-50 gal/min		
	Basalt, light gray	1/32"-1/16", angular					

Table 1. Cont'd.

Depth (feet)	Lithology	Cuttings Size and Shape	Drilling Action and Rate	Water Temperature	Amount of Water Being Blown	Water Level	Comments
655-665	Basalt, black	1/32"-1/16", angular		@658' water temperature is ≈ 30°C	less, ≈10-20 gal/min		
665-685	Basalt, grayish black to black, dark reddish-brown specks 675'-685'	1/32"-1/16", angular		@670' water temperature is 33°C	less, ≈ 5 gal/min @670'		
	Chlorite, grayish green, waxy, softness ≈1, 674' to 676' only	1/64"-1", subangular with rounded edges					
685-710	Basalt, grayish black with tinge of green, possibly enstatite? Few quartz grains 695-710' only and a few chips of hard transparent yellow 705'-710'	1/64"-1/8", 685'-695', 1/32"-1/8", 695'-710' angular					Chlorite ≈ 1-2% of total cutting 685'-695' Chlorite ≈ 5% of total cutting 695'-705'
	Chlorite, grayish green, waxy, softness ≈1, 685 to 705' only	1/32"-1/8", smaller chips than before, still subangular with rounded edges					
710-712	Sand, quartz, orthoclase, plagioclase with some red and brown specks, represents 92-95% of total cuttings	1/32"-1/8", coarse, subangular to rounded					Sand made up of ≈5-8 different minerals
	Chlorite, grayish green, waxy, softness ≈1, represents 3-5% of total cuttings	1/16"-1/4", smaller chips than before, still subangular with rounded edges					
712-715	Sand, quartz, orthoclase, plagioclase with some red and brown specks, represents 92-95% of total cuttings	1/64"-1/16", medium to coarse subangular to rounded grains		@715' water temperature is 39°C			Sand made up of ≈5-8 different minerals

Table 1. Cont'd.

Depth (feet)	Lithology	Cuttings Size and Shape	Drilling Action and Rate	Water Temperature	Amount of Water Being Blown	Water Level	Comments
715-720	Sand, same description except more reddish orange represents ≈5% of total cuttings	1/64"-1/16", medium to coarse, subangular to subrounded	Very slow, steady	@717½' water temperature is 40°C	@717½' well is producing ≈50-70 gal/min	206' 9:00 a.m. 5/19/81	
	Chlorite, mostly small green chips, some tan, represents ≈95% of total cuttings	1/16"-1/8", same description, chunks up to 1" diameter 715-717½'		@718' water temperature is 43°C			
720-737	Chlorite, same description, represents ≈70% of cutting 720'-721', 95% of cutting 721'-723", 725'-737'	1/16"-1/8", same description, up to 1" diameter 723'-725'	Very hard drilling especially when tan chlorite is encountered	@721' water temperature 44.5°C @723' - 46°C @728' - 46°C		350' 9:30 a.m. 5/26/81	No biotite or hornblende in sand samples
	Sand, quartz, orthclase, plagioclase, plus 2 or 3 other minerals, ≈30% of total cuttings from 720'-721', 5% from 721'-723", 10% from 723'-725'	1/16"-1/8", subangular to subrounded, coarse to very coarse					
737-741	Sand, quartz with some pink and brown grains	1/16"-1/8", very coarse, angular to subangular	Very hard drilling, Fred W. thinks it could be hard sandstone				
741-753	Sand, same description, some reflective specks in very fine sand 746'-752' probably mica, sand represents ≈ 95% of total cuttings 741'-746', 75% from 746'-752', ≈100% from 752'-753'	1/32"-1/16", coarse finer than above, angular to subangular 741'-746', very fine cuttings 746'-752' (coarse) angular to subrounded 752'-753'	Very hard drilling, Fred W. thinks it could be hard sandstone, easy drilling 745½' to 746', very hard drilling 746'-753' ≈1 ft/15 min	@748' soap foam, temperature is 46°C, @751' foam temperature is 47°C, @753' water temperature is 50°C	100-120 gal/min @753'		746'-753' most of cuttings are mixed in with soap, hard to obtain
	Chlorite, green and tan	1/32"-1/8", while drilling					

Table 1. Cont'd.

Depth (feet)	Lithology	Cuttings Size and Shape	Drilling Action and Rate	Water Temperature	*Amount of Water* Being Blown	Water Level	Comments
753-759½	Chlorite, same description. ≈95% of total cuttings 753'-755', greater ratio of tan/green 755'-759', 100% of total cutting 755'-759' green only, 95% of total 759'-759½'	1/32"-1/4", subangular with rounded edges, coarser cuttings 755'-759'	Hard to drill 753'-755', easier drilling 755'-759' (chlorite cutting only)	@753' water temperature 43°C, @755' - 41°C	Well produces 60+ gpm when tan chlorite is encountered (5-10 gal/min, 753'-755')	215' 9:00 a.m. 5/27/81 441-1/4' 3:50 p.m. (20 min after being blown) 5/27/81 295' 4:15 p.m. (45 min after being blown) 5/27/81 234' 4:30 p.m. (1 hr. after being blown) 5/27/81	Sand cutting very fine to silty - hard to identify
	Sand, same description, very fine, overall brown color	Very fine - being nearly silt, shape?					
759½-770	Sand, silt, brown ≈95% of cuttings 759½'-770'	Very fine, shape?	Very hard drilling 3'-5'/hr	@764' water while drilling	5-15 gal/min while drilling		
	Chlorite, same description, green only, ≈5% of total cuttings						
770-771'	Chlorite, same description, tan ≈80%, green ≈20%	1/32"-1/16"		@771' water temperature is 40°C while drilling	Well producing more water ≈60+ gal/min while drilling		
771-774½	Sand, quartz with some red, pink and brown grains	Fine, subangular to subrounded			less water, ≈10-15 gal/min @774'		
774½-787	Sand, silt, brown, ≈95% of cuttings	Very fine, shape?	Very hard drilling ≈2-3 ft/hr	@779' - 49°C @786' - 48°C @787' - 48°C (all while being blown	≈30-50 gal/min 774½'-784½', ≈70+ gal/min 784½'-787'		Hole is caving in 775'-779'
	Chlorite, same description, tan and green	≈1/16"					
@787	Sand, light brown, quartz, orthoclase, plagioclase garnets? spidite? A couple of larger fragments appear to be made of coarse quartz grains cemented by red-orange FeO	Very fine up to 1/8" diameter) larger fragments angular				215' 11:00 a.m. 5/28/81	

Table 1. Cont'd.

Depth (feet)	Lithology	Cuttings Size and Shape	Drilling Action and Rate	Water Temperature	Amount of Water Being Blown	Water Level	Comments
787'-789'	Chlorite, dark green, harder than previously encountered, ≈3 hardness, ≈60% of total cutting from 787'-789'	1/32"-1/8", more angular than before				212' a.m. 6/1/81	5-7/8 steel toothed bit has been installed
	Sand, mostly quartz, with some red, pink and black grains, ≈30% of cuttings	Fine, angular to subrounded				245' 5:30 p.m. 6/1/81 (water level probably not @ equilibrium)	
	Basalt, gray chips with plagioclase phenocryst	≈1/8" diameter, angular					
	Phlogopite?, brownish gold	This flakes to 1/2" diameter					
789-800	Sand, quartz, with some pink, red, and brown grains, ≈95% of total cuttings, finer @797'-800'	Very coarse, angular to subrounded 789'-797', coarse 797'-800'	drilling rate has been relatively fast until 797' when large volume of water was encountered	@789' - 49°C @797' - 49°C	Fred W. estimated ≈200+ gal/min 797'-800', well produced very little water 791'-797'		
	Chlorite, dark green, hardness of 3	1/16"-1/4", same description					
800-804	Basalt, light gray with plagioclase phenocrysts, very little quartz, ≈1% represents ≈70% of total cuttings	1/32"-1/8" angular	drilling is slowed				
	Chlorite, dark green to light green, 30% of cuttings	1/32"-1/4", chips, mostly flat					

Table 1. Cont'd.

Depth (feet)	Lithology	Cuttings Size and Shape	Drilling Action and Rate	Water Temperature	Amount of Water Being Blown	Water Level	Comments
804-805½	Sand, quartz, with some pink, red, brown, tan and black grains. A couple of the larger chips appear to be orthoclase	Medium to coarse, subangular to subrounded	Very slow, very few cuttings	@804' - 50°C	Well producing ≈40 gal/min 804'-804½', ≈120+ gal/min 804½'-805½'		
	Chlorite, light green, some pieces fringed with tan, ≈90% of total cuttings 804'-804½', ≈95% 804½'-805½', tan 40%-50% of total from 804½'-805½'	1/16"-1"					
	Phlogopite?, brownish gold, ≈2%-3% of total cuttings from 804½'-805½'	Thin flakes to ½" diameter					

Hydrologic Log of the Test Hole

The basalt (andesite?) above 653 feet yielded very little water during construction of the test well. More water (@30 gallons per minute (gpm)) was reported in the interval of 653 to 655 feet. The sand interval near the bottom of the well appeared to produce considerable quantities of water (estimated 100 gpm at 753 feet and 200 gpm at 800 feet).

The static depth to water in the well did not vary widely during construction. The depth to water was reported at 205 feet when the hole was 500 feet deep, 206 feet at 715 feet hole depth, 215 feet at 753 feet hole depth and 212 feet at 787 feet hole depth. The geophysical log indicated a static depth to water of 208 feet. The greater depth-to-water values noted on the geologic log were because of air pumpage of the well during drilling.

The elevation of the static water level in the test well is about 3,330 feet. This level is similar to the postulated water level elevation of 3360-3380 feet noted previously for the White Arrow-Tschanne system (Ralston and Prager, 1980, p. 17). Both water level evaluations are based upon extrapolation of land surface elevations from a topographic map with a 40-foot contour interval. The test well appears to penetrate the same flow system that feeds the hot springs.

GEOPHYSICAL LOGS OF THE TEST HOLE

Description of the Logging Procedure

The test well was logged on June 8, 1981, by Gene Thompson of EG & G Idaho. Temperature, caliper, and natural gamma logs were run in the hole. Rough copies of the logs were mailed to the author on July 8, 1981. The geophysical logs were drafted and scaled by U.U.R.I. and mailed to the author on July 20, 1981. The logs are presented on Plate 1.

Caliper Log

The caliper log provides a record of the diameter of the drilled hole and is useful for formation evaluation. The caliper log presented on Plate 1 shows the extent of the 6-inch casing from 0 to 246 feet. The log has a drift to the left that is not representative of the hole; the casing diameter is shown smaller at 240 feet than at the surface. Cave zones are shown at 290 and 330 feet opposite logged contact zones in basalt (andesite?). A basalt-clay zone was logged at 330 feet. The next major cave zones are 512 and 538 feet. No particular reason for these zones is apparent from the geologic log. Major caving occurred throughout the sand zone from 710 feet to the bottom of the hole. Much of this caving was probably due to washing resulting from continued drilling. The sand zone apparently is not highly cemented.

Gamma Log

The gamma log provides a measure of the natural gamma radiation emitted from geologic materials penetrated by the test hole. It is useful to aid stratigraphic interpretation. The gamma logger was run twice in the hole. The tool was first lowered down the hole with the horizontal chart scale set at 50 mv/inch. This log is poor because the tool hung up within the hole at 330 and 550 feet. Unexplained scale shifts occurred

For Gamma Ray ??

at both depths. The gamma tool was then withdrawn from the hole with the horizontal chart scale set at 100 mv/inch. This log, shown on Plate 1, is of limited value because of the compressed horizontal scale. The sand zone from 710 feet to the bottom of the hole is clearly shown by a shift of the gamma log to the left. The zone from 330 to 710 feet is monotonously uniform. It is not known why the gamma log from the bottom of the casing at 246 feet to 330 feet is shifted to the left.

Temperature Log

The temperature log was the first log obtained and was run from top to bottom in the hole. The sensitivity of the logging instrument or the logging speed were not given. The temperature data were scaled from the log to 0.1°F. The temperature and geothermal gradient data for selected depths are presented in Table 2.

The temperature log on Plate 1 shows an increase in air temperature from 66°F at land surface to 73°F just above the water surface. The considerable heat loss from the water to the air is shown in the steep temperature gradient immediately below the water surface. The geothermal gradient gradually decreases from 16°F/100 feet (300°C/km) at 260 feet to 10°F/100 feet (180°C/km) at 325 feet. The gradient remains less than 10°F/100 (180°C/km) from 325 feet through 720 feet. This zone correlates with the thick sequence of relatively uniform basalt (andesite?). The water temperature and geothermal gradient increase markedly throughout the sand interval of 710 to 805 feet. The large increase in temperature at the bottom of the hole probably indicates that drilling stopped in or just above a zone of higher hydraulic conductivity. The bottom hole

Table 2. Depth, temperature and geothermal gradient data from the White Arrow test well.

Depth (meters)	Depth (feet)	Temperature °C	Temperature °F	Geothermal Gradient °C/km	Geothermal Gradient °F/100 ft
5	16	18.9	66.0	20	1.1
10	33	19.0	66.2	20	1.1
15	49	19.1	66.3	20	1.1
20	66	19.2	66.6	20	1.1
25	82	19.3	66.8	20	1.1
30	98	19.4	67.0	20	1.1
35	115	19.5	67.2	20	1.1
40	131	20.3	68.6	160	8.8
45	148	20.8	69.4	100	5.5
50	164	21.2	70.2	40	2.2
55	180	21.7	71.1	100	5.5
60	197	22.4	72.4	140	7.7
65	213	26.9	80.5	900	49.4
70	230	29.4	85.0	500	27.4
75	246	31.1	87.9	340	18.7
80	262	32.6	90.6	300	16.5
85	279	33.9	93.0	260	14.3
90	295	35.1	95.1	240	13.2
95	312	36.3	97.4	240	13.2
100	328	37.2	99.0	180	9.9
105	344	38.0	100.4	160	8.8
110	361	38.6	101.5	120	6.6
115	377	38.9	102.1	60	3.3
120	394	39.4	103.0	100	5.5
125	410	39.7	103.5	100	5.5
130	426	39.9	103.9	40	2.2
135	443	40.4	104.8	100	5.5
140	459	40.7	105.3	60	3.3
145	476	41.1	106.0	80	4.4

Table 2. Cont'd.

Depth (meters)	Depth (feet)	Temperature °C	°F	Geothermal Gradient °C/km	°F/100 ft
150	492	41.6	106.8	100	5.5
155	508	41.7	107.1	20	1.1
160	525	42.0	107.6	60	3.3
165	541	42.2	107.9	40	2.2
170	558	42.4	108.3	40	2.2
175	574	42.7	108.8	60	3.3
180	590	42.8	109.0	20	1.1
185	607	43.0	109.4	40	2.2
190	623	43.3	110.0	60	3.3
195	640	43.6	110.5	60	3.3
200	656	44.0	111.2	80	4.4
205	672	44.5	112.1	100	5.5
210	689	45.1	113.1	120	6.6
215	705	45.6	114.1	100	5.5
220	722	46.2	115.1	120	6.6
225	738	47.2	116.9	200	11.0
230	754	48.2	118.8	200	11.0
235	771	49.4	121.0	240	13.2
240	787	51.1	124.0	340	18.7
245	804	54.7	132.5	720	39.5

temperature was noted as 132.5°F (55.8°C) at 804 feet. The maximum discharge temperature measured during drilling was 122°F (50°C).

HEAT FLOW ANALYSIS

Introduction

The following descriptions of heat flow analysis were taken from Brott, Blackwell and Mitchell (1976, pp. 3 and 11).

> Heat is produced in the earth mainly from radioactive decay of potassium, uranium and thorium. The heat generated in this manner causes the temperature in the interior of the earth to be greater than the temperature on the surface. In order to obtain equilibrium, heat flows to the surface and is radiated into space. The flow of the heat to the surface may be by convection or conduction. Convection of heat is transfer of heat by mass movement (water, for example). Conduction of heat is transfer of heat through a solid by lattice vibrations.
>
> A heat flow study measures the heat which originates within the earth and flows out of the surface of the earth. The units used for heat flow are quantities of heat (calories) per unit area (cm^2) per unit time (second). The world-wide average heat flow is about 1.5×10^{-6} cal/cm^2sec. Typical low values of heat flow are 0.5 - 1.0×10^{-6} cal/cm^2sec and typical high values of heat flow are 2-3 x 10^{-6} cal/cm^2sec. Values higher than 3×10^{-6} cal/cm^2sec are not usually found except in geothermal areas. To simplify reference to heat flow in this report the heat flow units (10^{-6} cal/cm^2sec = microcal/cm^2sec) will be referred to subsequently as HFU. Thus an average flow is 1.5 HFU.
>
> To obtain a heat flow measurement the geothermal gradients and thermal conductivity of the underlying rocks must be known. The thermal conductivity is a property of the rocks which describes the ability of the rocks to conduct heat. Thermal conductivity measurements on core or cuttings samples from a well can be made in the laboratory. The laboratory technique used in this study is the divided bar measurement for core and cuttings samples (Birch, 1950;

Sass, et al., 1971). The units used for thermal conductivity are TCU (millicalories/[cm-sec°C]).

The geothermal gradient is obtained by calculating the change of temperature over some given interval of depth. On a plot of temperature versus depth the slope of a straight line through the points is the geothermal gradient. The units used for the geothermal gradient are °C/km.

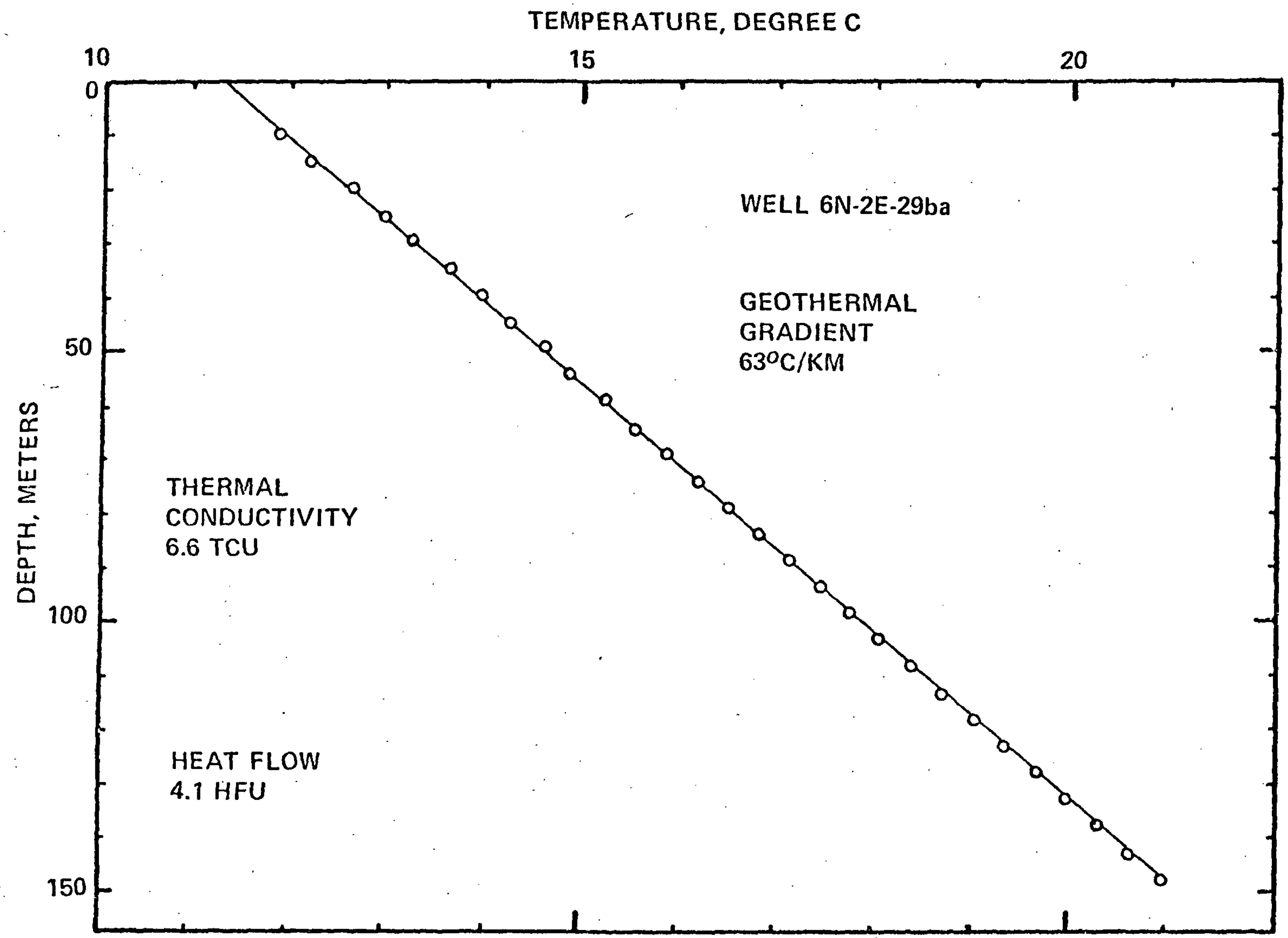
Heat flow is the product of the geothermal gradient and thermal conductivity. The units used for heat flow are HFU (microcalories/[cm^2/sec]). for example, the heat flow in a well is 4.1 HFU which is the product of the geothermal gradient (63°C/km) and the thermal conductivity (6.57 TCU). The decimal place changes because of the units.

The temperature-depth curve shown in figure 3 represents an ideal case because the thermal conductivity is uniform throughout the depth of the hole and the geothermal gradient has no major disturbances. In general, the geothermal gradient may not be uniform and the causes of this nonuniformity must be understood in order to obtain accurate heat flow values.

The geothermal gradient varies with stratigraphy because of different rock units, but the heat flow remains constant if the rocks are horizontally layered. Figure 4 shows a case where the geothermal gradient varies because of thermal conductivity changes due to changes in stratigraphy. The upper stratigraphic unit is welded tuff with a measured thermal conductivity of 4.90 TCU. The lower stratigraphic unit is welded tuff with a measured thermal conductivity of 4.90 TCU. The lower stratigraphic unit is a tuffaceous conglomerate with a measured thermal conductivity of 2.33 TCU. The geothermal gradients are 91.3 and 194.8°C/km, respectively. The heat flow, computed by the product of the geothermal gradient and thermal conductivity, is 4.5 HFU in both units in the well and so is constant with depth as is expected.

The major problems with heat flow analysis are disturbances to the geothermal gradient and complex geology. The most important factor that alters the geothermal gradient is vertical or horizontal circulation of ground water. This circulation can occur within the well such as flow

Figure 3. **Temperature-depth plot of well 6N-2E-29ba. The plot shows a uniform geothermal gradient.**



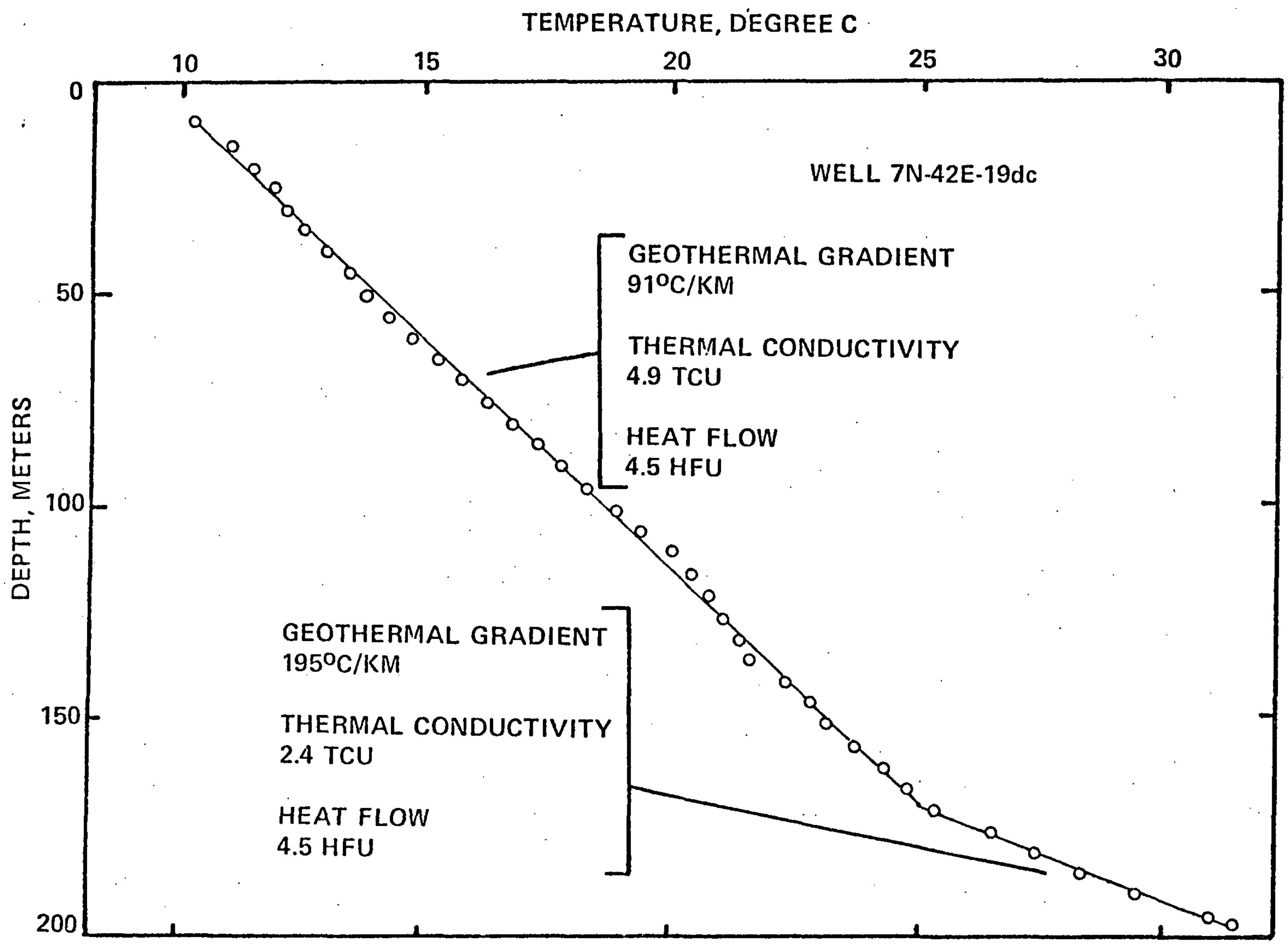


Figure 4. Temperature-depth plot of well 7N-42E-19dc. The plot shows a change in geothermal gradient due to a change in thermal conductivity (at 170 m).

from one aquifer to another and/or it can occur within the rock units penetrated by the well. Problems caused by geology include complex stratigraphy, lateral changes in thickness or thermal conductivities and structurally caused discontinuities.

The hydrogeologic setting of the White Arrow study area poses major problems for accurate heat flow analysis. The presence of the hot springs in the area indicate a major upward flow of water, probably along faults or geologic discontinuities. The stratigraphy of the Banbury formation is complex and is interupted by a series of west-northwest trending normal faults. Much care must be exercised in using calculated heat flow to predict temperatures at depth within the study area.

Thermal Conductivity

Values of thermal conductivity have not yet been determined for cutting samples taken from the White Arrow test hole. The two best sources of thermal conductivity values applicable to the study area are the heat flow studies of the Snake Plain Region and Western Snake River Plain by Brott, Blackwell and Mitchell (1976) and Smith (1980), respectively. A compilation of the bulk and "in situ" thermal conductivity values from these studies is presented in Table 3. The mean calculated "in situ" values for basalt and for sand and clay are believed to be representative of the basalt and sand portions of the Banbury formation within the study area.

Table 3. Bulk thermal conductivity results (from Smith, 1980).

	Rock Type				
Investigator	Basalt	Granite	Silicic Volcanics	Sand & Clay	Clay
1. Smith	3.7 ± 0.38*	6.67 ± 0.95	5.43 ± 0.90	5.10 ± 1.9	3.83 ± 1.11
2. Brott	4.5 ± 0.50	6.50 ± 0.30	4.83 ± 0.27	6.00 ± 8	3.60 ± 4.0
Change of 1. from 2.	18% less	18% more	12% more	15% more	6% more
Combined Average	4.03 ± 1.06	6.49 ± 1.57	4.83 ± 0.27	5.20 ± 1.84	3.78 ± 0.98
Assumed Porosity	10%	5%	5%	30%	30%
Calculated "*in situ*" Value	3.62 ± 0.85	6.01 ± 0.50	4.54 ± 0.24	3.49 ± 0.90	2.79 ± 0.51
Number of Samples					
Smith	45	9	9	138	46
Brott	16	24	16	15	15
Total	61	33	25	153	61

NOTE: *4.83 ± 0.27 = mean ± one standard deviation.

Units of Measurement = TCU Millicolorus/cm - sec °C)

Geothermal Gradient

The geothermal gradient data from the White Arrow test well, presented in Table 2, range from 900°C/km (49.4°F/100 ft) to 20°C/km (1.1°F/100 ft). The highest gradient values, 900°C/km and 720°C/km (49.4°F/100 ft and 39.5°F/100 ft) were near the water surface and at the bottom of the hole. The high gradient values near the water surface may be dismissed because they reflect heat loss to the air. Brott, Blackwell and Mitchell (1976) noted that gradient data taken in the 15-20 meters (45-60 feet) below the water table may be influenced by surface air temperatures. The high "stairstep" geothermal gradient near the bottom of the hole appears to reflect the existance of small hot water aquifers in the lower portion of the sand sequence. Smith (1980, p. 53) noted a similar feature in a deep well near Caldwell, Idaho.

The geothermal gradient data that appear to have most meaning are in the interval of 340 to 710 feet and 720-780 feet. The upper interval represents the basalt (andesite?) zone shown as generally montonous on the gamma and caliper logs. The lower zone represents the sand zone. The average geothermal gradient for the zone from 340 to 710 feet is 75°C/km (4.1°F/100 ft). The average geothermal gradient for the 720-780-foot zone is 213°C/km (11.7°F/100 ft).

Heat Flow Calculations

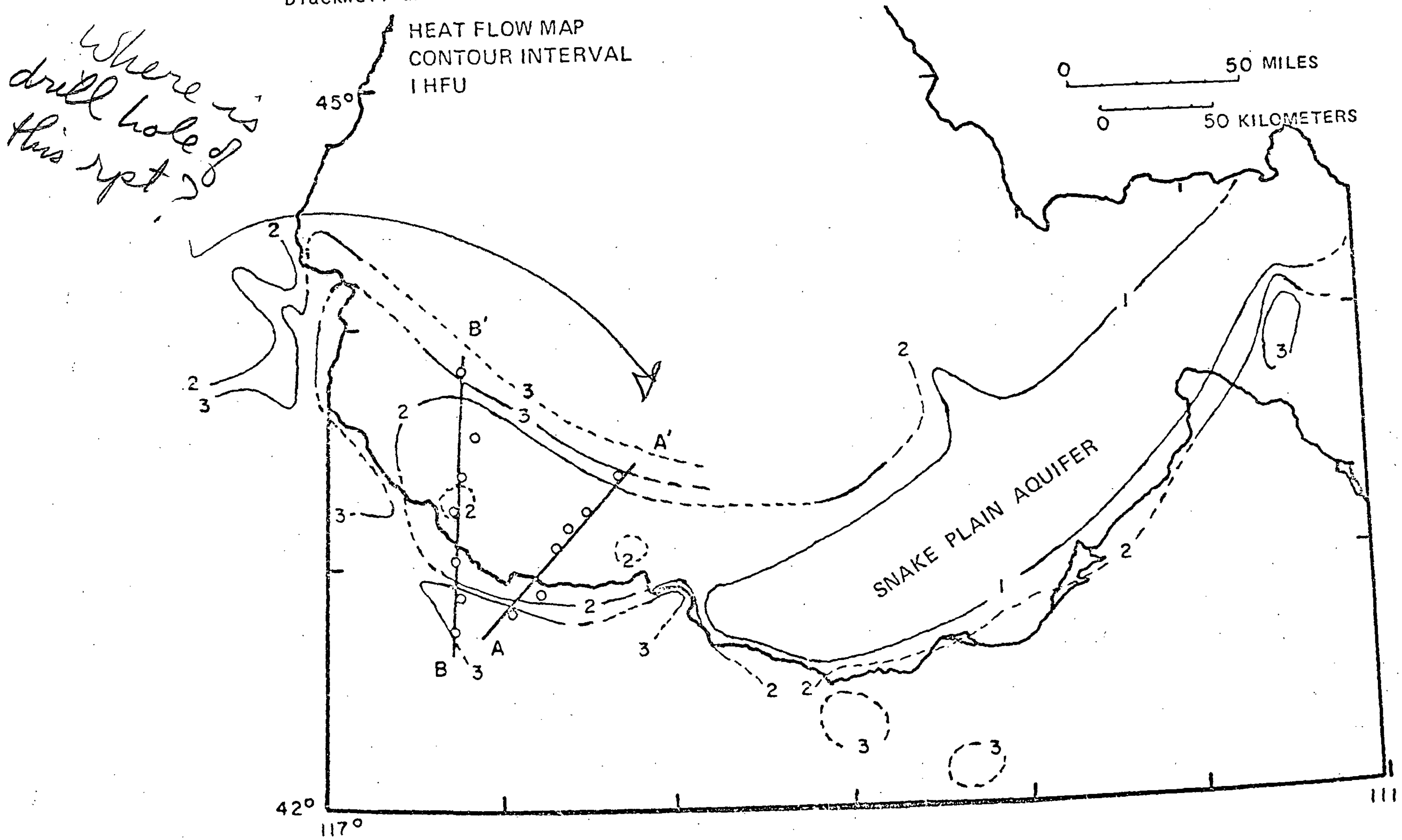
Heat flow in HFU is the product of the geothermal gradient in °C/km and the thermal conductivity in TCU divided by 100 to account for unit conversions. Two heat flow calculations are possible from data derived from the White Arrow test well. The first is for the basalts (andesites?) in the interval of 340-710 feet. The second is for the sands in the interval of 720-780 feet. The heat flow values are shown in Table 4.

Table 4. Heat flow calculations for the White Arrow test well.

Material	Depth Interval (feet)	Mean Geothermal Gradient (°C/km)	Mean "In Situ" Thermal Conductivity (TCU)	Calculated Heat Flow (HFU)
Basalt	340-710	75	3.6	2.7
Sand	720-780	213	3.5	7.4

The two heat flow values shown in Table 4 are markedly different indicating either major errors in geothermal gradient and/or thermal conductivity data or the presence of convective heat transfer by ground water flow. The calculated heat flow value for basalt in the interval of 340 to 710 feet is believed to best represent the area because of the following reasons. 1) The test well yielded small to very small quantities of water during penetration of most of the basalt sequence. The low hydraulic conductivity of the basalt would limit ground water movement and thus convective heat transfer. The sand zone yielded much more water and showed the stairstep temperature log characteristic of small hot water aquifers. 2) The heat flow value calculated for the basalt is consistent with other values found in and near the Snake Plain. The regional pattern of heat flow in southern Idaho as found by Brott, Blackwell and Mitchell (1976, p. 26) is shown in Figure 5.

Figure 5. Generalized heat flow map of southern Idaho. The 1 HFU contour in the eastern part of the Snake River Plain is from shallow water wells. The dashed contours are inferred. (after Brott, Blackwell and Anderson, 1976).



DISCUSSION OF RESULTS

Geothermal Flow Model

There is little doubt that the geothermal resource in the White Arrow area is dominated by convective heat transfer as water moves up along a fault system. The large discharge and high temperature (126 l/min and 65°C) of White Arrow Hot Spring indicate a major upward transfer of thermal energy. The heat flow measured in wells near the water bearing structural features will undoubtably be affected by the convective heat transfer.

Smith (1980) analyzed the heat flow characteristics of the Boise Front which is at least partially analogous to the White Arrow situation. His analysis was based upon models of Basin and Range-type convective geothermal systems as modeled by Blackwell and Chapman (1977). The cross-section prepared by Smith for the Boise area, presented in Figure 6, probably shows the general pattern of water temperature and heat flow that exists within the White Arrow study site. This basic model will be utilized as a basis for discussion of the geothermal potential of the study area.

Isogeothermal Horizons

Smith (1980, p. 39-43) outlined five steps in developing isogeothermal surfaces (lines of equal ground water temperature): 1) plot known lithology on cross sections, 2) plot temperatures recorded from well logs on the cross sections, 3) assign heat-flow values to each well from the heat-flow contour map, 4) calculate isogeothermal surfaces using the following equation

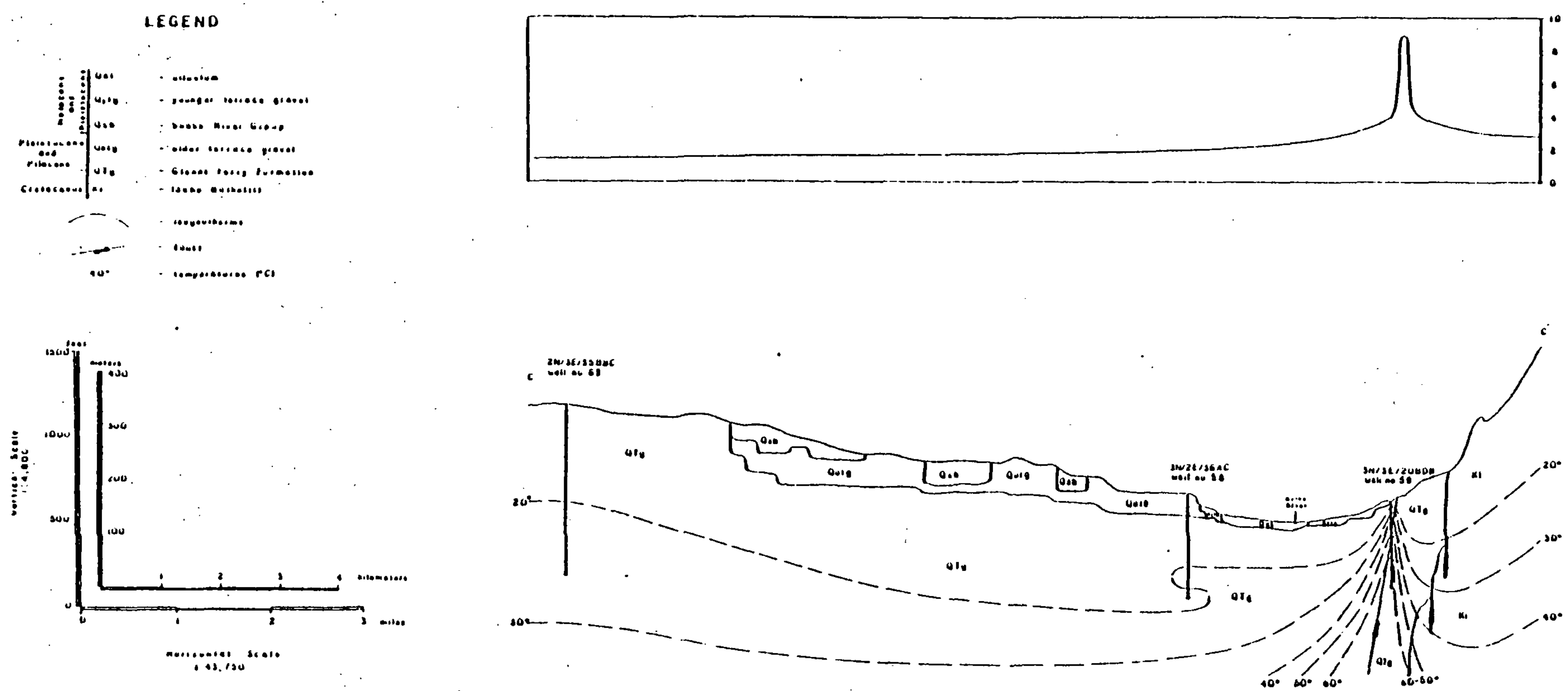


Figure 6. Cross-section C-C' showing isogeothermal horizons and heat-flow distribution.

Ref from ______.

$$\Delta t = \frac{(\Delta d)(q)}{K}$$

where: Δt = change in temperature (°C)

q = heat flow (HFU)

K = thermal conductivity (TCU)

Δd = change in depth (kilometers)

and 5) verify calculations by comparison with known temperatures in the wells. This full procedure is not possible in the White Arrow area because data are available on only one well. However, isogeotherms can be estimated if several assumptions are made.

If we assume that the heat flow value calculated for the basalt section (2.7 HFU) represents the regional pattern, then it is possible to calculate isogeotherms and speculate on the depth of circulation of the ground water flow system feeding the hot springs in the study area. The "in situ" thermal conductivity values for basalt and sand are similar (3.6 and 3.5 TCU). A mean value (3.55 TCU) may be used to represent the basalt-sediment sequence of the Banbury formation that underlies the site. The temperature-depth values are presented in Table 5. The data on Table 5 would indicate that the hot springs represent ground water flow to a depth of at least 720 meters (2400 feet). The chemical geothermometers reported by Mitchell, Johnson and Anderson (1980) for White Arrow Hot Springs indicated subsurface temperatures in the range of 108-135°C. According to the data on Table 5, these temperatures would indicate ground water flow to depths of 1300 to 1600 meters (4200 to 5400 feet).

The calculated heat flow of 2.7 HFU is much more likely to be a high estimate than a low estimate because of its proximity to the known

Table 5. Depths to isogeothermal horizons given K = 3.55 TCU and q = 2.7 HFU in a conductive geothermal system.

Water Temperature °C	°F	Depth meters	feet
60	140	660	2200
80	176	920	3000
100	212	1200	3900
120	248	1400	4600
140	284	1700	5600

Table 6. Depths to isogeothermal horizons given K = 3.55 TCU and q = 2.0 HFU in a conductive geothermal system.

Water Temperature °C	°F	Depth meters	feet
60	140	890	2900
80	176	1200	4100
100	212	1600	5200
120	248	2000	6400
140	284	2300	7600

fault controlled hot water discharge (see Figure 6). A reasonable low estimate for regional heat flow is 2.0 HFU based upon the work of Brott, Blackwell and Anderson presented earlier. Table 6 presents depth-temperature relationships based upon this heat flow value. In this case, the ground water flow system feeding the hot spring extended to a depth between 1000 and 2200 meters (3200 and 7300 feet).

Both of the above assumed conditions would change with a change in rock type with depth. The thickness of the Banbury formation within the study area is not known. The underlying Idavada volcanics have a higher thermal conductivity.

CONCLUSIONS

1. An 805-foot test well drilled in the study area penetrated basalt and sand of the Banbury formation. The basalt yielded little water while the sand was moderately productive.
2. The water temperature in the test well ranged from 27°C (80°F) at the water surface to 55°C (130°F) at the bottom. The geothermal gradient averaged 75°C/km (4.1°F/100 ft) in the basalt interval from 340 to 710 feet. The measured gradient was 213°C/km (11.7°F/100 ft) in the sand interval of 720 to 780 feet.
3. The best estimates of "in situ" thermal conductivity are 3.6 TCU for the basalt and 3.5 TCU for the sand.
4. The most representative heat flow value is 2.7 HFU for the basalt sequence from 340-710 feet.
5. Two calculations were presented representing the depth to isogeothermal horizons in the area. The calculations based upon a heat flow of

2.7 HFU are believed to be most nearly representative. Based upon this heat flow value, the depth of flow of ground water feeding the spring was estimated as 720 meters (2400 feet) based upon the discharge temperature. Chemical geothermometers indicate flow as deep as 1600 meters (5400 feet).

6. The results of this investigation must be considered in light of the complexity of the hydrogeologic system and the sparcity of data. The calculated depths to isogeothermal horizons are only approximations.

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APPENDIX

Report #1 -

Evaluation of Geothermal Potential

White Arrow Ranch Vicinity

Bliss, Idaho

Tasks A, B and C

Dated December 1980

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EVALUATION OF GEOTHERMAL POTENTIAL
WHITE ARROW RANCH VICINITY
BLISS, IDAHO:
TASKS A, B AND C

by

Dale R. Ralston
and
Gerald D. Prager

Moscow, Idaho
December, 1980

INTRODUCTION

Statement of the Problem

Low temperature geothermal systems are evident at a number of sites along the margin of the Snake Plain in southern Idaho. The White Arrow Ranch property located in Gooding County is a prime example of the dominant type of geothermal resource that exists within the state (figure 1). The work described within this document was undertaken under funding from the U. S. Department of Energy administered through the University of Utah Research Institute. Although the research results are directed to the resource development at White Arrow Ranch, the results are applicable to geothermal development throughout the lower Clover Creek area.

Purpose and Objectives

The purpose of this project is to evaluate the geologic and the hydrologic controls and the extent of the shallow geothermal systems in the vicinity of the White Arrow Ranch near Bliss, Idaho. The project consists of geologic and hydrologic investigations including the construction of a shallow (less than 1,000-foot) geothermal gradient test hole.

The objectives of the work are listed as a series of six tasks.

Task A - Summarize geologic knowledge and obtain field data where necessary to formulate a preliminary geologic framework for geothermal flow systems in the general study area.

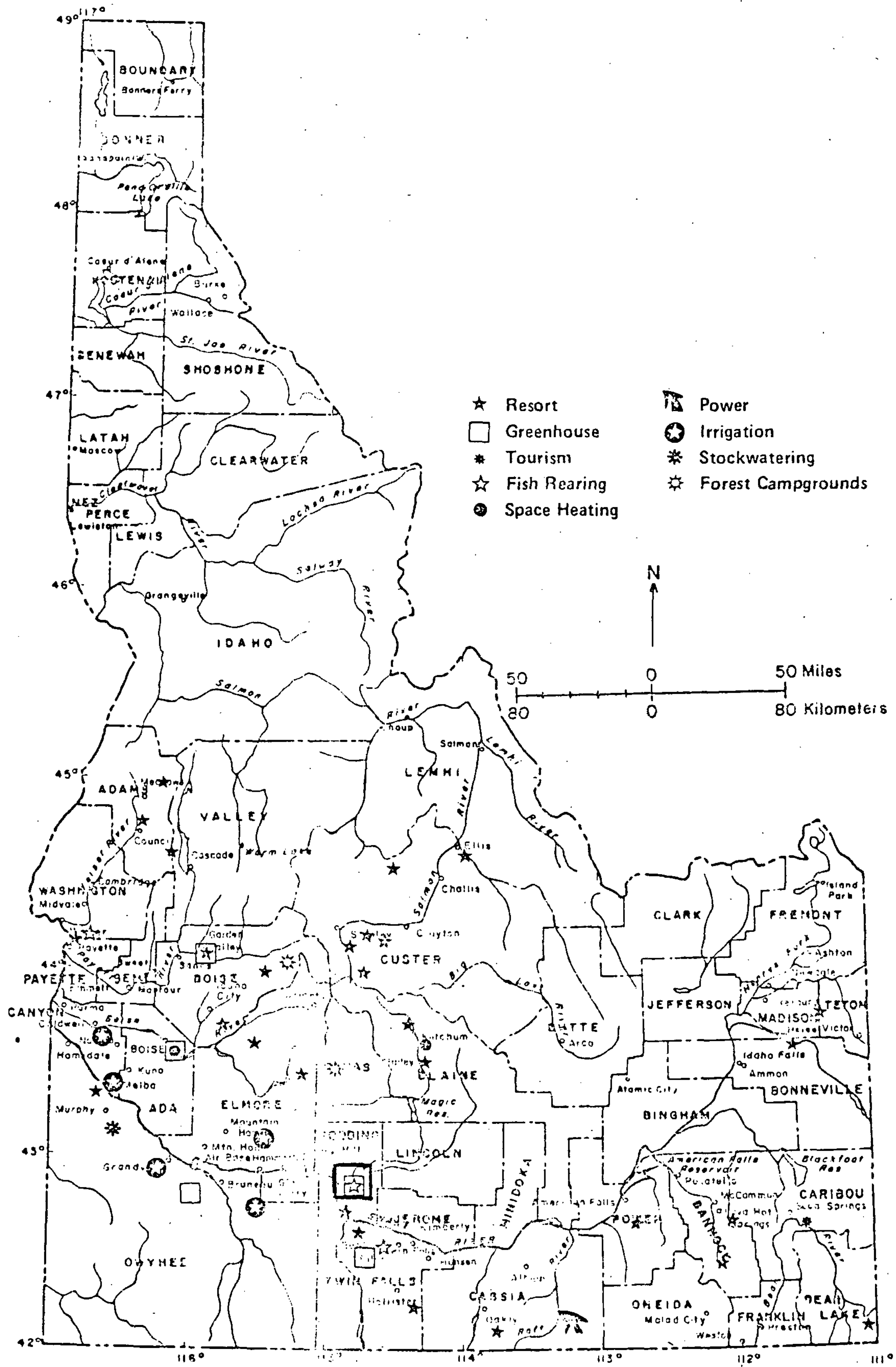


Figure 1. Location map of White Arrow Hot Springs in Idaho.

Task B - Summarize hydrogeologic knowledge and obtain field data where necessary to formulate a preliminary conceptual model of the geothermal flow system in the general study area.

Task C - Utilize geologic and hydrologic interpretations, possibly supplemented by surface geophysical investigations to locate a target site for a 700-800 foot geothermal gradient test hole.

Task D - Construct a small diameter test hole to a target depth of 700-800 feet for the purpose of obtaining hydrogeologic and heat-flow data.

Task E - Utilize standard borehole geophysical techniques to obtain a temperature log of the test hole.

Task F - Administer the project and combine the results of investigations described in tasks A-E into a report of findings.

Method of Study

This report is presented as fulfillment of Tasks A, B, and C as noted in the previous section. As such, the method of study involved four steps.

1. Collect and summarize available geologic, hydrologic and geothermal data on the area.
2. Conduct a brief geologic investigation of the site to confirm mapped geology and obtain more detailed data on structural features in the area.

3. Conduct a brief hydrologic investigation of the site to confirm published spring and well locations and to obtain more data on shallow ground water flow patterns associated with the geothermal system.
4. Select a test well site based upon Steps 1, 2 and 3.

HYDROGEOLOGIC FRAMEWORK

Areal Geology

The regional geology of the part of the Snake River Plain occupied by the White Arrow Ranch consists primarily of a series of Tertiary and Quaternary basalt flows overlain in lower areas by Quaternary alluvium. The Tertiary basalts, locally of the Banbury formation, are divided into an upper and lower member with an intervening unit which is mostly sedimentary in nature. The latter unit is highly variable in thickness, pinching out altogether in many places, and is typified by sands and rounded felsic pebbles of various sizes that were washed in from the highlands to the north and west. This unit appears to contain some thin basalt flows from place to place. It tends to weather to a reddish color and its contrast to the basalts in color and lithology make it the most useful marker bed of the region.

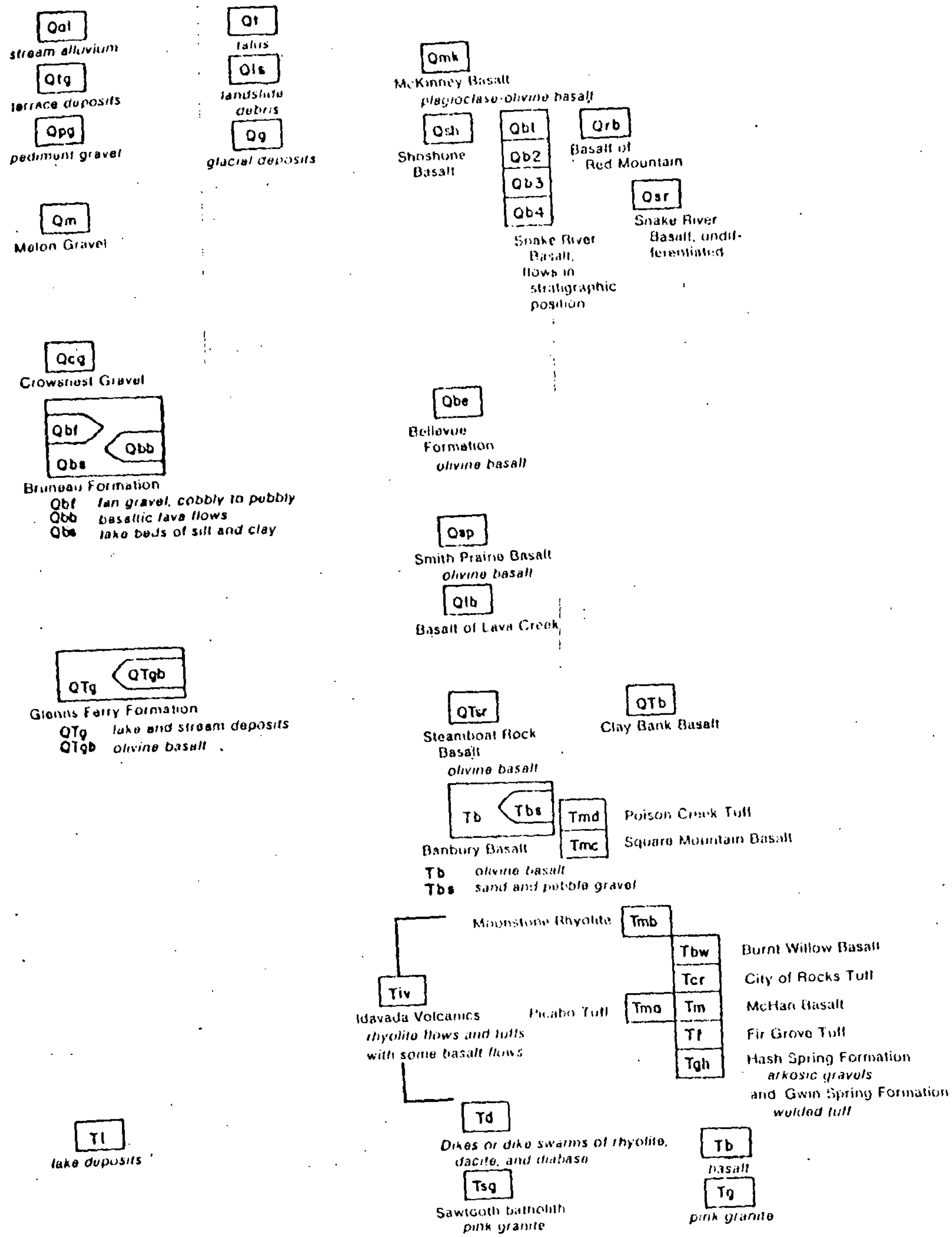
The Quaternary basalts are highly vesicular and actually scoriaceous in places. They are neither as thick nor widespread as the Tertiary flows and tend to follow existing topography and fill in low plains. Source beds for these flows can be seen throughout the region; one of these, called Hot Sulfur Lake, is located only a mile east of White Arrow Ranch and was the source of the Quaternary basalts that flowed over the ranch. Certain interesting features such as caves, tubes and natural bridges are found in these basalts.

The regional structural geology, according to a map by Malde, Powers and Marshall (1963) (updated by Rember and Bennett, 1977), consists primarily of a series of west-northwest trending normal faults south side down (figure 2). One of these is shown to cross White Arrow Ranch only perhaps 50 yards south of the primary hot spring location. It may be significant that six miles north of the ranch the trend of south dipping normal faults is mapped as north-northeast. These faults occurred subsequent to the Tertiary basalt flows and prior to any Quaternary deposition.

Local Structural Geology

Field work on the White Arrow Ranch and its vicinity indicates that the structure is more complex than that shown on figure 2 from previous mapping. In fact, the situation appears to be one of complex block faulting with several south-dipping, east-northeast trending normal faults branching off from the main north-northeast trending fault and crossing the small valley occupied by the hot spring (figure 3). This relationship is shown schematically on figure 4, a north-south cross section near the spring.

Notable features in the area include numerous white patches visible in the outcrops along road cuts and on the hillsides. These are lenticular in cross section and vary in size from several feet to about 100 yards across. Close examination shows them to consist of sand, chalky lumps, and white coated chunks of basalt and other rock.



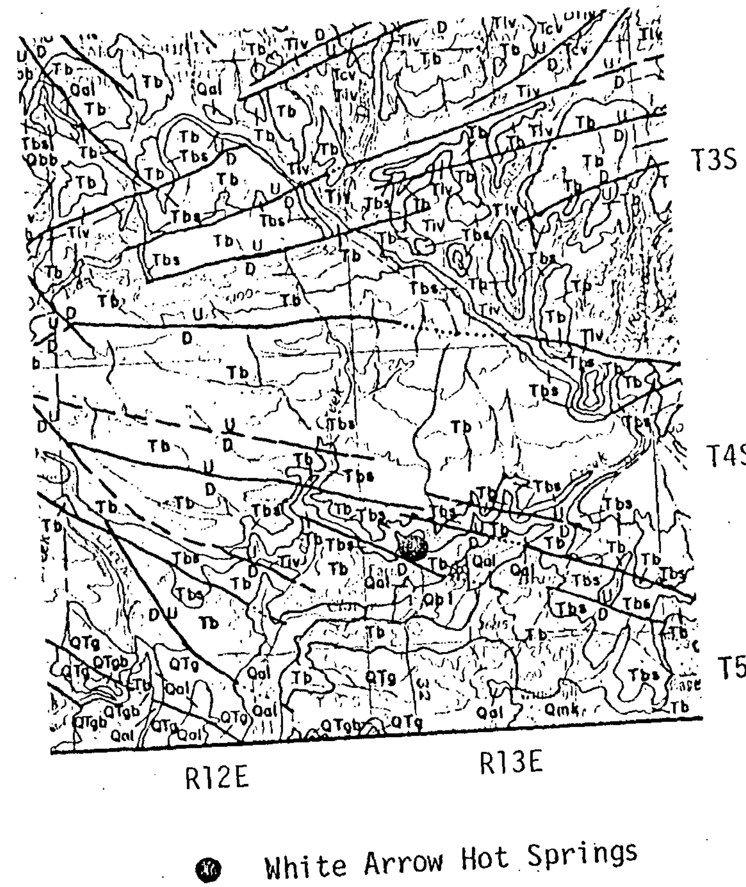
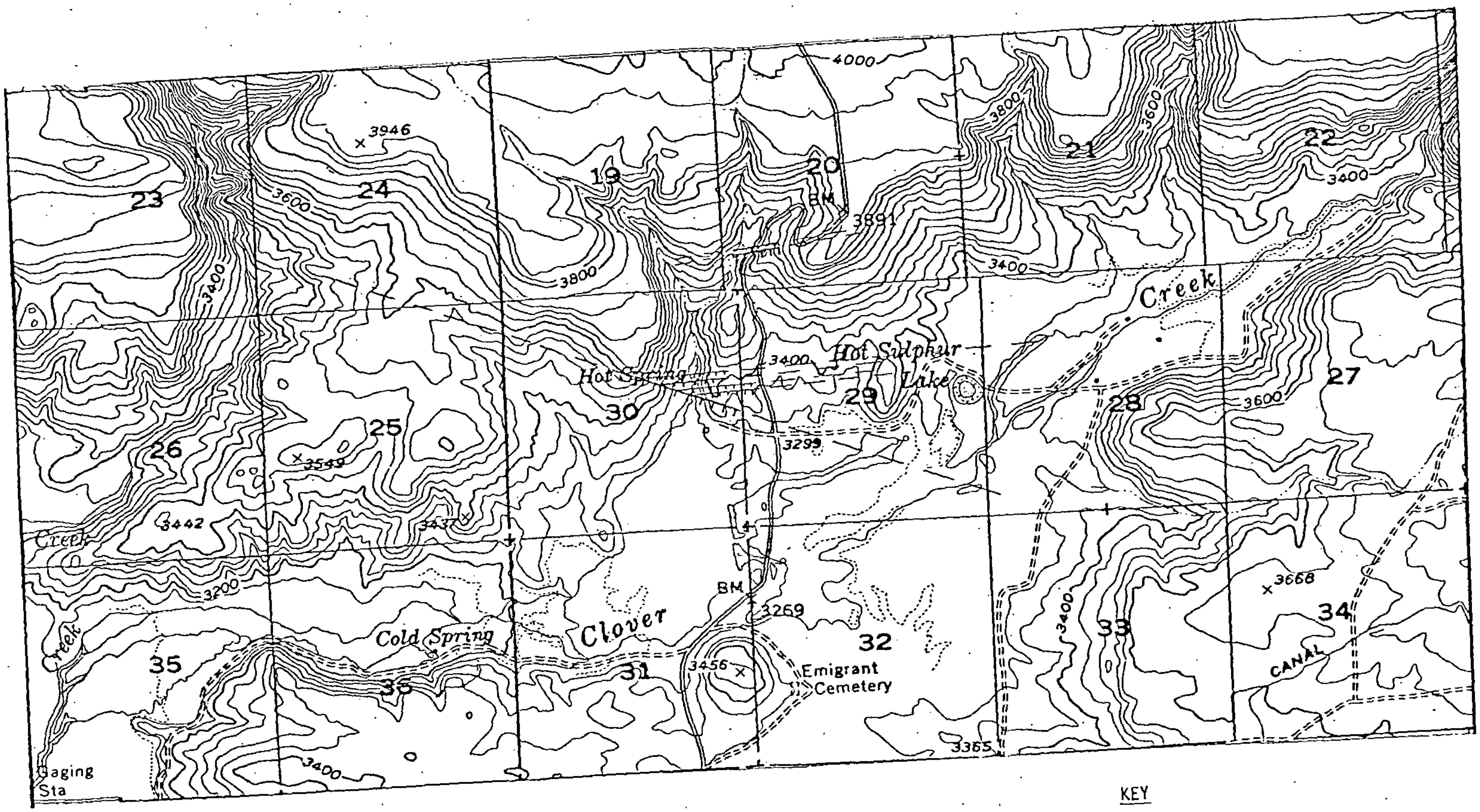


Figure 2. General Geologic map of the vicinity of Whitearrow Hot Springs, Idaho (after Rember and Bennett, 1977).



0 1 mile

Scale

KEY

Normal Fault (down block hatchured)

Normal Fault (approximate location)

Figure 3. Structural features in the vicinity of White Arrow Hot Springs.

[redacted]

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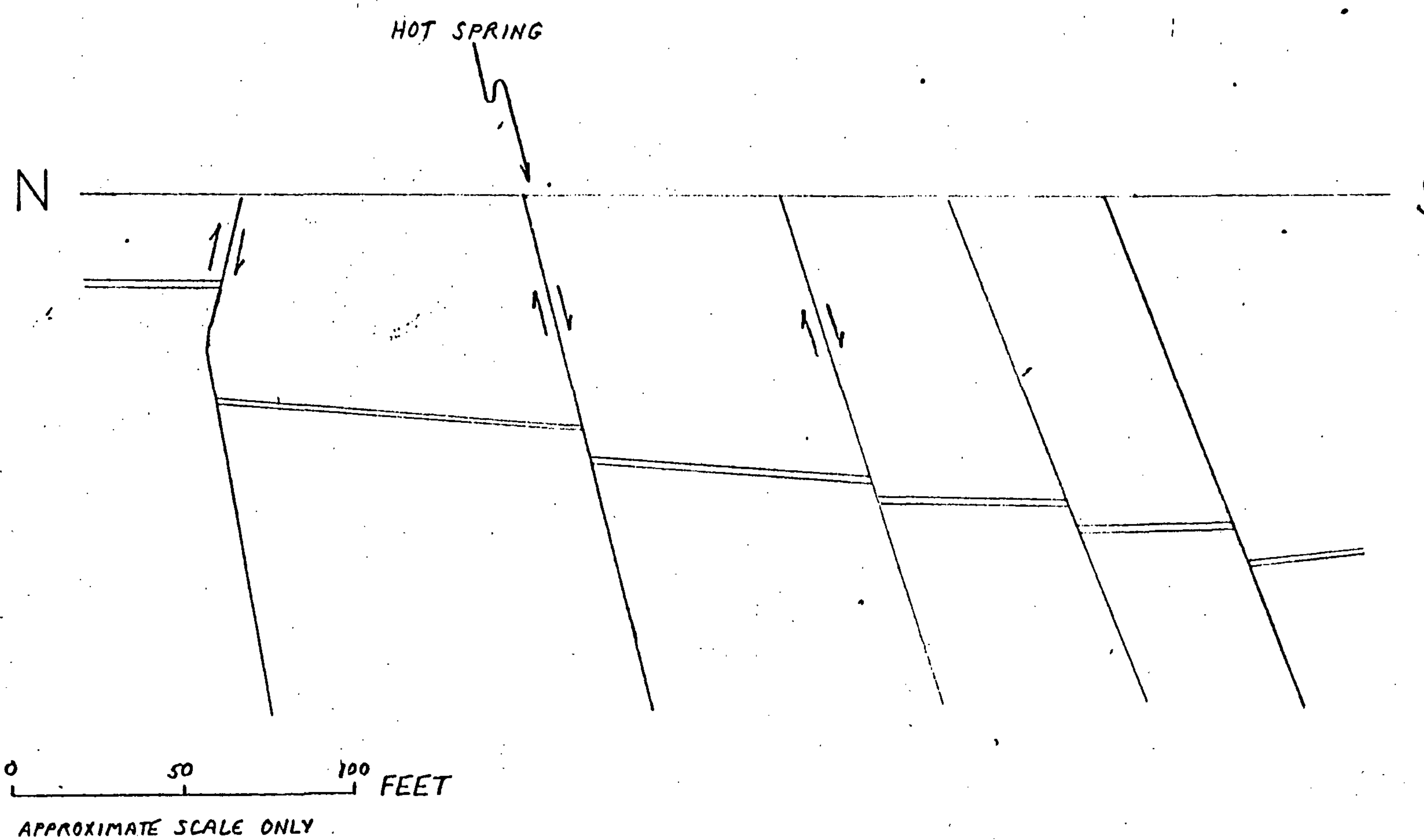

Figure 4. SCHEMATIC CROSS-SECTION
North-South Through Hot Spring

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Because of their form and sandy lithology, they are interpreted as being stream lain deposits, mainly channel sands. The white coatings found in the stream deposits are identical to that found over the rocks and pebbles lying in the stream from the modern hot spring at White Arrow Ranch. It is reasonable to infer that the white lenticular patches in the outcrops represent evidence of similar geothermal activity in the geologic past. Some support for this interpretation can be found in a remarkable outcrop in a roadcut on the route to Hill City, 0.85 miles north of its junction with the White Arrow Ranch access drive. Here, a 50-yard length of the Tertiary interbasaltic sedimentary material, red in color and with numerous round pebbles in a sandy matrix, is bounded to the north and south by high angle faults, south-dipping probably normal. Masses of Tertiary basalt occur across the faults, with that on the north differing sharply in appearance from that on the south. The attitude of the fault to the north was measured in one place as N.80°E., 65°S., and that on the southern fault appears to be similar. White coated material occurs along the faults and is practically confined to them. The southern block of basalt appears to be the upper member of the Banbury formation and the northern block is the lower member with the intermediate sedimentary member juxtaposed between by the faulting. In style, spacing and attitude, the faulting at this outcrop is very similar to that inferred for the valley of the hot spring just over a half mile to the south-southwest.

Also significant is the presence of a large white-coated outcrop, nearly continuous and 100 yards long, located along the Hill City road about 0.4 miles north of the junction of White Arrow Ranch access drive.

This is on strike with the inferred trend of normal faulting as traced from the point of branching off, just under the rim of the west side of the hot spring valley at its southern end (figure 3). This is notable because these evidences of past geothermal activity appear to be closely linked spatially to faults. The main east-southeast trending fault is exposed in a small cut on the east side of the hot spring valley, south of the present hot spring.

Finally, a brief aerial reconnaissance of the area not only tended to confirm the foregoing interpretation but also indicated the preferential grouping of white patches in a number of small north-northeast trending valleys extending northward from the main fault. The valley which is occupied by the hot spring is an example of one of these small valleys. This seems to indicate a further contribution to the structural control of the hot spring distribution by a set of north-northeast trending fractures, probably large joints.

Summary

It appears that the primary structural control for the distribution of hot springs in this area is a set of east-southeast trending, southward dipping normal faults with east-northeast trending, southward dipping branches. A secondary control appears to be a widely spaced (about 2 miles) set of north-northeast trending features which also control some of the smaller surface drainage channels. The age of this faulting is middle Pliocene.

The hot spring which is the main subject of this study is located in a zone of small fault blocks formed by movement along normal faults oriented approximately N.80°E., 70°S., branching off from a larger normal fault to the south that trends N.60° to 65°W. and also dips steeply to the south. Displacement along these faults is not great. The northernmost shows the greatest dip-slip along the branch faults; it is only 30 to 40 feet. The other branch faults show dip-slips at the surface of 5 to 10 feet. It is doubtful that displacements are significantly greater at depth, although the depths to which the faults extend is, of course, uncertain. There is a possibility that some strike-slip movement which may have occurred on the north-northeast trending branch faults may have occurred on the east-northeast trending branch faults, in which case a greater depth of faulting is possible. In general, however, depths greater than 5,000 to 10,000 feet should be considered unlikely. The main east-southeast trending fault does not seem to have undergone much greater displacement according to aerial map patterns. It appears that dip-slip movement was on the order of 50 to 60 feet and map patterns indicate that essentially all the displacement was dip-slip.

GEOTHERMAL SYSTEMS

Geothermal Occurrences

Most of the springs and wells in the vicinity of the White Arrow Ranch show the presence of the geothermal system. These may be roughly grouped into springs and wells that discharge hot water, warm water, or cold water. See table 1 and figure 5 for information and location of these sites.

Two springs and three wells have surface temperatures in excess of 40°C. Two of the Tschanne sites, well 4S/13E 21dcbl and spring

Table 1. Spring and Well Temperatures and Locations Near White Arrow Ranch, Idaho

Location	Owner's Name	Temp.	Well Depth (feet)
		Well Data	
4S/12E 35cad1	Dave Archer	45°C[1]	551
4S/12E 36abc1	Dave Archer	slightly warm[4]	620
4S/13E 21dcb1	John Tschanne	53°C[1]	150
4S/13E 22cac1	John Tschanne	warm[2]	190
4S/13E 22cac2	John Tschanne	warm[2]	275
4S/13E 28acd1	Sterling Bray	warm[3]	@150
4S/13E 28bdd1	Fran Wallace	warm[3]	275
4S/13E 28bdd2	Fran Wallace	warm[3]	122
4S/13E 28bdd3	Fran Wallace	warm[3]	@ 90
5S/12E 3aaa1	Dave Archer	57°C	1070
		Spring Data	
4S/12E 36acd1S		cold	
4S/13E 21dcc1S	Tschanne Spring	43°C[1]	
4S/13E 28aad1S	Seeps in Clover Creek	warm[2]	
4S/13E 29add1S	Hot Sulfur Lake	27°C[1]	
4S/13E 30adb1S	White Arrow Hot Springs	63°C	

[1] Mitchell and others, 1980

[2] Communication with John Tschanne, 11/12/80

[3] Communication with Sterling Bray, 11/12/80

[4] Communication with Vic Chenney, driller, 11/20/80

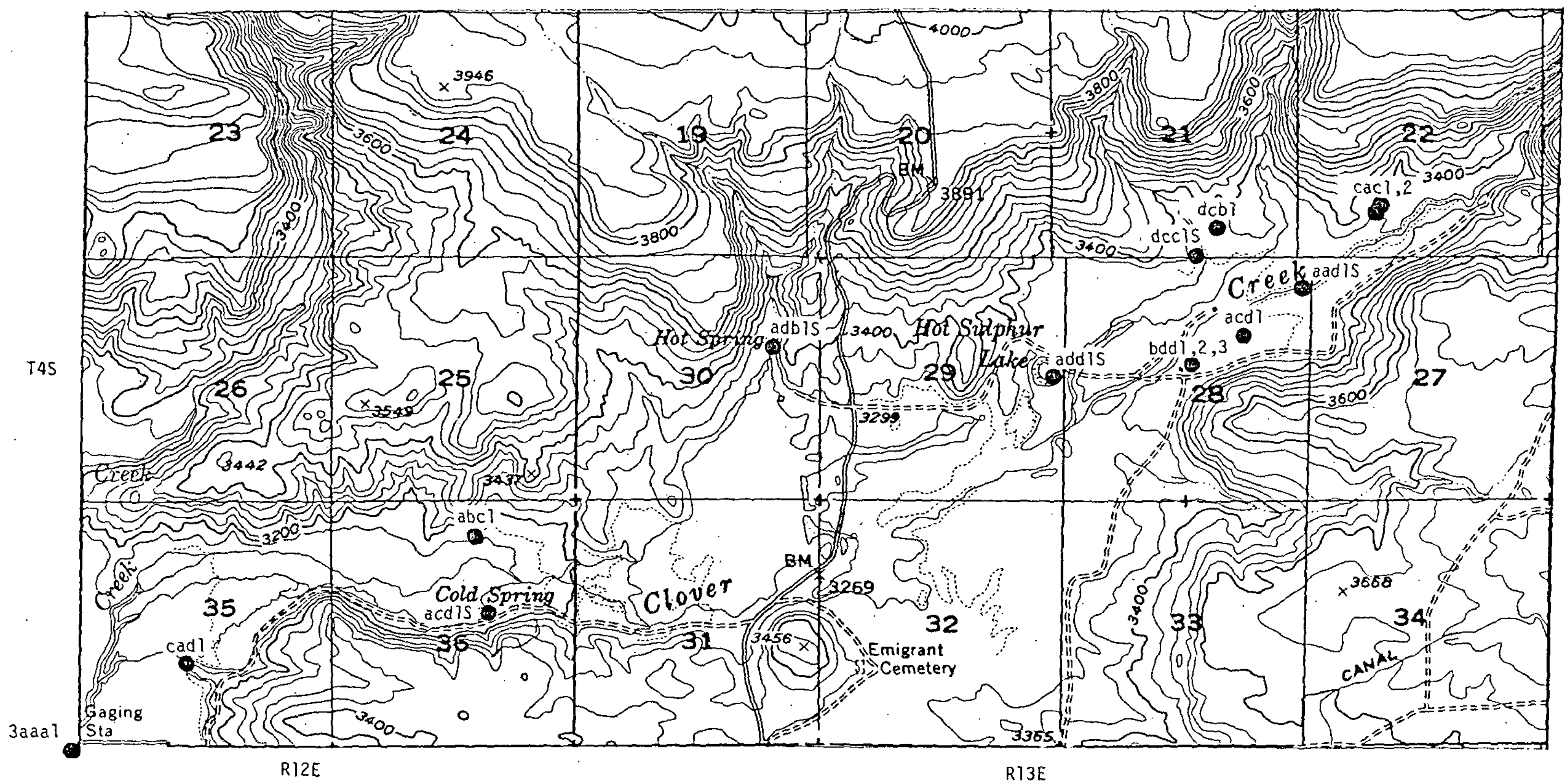

Figure 5. Location of Springs and Wells in the Vicinity of Whitearrow Ranch, Idaho.

4S/12E 21dcc15, represent the same system. The well was drilled early in the century at the hot spring site. A log is not available. The spring at White Arrow Ranch (4S/13E 29add15) is believed to be in the same system as the Tschanne sites. All of these geothermal occurrences lie along a fault system identified earlier in the report (see figures 3 and 5). The warm seeps along Clover Creek (4S/13E 28aad15) are also believed to be associated with this system.

The two Dave Archer hot wells (4S/12E 35cad1 and 5S/12E 3aaa1) are believed to be associated with a hydrologically separate geothermal system associated with a west-northwest trending fault that lies south of the structure that controls the White Arrow-Tschanne sites. The strongest evidence for this separation is the slightly warm 620-foot well (4S/12E 36abc1) located in between the two systems. This well was test pumped at about 1,000 gallons per minute and yielded water that was only slightly warm to the touch (Vic Chenny, personal communication, November 20, 1980).

The narrow band-like nature of the White Arrow-Tschanne system is further delineated by examination of irrigation and domestic wells drilled both north and south of the fault structure. The Tschanne warm wells (4S/13E 22cac1,2) are located north of the fault. These wells yield up to 450 gallons per minute of water noted by John Tschanne as "warm" (personal communication 11/12/80). The 275-foot irrigation well drilled near the Fran Wallace residence (4S/13E 28bdd1) also yielded only warm water. This is in sharp contrast to the 53°C water yielded by the 150-foot well (4S/13E 21dcb1) located on the fault system.

Table 2. Selected Drillers Logs for Sites Near White Arrow Hot Springs (depth in feet).

4S/12E 35cad1

0-31	clay some gravel
31-32	lava ledge
32-41	clay yellow and pink
41-51	lava green
51-55	clay ashes bed
55-64	lava pink
64-75	clay brown
75-93	clay yellow
93-97	lava grey
97-102	loose rock, sand and clay
102-119	clay yellow and blue
119-123	lava grey
123-126	clay, loose rock
126-137	lava gray
137-141	clay red
141-149	lava pink
149-156	clay pink
156-164	lava pink
164-173	clay borwn
173-185	clay blue
185-191	lava broken
191-201	lava
201-206	clay red sticky
206-210	lava broken
210-300	rock pink
300-306	clay sand redish black sticky
306-324	lava pink
342-326	layer blue clay over sand
326-368	coarse sand sticky clay
368-376	lava pink
376-394	clay pink and brown
394-412	blue clay some sand and rock pieces
412-471	rock blue black
471-486	rock pinkish grey
486-554	rock pinkish grey, water - flows 37 gpm

Log from I.D.W.R., Boise

4S/12E 36abc1

0-121	grey clay, water flowed 180 gpm
121-138	rock, lava
138-168	sand, more water
168-228	grey clay
228-288	gravel, more water
288-368	clay
368-386	rock
386-486	clay
486-620	gravel and sand, more water, test pumped at 1,000 gpm

Log from Vic Cheney, Gooding

4S/13E 22cac2

0-100	sediments
100-275	rock

Log from John Tschenne, Bliss

4S/13E 28bdd1

0-7	overburden
7-22	grey clay
22-53	clay and gravel
53-70	grey lava
70-75	brown clay
75-78	block cinders
78-80	grey hard basalt
80-101	cinders, rock, clay
101-165	grey clay and gravel - warm water

- hole later depened to 275
- no log available

Log from Sterling Bray, Bliss

Table 2. Cont'd.

5S/12E 3aaa1

0-70	top soil
70-90	loose lava
90-115	solid basalt
115-176	solid lava
176-190	granite, sand and small gravel
190-276	blue clay, water
276	water started to flow
276-305	gray granite sand
305-325	brown sticky clay
325-335	gray granite sand
335-480	hard rock (lava, lots of fissures)
480-490	red and brown clay, sticky
490-556	shaley blue clay
556-560	muddy yellow sand (bailed)
560	tested; pumped approx. 65". Checked hole after test. Hole 360. Bailed back to 530. Drilled out from 530 to 560.
560-610	lava
610-665	basalt, hard, fissured
665-692	red cinders and quartz
692-710	no log
710-724	brown and black rock
724-749	brown shale
749-755	grey shale
755-780	grey rock
780-786	grey shale
786-804	grey rock
804-809	brown clay (sticky)
809-816	grey shale
816-826	brown rock
826-841	brown shale
841-850	brown rock
850-889	brown shale
889-926	grey rock (basalt)
926-954	brown shale
954-963	grey basalt
963-985	white quartz sand, water
985-1014	brown quartz sand
1014-1032	grey sand
1032-1053	brown shale with thin layers of grey sand
1053-1055	green clay
1055-1070	grey sand with layers of sticky clay

All of the well logs that are available indicate a variable sequence of basalt and sediments. Drillers data on these sites are presented in table 2. Generally, basalt makes up from 6 to 64 percent of the material penetrated. Both the basalt and coarse sediments are noted to yield water.

Many of the wells in the area flow at land surface. Based upon the estimated land surface elevation at the Tschanne hot well (4S/12E 21dcb1), the White Arrow-Tschanne system has a water level elevation of about 3,360-3,380 feet. This is the minimum water level elevation that might be anticipated in a test well near White Arrow Hot Springs. The Dave Archer hot wells (4S/12E 35cad1, and 5S/12E 3aaa1) both flow but are located at a considerably lower land surface elevation. Well 5S/12E 3aaa1 has a land surface elevation of about 3120 feet above mean sea level. The shut-in pressures of these wells are not known.

Chemistry of Geothermal Systems

The water chemistry at three sites in the study area is presented by Mitchell and others (1980). These sites are White Arrow Hot Spring (4S/13E 30adb15), the Tschanne hot well (4S/13E 21dcb1) and the deeper Dave Archer hot well (5S/12E 3aaa1). The water chemistry data for these sites are presented in table 3. The waters from all three sites have similar chemistries. Calculated parameters such as estimated aquifer temperatures, atomic ratios and molar ratios from Mitchell and others (1980) are presented for the three sites in table 4. The estimated aquifer temperatures of the White Arrow-Tschanne sites are uniformly higher than the Archer well. These results support the hypothesis that the two systems are hydrologically isolated.

Table 3. Chemical Analyses of Thermal Water from Selected Springs and Wells in Idaho.

Spring or Well Identification Number and Name	Sample Collection Date	Measured Surface Temperature °C	Reported Well Depth below Land Surface (meters)	Discharge (l/min)	Silica (SiO_2)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Carbonate (CO_3)	Sulfate (SO_4)	Phosphate (PO_4)	Chloride (Cl)	Flouride (F)	Nitrate (NO_3)	Boron (B)	Ammonia (NH_3)	Specific Conductance (field)	pH (field)	Total Dissolved Solids (TDS)	Hardness: Carbonate	Hardness: Non-Carbonate	Alkalinity as $CaCO_3$	Percent Sodium (%Na)	Sodium Absorption Ratio (SAR)	Cation-Anion Balance	Data Reference*
Gooding County																												
J. SHANNON WELL 4S 13E 28ABB1	6/21/72	47	49.	0.	92	9.8	1.20	100	5.90	278.	0.0	19.00	0.05	8.2	12.00	0.49	0.0	0.0	497	7.0	385	29.	0.	228.	85.5	8.0	-7.062	3
WHITE ARROW H S 4S 13E 30ADB1S	5/26/72	65	0.	3126.	97	1.2	0.0	91	1.60	141.	22.00	15.00	0.03	6.6	12.00	0.11	0.0	0.0	407	7.5	315	3.	0.	152.	97.5	22.9	-1.598	3
DAVE ARCHER WELL 5S 12E 3AAA1	6/19/72	57	211.	0.	62	1.6	0.10	90	0.80	83.	42.00	19.00	0.03	8.4	19.00	0.17	0.0	0.0	413	8.6	283	4.	0.	138.	97.3	18.7	-4.755	3

Table 4. Estimated Aquifer Temperatures, Atomic and Molar Ratios of Selected Chemical Constituents, Free Energies of Formation of Selected Minerals, Partial Pressures of CO_2 Gas and R Values from Selected Thermal Springs and Wells in Idaho.

Spring/Well Identification Number & Name	Discharge (l/min.)	Measured Surface Temperature (°C)	Aquifer Temperatures and Percentage of Cold Water Estimated from Geochemical Thermometers (see footnotes): T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}	T_{11}	$\%_9$	$\%_{11}$	Atomic Ratios: Sodium/Potassium Na/K	Sodium/Calcium Na/Ca	Magnesium/Calcium Mg/Ca	Calcium/Fluoride Ca/F	Chloride/Boron Cl/B	Chloride/Fluoride Cl/F	Calcium/Sodium Ca/Na	Molar Ratios: Calcium/Bicarbonate Ca/HCO_3	Chloride/Carbonate & Bicarbonate $Cl/(CO_3+HCO_3)$	Ammonia/Chloride NH_4/Cl	Ammonia/Fluoride NH_4/F	Chloride/Sulfate Cl/SO_4	$\sqrt{Calcium}$/Sodium $\sqrt{Ca}/Na$	Free Energies of Formation of: Quartz ΔG Quartz	Chalcedony ΔG Chalcedony	Amorphous Silica ΔG Amorphous	Partial Pressure of CO_2 Gas (atmospheres) PCO_2	R = Magnesium/(Magnesium + Calcium + Potassium) $Mg/(Mg+Ca+K)$ **
Gooding County																																	
J. SHANNON WELL 4S 13E 28ABB1	0.	47	132	128	12	105	98	98	129	97	245	161	224	85	83	28.8	17.79	0.20	0.37	0.0	0.39	0.06	0.05	0.05	0.0	0.0	1.17	3.59	1.26	0.74	-0.04	0.04091	15.4
WHITE ARROW H S 4S 13E 30ADB1S	3126.	65	135	131	15	108	112	112	45	79	202	147	160	72	64	96.7	132.21	0.0	0.29	0.0	0.05	0.01	0.01	0.07	0.0	0.0	1.19	1.58	1.01	0.54	-0.26	0.00866	0.0
DAVE ARCHER WELL 5S 12E 3AAA1	0.	57	112	111	-5	83	70	70	9	70	152	127	110	67	57	191.3	98.06	0.10	0.24	0.0	0.04	0.01	0.03	0.11	0.0	0.0	1.20	1.61	0.97	0.43	-0.33	0.00024	7.6

TEST WELL LOCATION AND DESIGN

Criteria for Location

The 700-800-foot test well included in this project is to be constructed to gain a better understanding of the hydrogeologic controls for the geothermal system and to gain information on heat flow characteristics of the region. As such, it is important to locate the test well near but not on the primary geologic structure controlling the geothermal system at a site where the well would not flow at land surface.

Well data from the area indicate that the hot water in the White Arrow-Tschanne area occurs in a narrow band following a fault structure. Wells drilled both north and south of the structural feature yield only warm water. It is thus important to drill the well near the structural feature to gain hydrogeologic data on the geothermal system.

The water level elevation at the Tschanne hot well (4S/13E 21dcb1) is in the range of 3,3600-3,380 feet elevation based upon interpretation of 40-foot contours on a U. S. G. S. topographic map. The well when drilled did not flow at land surface. A ditch was later constructed to the well to allow interception of hot water at a point about 10 feet below land surface. The well has been allowed to flow through this below ground pipe to heat several homes since early in the century. This diversion arrangement allows a fairly accurate assessment of the water level elevation in the White Arrow-Tschanne geothermal system. It is important to drill the test well at a land surface elevation greater than about 3,400 feet to minimize the potential of having water levels above land surface.

Location and Construction of the Test Well

It is recommended that the test well be constructed at a site approximately 200 feet north and 200 feet east of the White Arrow hot srpings immediately south of the north boundary of the White Arrow Ranch. This will place the well slightly north of the major fault at a land surface elevation greater than 3,400 feet. The site should be suitable for erection of the drilling rig and utilization of all required equipment. A small amount of site preparation may be necessary because of the gentle slope of the land. Access across the small stream formed by the hot spring will need to be provided.

Borehole Geophysical Program

Many of the wells in the immediate vicinity of the White Arrow hot springs are open and available for geophysical logging. This method of data collection is particularly important because of the poor information presently available on the geology of these sites. Listed below are the wells that should be logged in conjunction with logging of the completed test well.

Well	Depth (feet)	@ Temp.
4S/13E 21dcb1	@150	45°C
4S/13E 22cac2	@275	warm
4S/13E 28bdd1	@275	warm
4S/12E 36abc1	@620	slightly warm

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