Report on

RECONNAISSANCE HEAT FLOW AND GEOTHERMAL GRADIENT STUDY IN NORTH CENTRAL OWYHEE COUNTY, IDAHO

by

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submitted to

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DISCLAIMER

Abstract

Temperature data were obtained in 41 wells, thermal conductivity in 12 wells, and published data were synthesized in order to investigate the geothermal character of an area in northern Owyhee County, Idaho. This area includes the Bruneau and Grand View-Castle Creek KGRA's and is characterized by a large number of warm water artesian irrigation wells. In the Oreana-Grand View areas the geothermal gradient to 3,000 feet is 4.0 ± 1°F/100 ft and the heat flow is about 2.1 ±.2 HFU (about normal for the western United States). The southern part of the Oreana area along the upper part of Castle Creek and the Little Valley-Bruneau areas have geothermal gradients ranging from 5° to 8°F/100 ft and heat flow values from 50% to 100% above the regional average. Part of the Murphy area has a geothermal gradient of about 4.0°F/100 ft and normal heat flow while the other part has gradients of 6° to 10°F/100 ft and above-regional heat flow. The high values may be directly or indirectly (via geothermal systems) associated with shallow magmatic heat sources, or with regional ground water flow. If local magmatic heat sources are present they may occur along the southern hingeline of the Snake River Plains. Suggestions for further work are included.

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INTRODUCTION

This report deals with the results and interpretation of a regional geothermal gradient and heat flow survey in the Bruneau-Grand View-Murphy area of north central Owyhee County, Idaho. The survey was carried out during June of 1975. The area has been extensively drilled for irrigation and domestic water supplies, and the method of operation was to inquire locally for dry wells, temporarily unused wells, or wells in the process of being drilled, in which temperature information could be obtained. Forty-one wells were logged; the results are included in Appendix B. Another 10-20 were visited, but could not be entered past 5-10 meters and no useable results were obtained. A limited number of samples were obtained for thermal conductivity studies. The results of the thermal studies will be discussed separately, and in conjunction with regional geological and geophysical data available in the literature.

The area of the survey (see Figure 1) is bounded on the north by the Snake River, on the west by Squaw Creek (approximately the township line common to Ranges 4W and 5W), on the east by the township line common to Ranges 8E and 9E, and on the south and southwest by the surface water drainage divide and by the township line common to Townships 8S and 9S. A very useful report containing much background information on the geology and hydrology of the area is available (Ralston and Chapman, 1969).

The actual location and identification of the logged wells are shown in Figure 2. The area actually sampled by the data includes about 1000 mi^2 and so the results described here are of a reconnaissance nature. The motivation for the study was the existence of extensive displays of hot artesian fluids in the general area and in the Oreana-Bruneau area particularly (Ralston and Chapmna, 1969; Ross, 1971; and others). In spite of the abundant evidence of geothermal fluid, almost nothing is known of the geothermal gradient in the area and the

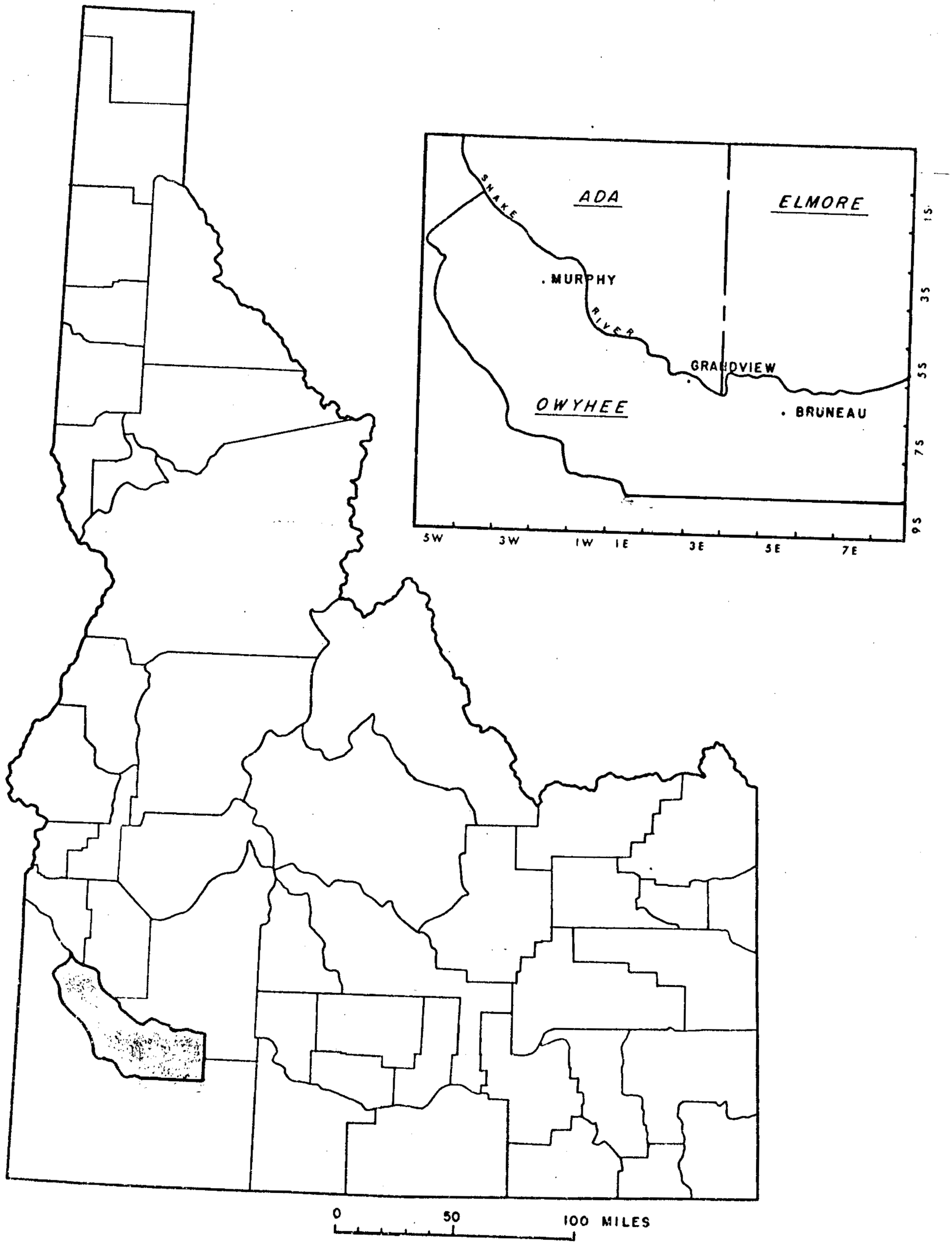


FIGURE 1. Index map showing the area covered by this report

commercial geothermal implications of the many manifestations. Thus this study was undertaken in order to furnish information upon which to locate smaller areas of interest and upon which to base more detailed studies.

Several hundred wells have been drilled in the study area for irrigation and domestic water supplies. The general locations for the wells are the same as described by Ralston and Chapman (1969) although many more wells have been drilled since that report. Many wells are being drilled on the periphery of the exploited area as many new areas of land are being brought under cultivation via the desert entry program. It is important to remember that the areas of hole location as shown by Ralston and Chapman (1969), and as reflected in the holes logged during this study, are determined by suitability of land for cultivation, not by geographic limits on the aquifers! Therefore the extent of the aquifer systems is undoubtedly greater than the developed areas would indicate.

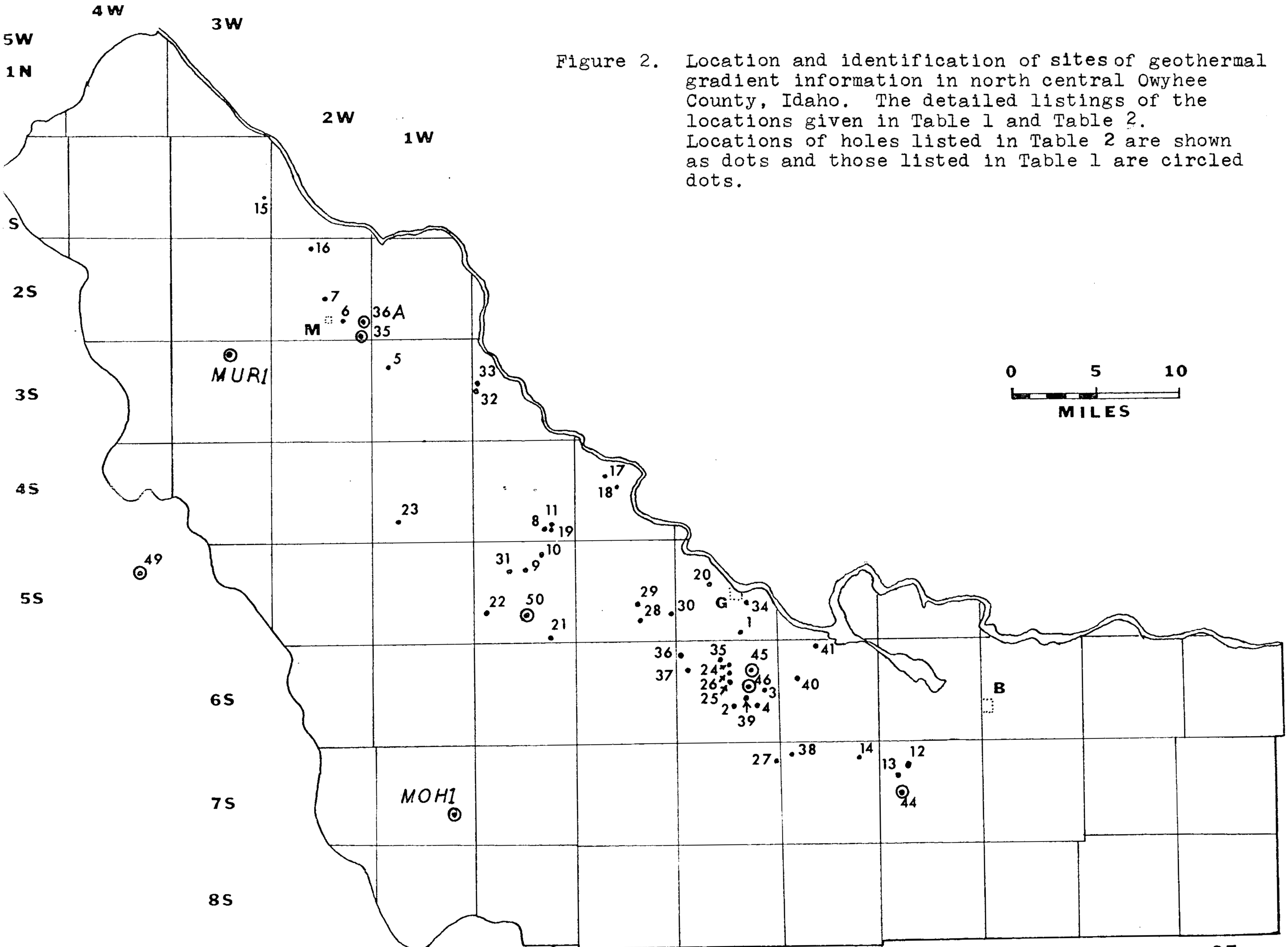


Figure 2. Location and identification of sites of geothermal gradient information in north central Owyhee County, Idaho. The detailed listings of the locations given in Table 1 and Table 2. Locations of holes listed in Table 2 are shown as dots and those listed in Table 1 are circled dots.

GEOLOGICAL AND GEOPHYSICAL BACKGROUND

In exploration of any geothermal area applications of extensive and varied exploration techniques are necessary due to the general complexity of the geologic settings. Fortunately a number of geologic and geophysical studies are available for the general area in the detail appropriate for the study described here. The nature of the information available in this area will be briefly outlined in this section while the data will be described in more detail in the interpretation section. The most serious shortcoming of the information available is the lack of a good geologic base upon which to pin the geophysical results. A number of geophysical anomalies are present in the area, but the interpretation of all of them is ambiguous or even impossible given the present level of geological information available.

The geology of the study area is characterized by (Ralston and Chapman, 1969, p. 9-10):

> "(1) a rugged mountain range in the southwestern portion, (2) a rolling upland in the southeastern portion, and (3) a foothill and lowland area extending from the upland and mountainous areas to the Snake River. The mountainous region is composed of a granitic core overlain by younger igneous and sedimentary rocks. The rolling upland is characterized by a mineralized rhyollitic core overlain by a sequence of rocks similar to that of the mountainous regions. The foothill and lowland area consists of several poorly consolidated sedimentary formations interspersed with thick sections of basaltic lava. The upland and mountainous regions are important as source areas for recharge to the aquifers that have been developed for irrigation and domestic usage in the study area."

The basement rocks in the area are Mesozoic granitic rocks correlative with the Idaho batholith north of the Snake River Plain. The granitic rocks are overlain by a complex sequence of predominantly silicic volcanic rocks ranging in age from perhaps 20 to 8 MY or younger. This sequence of rocks holds the key to the geothermal potential of the area and to the interpretation of the geophysical data, yet the rocks are essentially unstudied. A few of the units have recently been dated (Armstrong et al., 1975), but infinitely more remains to be done. The silicic rocks probably underlie at depth all of the area described in this report.

Overlying the silicic rocks is a complex, interfingering sequence of lacustrian sedimentary rocks and basalts. In older usage the whole packet is referred to as the Idaho Formation, although later workers have subdivided the unit. Some of the names that have been used in the report area are shown in Figure 3 (after Ralston and Chapman, 1969); the most accepted usage seems to be that of Malde and Powers (1962).

The Poison Creek Formation is composed of lacustrian deposits consisting of clay, silt, shale, volcanic ash and sandstone, with bentonitic silt and poorly consolidated shale most common. The unit may be over 700 feet thick in places, but is absent in the eastern portion of the area. It overlies the silicic volcanic rocks.

The Banbury Basalt is a complex unit containing perhaps one-half basalt and one-half lacustrian deposits and may interfinger with the sedimentary units above and below. Radiometric age-dates (Armstrong et al., 1975) indicate that several basalts of different ages are called Banbury. In the western part of the report area the Banbury is highly altered and a poor aquifer, while in the east it is relatively unaltered and is a good aquifer.

The overlying formations are the Chalk Hills and Glenns Ferry Formations. The Chalk Hills Formation is similar to the Poison Creek Formation as is the lacustrian environment portion of the Glenns Ferry Formation. The Glenns Ferry also includes fluviatile sediments such as sand, silt and gravel. The sand and gravel zones are tapped primarily for domestic water. The two formations cannot be distinguished on drillers' logs. The Chalk Hills Formation also includes thin flows of basalt. Wells typically penetrate 1000-2000 feet of these units in the Grand View area. The general structure and topography are

GEOLOGIC TIME SCALE			Malde & Powers (1962) Formations	Anderson (1965) Formations	Littleton & Crosthwaite (1957) Formations
TERTIARY	Pleistocene	Upper	Melon Gravel Snake River Basalt Crowsnest Gravel Sugar Bowl Gravel	Snake River Basalt Hart Creek Fanglomerate*	Snake River Basalt
		Middle	Black Mesa Gravel Bruneau Formation	Upper member, Jackass Butte Formation, Montini Formation, Otter Basalt	Pediment Gravel*
		Lower	Tuana Gravel Glenns Ferry Formation	Lower member, Jackass Butte Formation, Oreana Formation	Idaho Formation
	Pliocene	Upper			
		Middle	Chalk Hills Formation Banbury Basalt	Upper member and Sinker Creek Basalt member, Brown Creek Formation	Idaho Formation Basalt of Pliocene(?) age
		Lower	Poison Creek Formation Idavada Volcanics	Lower member Brown Creek Formation Tertiary Silicic Volcanics*	Idaho Formation Silicic Volcanic Rocks
	Miocene	Upper & Middle	Undifferentiated Rocks		Rhyolitic Rocks
			Unconformity		
CRETACEOUS			Granitic Rocks		

*Correlation, tentative or doubtful

FIGURE 3. Equivalent Geologic Formations present in northern Owyhee County (Ralston and Chapman, 1969, Figure 5)

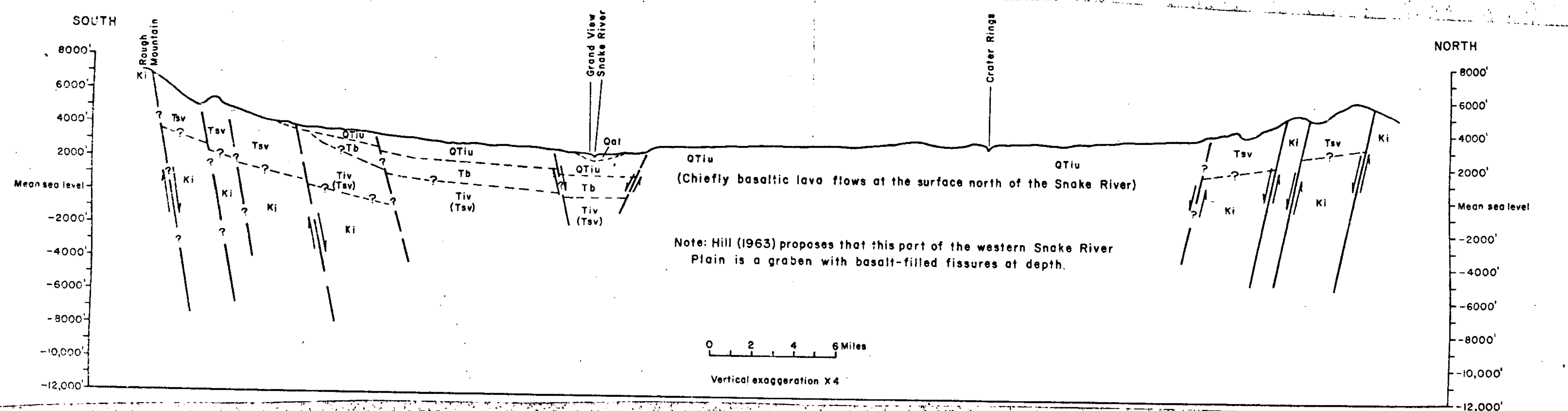


Figure 4. Generalized cross section of the Snake River Plains in the vicinity of Grand View (Young and Whitehead, 1975, Figure 6)

illustrated in Figure 4 (after Young and Whitehead, 1975). South of the area the silicic volcanics and the Mesozoic granites are exposed in the Owyhee Mountains at elevations of 3000-6000 feet. By a combination of downwarping and faulting along the margins of the Snake River Plain these units have been displaced downwards and are now covered by up to several thousand feet of Cenozoic basalts and continental sedimentary rocks.

Most of the wells logged as part of this study penetrate the Chalk Hills and/or Glenns Ferry Formations. Wells penetrating the deeper formations are either productive and in use as artesian or pumped irrigation wells or have caved somewhere in the sedimentary units above the Banbury Basalt and are no longer open to drilled depth.

Recent reports include an extensive amount of information on the geochemistry of fluids in the study area (Young and Mitchell, 1973; Young and Whitehead, 1974, 1975). These data will also be discussed in more detail in the interpretation section of this report.

The geophysical data available are sufficient for regional correlations with the geothermal data; however, little information is available on a detailed scale. The gravity and magnetic data are summarized by Young and Whitehead (1974, 1975) although theyattempt no interpretations. The results of an audiomagnetic-telluric (AMT) survey have also been described (Hoover and Tippens, 1974, 1975). An anomaly was found during the AMT survey in the Grand View area which was interpreted to have geothermal significance. The correlations of these data with the heat flow results will be described below.

SURVEY RESULTS

Background. Before discussing the results of the study some possible *a priori* models will be briefly mentioned; the models are described in more detail in Appendix A. The fact that most of the deeper aquifers have artesian pressure suggests a regional hydraulic gradient and flow from the Owyhee Highlands in the south of the area toward the Snake River Plain on the north. Thus a regime as shown in Figure A1-c (Appendix) might be expected. Because the aquifers in the sedimentary rocks are separated by aquicludes (clay layers), and head differences are common in the wells, intrahole circulation effects as described in Figure A1-a are to be expected. Finally, it has been postulated that hot water moves upward along faults in the area and that some of the warm water at shallow depths (between 1000-3000 feet) is due to leakage along the faults. Therefore the effects described in Appendix A and illustrated in Figure A2 must be anticipated.

One of the important unknowns is the source of heat for the system in the Bruneau-Grand View-Murphy area. Is the heat flow for the region normal or is it high? If the heat flow is high, what is the source of the heat -- regional ground water flow, local heat sources, or something else? The survey described here cannot answer this important question unequivocally because of the lack of detailed sampling of the sections cut by the wells for thermal conductivity and heat flow, and finally because of the large area covered.

The background heat flow and geothermal gradient are not well known. However, three heat flow values have been published for the Owyhee Mountains that are either in or near basement rocks (Table 1). A value of 2.4 $\mu cal/cm^2 sec$ (HFU) was found in Miocene (?) basalt above granite in the Silver City area (Brott et al., no. 74I-49, 1975) and values of 3.0 and 2.1 HFU were found in granite southwest of Murphy and Oreana respectively (Urban and Diment, 1975). The regional average for much of the western U.S. is 2.0 HFU, but consideration of basement

Table 1. Published temperature, gradient, thermal conductivity, and heat flow data information in north central Owyhee County, Idaho. References for the data are Brott et al. (1975) and Urban and Diment (1975). One HFU is 1 μcal/cm²sec.

Hole No	Location	Depth, feet	Maximum Temperature, °F	Geothermal Gradient, °F/100 ft	Interval, feet	Thermal Conductivity mcal/cm sec°C	Heat Flow HFU
74I-35	T2S R2W 36 cd	1,175	86.3	6.3	33-330		
74I-36A	T2S R2W 36 bd	330	71.8	6.7	33-262		
74I-44	T7S R5E 19	85	73.7	--			
74I-45	T6S R3E 11 ca	177	64.7	7.7 ± 0.8 3.0 ± 0.2	33-98 115-197		
74I-46	T6S R3E 14 bcb	180	62.1	2.9 or 4.0	30-165		
74I-49	T5S R4W 3 acc	1,280	73.4	2.6 ± 0.1	66-1,280	4.8	2.4
74I-50	T5S R1W 27 dc	194	109.3	29.3	33-180		
USGS-MUR-1	T3S R3W 2	827		2.6		6.6	3.1
USGS-MOH-1	T7S R3W 24	827		1.7		7.0	2.2

rock type suggests that a value of 1.7 HFU would be more appropriate for the Owyhee Mountains. Since all the measured values are above 1.7 HFU, either regionally higher heat flow (associated with the formation of the Snake River Plains?), or local heat sources are present in the Owyhee Mountain area.

Other geothermal data bearing in general on the area of interest are the report by Brott et al. (1975) which contains regional data on the Snake River Plain in Idaho, and Bowen and Blackwell (1975) which contains data from the western Snake River Basin. Drilling is in progress by the Idaho Department of Water Resources on two profiles across the Snake River Plains which intersect in the Bruneau-Grand View area. Results of that program should be available in late 1975 or early 1976. The holes in the study area available prior to this study are summarized in Table 1.

The location, identification, and geothermal data for the measured wells are listed in Table 2 and plotted in Figures 2, 12 and 15. The data listed in Table 2 include the logged depth, depth to water, geothermal gradient, calculation-interval of geothermal gradient, and the maximum temperature recorded for each well. The water depth is important, as sometimes the only useful gradient information is obtained above the water table and in this area of common artesian flow the best data came from holes which did not penetrate the water table or had caved in above the water table. Preexisting data are also included in the figures and listed in Table 1. The results will be described by subarea first, then the overall regional results will be discussed and compared to available geological and geophysical information. The data are grouped into four subareas because of the geographic extent of the well drilling. These are, from northwest to southeast, the Murphy, Oreana, Grand View, and Little Valley-Bruneau subareas. This division corresponds closely to the subarea divisions of Ralston and

Table 2. Results of temperature measurements in wells in north central Owyhee County, Idaho. Gradients for artesian wells are indicated by an asterisk. The standard error is shown for the gradient only where the temperature-depth curves are linear over some depth range (shown in column 8). Values with greater than or less than symbols are bounds only.

Hole No	Location	Collar Elevation, feet	Depth, feet	Water Level, feet	Maximum Temperature, °F	Gradient, °F/100 ft	Interval, feet
1 G	T5S R3E 34 daa	2480	397		70.1	3.7 ± 0.1	131 - 394
2 G	T6S R3E 22 ddb	2725	161	16	59.2	> 2.2	33 - 164
3 G	T6S R3E 13 bdc	2620	197	66	59.1	> 1.8	33 - 197
4 G	T6S R3E 23 ddd	2770	348	0	85.5	< 8.0*	
5 M	T3S R1W 17 cbb	3205	413	--	84.0	5.5 ± 0.2	164 - 410
6 M	T2S R2W 35 aaa	2900	444	--	70.0	6.1 - 6.6	66 - 444
7 M	T2S R3W 22 dbc	2790	144	--	64.5	4.2 ± 0.2	33 - 144
8 O	T4S R1E 35 bbd	2540	912	0	96.8	4.1 ± 0.5*	
9 O	T5S R1E 10 bdc	2645	344	0	91.5	4.1 ± 0.5*	
10 O	T5S R1E 2 aaa	2610	49	16	57.8	3.8	33 - 49
11 O	T4S R1E 35 acb	2545	103	0	62.5	4.1 ± 0.4*	33 - 98
12 B	T7S R5E 7 ddc	2610	43	0	72.3	> 2.4*	
13 B	T7S R5E 18 acc	2650	394	< 33	91.4	7.1*	
14 B	T7S R4E 2 dbc	2665	98	< 33	64.9	(-2.4)	66 - 98
15 M	T1S R3W 24 cab	2600	732		95.4	7.4	30 - 164
						4.8	230 - 525
						5.5	0 - 722

Table 2. (Continued)

Hole No	Location	Collar Elevation, feet	Depth, feet	Water Level, feet	Maximum Temperature, °F	Gradient, °F/100 ft	Interval, feet
16 M	T2S R2W 4 dab	2500	108	66	62.9	3.9 ± 0.2	33 - 98
17 O	T4S R2E 20 bda	2485	292	0	93.5	3.5*	
18 O	T4S R2E 20 dbd	2550	207	33	66.6	3.6 - 4.2*	
19 O	T4S R1E 35 acc	2548	279	0	87.4	(4.4 - 6.0)*	
20 G	T5S R3E 15 cbb	2360	171	0	76.0	< 6.0*	
21 O	T5S R1E 35 ddd	3000	208	197	66.8	5.2 ± 0.2	49 - 197
22 O	T5S R1E 29 da	3000	154	49	87.1	20.2	16 - 148
23 O	T4S R1W 29 bdc	3310	282	16	50.2	--	
24 G	T6S R3E 10 bab	2580	525	3	77.7	2.6 - 3.9	197 - 525
25 G	T6S R3E 10 bdb	2542	36	36	59.1	--	
26 G	T6S R3E 10 bac	2615	69	49	58.7	--	
27 GB	T5S R3E 12 bda	3010	413	328	83.4	7.4 ± 0.4	98 - 330
28 G	T5S R2E 27 daa	2840	62	49	59.0	--	
29 G	T5S R2E 22 dcd	2810	230	>213	68.0	4.9 ± 0.3	33 - 213
30 G	T5S R2E 25 aad	2640	177	47	75.5	< 8.8*	0 - 177
						2.7 ± 0.1*	49 - 177
31 O	T5S R1E 9 cca	2760	390	66	67.2	1.5 ± 0.1	246 - 377
32 M	T3S R1E 18 acc	2425	226	33	64.4	> 3.3	33 - 223
33 M	T3S R1E 18 caa	2430	98	16	59.2	5.9 ± 0.7	33 - 98
34 G	T5S R3E 23 caa	2395	62	0	94.3	--	
35 G	T6S R3E 4 ddb	2585	56	33	69.9	--	

Table 2. (Continued)

Hole No	Location	Collar Elevation feet	Depth, feet	Water Level, feet	Maximum Temperature, °F	Gradient °F/100 ft	Interval, feet
36 G	T6S R3E 6 cab	2770	116	>116	58.5	2.7 ± 0.1	49 - 114
37 G	T6S R3E 7 cbd	2800	259	213	82.1	4.1 ± 0.4	33 - 98
						> 2.8	0 - 902
38 GB	T7S R4E 6 cda	2935	272	>272	76.0	6.4 ± 0.3	82 - 262
39 G	T6S R3E 23 bbb	2675	115	95	61.7	4.6	33 - 82
						1.0	82 - 114
40 G	T6S R4E 17 bbb	2660	92	92	62.0	7.5 - 4.6	33 - 82
41 G	T6S R4E 4 bdb	2530	253	33	68.7	2.3	33 - 180
						4.6	33 - 253

*Gradients from artesian wells

Chapman (1969) except that not enough data were obtained in the Walters Ferry or Bruneau subareas to consider them separately. Probably at least another 20-30 useful holes in poorly sampled locations in the Murphy, Walters Ferry and Bruneau subareas could have been located and logged, but there was no remaining field time. Thus the results of the survey are time limited rather than hole limited. Nevertheless sufficient data have been obtained for development of a picture of the shallow (less than 1000 feet) geothermal regime and for some inferences on the deeper geothermal regime.

Thermal Conductivity. Samples of cuttings from only 12 wells could be collected for thermal conductivity determinations because most of the holes logged were old and the cuttings no longer existed. The results of the measurements, made by the technique of Sass et al. (1971), are shown in Table 3 as are the measured geothermal gradients and calculated heat flow values for each sampled well. The bulk thermal conductivity is the conductivity of the rock if it had zero porosity. The actual conductivity in the ground is a function of the bulk conductivity and the porosity. Extensive measurements on equivalent rock units in the Vale, Oregon, area indicate a best value for porosity of the Idaho Group rocks of 0.3. The *in situ* values in Table 3 were calculated assuming this value for porosity. The heat flow shown for each well is an estimated value only. Because there is no depth control on the cutting samples, it is not certain that the thermal conductivity values are associated in the well with the depth interval over which the gradient was measured. A minimum error of ± 20% is thus associated with the heat flow values. The conductivity measurements are evidence for at least two distinct thermal conductivity units in the Idaho Group, one with a bulk thermal conductivity of about 3.5 and the second with a bulk thermal conductivity of about 5.7. These two values may correspond

Table 3. Measurements of thermal conductivity in north central Owyhee County, Idaho. Also shown are geothermal gradients for the well where thermal conductivity values were obtained and apparent heat flow values. The bulk thermal conductivity is the conductivity of the constituent mineral and rock fragments with zero porosity. The *in situ* conductive was calculated from the equation $K = (1.4)^{\phi} x (K_B)^{1-\phi}$ where ϕ is porosity (assumed to be 0.3). A change in porosity of 0.1 is equivalent to about a 10% change in thermal conductivity.

Hole No	Bulk Thermal Conductivity 10^{-3} cal/cm sec°C	*In situ* Thermal Conductivity 10^{-3} cal/cm sec°C	Geothermal Gradient °F/100 ft.	Heat Flow HFU
6 M	3.51	2.7	6.3	3.1
13 B	5.34	3.6	7.1	4.7
17 O	5.57	3.7	3.5	2.3
21 O	3.44	2.6	5.2	2.5
27 GB	4.78	3.3	7.4	4.4
28 G	4.32	3.1	--	--
29 G	6.02	3.9	4.9	3.5
32 M	5.14	3.5	≥ 3.3	≥ 2.1
36 G	5.41	3.6	2.7	1.8
37 G	3.81	2.8	4.1	2.1
			4.6*	2.9*
40 G	5.16	3.5	7.5	4.8
			2.3	1.1
41 G	3.42	2.6	4.6*	2.2*

*Preferred value

Table 4. Sample thermal conductivity values for lithologies found in north central Owyhee County, Idaho. Gradient is calculated assuming a representative lower bound on the heat flow of 2 μcal/cm^{2}sec. The actual gradient for any heat flow is calculated by multiplying that gradient times the heat flow divided by 2.0.

Unit	Lithology	Thermal Conductivity Range (millical/cm sec°C)	Average Thermal Conductivity (millical/cm sec°C)	Gradient °F/100 ft.
Idaho Group $\phi = .3$	Silt and Clay	2.5 - 3.5	2.6	3.7
	Lithic Sandstone	3.5 - 6.0	3.6	3.7
	Quartz Sandstone	4 - 10	6.0	1.8
Banbury Basalt $\phi = .1$	Basalt	2.5 - 3.5	3.0	3.7
Silicic Volcanics $\phi = .1$	Rhyolite	4.0 - 6.0	5.0	2.2
	Glass or Vitrophyre	3.0 - 3.3	3.2	3.4
Miocene Volcanics* $\phi = .1$	Andestitic Basalt (?)		4.8	2.3
Basement $\phi = .05$	Granite	6.0 - 8.0	7.0	1.6

*Silver City area, hole 74I-49

to the clay and lithic sandstone interbeds in the Idaho Group. It is not known whether these differences are due to lateral or vertical variations in lithology in the Idaho Group. Drill holes 36 and 37, and drill holes 40 and 41 are close together and yet have very different thermal conductivity values. The variations in the gradients with depth in hole 40 and in hole 41 might indicate vertical lithologic variations. The heat flow values will be discussed in more detail in a subsequent section.

Synoptic values of thermal conductivity and representative lithology are shown in Table 4. Estimated porosity values for each unit, upon which the average values in column 4 are based, are shown with the unit name. Thermal conductivity values for the various units include the data in Table 3 and in the references (primarily Brott et al., 1975; Bowen and Blackwell, 1975; and Urban and Diment, 1975). For the Idaho Group rocks large variations in porosity might occur. Lower porosity, or higher quartz content of the sediments would increase the thermal conductivity while higher porosity would decrease the values of thermal conductivity shown. If gradients are known across only a few feet in a bore hole and the lithology is unknown then use of these average values to calculate heat flow can lead to large errors. However, if gradient and lithology are known over several hundred feet in a bore hole then the appropriate thermal conductivity value from Table 4 will allow a valid calculation of heat flow.

Oreana Subarea. The most definitive and interesting results come from the Oreana area. The location and gradients in the area are shown in Figure 5 and are listed in Table 1. The temperature-depth curves for most of the wells are shown in Figure 6. The holes are well distributed along a NE-SW line approximately perpendicular to the regional strike and from very near the rhyolite outcrop, northeast to the Snake River. The measured wells also coincide closely with the

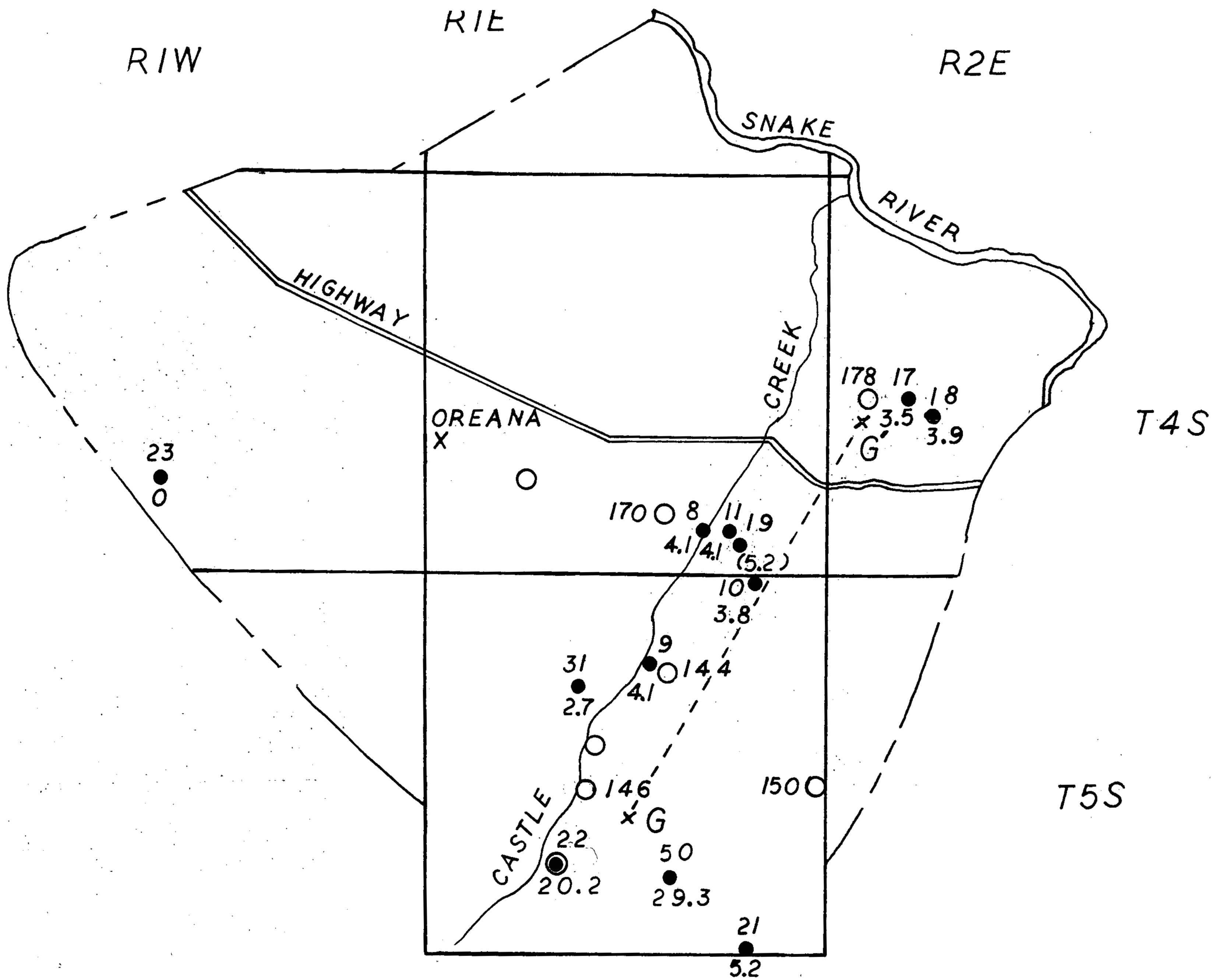


Figure 5. Location map of wells in the Oreana subarea. The locations of measured wells are shown by dots with hole numbers above and the gradient below the hole location. The locations of deep artesian wells are shown by circles. The temperatures of the artesian wells, where known, are shown beside the wells.

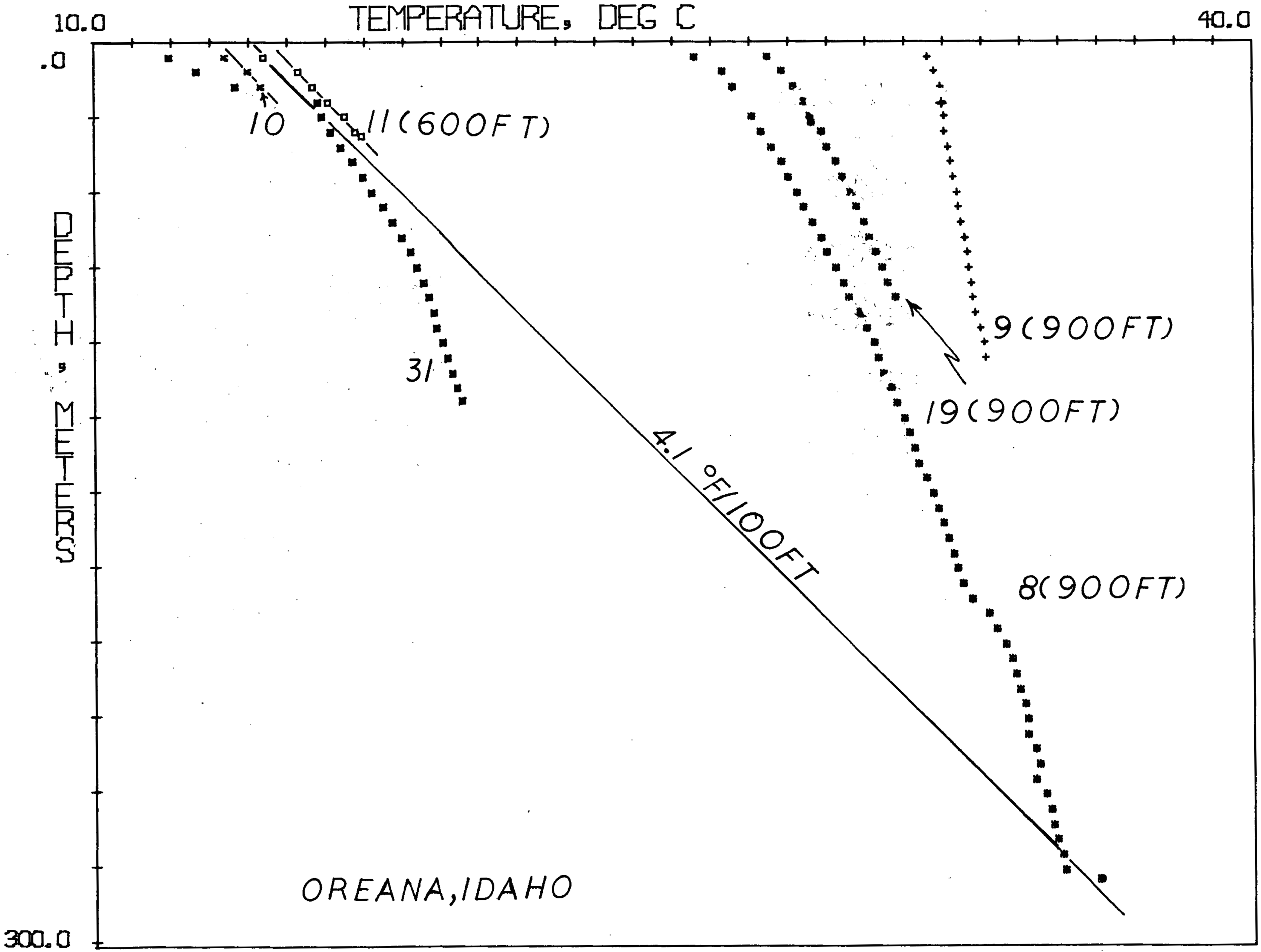


Figure 6a. Temperature-depth curves for wells in the Oreana subarea (Drilled depths in parenthesis)

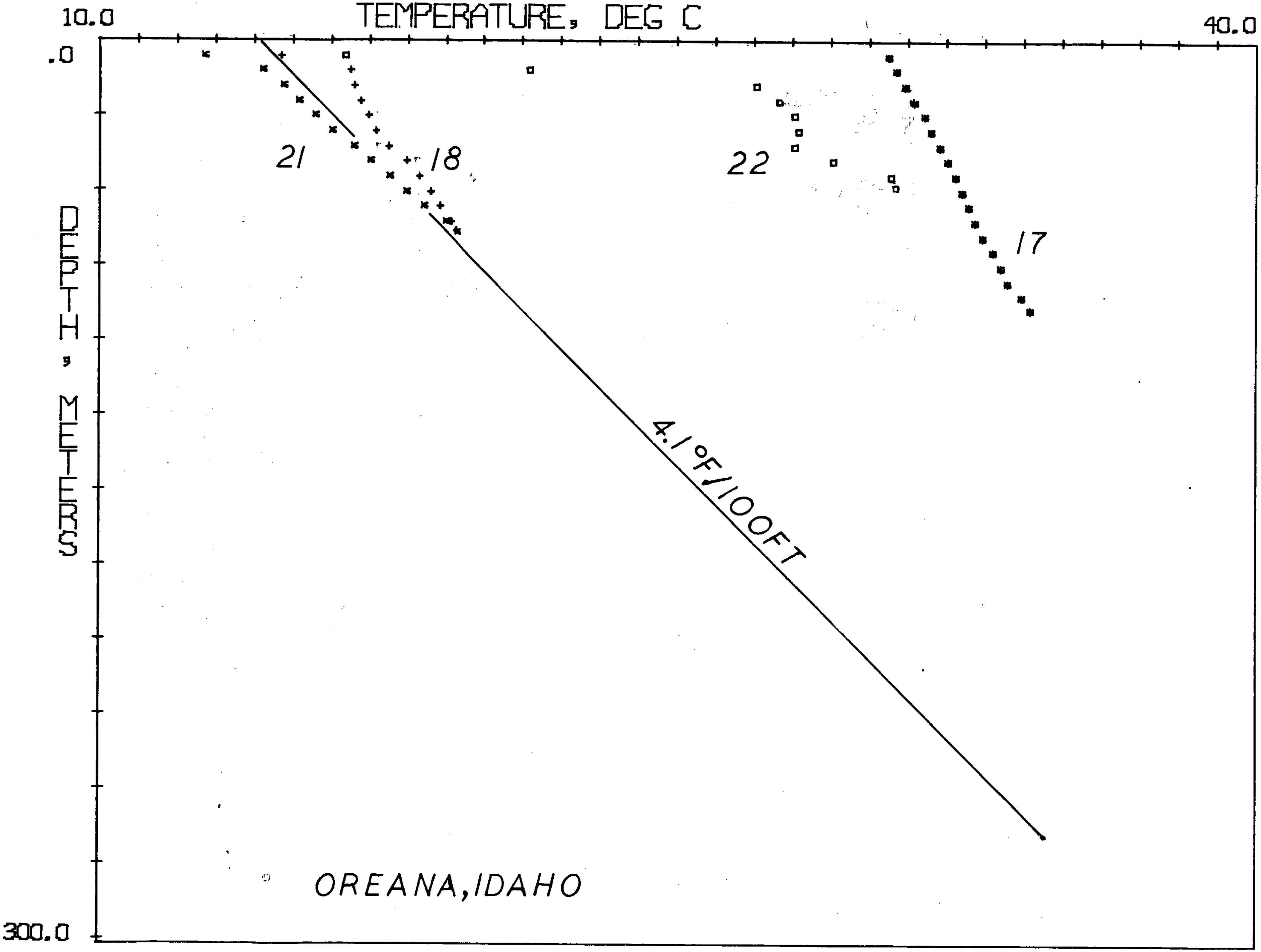


Figure 6b. Temperature-depth curves for wells in the Oreana subarea

location of the hot artesian wells (shown in Figure 5) in the area.

Most of the holes logged were artesian (8, 9, 11, 17 and 19) with flows that ranged from about one quart (number 11) to several gallons per minute (gpm). The reported depths of the artesian wells are indicated in Figure 6. The minimum gradient for a particular well was obtained by projecting the observed gradient in the presence of fluid flow to the reported depth of the well to obtain the bottom hole temperature, assuming 57°F (the average annual ground temperature) as the surface temperature, and calculating the gradient from the temperature difference divided by the depth of the well. One well (number 8) was measured to its reported depth (900 feet); in general, however, the holes could not be logged to the reported depth. These holes were partially blocked by cave zones which prevented the relatively light logging tool used from going deeper, but allowed slow water flow through the plug. The geothermal gradients calculated as described above agree remarkably well; the range of gradients, excluding the ones at the southern end of the profile, is 3.6 - 4.9°F/100 ft (65 - 100°C/km). The gradients observed in nonflowing shallow wells (number 10 and 18) and well number 11 (which was flowing only 1 quart/minute) are 3.8 - 4.1 (70 - 75°C/km). The only exception is well number 31 (nonflowing) which has two distinct segments of gradient (2.7 and 1.5°F/100 ft.), both of which are much lower than the average value. The reason for the low gradients is not apparent from the information available. The best value of all the data taken together is 4.1°F/100 ft (75°C/km).

There are a number of deep artesian wells in the general area. The locations of several of the wells are shown in Figure 5 as are the flowing temperatures, where available. Most of the wells flow 1,000 gpm or more under high artesian pressure from the Banbury Basalt and/or the silicic volcanics.

The depths of most of the wells, except in the southern portion of the map, are 2500-3000 feet and the measured flowing temperatures range from 146-178°F.

The depths from which these wells are producing are not known. However, the flow must be from the Banbury or silicic volcanics and the temperature-depth projections are consistent with flow from the silicic volcanics. As shown in Figure 3 the deep wells were completed after penetrating only a few feet of the silicic volcanics. Since the wells flow at high temperature and pressure, it seems likely that the wells were drilled until they reached the hot artesian aquifer, at which point drilling ceased. By this reasoning, most of the flow would come from the silicic volcanics.

The reported temperatures in a number of wells in the Oreana-Grand View-Bruneau area are shown in Figure 7 (from Young and Whitehead, 1975). The well identification, where known, is shown on the figure. Young and Whitehead (1975) give a gradient of 3.6°F/100 feet as a fit to this data. The curve actually drawn, however, has a slope of 3°F/100 feet (54°C/km). The greatest uncertainty in these data is the unknown percentage of fluid in the total flow from shallow horizons in the well, which may cool the deeper fluid. The data plotted by Young and Whitehead (1975) are from wells which are cased at least 60% of their total depth. Therefore these data are presumably least affected by shallow dilution. A third curve with a slope of 3.7°F/100 feet (68°C/km) has been added to Figure 7 and is drawn to pass through or above (in temperature) all but two of the 17 wells plotted. This curve originates at the surface temperature (57°F) observed in this study. This curve should give the highest (least diluted) gradient consistent with the data. Points which fell below this line in temperature represent wells with lower geothermal gradients, or wells in which the

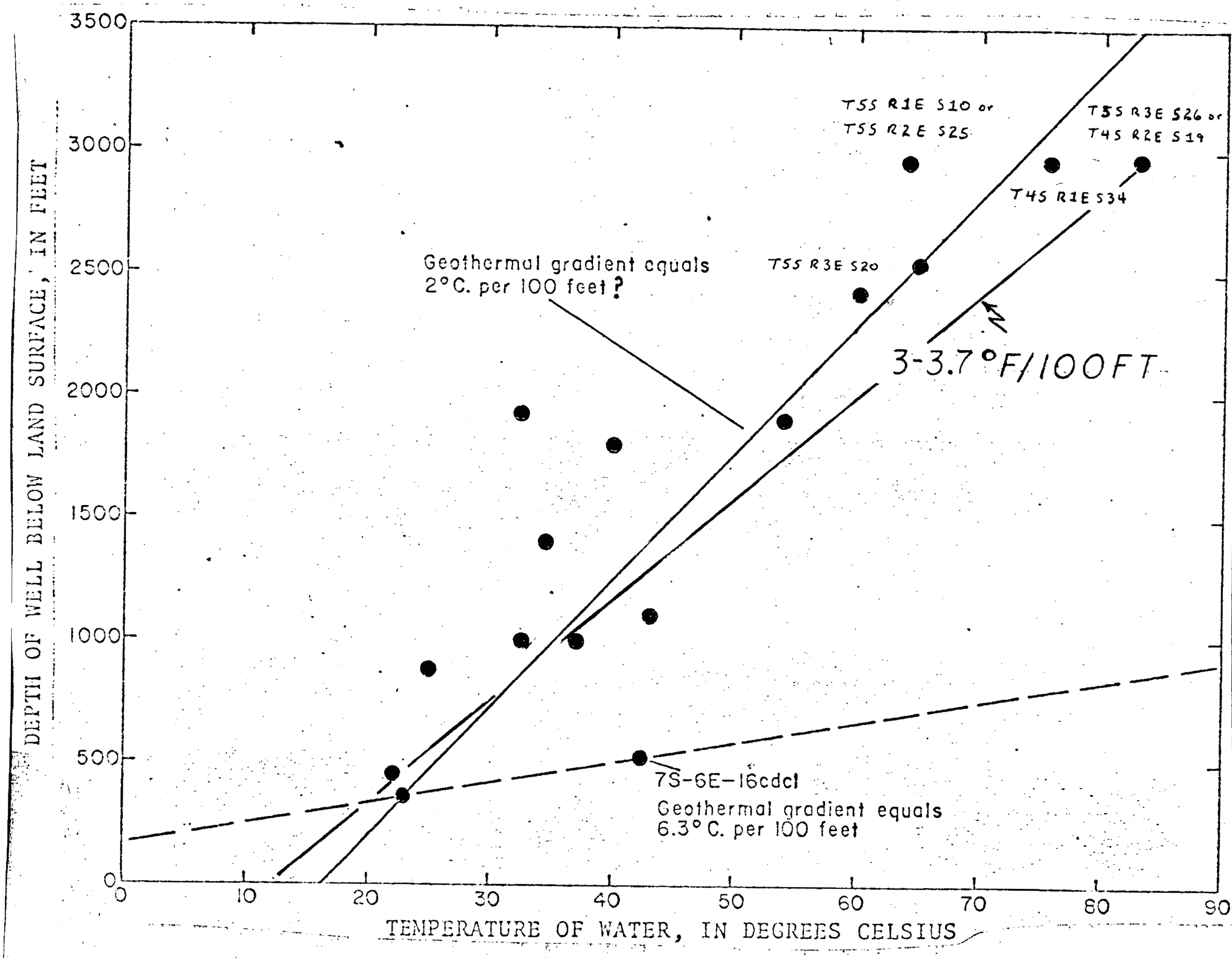


Figure 7. Temperatures in wells in relation to depth in the Oreana-Grand View-Bruneau subareas (after Young and Whitehead, 1975).

water has been diluted or cooled on its way up the well. Points well above this curve (only one) are interpreted to represent wells tapping shallow hot water which has moved up along a fault or fracture zone. It is clear that there is excellent agreement between the gradient determined from the holes logged during this study and the gradient obtained from flowing temperatures of the deep artesian wells at a depth of 3000 feet or so. This correspondence is very strong evidence that the geothermal gradient characteristic of this subarea to a depth of at least 3000 feet is about $4^{\circ}F/100$ ft ($70^{\circ}C/km$).

A deep oil test was drilled in 1974 by Anschutz in Section 11 T5S R1E. According to local reports the depth of the well was 11,125 feet and the bottom hole temperature was $480^{\circ}F$. There is no information on whether the reported temperature represents equilibrium conditions, but if it does the indicated gradient is about $4^{\circ}F/100$ ft. ($70^{\circ}C/km$), very similar to the results discussed in the previous paragraphs. The Anschutz well will be referred to below also.

Near the southern margin of the map in Figure 5 the geothermal gradient is apparently much different. Wells 22 and 74I-50 (Brott et al., 1975) display extremely high gradients. Both of these wells previously may have been artesian wells and the high gradients may be due to hot water moving upward and out at shallow depths into the ground water table. A hole (number 21) which has a conductive gradient of $5.2^{\circ}F/100$ ft. ($95^{\circ}C/km$) is located respectively about $1\frac{1}{2}$ and $2\frac{1}{2}$ miles from number 74I-50 and 22. This gradient predicts that water at 95-$104^{\circ}F$ will be found at 720-850 feet. The drilled depths of the wells (74I-50 and 22) are probably in the range of 600-900 feet, although no firm information is available. So the observed temperatures at shallow depths are consistent with upflow from 600--900 feet to the water table.

An interpretation of the geologic structure along a north-south profile is shown in Figure 8 (Young and Whitehead, Section GG', 1975; Ralston and Chapman, Figure 6, 1969). The flowing temperatures of the artesian wells (where known) and the location and gradients from the shallow wells discussed here are also shown. The temperatures of the flowing wells do not change much, even though the depths of the wells decrease southward by about a factor of 3 when the fault running through Sections 21 and 22,T5S, R1E, is crossed. The whole system is closely related, however, as the artesian pressure in the southern wells has decreased, and even disappeared, as the deeper wells to the north have been drilled and allowed to flow. Former hot springs in Section 29,T5S, R1E, near the site of well number 22, have also ceased to flow as the pressure has been reduced by production to the north. Thus the flow from the deeper wells has decreased the aquifer pressure to the point that shallow holes in the southern part of the area, about 100 - 300 feet higher in elevation than wells to the north, have ceased to be artesian. The gradient data discussed above do suggest, however, that there is still upflow in the wells; it just doesn't get all the way to the surface.

The U.S. Geological Survey drilled a well to 827 feet in granite in T7S, R1W,Section 24 about 10 miles south of the Oreana subarea in 1974. The heat flow in that hole is 2.1 HFU. Similarly the heat flow values calculated for the area in Table 3 are about 2.3 - 2.5 HFU. All these values are identical within the accuracy of the data. Thus the geothermal gradient measured from shallow wells and inferred from the deep artesian wells corresponds to the regional value of heat flow. The high gradient is due to low conductivity of the rocks above the silicic volcanics. I conclude that, in spite of the artesian pressures of the aquifers,

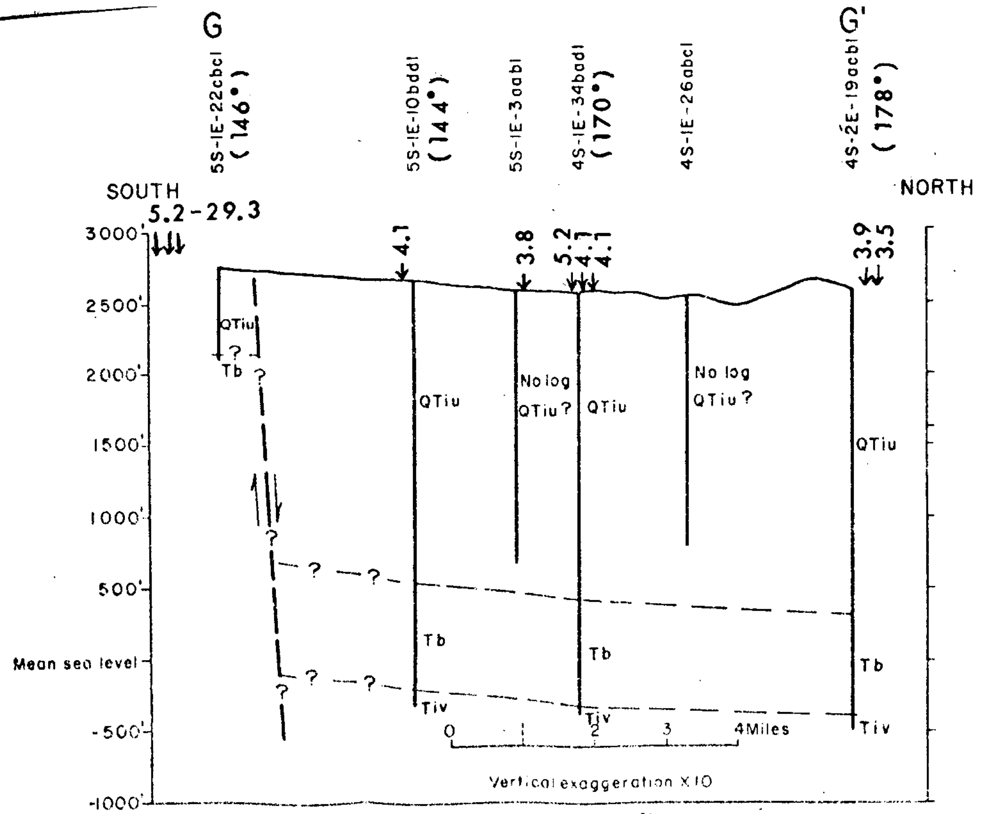


Figure 8a. Geologic cross section (Young and Whitehead, 1975, Section GG')

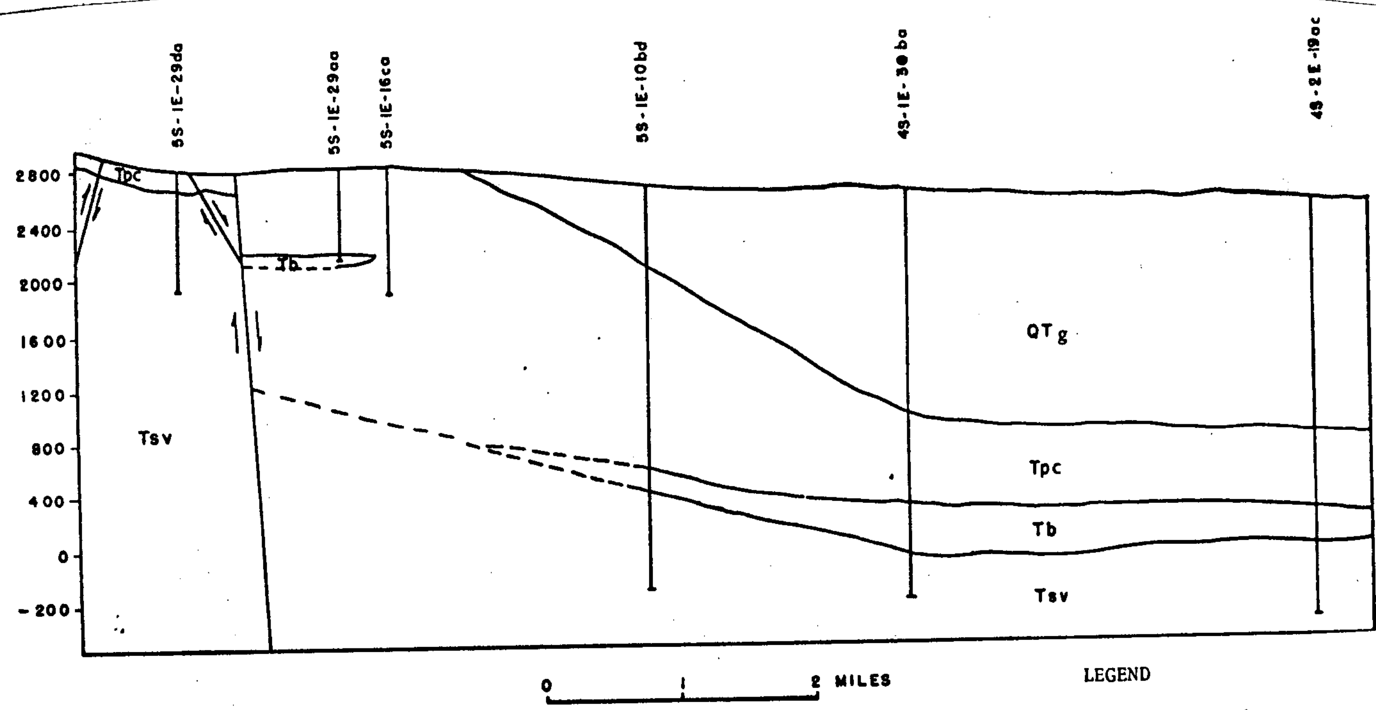


Figure 8b. Geologic cross section (Ralston and Chapman, 1969, Figure 6).

LEGEND

Qtg Glenns Ferry Formation

Tpc Poison Creek Formation

Tb Banbury Basalt

Tsv Tertiary Silicic Volcanics

Geologic cross section in the Castle Creek Valley

Figure 8. Geologic cross sections, artesian well temperatures, and gradients from logged wells. The abbreviated units (8a) are the Idaho Group (QTiu), the Banbury Basalt (Tb), and the Idavada Volcanics (Tiv).

little heat is being transported regionally by natural lateral and vertical water flow in this area. According to H.W. Young (personal communication, 1975) isotopic evidence indicates that the water is very old (Pleistocene) in the Oreana and Grand View aquifers and these data, combined with the lack of an obvious discharge system for the aquifers (Ralston and Chapman, 1969) are consistent with the heat flow results, suggesting little or no lateral or vertical transport of heat by ground water. Alternatively the Oreana area may be in the conductive-appearing portion of a regional ground water system (Curve 2 in Figure A1-c). In such a case the main discharge areas would be north of the Snake River. There is no evidence for such a system (Ralston and Chapman, 1970) so the first hypothesis is the more likely one.

The area of shallow hot wells and old hot springs in the southwestern part of T5S, R1E, remains to be explained, however. The high gradients and heat flow there could be due (1) to a nearby heat source, or (2) to upward motion of water along the faults blocking out the southern margins of the Snake River Plain, or (3) a combination of both. There have been published suggestions (Ralston and Chapman, 1969; Ross, 1971; Young and Whitehead, 1975) that hot water leaking up along faults or flowing over some heat source was responsible for the warm artesian water in the northern part of the area. The <u>normal</u> geothermal gradients (4.1°F/100 ft) estimated for the artesian system with regard to the regional heat flow, and the lack of evidence of water through-flow make it clear that such hypotheses are <u>not</u> necessary and the heat in the aquifers is merely a reflection of the heat escaping from the earth's interior at that point. In view of the apparent connection of the hot springs and shallow wells in the south to the deeper system in the north, hypothesis (2) is the most likely one. If a heat source exists in addition to the regional background heat flow it must be in some direction other than to the northeast because of the evidence for merely regional heat flow values there. The various possible explanations for the higher gradients will be discussed in a following section.

Grand View Subarea. Eighteen holes were logged in the Grand View subarea and an additional two holes are available in an open file report (Brott et al., 1975, number 74I-45 and 75I-46). The locations of these wells are shown in Figure 9. Temperature-depth curves for the wells deeper than 70 feet are shown in Figure 10. Of all the subareas, the least satisfactory data were obtained here. Very few of the wells logged show linear temperature-depth curves. The holes which have linear temperature-depth curves are numbers 1, 24 and 29. Many of the curves, including ones from weakly artesian wells (4, 20, 30) and a recently pumped well (37) and the non-artesian wells (34, 40-41) have a sigmoidal shaped temperature-depth curve. The differences in gradient (a factor of 2 or more) are too great to be associated with thermal conductivity variations in the shallow part of the Idaho Group (see Tables 3 and 4) and must reflect a complicated natural or irrigation-caused interaquifer circulation in the shallow subsurface. Several of the wells also appear to have intrawell water movement between aquifers.

Except for the very shallow sections of some of the logs, the gradients are in the range of 2.3 - 4.9°F/100 ft. The most reliable gradients are considered to be from no 1 (3.7°F/100 ft between 131 and 394 ft), no 24 (2.6°F/100 ft between 197 and 525 ft), no 29 (4.9°F/100 ft from 33 - 213 ft), no 36 (2.7°F/100 ft between 49 - 114 ft), no 37 (4.1°F/100 ft between 33 and 98 ft), no 41 (2.3 to 4.6°F/100 ft between 30 and 197 ft), 74I-45 (3.0°F/100 ft between 115 and 197 ft), and 74I-46 (either 2.9 or 4.0°F/100 ft between 33 and 160 ft). There is a distinct difference in the Grand View subarea and the logs of wells 27 and 38 which are just to the southeast toward Little Valley as much higher gradients are measured there (see following section).

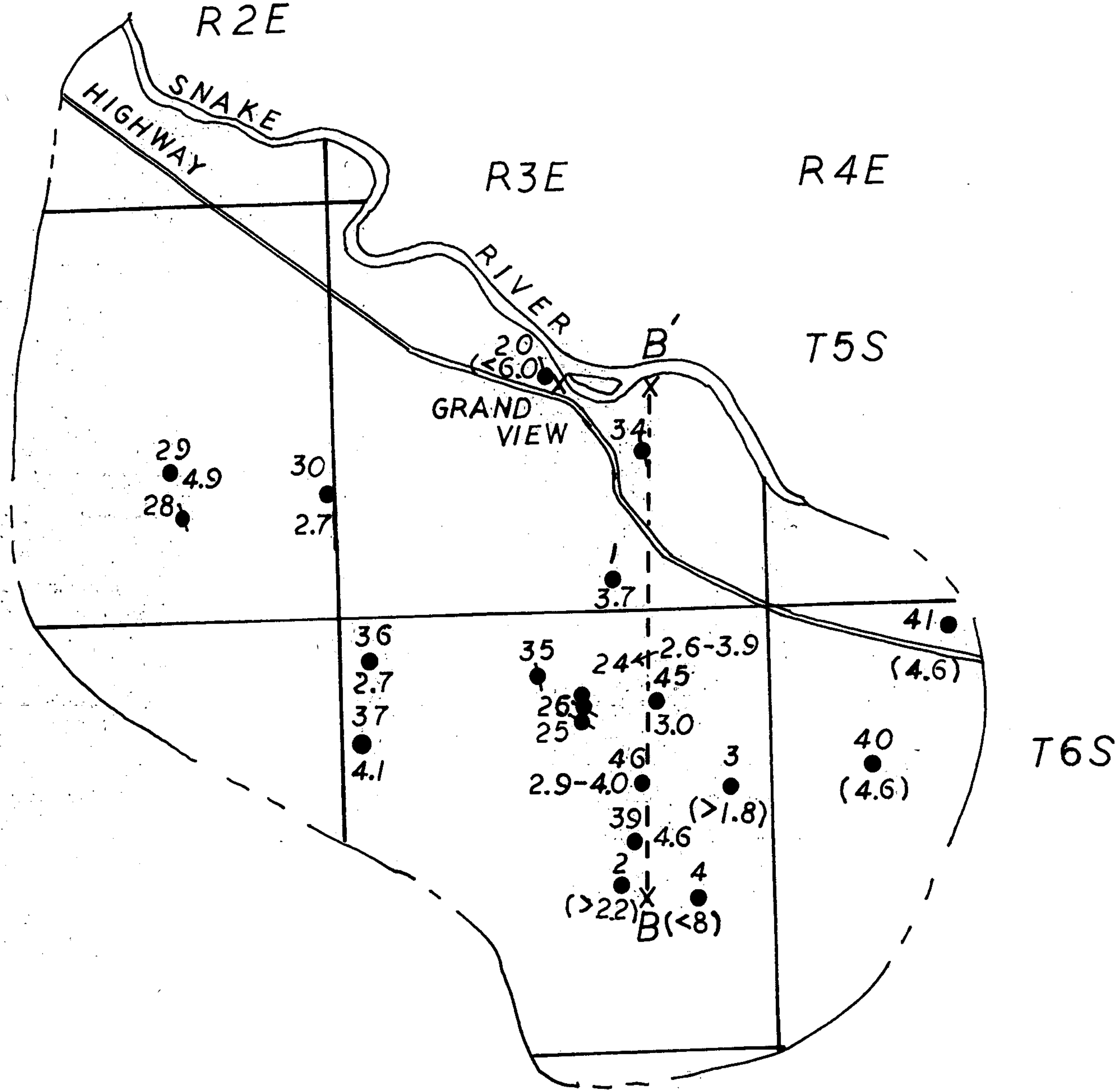


Figure 9. Detailed location map of wells in the Grand View subarea. The locations, identification, and gradients (in °F/100 ft.) of measured wells are indicated. Gradients in artesian wells or of doubtful validity are in parentheses. Holes which gave no gradient information have a slash through location dot. The line of section BB' is shown.

Figure 10c. Temperature-depth curves for wells in the Grand View subarea.

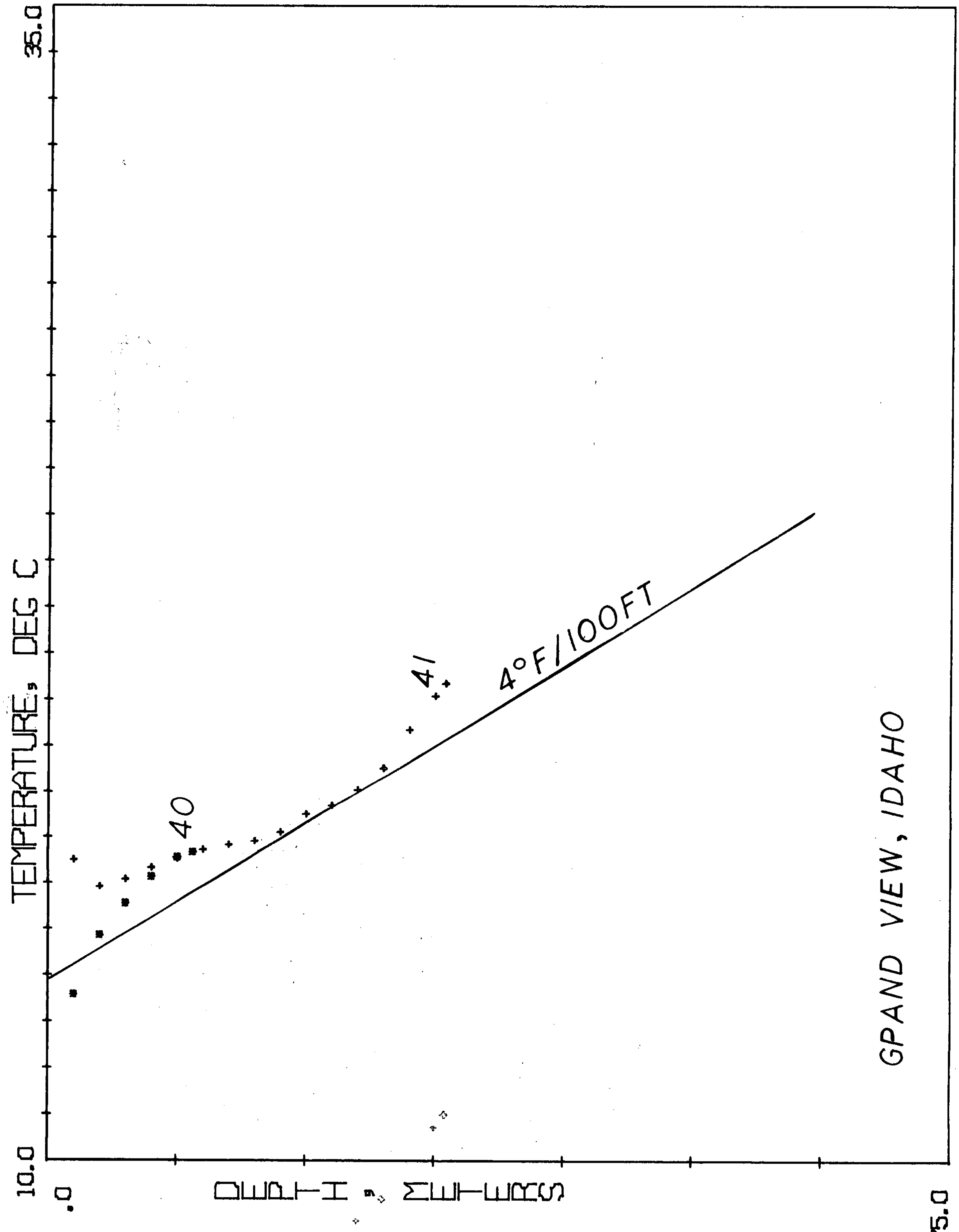


Figure 10b. Temperature-depth curves for wells in the Grand View subarea.

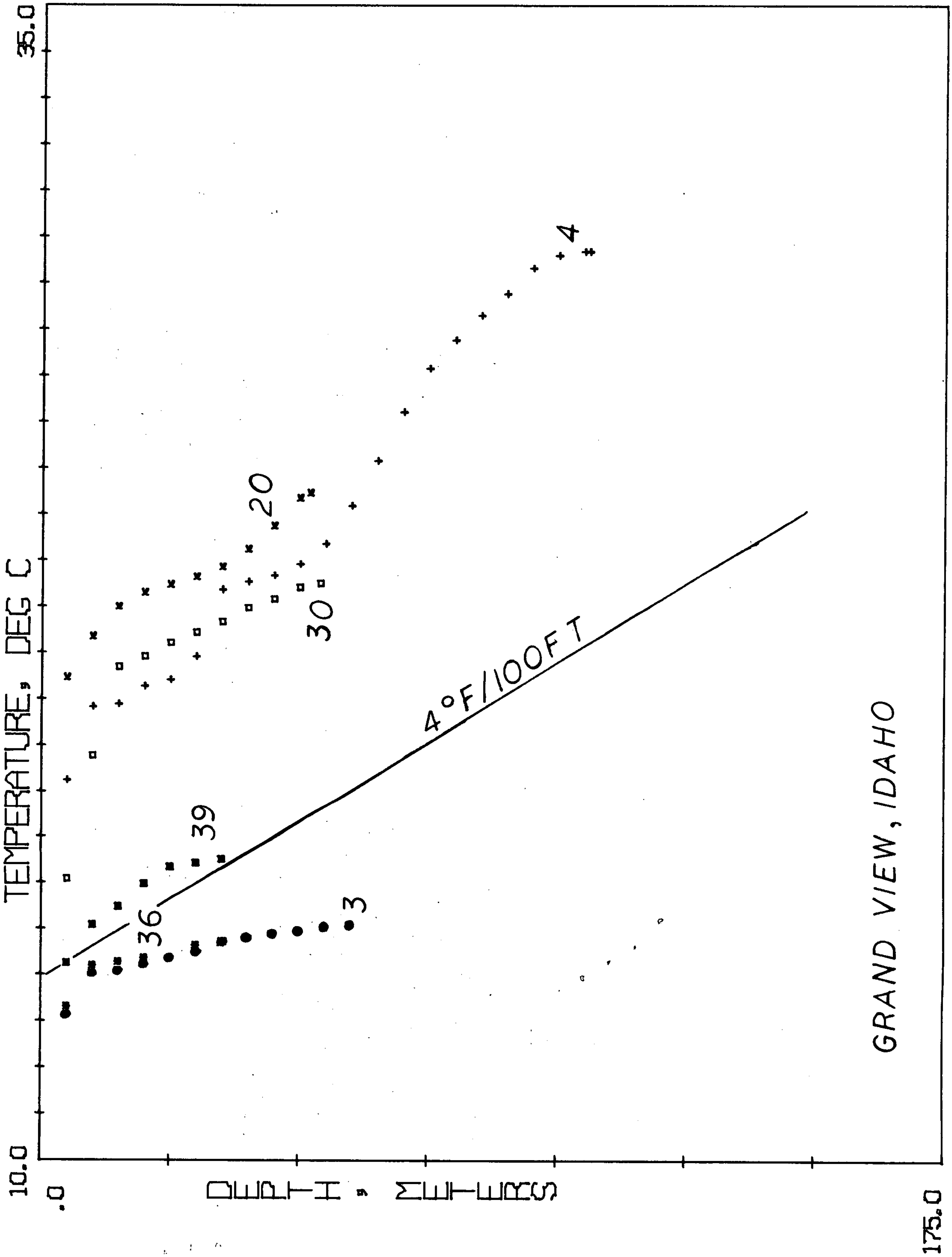
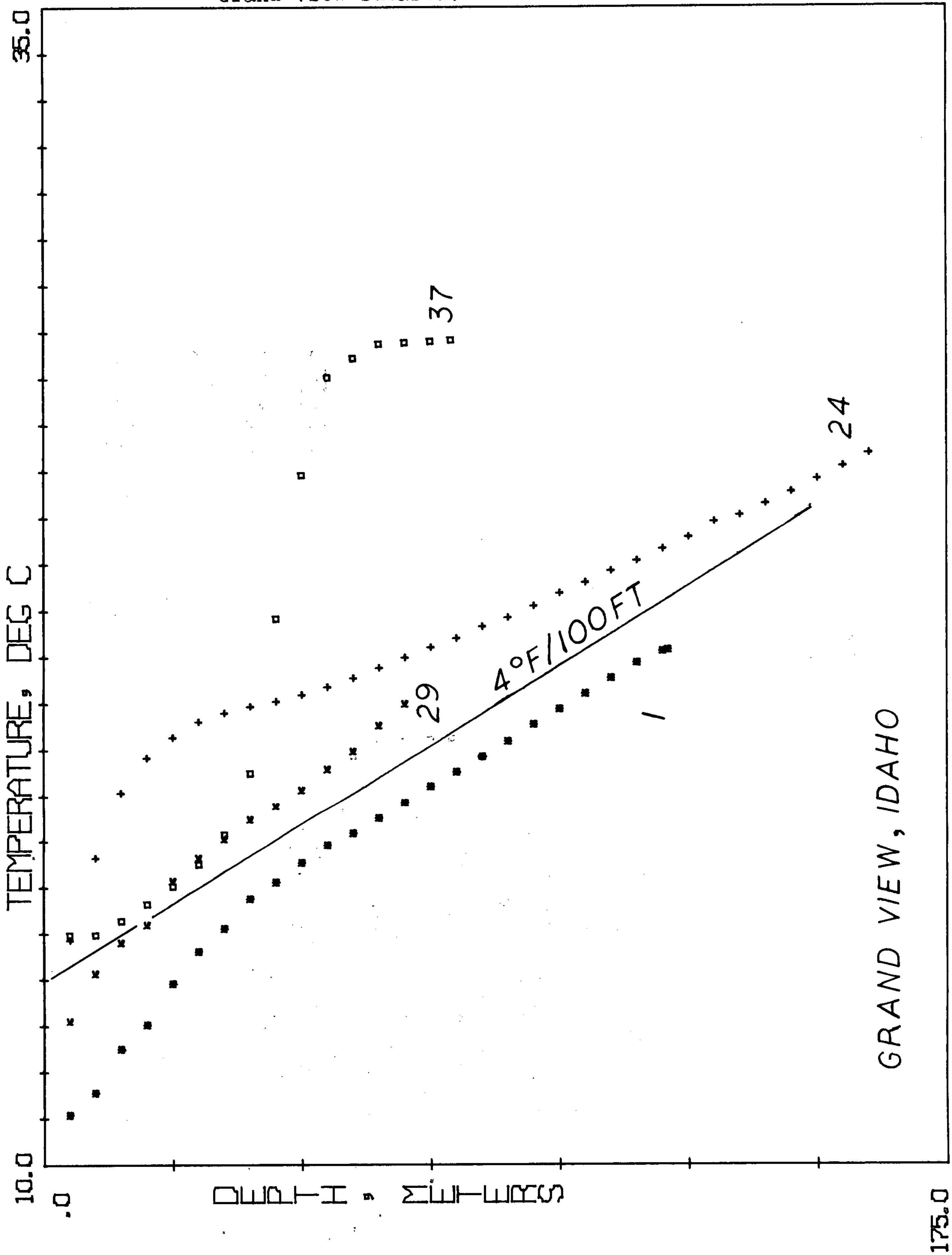


Figure 10a. Temperature-depth curves for wells in the Grand View subarea.



The thermal conductivity measurements range between 2.6 and 3.6 mcal/cm sec°C. If the lower value of thermal conductivity is associated with the higher geothermal gradients (about 4.5°F/100 ft) and vice versa, the heat flow values would be 2.1 HFU (for a gradient of 4.5°F/100 ft) and 2.0 HFU (for a gradient of 3°F/100 ft). These heat flow values, as described above, are apparently about normal for the area. Thus I believe that the variation in gradient is due to the variation in thermal conductivity.

Some of the deep artesian wells described in the literature are in the Grand View subarea and data from these wells were included in Figure 7. These deeper temperature data are very nearly the same as those from the Oreana subarea, although the temperatures in the Grand View subarea may be 5 - 10°F warmer at 3000 feet.

A geologic cross section for the Grand View subarea is shown in Figure 11 based on section BB' of Young and Whitehead (1975). Numerous faults are shown on the section between the south end and the midpoint of the section. The result is that the Banbury Basalt is dropped down systematically to the north as far as T6S, R3E, Section 2. An alternative interpretation for this faulting, remembering the vertical exageration of the section (10:1) is a gentle regional dip to the north with no faulting or other structural or stratigraphic complexities required except in the north half of the profile. Near the center of the cross section there is an apparent thickening of the Banbury from about 500 - 1500 feet, possibly associated with faulting.

In summary, the shallow gradient information in the Grand View subarea is ambiguous, but temperature gradient seems to vary from slightly less to slightly greater than the Oreana subarea. The shallow subsurface appears to be much more complicated lithologically and hydrologically than the other areas (or there is just more data available). The deeper temperature

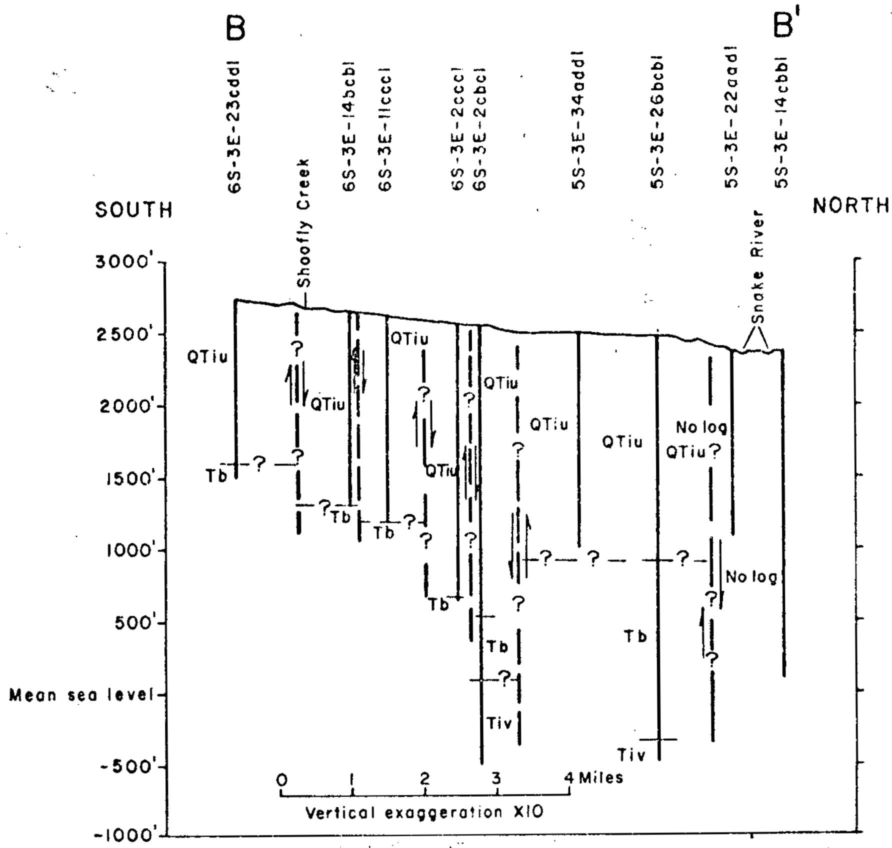


Figure 11. Geologic cross section for the Grand View subarea (after Young and Whitehead, 1975, Section BB'). The abbreviations are the same as in Figure 8.

information from artesian wells is essentially the same as in the Oreana subarea. The average gradient in the Idaho Group is $4.0 \pm 1^{\circ}F/100$ ft.

Little Valley-Bruneau Subarea. Data are available for only six holes in this subarea (numbers 12, 13, 14, 27, 38, 74I-44), and useful data were obtained only from numbers 13, 27 and 38. The temperature-depth curves for 13, 27, and 38 are shown in Figure 13 and the locations of the wells are shown in Figure 12. Wells 27 and 38 are actually between the Grand View and Little Valley subareas, but have T-D curves that are distinctly different from those of the Grand View subarea. Well 27 shows downward circulation of water in the bottom of the hole but otherwise has a linear temperature-depth curve. Well 13 was a former artesian well which was being redrilled; its gradient was obtained by assuming a surface temperature of $57^{\circ}F$. The gradients in these wells average $6.9^{\circ}F/100$ ft, significantly higher than the gradient in the Oreana and Grand View subareas.

The temperatures in deep artesian irrigation wells are not as definitive for this subarea as for the Oreana and Grand View subareas. Because all the permeable zones are artesian, it is common practice to complete the deep irrigation wells in as many aquifers as possible, in order to cool the deeper water as much as possible. According to Ralston and Chapman (1969, Table 2) the average temperature recorded on drillers' logs is about $110^{\circ}F$ as opposed to about $90^{\circ}F$ in the Grand View area, although no well depths are given. Thus I conclude that the evidence favors a higher geothermal gradient in the Little Valley subarea than in the Oreana or Grand View subareas. The higher geothermal gradient is not due to thermal conductivity variations because the wells are in Idaho Group sediments and so the variations must be either due to higher heat flow from the basement or lateral heat transport by water flow with or without above-regional heat flow. These results will be discussed in relation to the rest of the areas in a subsequent section.

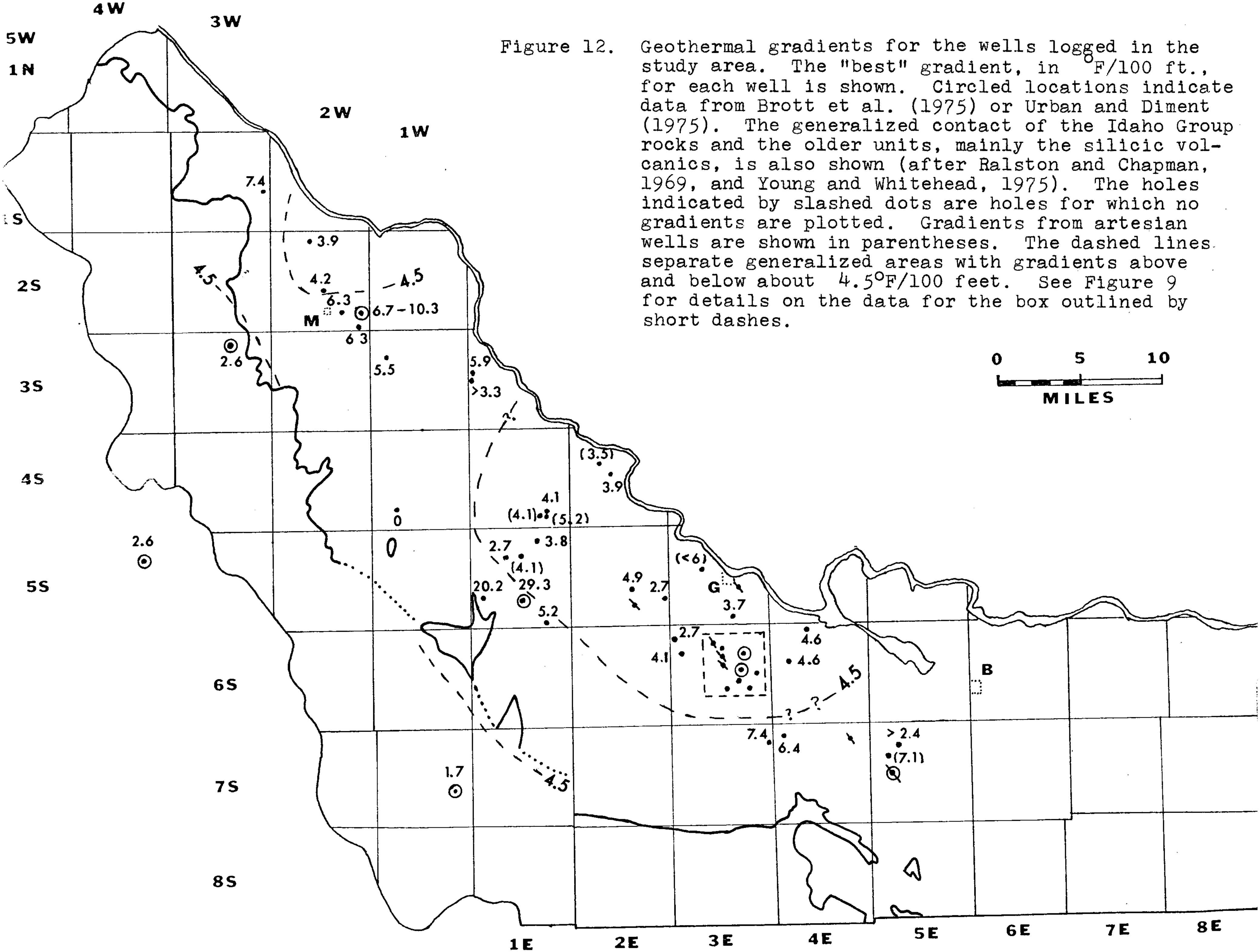


Figure 12. Geothermal gradients for the wells logged in the study area. The "best" gradient, in °F/100 ft., for each well is shown. Circled locations indicate data from Brott et al. (1975) or Urban and Diment (1975). The generalized contact of the Idaho Group rocks and the older units, mainly the silicic volcanics, is also shown (after Ralston and Chapman, 1969, and Young and Whitehead, 1975). The holes indicated by slashed dots are holes for which no gradients are plotted. Gradients from artesian wells are shown in parentheses. The dashed lines separate generalized areas with gradients above and below about 4.5°F/100 feet. See Figure 9 for details on the data for the box outlined by short dashes.

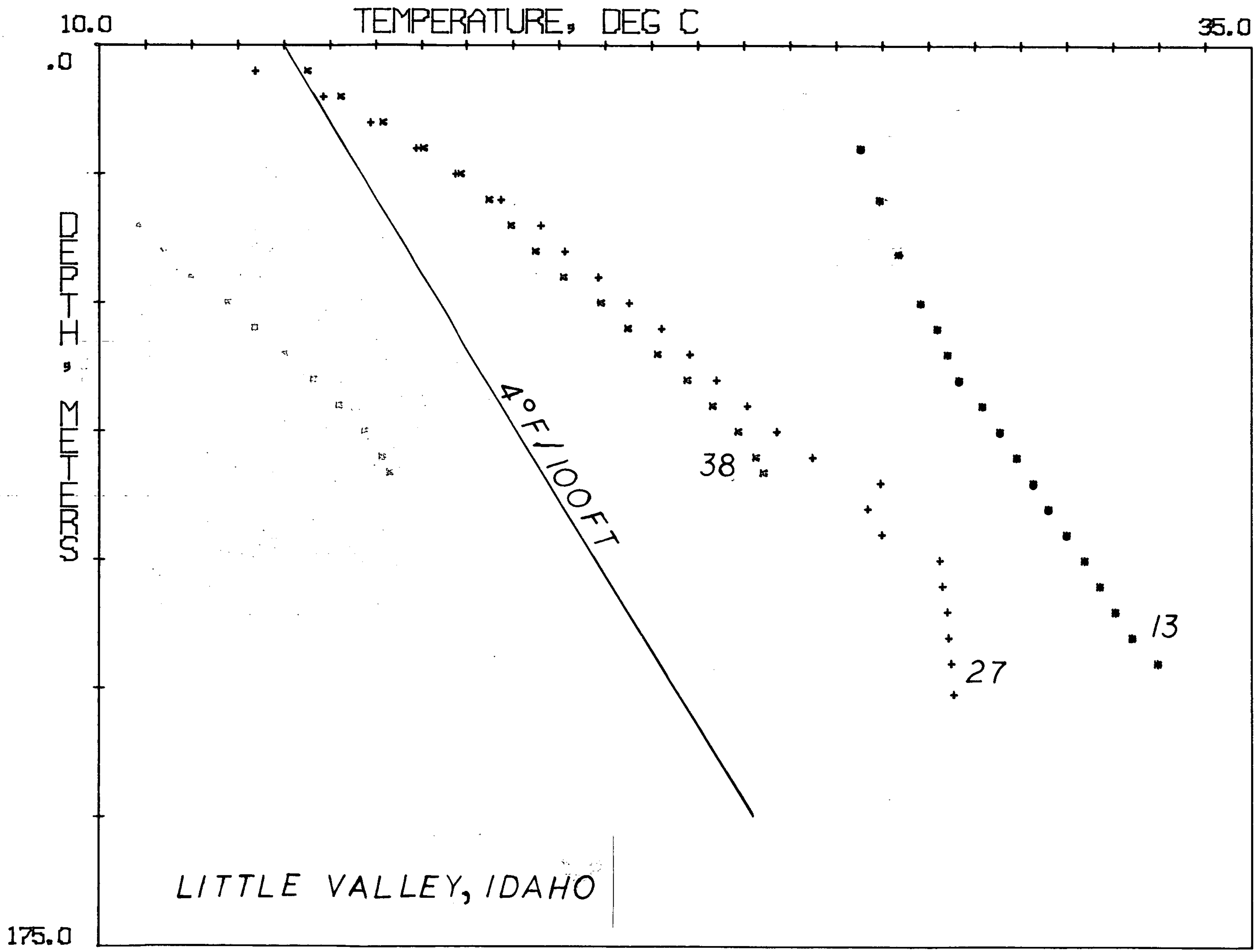


Figure 13. Temperature-depth curves for wells in the Little Valley-Bruneau subarea.

Murphy Subarea. Seven wells were logged in the Murphy and Walters Ferry subareas of Ralston and Chapman (1969), and data are available from an additional two wells (Brott et al., 1975, number 74I-35 and 36A). The temperature-depth curves for wells 5, 6, 7, 15 and 33 are shown in Figure 14 and the locations are shown in Figure 12. Well number 16 was not plotted, but is almost identical to number 7. Several of the wells in the Murphy subarea give good gradient information. The temperature-depth curve for number 6 shows a classic downward water flow, with the high gradients below the water loss zone (compare with Figure Al-b, curve 1). The gradients are about $7^{o}F/100$ feet in wells 5, 6, 15, 33, 74I-35 and 74I-36A and about $4^{o}F/100$ feet in wells 7 and 16 (the same as in the Oreana subarea). Wells 15 and 74I-35 are the deepest non-artesian wells logged, but both give ambiguous information. Well 74I-35 has down-flow of water in the bore hole between 330 feet and the bottom (1170 ft) which completely destroys the gradient in that interval. Well 15 has a gradient of $7.4^{o}F/100$ feet in the upper part of the hole which decreases smoothly to zero in the last temperature interval. The gradient variation could be due to up-flow or down-flow in the bore hole, it could be due to regional water motions (compare with Figure Al-c3), or there could be thermal conductivity variations in the rocks cut by the bore hole. Unfortunately, no drill logs appear to have been filed with the Idaho Department of Water Resources on the deeper wells in T1S, R2W or 3W, so there is no lithologic information available for this or nearby wells. This hole (an old, 20" irrigation well) also shows an offset of temperature at the water table, although the same average gradient is found at a distance of a few meters above and below the water table disturbance.

A few miles to the north along the Snake River there are numerous old artesian wells with only small flow. Reported depths and temperatures correspond to a geothermal gradient on the order of $6^{o}F/100$ feet to depths of 1,000 - 1,300 feet.

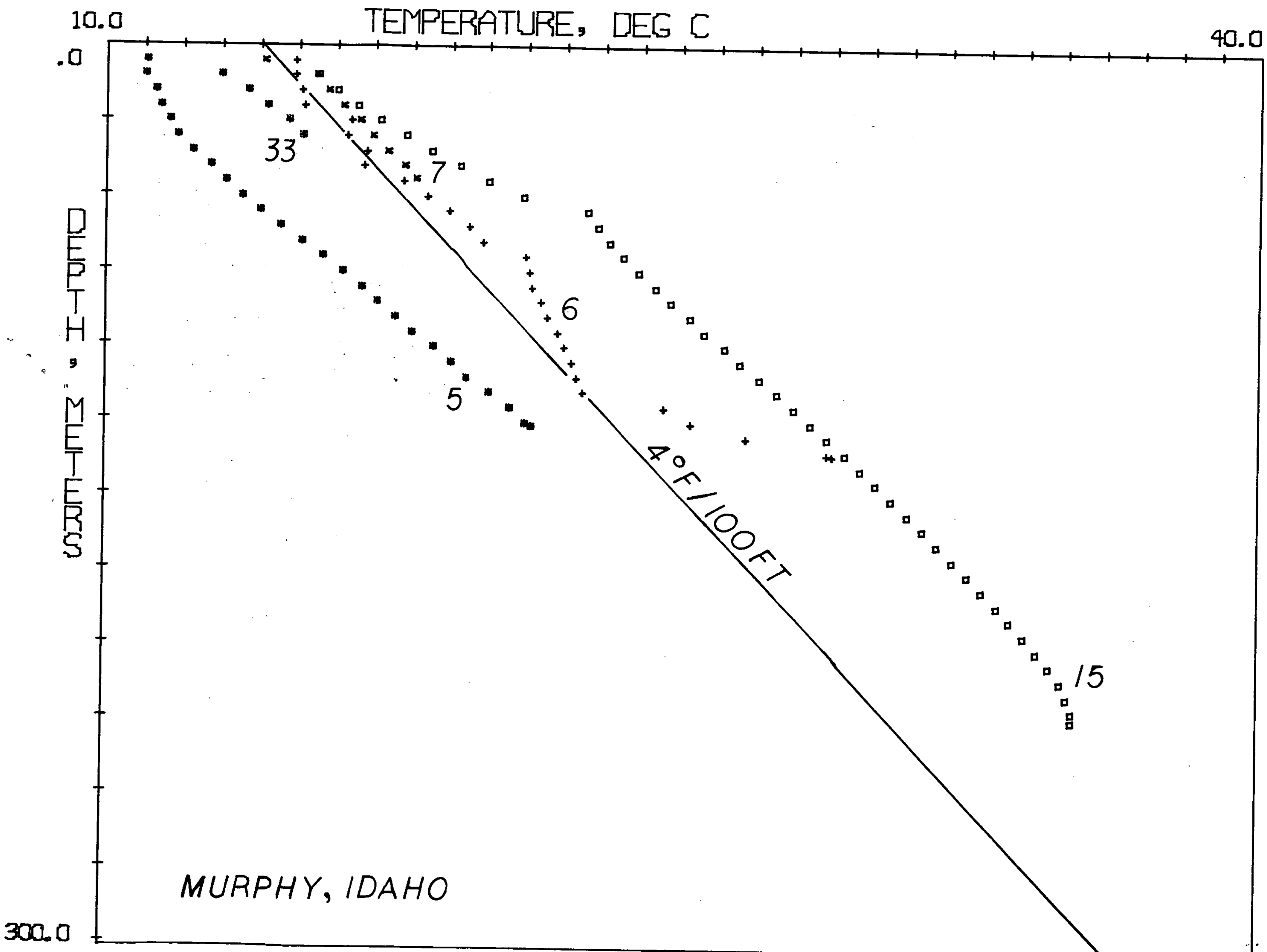


Figure 14. Temperature-depth curves for wells in the Murphy subarea.

At least one home uses water from an artesian well at about 120°F for space heating (in Section 7, T1S, R2W). Most of the wells apparently are in the Poison Creek Formation, the basal unit of the Idaho Group.

Unlike most of the remainder of the area, most wells in the vicinity of Murphy are not artesian, and the temperature-depth logs in fact indicate that the shallow aquifers have higher heads than the deep aquifers. As is the case for the Little Valley-Bruneau area, the high gradients may be due either to heat transport in the ground-water system or to high intrinsic heat flow. The T-D curve for well 15 suggests the water transport hypothesis, but the lack of artesian pressure in the area suggests that the pressure difference driving any large-scale ground-water circulation must be lower than that found to the northwest and southeast. Because the gradients are higher than in the Oreana area, for example, even though evidence for a large-scale integrated aquifer system is less clear, the regional water-circulation hypothesis is not as strongly suggested as in the Little Valley-Bruneau area.

The heat flow observed in the well in granite in T3S, R3W is about 50% above the regional average and, taken at face value, suggests a nearby magmatic heat source. That value may not have been corrected for topography and, as it is in a steep valley, the value could be high by 10 - 30%. For a heat flow of 3.0 HFU, the geothermal gradient observed in the wells cutting the Idaho Group would be in the range of 5° to 6°F/100ft, which is the gradient found for some of the wells. On the other hand the gradients in wells number 7 and 16 would suggest heat flow values of 2.1 - 2.3 HFU, similar to the values observed near Silver City and south of Oreana.

Heat Flow. The heat flow values have been mentioned above for most areas, but it is the purpose of this section to summarize these results. The heat flow values actually calculated for individual wells are shown in Figure 15. The thermal conductivity of the Idaho Group sediments apparently ranges from about 2.6 - 3.6 mcal/cm sec°C. As discussed above, an inaccurate picture of the heat flow may result from literal interpretation of the heat flow data shown in Table 3, because the depth interval of the geothermal gradient may not be the depth interval from which the cuttings sampled came. Therefore, based on the general geothermal gradient results (Figure 12) and the range of thermal conductivity values, an interpretation of the heat flow distribution is also shown in Figure 15.

Based on this interpretation, most parts of the Oreana and all parts of the Grand View subareas studied have heat flow values near or only slightly higher (10-15%) than the regional norm. Part of the Murphy subarea also has normal heat flow. The northern part of the Murphy area, the southwestern part of the Oreana, and the Little Valley subareas have heat flow 50% to 100% above the regional norm. A heat flow value much above the regional norm is also found in basement rocks southwest of the Murphy subarea. On the basis of the heat flow data, I recommend followup studies in these three areas in order to better define the anomaly areas and to determine the cause of the high heat flow values. A tentative conclusion is that the high values of heat flow seem to lie along the southern hinge line of the Snake River Plains where the silicic volcanics are down faulted or sharply warped from near the surface to 2,000 - 3,000 feet below the surface (see Figures 4, 8 and 11).

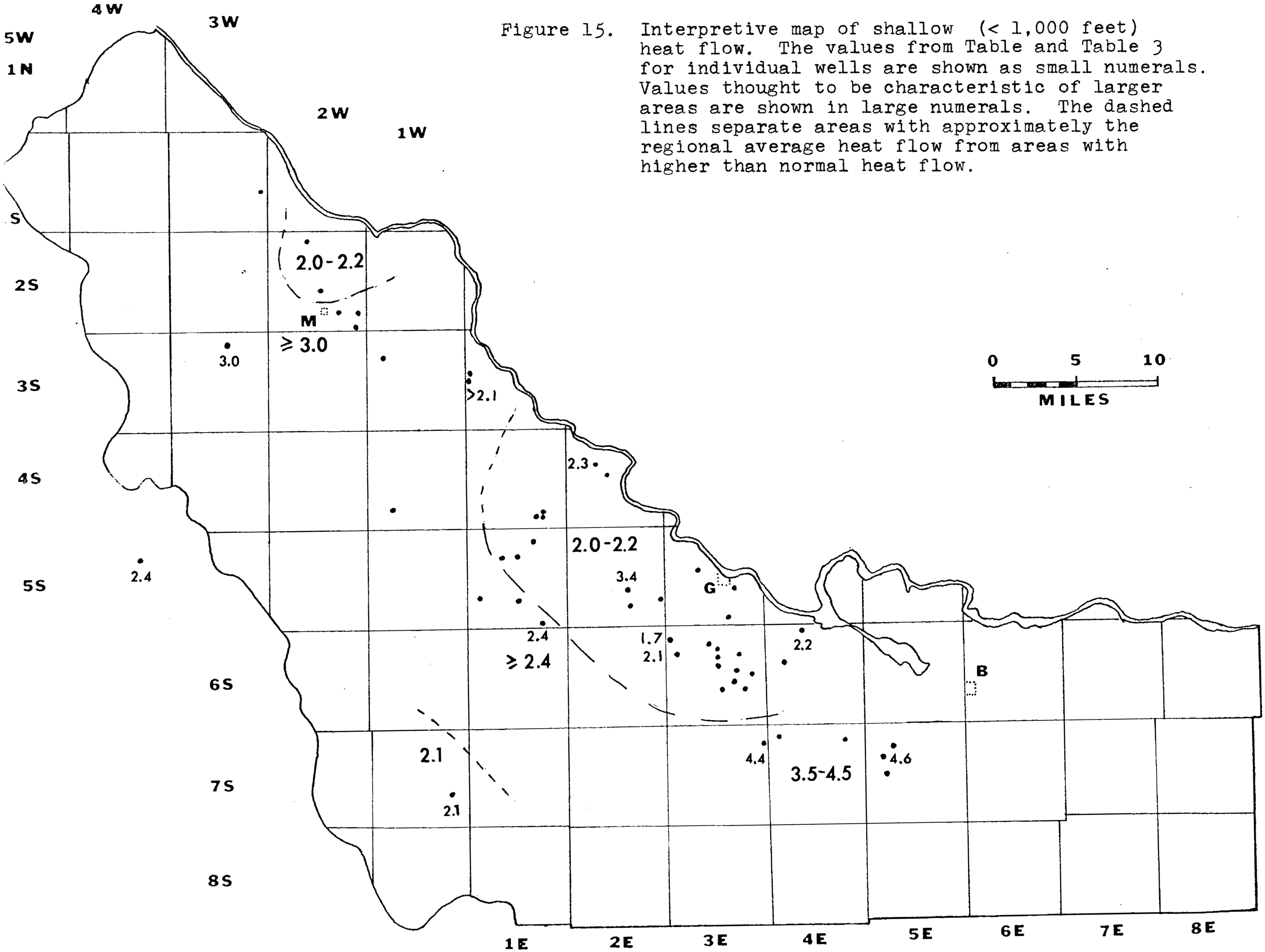


Figure 15. Interpretive map of shallow (< 1,000 feet) heat flow. The values from Table and Table 3 for individual wells are shown as small numerals. Values thought to be characteristic of larger areas are shown in large numerals. The dashed lines separate areas with approximately the regional average heat flow from areas with higher than normal heat flow.

DISCUSSION

General. The location and geothermal gradient values are summarized for the whole area in Figure 12 and the heat flow results are summarized in Figure 15. A contour has been drawn on the map in Figure 12 separating the areas of "normal" gradient (about 4°F/100 ft), such as the Oreana, Grand View and part of the Murphy subareas, from the areas with high geothermal gradient (5°F/100 ft or greater). Also shown on Figure 12, for comparison, is the generalized contact of the silicic volcanics and the overlying rocks (from Ralston and Chapman, 1969; and Young and Whitehead, 1975). As a generalization, the gradient and heat flow tend to be highest in the updip direction of the sedimentary rocks. The gradients of 4°F/100 ft reflect areas of "normal" conductive heat loss for the area, and as such either do not have heat transport by through-flow of water, or are in the midrange of a regional ground-water system. The high gradients reflect above-average heat loss either due to discharge of the regional aquifer system or due to presence of a local heat source, or both.

Before considering the geothermal models in more detail, the heat flow results will be compared to other available geological and geophysical information. Figure 16 shows gravity data in the Oreana-Bruneau area (Young and Whitehead, 1975); Figure 17 shows a contour map of magnetic data (Young and Whitehead, 1975); Figure 18 shows a map of the AMT results (Hoover and Tippens, 1975) and KGRA's; and Figure 19 shows an interpretive map of the top of the silicic volcanics based on well log data summarized by Young and Whitehead (1975). The gradient contour from Figure 12 is superimposed on all of these maps. The emphasis in this section of the report is on regional correlations between the geothermal gradient and heat flow data and other information of possible geothermal significance. These regional correlations may help interpret the geothermal regime in the area and suggest areas of particular interest or where additional information is needed. Detailed analysis of the data is beyond the scope of

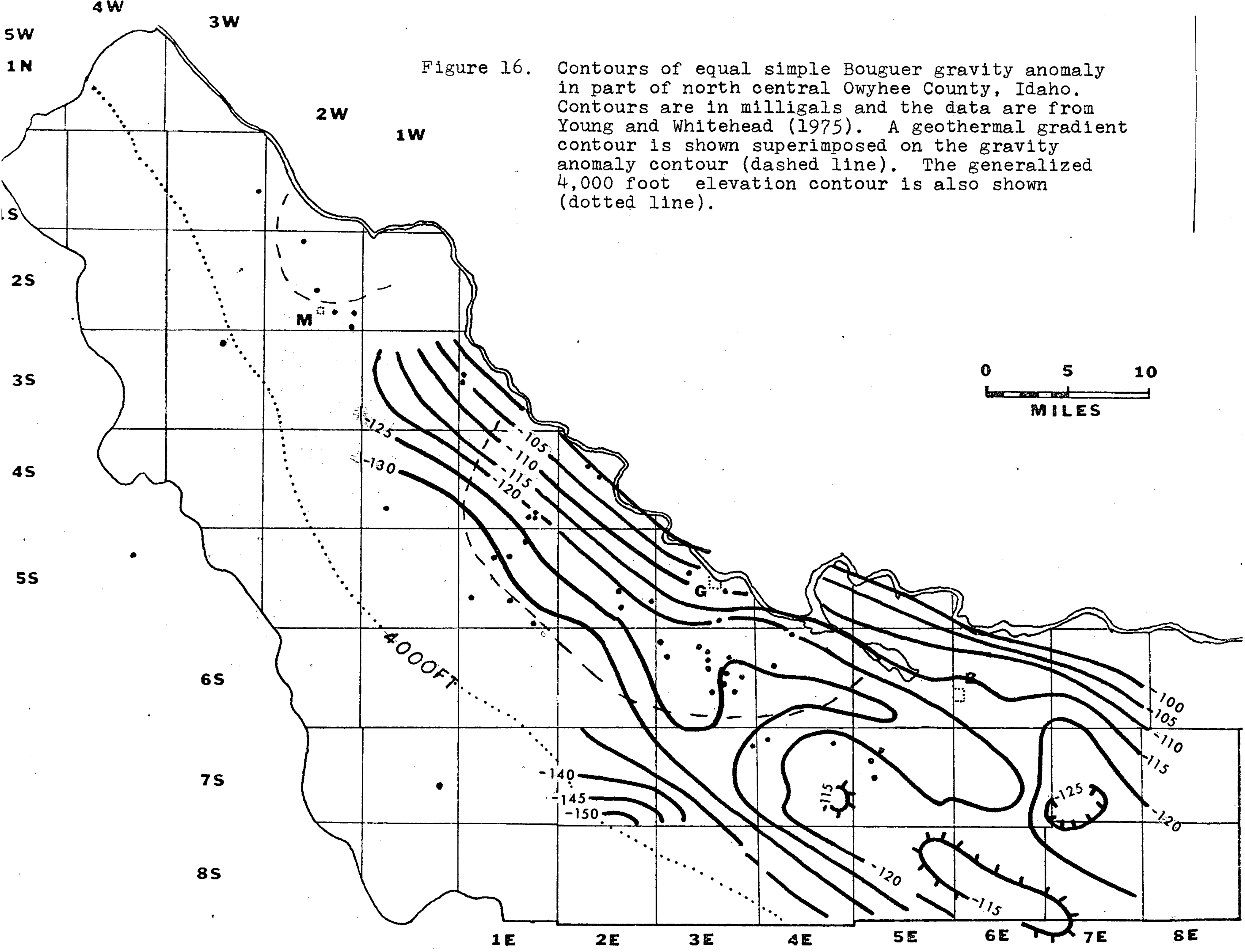


Figure 16. Contours of equal simple Bouguer gravity anomaly in part of north central Owyhee County, Idaho. Contours are in milligals and the data are from Young and Whitehead (1975). A geothermal gradient contour is shown superimposed on the gravity anomaly contour (dashed line). The generalized 4,000 foot elevation contour is also shown (dotted line).

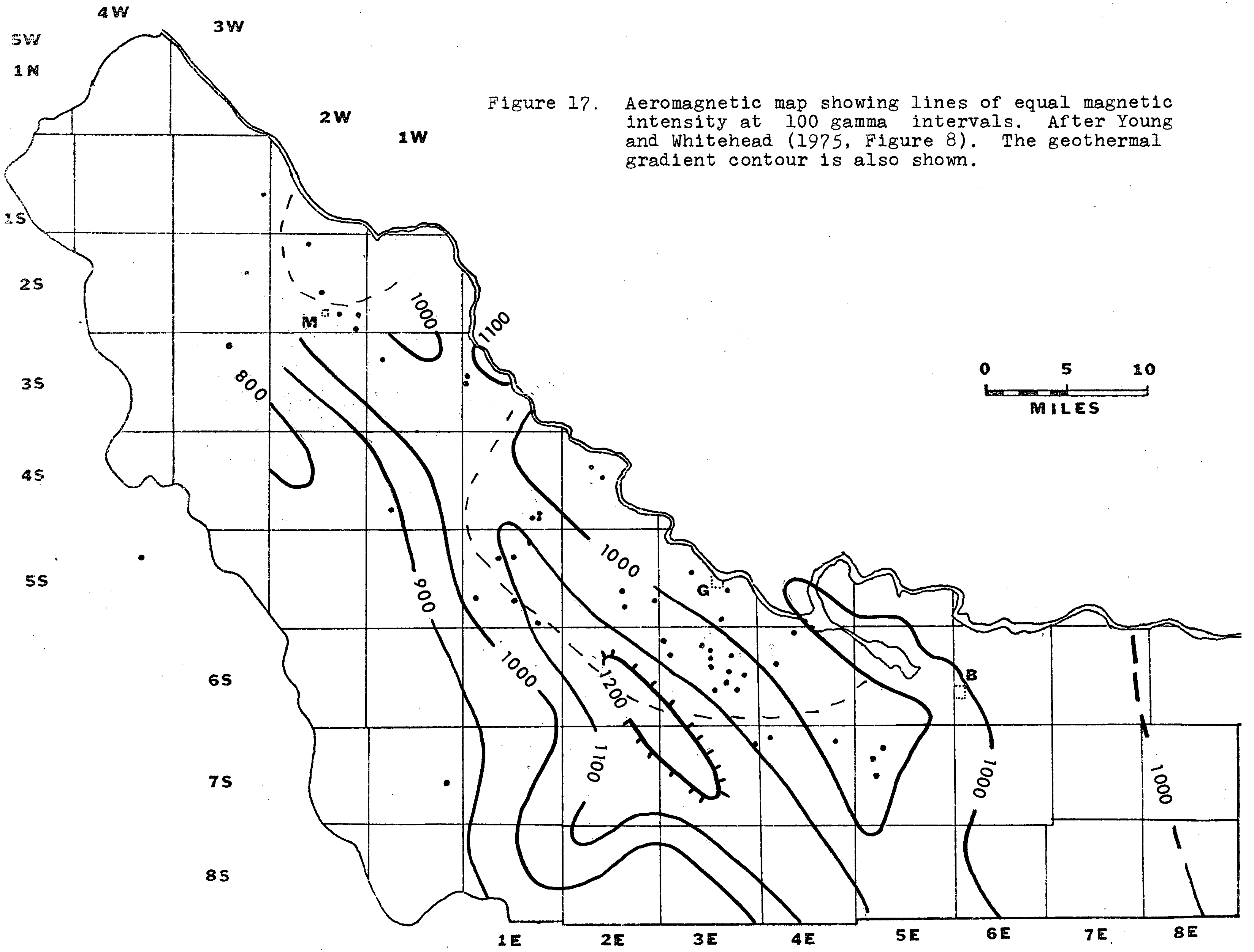


Figure 17. Aeromagnetic map showing lines of equal magnetic intensity at 100 gamma intervals. After Young and Whitehead (1975, Figure 8). The geothermal gradient contour is also shown.

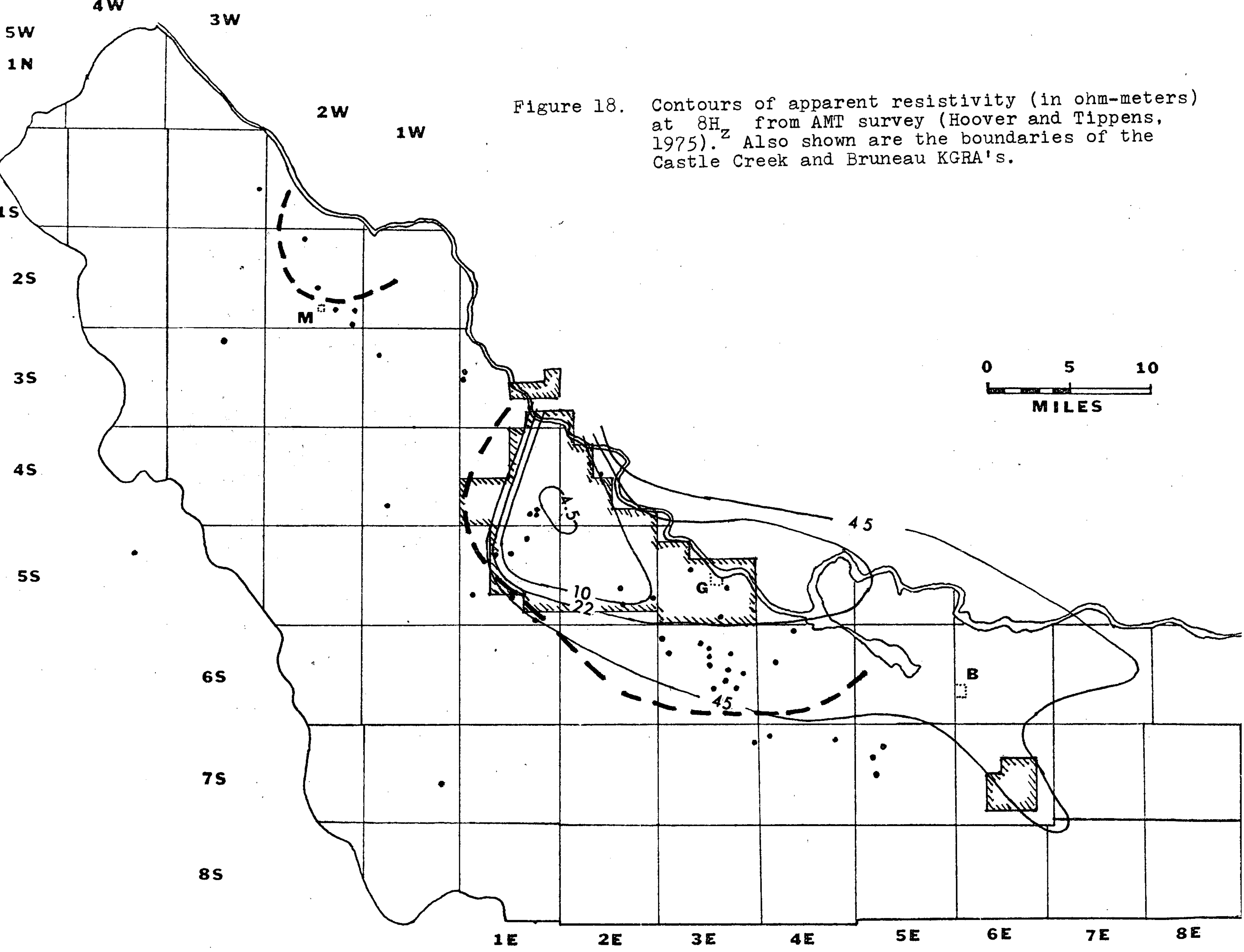


Figure 18. Contours of apparent resistivity (in ohm-meters) at 8Hz from AMT survey (Hoover and Tippens, 1975). Also shown are the boundaries of the Castle Creek and Bruneau KGRA's.

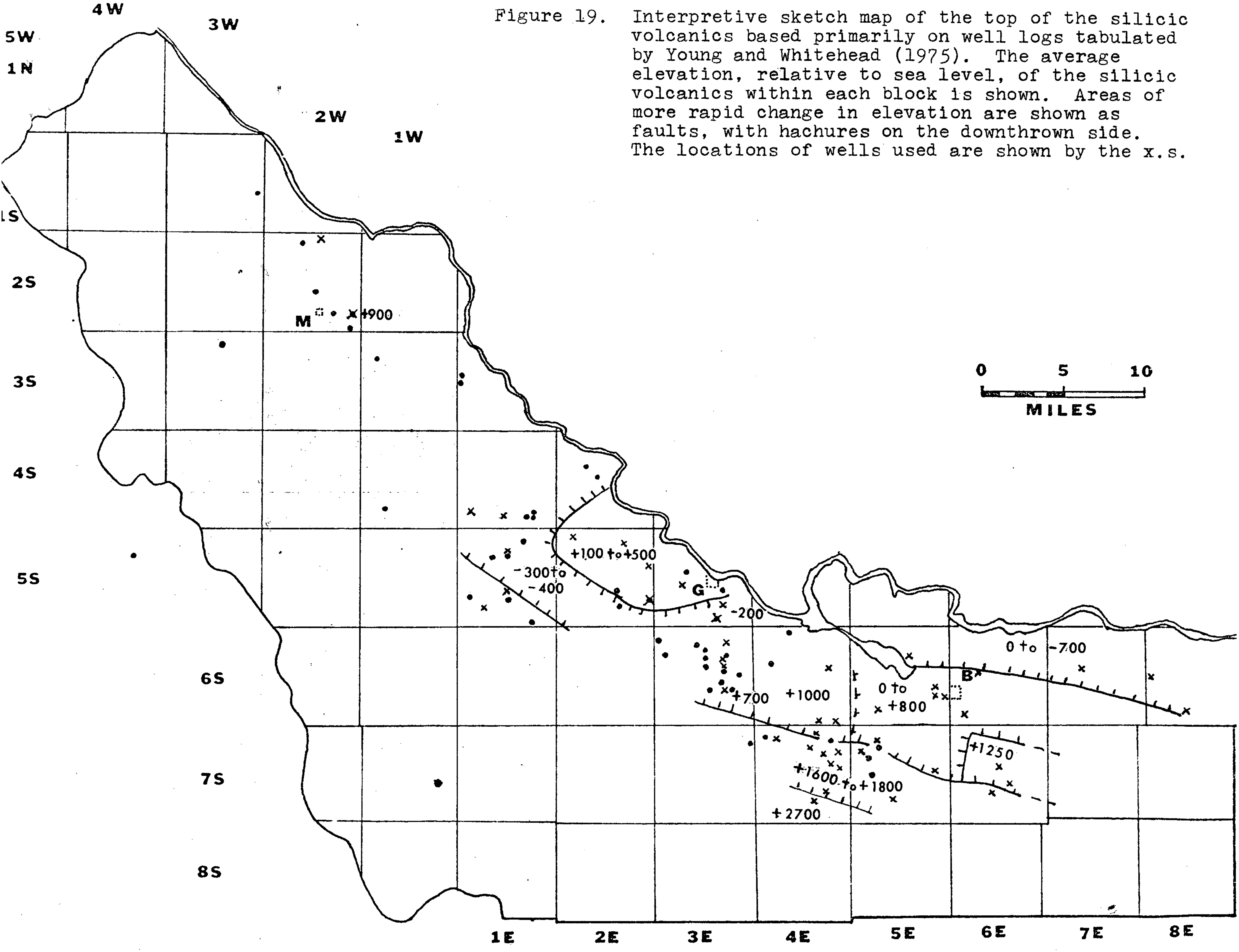


Figure 19. Interpretive sketch map of the top of the silicic volcanics based primarily on well logs tabulated by Young and Whitehead (1975). The average elevation, relative to sea level, of the silicic volcanics within each block is shown. Areas of more rapid change in elevation are shown as faults, with hachures on the downthrown side. The locations of wells used are shown by the x.s.

this report, although such analysis is strongly recommended if further work in the area is planned.

The map of the top of the silicic volcanics is based on the well log data of Young and Whitehead (1975), but differs in the interpretation of the faulting. As pointed out in the section on the Grand View subarea, the interpretation of Young and Whitehead (1975) is a maximum fault model, and some areas that appear to have a uniform regional dip to the north have been shown chopped up by faults. The average depth to the top of the silicic volcanics is shown for each structural block and faults are shown only where large changes are noted in depth to the top of the unit. Some of these changes in elevation might also reflect original topography or original dip instead of faulting and the map is interpretive only.

The AMT data have been interpreted to have major geothermal significance and the Castle Rock-Grand View KGRA is based in large part on AMT data. It is interesting that the area of low resistivity corresponds with the area of <u>normal</u> heat flow where gradients are about 4°F/100 ft. The lowest values of resistivity are in the Oreana subarea and the northwestern part of the Grand View subarea. Comparison of the AMT results with the map of the top of the silicic volcanics shows that the low resistivity area in general coincides with the area where the top of the silicic volcanics is 1,000 feet or less above sea level and the Idaho Group is thicker than 1,000 feet. As pointed out (Hoover and Tippens, 1974, p. 92), given the low resistivity values found in the center of the anomaly, the sounding depths do not reach the top of the silicic volcanics; yet geothermal potential is associated with the silicic volcanics on the basis of the resistivity data (p. 93). The structural high on the silicic volcanics (see Figure 19) which is correlated with the low resistivity is penetrated by a well in Section 25aa, T5S, R2E. According to the drillers log the well cut the silicic volcanics at about 400 feet above sea level at a depth of 2,237 feet, had a total depth of 3,025 feet, was cased to 1,826 feet, and had a temperature of 140°F. If the water comes from the top of the silicic volcanics the indicated geothermal gradient would be about 4°F/100 feet, the average value found for the general area. Thus, I believe that the low resistivity is related to the stratigraphy of the Idaho Group and has no geothermal significance. The structural information inferred from the AMT data is useful, but to attach geothermal significance to the resistivity data when drilling has penetrated below the depth of penetration of the AMT survey seems tenuous at best.

The gravity data appear to correlate on a qualitative basis with the thickness of the Idaho Group, particularly west of the township line common to R2E and R3E. The contours of gravity in T5S, R3E parallel the interpreted southern margin of the structural high on the silicic volcanics and the gravity trough southwest of the Bruneau River corresponds to an apparent graben or trough in the top of the silicic volcanics (see Figure 19). To the northwest, the major gravity trends parallel the main topographic break of the Snake River Plains that extends NW-SE across the whole area (compare with the regional 4,000 foot elevation contour shown in Figure 16). The magnetic data also clearly parallel this trend (Figure 17) and the major anomaly must reflect a major upper crustal effect. In the northwestern portion of the study area the geological and gravity trends are parallel. In the southwestern portion of the map area, however, they diverge, with the faults and rhyolite outcrop pattern trending east-west and the gravity trends continuing the NW-SE trend.

The study area can be divided into three parts on the basis of geothermal gradient: (1) the Grand View-Oreana area and part of the Murphy area (the northeast part of T2S, R2W) with an average geothermal gradient of about 4°F/100 ft; (2) the Little Valley subarea and that part of the Murphy subarea with a gradient of 5° to 8°F/100 ft; and (3) the area in the southwest part of T5S,R1E south of Oreana where there is evidence of very high geothermal gradients, at shallow depths at least.

Grand View-Oreana-Murphy Area. Little is known about the deeper regime in the area of normal gradient near Murphy, but there is extensive information on the Grand View area. Drilling suggests that the geothermal gradient is about $4^{o}F/100$ ft to depths of 3,000 feet and possibly as deep as 11,000 feet. Assuming that the Anschutz well did not penetrate a long interval of granitic rock, the indicated thickness of Cenozoic volcanic and sedimentary rocks below the top of the silicic volcanics (about 2,500 - 3,000 feet below the surface) is 8,000 feet or more. The potential for fluid production of this section is not known, but Owyhee Basalt, the Columbia River equivalent in this area and stratigraphically below the silicic volcanics (the topmost silicic volcanics at least), is a productive aquifer where it has been drilled at shallow depths in Oregon and Washington, and other aquifer zones may be present in the sequence.

The thickness of the Cenozoic volcanic and sedimentary sequence below the Banbury Basalt must depend on the stratigraphy, source areas, and PreBanbury structure of these older units, which are at present unknown. It might be argued that the Anschutz well went into a volcanic vent area, and thus cut a much thicker sequence of Tertiary volcanic rocks than would other wells in the general area. In 1973 Standard Oil Company drilled a well ("Highland") near Parma, Idaho, about 50 miles northwest of the study area. The well is on top of one of the positive gravity anomalies characteristic of the Snake River Plain. The stratigraphic section of the well included sedimentary rocks between 0 and 3,800 feet, the Grassy Mountain Basalt (?) and older sedimentary rocks between 3,000 and 6,720 feet, the Owyhee Basalt at 6720 feet, followed by a sequence of siliceous volcanics, lacustrian sediments and basalts, to a total depth of almost 12,000 feet. The Grassy Mountain Basalt occupies the same stratigraphic position as the Banbury Basalt in the study area and there are no silicic volcanics on top of the Owhyee Basalt in the western Snake River Basin. Thus the Standard well penetrated over 5,000 feet of volcanic and sedimentary rocks below the Idaho Group rocks. The well had a reported temperature of $400^{\circ}F$ in the Owyhee Basalt, which would correspond to an average geothermal gradient of about $5^{\circ}F/100$ feet. Therefore neither the thickness of volcanic and sedimentary rocks cut by the Anschutz well, nor the temperatures encountered seem unusual for the Snake River Plain.

Young and Whitehead (1975) have presented geochemical temperatures for many of the wells in the Oreana-Bruneau area. They find geochemical temperatures for waters from the silicic volcanics of 220° - $300^{\circ}F$ for the SiO_2 geothermometer, 140° - $400^{\circ}F$ for the Na-K-Ca geothermometer, and 338° - $473^{\circ}F$ for the mixing models, where calculated. They discard results from water coming from the overlying sedimentary rocks, because they think that the SiO_2 contents are in equilibrium with amorphous silica instead of quartz. The significance of the high temperatures is difficult to estimate. They have been attributed to mixing of hotter water from depth with the shallower water in the silicic volcanics and resultant heating of the shallower water. However, there may not be as many faults as proposed, the normal gradients do not suggest a significant mixing of shallow and deep water, and there are few reports of abnormally hot water (water requiring gradients much above $4^{\circ}F/100$ feet) for a given depth in wells. I think that the SiO_2 contents may be high for waters in the silicic volcanics because of their equilibration with glass in the volcanics, rather than with quartz. There is no obvious place for the waters to have mixed or been heated to temperatures of this magnitude unless there is a very high vertical permeability and mixing in the silicic volcanics and lower units. Such a vertical mixing might lead to low convective gradients rather than the conductive gradients of $4^{\circ}F/100$ feet observed above the volcanics. The reported temperature in the Anschutz well is consistent with the projected temperature based on conductive heat transfer and the thermal conductivity of the units involved, however, and there is no evidence for the discharge required if rapid through flow occurs. Therefore the geothermometers are of little usefulness in this area and I feel that their results must be treated with caution.

In summary, the Oreana-Grand View areas have a demonstrated geothermal gradient of about 4°F/100 feet to a depth of 3,000 feet and, based on unconfirmed well data, to 11,00 feet. Thus temperatures of 400°F should occur at about 8,000 feet in Cenozoic volcanics, whose reservoir characteristics are not known, but which may be favorable for geothermal development. There is an electrical resistivity anomaly present in the area at depths of 1,000 to 3,000 feet, and calculated geochemical temperatures are quite high. On the other hand, the area has been declared a KGRA and thus leasing may be more expensive; the geothermal gradient may be higher in surrounding areas; there is no evidence that the thickness of Cenozoic volcanics and sediments is much different elsewhere; the geothermal significance of the electrical resistivity anomaly is not obvious; and the geochemical data do not appear to be reliable.

Little Valley-Murphy Areas. These areas are summarized together because of their similar geothermal gradients, although the origin of the similar gradients may be completely different. The gradients in these areas are 5° to 7°F/100 feet or more. Much more other geological and geophysical data are available for the Little Valley-Bruneau areas than for the Murphy area, but there is no simple correlation of the information with the geothermal gradients. The thickness of the post-silicic volcanic units is less in this area than in the Grand View area so the thinner Idaho Group rocks may act here as an aquitard, thereby allowing some water, and heat, to discharge from the deeper artesian system in the silicic volcanic rocks. Ralston and Chapman (1969) note that the water piezometric levels are lower in the Little Valley area than elsewhere, suggesting this area as a possible discharge zone. The low resisistivity zone extends into the northern part of the area, where the Idaho Group sediments are thickest. There is much more character to the gravity field than in the Oreana-Grand View area, suggesting more complicated subsurface conditions. The geochemical temperatures are similar to those in the Oreana-Grand View area.

If the high gradients are due to water flow, the average gradient to depths of several thousand feet still should be about 4°F/100 feet or higher, allowing of course for thermal conductivity differences in the sections. If the higher gradients are due to higher heat flow, temperatures will be much higher at equivalent depths in the area of higher gradient. For example, a temperature of 400°F would be reached at a depth of about 5,000 to 6,000 feet if the gradient is about 6°F/100 feet, as opposed to a depth of about 8,000 feet in the Oreana-Grand View areas. On the other hand, the deeper temperatures and structure are unknown in the Little Valley area, whereas in the Grand View area there is some information available.

There is much less information available for the Murphy subarea. The shallow gradient is about the same as in the Little Valley area, but there is some evidence that the gradient may decrease with depth. A very favorable piece of data is the measurement of higher than regional heat flow in the basement rocks near Murphy. This alone justifies more consideration of the Murphy area, in my opinion.

Upper Castle Creek Area. The highest gradients were found in the southwestern part of T5S, R1E, along the upper part of Castle Creek. Hot springs are reported to have occurred in this area in the past. This area is the only one found that has evidence for upward flow of water along faults; therefore, this area may offer the location where the deeper temperature regime might be tested in wells 1,000 to 3,000 feet deep. On the other hand, the most likely result is that temperatures of 140° to 180°F will be encountered at shallow depths and that the temperatures will be isothermal or even become lower for some depth below the shallow high temperatures.

The hot springs along the Bruneau River southeast of Bruneau occupy a similar geologic setting to the upper Castle Creek area. Thus it may be that the higher gradients found near the southern limits of the Oreana area (where the silicic volcanics are faulted against Idaho Group sediments) may be much more common and exploration along the faults often marking the contact of the silicic volcanics and the younger sediments (Figure 8 and Figure 12) might discover many other geothermal systems.

Geothermal Model of the Snake River Plain. In spite of the abundant geothermal manifestations and young volcanism characteristic of the Snake River Plain, no rationale for geothermal exploration has yet been proved. All the data suggest a deep basin (10,000 feet or more) of porous and permeable rocks, with average geothermal gradients of 4°F/100 feet or higher. Thus, at the very least, abundant very hot water must be available at depths of several thousand feet. The basin is at least partially fault-bounded and its internal structure may be very complicated. Therefore, there must be structural conditions that allow shallow circulation and trapping of the deep hot water and there may be shallow geothermal systems over still-cooling magma bodies associated directly or indirectly with the abundant young volcanism, although no such systems have yet been recognized.

In some respects the geothermal characteristics of the Snake River Plain may be similar to the Imperial Valley. There, in a deep sedimentary basin, the most attractive prospects are areas of shallow penetration of the deeper fluids. The traps are clay caps on or near active fault zones which apparently act as the zones of upward migration. In the Snake River Plain, the average heat flow and geothermal gradient is as high as or higher than in the Imperial Valley and porous and permeable volcanic units are intercolated with the sedimentary rocks. The only well-documented trap similar to the shallow anomalies in the Imperial Valley, however, is the Cow Hollow anomaly near Vale, Oregon (Bowen and Blackwell, 1975), where gradients of 10^{o} to 13^{o}F/100 feet occur along a northwest-trending fault zone. Upward motion and entrapment of hot fluids do not seem to be common in the areas described here, although upper Castle Creek and the Bruneau Hot Springs areas may represent such features.

Other than along natural pluming systems, such as major fault zones, the obvious places for exploration in the Snake River Plains are near centers of intrusive activity, particularly if such centers are less than a few million years old. The basalt centers may not be too attractive because of the smaller amount of intrusive activity as opposed to extrusive activity, although centers of repeated volcanism might be promising. There is no evidence of any anomaly associated with the centers of Bruneau Basalt along the Snake River in the study area, although the results are certainly not definitive. The centers of the silicic volcanics exposed in the study area are not known, and the dated rocks are fairly old, but so little is really known about these rocks that their geothermal significance cannot be dismissed without more positive information. The high heat flow in the basement rocks south of the area and the abundant thermal manifestations are evidence for possible geothermal concentrations in the silicic volcanics.

RECOMMENDATIONS

Based on the geothermal gradient data summarized here and the correlations with the other geophysical data, the following studies are recommended:

(1) Additional logging of shallow holes and collection of artesian well temperatures in the Bruneau area and Murphy area, where time did not permit measurement of all available holes.

(2) Quantitative interpretation of the geophysical data (gravity and magnetic results particularly), in combination with the geological and geothermal results, to locate structures of possible geothermal significance, such as deep fault zones.

(3) Geological studies of the silicic volcanics, including age dating, in an effort to determine thickness and to note centers of eruption.

(4) Geothermal gradient and heat flow studies in the silicic volcanic outcrop and near its fault contact with Idaho Group sediments, beginning in the Bruneau, Murphy and upper Castle Creek areas.

(5) Micro-earthquake studies to locate possible zones of active faulting, as likely paths for subsurface fluid migration.

(6) Detailed local exploration in anomalous areas located, and in upper Castle Creek area.

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