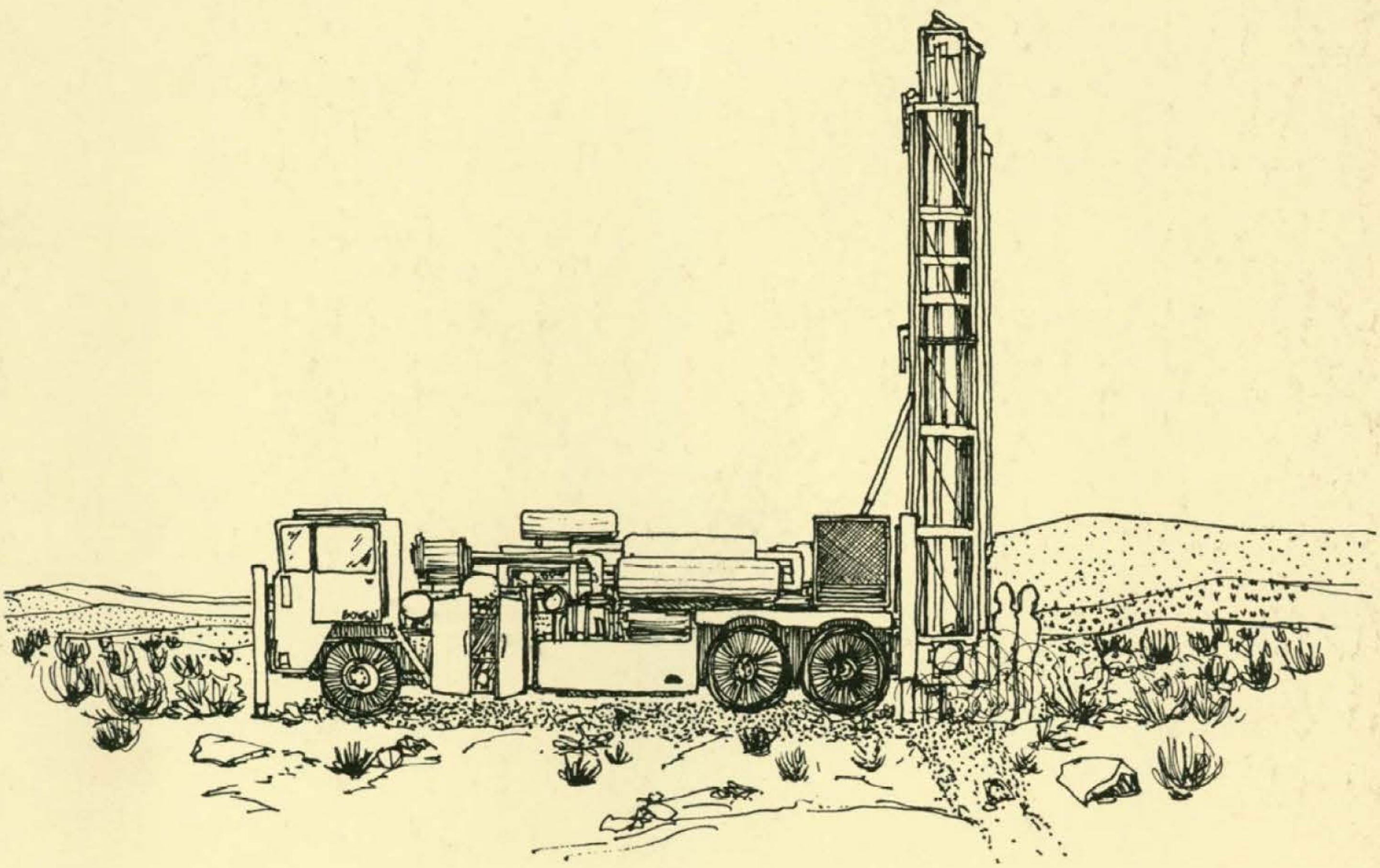
Miscellaneous Paper 19

GEOTHERMAL EXPLORATION STUDIES

IN

OREGON



STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
RALPH S. MASON, STATE GEOLOGIST

STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
1069 State Office Building, Portland, Oregon 97201

Miscellaneous Paper 19

GEOTHERMAL EXPLORATION STUDIES IN OREGON

by

Richard G. Bowen
Consulting Geologist, Portland, Oregon

David D. Blackwell
Associate Professor of Geology, Southern Methodist University, Dallas, Texas

and

Donald A. Hull
Oregon Department of Geology and Mineral Industries

Supported by U.S. Bureau of Mines
Contract No. SO122129

1977

CONTENTS

ILLUSTRATIONS

Cover drawing

Figures

Mop in pocket

Tables

ABSTRACT

This report presents a compendium of geothermal data on the State of Oregon gathered under U. S. Bureau of Mines Study Contract SO122129. Geothermal gradients were measured in 86 predrilled holes. The data are divided into a group for the Western Snake River Basin and a group for the remainder of Oregon. In the Western Snake River Basin 35 heat-flow values were obtained including five values from holes drilled for the study. Outside the Western Snake River Basin, 36 heat-flow values were obtained in 13 different areas. The data gathered so far have resulted in the identification of seven areas of anomalously high heat flow.

The geothermal data indicate that the portion of Oregon within the Basin and Range physiographic province shares the high heat flow characteristic of the region. The low thermal conductivity of the extensive lacustrine sedimentary deposits of the region causes the geothermal gradient to be higher than normal, the median being 88°C per km, with many readings above 100°C per km. This indicates that outside of recharge areas temperatures in the range of 75° to 150°C will be nearly ubiquitous at depths of 1 km (0.6 miles). If suitable traps and circulation systems are present, the area should be extremely favorable for the occurrence of higher temperature geothermal waters.

Also included in the report are data from six monitor wells located in areas with differing geographic, geologic, and climatic conditions. Temperatures in the monitor wells were recorded at depths ranging from 1 to 25 m (3.3 to 82 feet) for periods of time sufficiently long to show the patterns of seasonal variations.

A total of 48 shallow (3 to 8 m) (10 to 26 feet) holes were drilled to investigate the shallow temperature field over an anomaly identified by deeper (62 to 152 m) (200 to 500 feet) drilling. No pattern of temperature was identified at 1 or 3 m (3.3 or 10 feet) that correlated with the deep heat-flow variations. Data in the report are presented in the form of text, graphs, tables, and maps. A glossary of terms used in the report is included.

INTRODUCTION

Purpose and Scope of the Investigation

The purpose of this study was threefold: first, to develop information on the subsurface temperature conditions of Oregon; second, to experiment with different concepts and techniques in obtaining this information; third, to obtain supporting geophysical evidence of other sorts. The major portion of the present investigation consisted of a concentrated program for locating and measuring temperature gradients in predrilled holes such as abandoned water wells, mineral exploration holes, and petroleum test holes. Measurement of predrilled holes represents the most efficient means of rapidly securing temperature gradient information over a large area. To date 86 holes have been measured throughout Oregon (see Map 1). The bulk of the holes lie in southeastern Oregon where water wells and mineral exploration holes are more abundant. The gradients measured in predrilled holes have been periodically published or placed on open file (Bowen, 1972; Bowen and Blackwell, 1973; Bowen, 1975; and Hull, 1975). In order to complete this program, the Oregon Department of Geology and Mineral Industries drilled five deep holes in the Western Snake River Basin (see Map 1).

Presentation of Data

The deep-hole data obtained during the study and discussed in this report fall into two main categories: 1) deep holes outside the Western Snake River Basin for which only gradient measurements were determined, and deep holes outside the Western Snake River Basin for which both gradient and heat-flow values were obtained; 2) deep holes within the Western Snake River Basin, where density of wells provided a considerable amount of information.

Two further parts of the study included in this report deal with some of the research on new techniques for determining heat-flow values. The first of these was a study of the annual temperature profile to a depth of approximately 20 m (66 feet) in several places throughout the State to characterize this disturbance so that geothermal gradient effects can be more easily recognized in such shallow bore holes. Second was a detailed experiment carried out to investigate the feasibility of using 1- and 3-m (3.3- and 10-foot) drill holes to make temperature measurements and to relate the absolute temperature at these depths to the heat flow from the earth. It has been suggested that significant absolute temperature differences at the surface are associated with differences in heat flow of a factor of 2 or so from the interior of the earth (Poley and van Stevenick, 1970).

Several areas of anomalous heat flow were discovered during the study and the results are summarized briefly here. We believe that further exploration may reveal other areas of geothermal potential and that deep drilling may show that they contain resources of significant commercial value. These anomalies are discussed individually in the body of the text.

Explanation of Location Designations

The method used in identifying all bore holes follows the practice established by the U. S. Geological Survey for locating water wells and springs. The hole numbers represent location by Township, Range, section, $\frac{1}{4}$ section and $\frac{1}{4}/\frac{1}{4}$ section in the order given. The location designation within a section to $\frac{1}{4}$ and $\frac{1}{4}/\frac{1}{4}$ section is A, B, C, D representing the northeast, northwest, southwest, and southeast $\frac{1}{4}$ or $\frac{1}{4}/\frac{1}{4}$ sections. Thus a bore hole numbered 1S/45E-16AB would mean Township 1 South, Range 45 East of the Willamette meridian in the NW$\frac{1}{4}$ of the NE$\frac{1}{4}$ of section 16. If a hole can be located no closer than a $\frac{1}{4}$ section, the last alphabetical designation is omitted.

Related Studies

Financial support of $2,000 was provided to the Geophysical Research Group, Department of Oceanography, Oregon State University, for field work in telluric current studies. Because telluric currents are strongly affected by the earth's thermal field, this work was complimentary to the goals of this contract. The preliminary results of these studies were compiled to make an east-west telluric profile across the State and were published earlier (Bodvarsson and others, 1974).

Nearly all the gradient data in this report was released in 1975 by the Oregon Department of Geology and Mineral Industries as Open-file Report 0-75-7. The present report summarizes the data placed on open file, gives new data reported later in 1975, and presents the authors' interpretation of this information.

Acknowledgments

Financial support for this study was provided by the U. S. Bureau of Mines Study Contract SO122129.

The authors are grateful to the several people who contributed to the successful completion of the study. Deborah Miles helped immeasurably in the gathering, reduction, and interpretation of data. Alan Preissler served as principal field assistant for two years, doing an excellent job of whatever task he was assigned. The success achieved in locating and in measuring gradients in predrilled holes was largely due to Alan's dedication and perseverance. Others who helped on the program were Rick Kent, Mike Miller, Osveldo Valdez, and David Harris.

The temperature logging equipment used in the study was built and calibrated by Robert Spafford, Southern Methodist University, Dallas, Texas. The thermal conductivity measurements and part of the heat-flow studies were supported by National Science Foundation Grant GA-11351 to Southern Methodist University. John Steele and Chu Jiaw made most of the thermal conductivity measurements.

Mr. Walter Lewis, Bureau of Mines Contracting Officer, was very helpful, particularly in working as liaison with other Federal agencies to expedite the obtaining of bonds, permits, etc. as necessary to complete the project.

THERMAL MEASUREMENT METHODS

A Tool for Geothermal Exploration

The object of geothermal exploration is to locate a sufficient concentration of thermal energy within exploitable depths for economic extraction and utilization. Historically, the initial exploratory method was to drill either into or adjacent to hot springs or fumaroles. This method, although quite successful on a local basis, is not adequate if there are no surface manifestations. The fact that geothermal energy is not limited to those areas with surface indications has been shown many times by explorers inadvertantly drilling into accumulations of hot water or steam when they were searching for other minerals. The increase of knowledge and understanding of the earth that has come from exploratory drilling and from related scientific studies has led to the conclusion that geothermal resources are more widespread than their surface manifestations indicate.

Realization that geothermal energy is more widespread than was assumed in the past and that conventional energy sources are finite and dwindling has led to the expanding search for geothermal energy deposits. Several exploration tools have been used with success in locating hidden geothermal reservoirs, but at this time measurements of variations of the thermal characteristics of the regions under study appear to be the least ambiguous and most useful exploration method. For a thorough exposition of geothermal exploration philosophy and techniques, several articles are available, but the summary by Combs and Muffler (1973) is especially recommended.

For the purposes of this paper only the philosophy and techniques of thermal measurements will be discussed. The techniques are divided here into three types: shallow (1 to 6 m (3.3 to 20 feet)) temperature measurements, geothermal gradient holes, and heat-flow determinations.

The shallow temperature measurement method has been extensively utilized both as a tool to determine the amount of heat energy being released from known regions of thermal springs and hot ground and as a reconnaissance technique to locate shallow temperature variations that might indicate buried geothermal reservoirs. The limitations of this method are based on the fact that the variations of temperature near the surface are strongly affected by other factors, principally variations in solar radiation. The solar flux will normally exceed the geothermal component by a factor of 25,000, severely limiting the usefulness of this tool except in areas of very high geothermal flux. Movement of ground water is another factor that causes significant variations in the shallow-temperature field and greatly complicates interpretation of the results of this method.

Geothermal gradient surveys utilizing the measurements of temperatures in holes generally from about 15 to 60 m (50 to 200 feet) in depth are more useful but also more costly. In gradient studies temperature increase with depth is measured and related to possible buried thermal reservoirs or sources. Several variables such as rock thermal conductivity, topographical features, structural complications, and shallow water movements can produce quite different geothermal gradients within a region of relatively constant deeper thermal conditions. Within limits, however, these variables can be accounted for, so that the geothermal gradient method is a very good exploration tool. To understand and utilize geothermal gradient information it is necessary to know the local normal gradient and what kind of departure from normal is significant. On a worldwide basis the normal geothermal gradient is approximately 30° C per km (87°F per mile), while in geothermal areas the gradients will often exceed normal by a factor of 5 to 10 (150° to 300°C per km). Within the Basin and Range physiographic province of Oregon the median gradient appears to be between 60° and 90°C per km. This high median is caused by two factors: a thin crust overlying a hot mantle, and an overlying cover of rocks that have lower than average thermal conductivity. Consequently, to be considered anomalous in this region a geothermal gradient should be in excess of this range.

Heat flow, the product of geothermal gradient and rock thermal conductivity, gives the most representative picture of subsurface conditions but is also the most expensive measurement. Units used in heat-flow measurements are microcalories per cm^2 per second and are commonly referred to as HFU's (Heat-Flow Units). Worldwide average heat flow of continental areas is about 1.5 HFU. In areas of Tertiary volcanic rocks, such as the Basin and Range province, average heat flow is closer to 2 HFU (Blackwell, 1969; Roy and others, 1968). Heat-flow values have normally come from geothermal gradients measured in deep mines or bore holes greater than 100 m (330 feet) deep. In the course of this study heat-flow determinations were made on 71 of the bore holes in which temperature measurements were made.

A goal of this study was to establish a basic data base in Oregon so that the differing types of thermal exploratory studies could be correlated to obtain the most useful data at the lowest cost. By establishing a series of monitor holes in differing geologic and climatic conditions in the State, the effect of solar radiation was investigated so that the geothermal component of the shallow wells could be more easily identified. By knowing what temperature would be expected from solar radiation, a significant variation at depths as shallow as 1 to 3 m (3.3 to 10 feet), could allow identification of an anomaly worthy of further investigation. The application and results of the monitor-well and shallow-well exploratory programs are discussed in more detail in following sections of this report.

The five deep holes that were drilled as a part of this study were located to evaluate the high geothermal gradient and heat-flow values observed in predrilled holes in the Western Snake River Basin and to investigate the implications of data from the shallow-temperature holes and predrilled gradient holes.

Equipment and Techniques of Temperature Logging

Bore-hole temperatures were determined by lowering a probe containing a calibrated thermistor, a temperature-dependent resistance element, into the well bore and measuring the resistance at different depths. Within the shallow temperature holes, measurements were made at 1-m (3.3-foot) intervals from the surface. In deeper holes measurements were made normally at 2.5-m (8-foot) intervals to 20 or 50 m (66 or 164 feet) and at 5-m (16-foot) intervals below 50 m (164 feet). Measurements were made with equipment similar to that described by Roy and others (1968). Thermistors were calibrated in water baths, using National Bureau of Standards thermometers with precision of 0.005°C. The main limitation placed on accuracy and repeatability of the temperature measurements is in positioning the probe at precise depths; consequently, absolute temperature given for a particular depth is accurate to about 0.1°C. Gradient measurements, or the difference in temperatures for a given set of readings, are probably accurate to about 0.01°C. A few holes were initially logged with a different set of instrumentation (Bowen, 1972) which was not quite as accurate. For this study, however, all the data are considered equivalent.

DEEP WELL DATA FROM OUTSIDE THE SNAKE RIVER BASIN

Geothermal Gradient Data

This section of the report presents information on deep wells outside of the Western Snake River Basin for which only temperature gradients were measured. Table 1 gives the location, elevation, depth, and depth interval for which geothermal gradients were calculated, and the average geothermal gradient over the interval calculated. Map 1 shows the locations of the individual wells listed in Table 1.

The values shown below the gradients in Table 1 are the standard error of the slope of a straight line fitted to the temperature-depth information in the interval shown next to the gradient. These error values are statistical and do not indicate possible effects on the gradients from systematic errors. Such outside influences are present in these wells primarily in the form of water convection within the bore holes. Artesian wells, i. e. where water entered the bore hole, flowed up, and flowed out at the surface under an artesian head, were not logged because this water circulation destroys the original rock temperatures in the section of the well subject to the water flow. The opposite situation, however, in which lower aquifers penetrated by a well may have lower pieziometric levels than upper aquifers resulting in downflow with water within the well cannot be so easily avoided. This downflow of water causes low gradients to be observed between the depth of entry of the water in the well and its point of exit and high gradients below the exit point, with a resulting stairstep-shaped temperature-depth curve. Commonly, wells above the water table will show a linear temperature-depth curve with a typical regional gradient, while below the water table the curves may be very irregular, with segments of very low and very high gradients caused by the intercommunication of aquifers in the bore hole. Such water flow destroys the geothermal gradient in sections in a number of the wells logged. Where possible, estimates of the gradient have been made either above the water table or below water circulation effects; but, for example, in well 3N/36E-2DB the geothermal gradient is 0 from 25-55 m (82-180 feet), the total depth logged, because of the downward flow of water. The wells with this type of geothermal gradient are indicated by the asterisk in Table 1.

In some of the wells distinct segments of geothermal gradient were observed. Most of these gradients, where not modified by intrabore-hole water flow, are probably correlated with lithology; but for many of the wells no lithologic information is available. In general these sections are tabulated separately in Table 1, to show that there are variations in gradient within the well. Thus, no one geothermal gradient, in absence of knowledge of thermal conductivity or water flow in the well, is necessarily meaningful.

Gradient data alone, as shown in Table 1, should be utilized with caution because the geothermal gradient is dependent on both heat flow and rock conductivity. Even where heat flow is uniform, the geothermal gradient will vary inversely with the thermal conductivity if the materials are horizontally layered or have only a small dip. The relatively uniform surficial geology of southeast Oregon makes these gradients more useful than in areas of widely varying rock types because conductivities vary within a narrow range of about 2 to 4 mcal per cm sec °C. In practice in southeastern Oregon, most of the tuffaceous sediments have conductivities of 2.5 ± 0.5 mcal per cm sec °C. This uniformity means that gradients in general, although not exactly comparable, can yield useful information on the relative heat flow of different bore holes. In other parts of the State, however, where bedrock geology is not so consistent, comparisons should be made with special care.

Table 1.

Temperature gradients in predrilled holes outside Western Snake River Basin. (The standard error of a least-squares straight line fitting the temperature-depth information in the interval indicated is shown below the gradient value.)

Location T., R., section	Location Geographic Coordinates		Elevation meters	Depth meters	Depth Interval meters	Gradient $^{\circ}$C/km
3N/21E-19BA	45°44'	120°14'	120	70	35-70	54.3 1.7
3N/36E-2DB	45°45.9'	118°16.8'	1067	55	25-55	0
3N/47E-26AA	45°42'	116°54'	1400	65	35-65	16.5*
2N/27E-7A	45°40'	119°29'	310	305	30-213	90.1 3.9
					213-305	19.0* 3.4
1S/35E-36CC	45°25'	120°08'	1300	70	35-70	14.3 1.3
8S/15E-9AB	44°51'	120°54'	954	155	15-155	28.6 1.3
8S/37E-28	44°51'	118°11'	1800	100	60-100	10.6** 0.6
8S/37E-29D	44°51'	118°12'	2100	105	55-105	18.1** 0.5
8S/37E-32	44°50'	118°13'		85	10-85	3 *
8S/41E-34CB	44°50'	117°41'	1130	130	15-130	42.0 1.5
8S/42E-24CD	44°51'	117°31'	832	70	10-70	31.3 2.3
8S/42E-29AB	44°50'	117°36'	847	45	15-45	12.2* 0.4

* Low value of gradient caused by downflow of water in bore hole.

** Hole inclined at 60° from the horizontal.

Table 1.(cont.)

Location T., R., section	Location Geographic Coordinates		Elevation meters	Depth meters	Depth Interval meters	Gradient °C/km
9S/39E-13AB	44°47'	117°53'	1067	72.5	15-72.5	31.7 0.6
9S/41E-7BB	44°47'	117°44'	1128	25	10-25	47.0 2.1
9S/41E-15CB	44°46.8'	117°40.9'	1042	40	10-40	0
13S/29E-9	44°26.8'	119°13.3'	1050	150	20-150	33 *
13S/31E-26BA	44°24.8'	118°56.8'	940	70	35-70	44.0 0.9
19S/31E-13DD	43°55.1'	118°56.2'	1400	240	10-240	30.0 3.0
22S/31E-9	43°40'	120°12'	1350	129	15-40	55.4 4.8
25S/6W-21CA	43°23'	123°25'	122	90	25-90	9.2* 0.2
28S/8E-5AA	43°10'	121°48'	1430	75	15-75	0 *
33S/34E-24AB	42°40.0'	118°27.5'	1290	240	25-240	0 *
37S/41E-34C	42°20.5'	117°09.2'	1750	110	10-80	45.4 7.4
					80-110	114.3 6.5
38S/11E-7AD				140	30-140	15.4* 0.8
39S/21E-29	42°10'	120°16'	2865	40	10-35	

Heat Flow Data

This section of the report presents information on deep wells outside the Snake River Basin for which heat flow and other pertinent data could be determined. Table 2 gives the location, elevation, depth interval of calculation of geothermal gradient and heat flow, the thermal conductivity, the geothermal gradient, the heat flow, and the lithology encountered in the well. Map 1 shows the locations of the individual wells listed in Table 2.

The uncorrected geothermal gradient column of Table 2 refers to the gradient observed in the well. The correction, where calculated, is for the effect of topography on gradients. At many sites in Oregon the effect of topography is minimal; and on the values where the correction is estimated to be less than 5 percent, the abbreviation NG is included in the column of corrected gradients to indicate that the terrain correction is negligible. The uncorrected heat flow is merely the product of thermal conductivity times the geothermal gradient. Thermal conductivity is calculated as the average harmonic value of the samples measured. The values shown below each of the thermal conductivity values are the standard errors of the mean calculated for the thermal conductivity. Where terrain corrections are negligible, the uncorrected and corrected heat-flow values will be the same. A quality indicator is included in order to allow estimation of the possible errors, both systematic and relative, which pertain to various sets of data. Lithologic information for the intervals indicated is shown in the last column of Table 2.

The heat-flow quality indicators used are A, B, and C. The C quality indicator is used where thermal conductivity values were not available from near the well, where heat-flow values within the well were inconsistent with one another, where geothermal gradient segments do not correspond to changes in lithology, or where for some other reason the values are suspect. The heat-flow values associated with the C quality indicator may have large errors, perhaps as much as ± 50 percent for individual measurements, although taken as an overall set of data the error is much smaller. In general, terrain corrections were not made to this set of data. Values for which quality indicator B is used are values in which the errors are probably less than ± 25 percent and in which there are no large inconsistencies in the available data. In some cases terrain corrections have not been made; and where these may be about 10 percent, the quality indicator applied to the heat-flow measurements is B instead of A. All heat-flow values with an A designation have an error of ± 10 percent or less in the heat-flow value. For all the values indicated by A, terrain corrections have been made or are negligible.

Oregon can be divided into two areas based on heat-flow variations. West of the Cascade Range the heat-flow values are low (less than 1.2 HFU). Somewhere in the vicinity of the Western Cascades (the exact position is at present unknown because of lack of data) the heat flow increases so that most of the Cascade Range and all of eastern Oregon is characterized by high regional heat flow. Because of the obvious implication that the geothermal potential of the area of high heat flow is greater than that of western Oregon, this study was concentrated in eastern Oregon. The areas where heat-flow values were obtained are listed below.

Warrenton

The only value which was obtained in the low heat-flow province of western Oregon is the value in the well 8N/10W-25. This well is near Warrenton on the bank of the Columbia River. Temperature gradients were obtained from data published by Spicer (1964), in turn obtained from data collected by Van Ostrand in the 1920's. The well penetrates over 1,000 m (3,300 feet) of uniform Keasey Formation siltstone. Six samples were collected from the surface, and crushed hand samples were measured by the divided bar-cell technique (Sass and others, 1971). The average porosity was found to be about 20 percent for these siltstones, and this porosity was combined with the bulk thermal conductivity of the siltstones to obtain an *in situ* thermal conductivity of 3.1 mcal per cm sec °C. This thermal conductivity combined with a geothermal gradient of 30.7°C per km gives a heat-flow value of 0.95 HFU, consistent with other heat-flow values (Blackwell, 1971, 1974) in this area of low heat flow.

Table 2.
Heat flow data from wells in Oregon outside the Western Snake River Basin area. The corrected and uncorrected heat flow and geothermal gradient values refer to presence or absence of a correction for topography. The "N" column indicates the number of thermal conductivity samples available from each location.

Location T., R., section	Location Geographic Coordinates		Elev. meters	Depth Interval meters	N	Thermal Conductivity mcal/cmsec°C	Gradient Uncorr. °C/km	Gradient Corr. °C/km	Heat Flow Uncorr. µcal/cm²sec	Heat Flow Corr. µcal/cm²sec	Quality	Lithologic Information
						Warrenton						
8N/10W-25 *	46°09'	123°52.5'	5	76-1152	6	3.1	30.7	NG	0.95	0.95	A	Keasy Formation Siltstone
						0.2	0.2					
						Arlington						
3N/21E-36BB	45°43'	120°08.4'	147	25-45	2	4.1	28.1	NG	1.15			Pomana Basalt
							2.2					
				45-120	6	2.2	57.1	NG	1.26	1.3	C	Selah Tuff
						0.3	1.1					
				120-145	4	3.7	45.2	NG	1.67			Columbia River Basalt
						0.5	1.7					
2N/21E-1AC	45°41'	120°08'	226	20-60		2.2	46.6	NG	1.03			Selah Tuff
						0.3	1.9			2.1		
				60-130		3.7	73.9	NG	2.73			Columbia River Basalt
						0.5	2.8					
2N/22E-6CC	45°41'	120°07.2'	241	25-50	2	4.1	25.4	NG	1.04		C	Pomona Basalt
							0.9			1.2		
				50-130	6	2.2	54.7	NG	1.20		C	Selah Tuff
						0.3	1.0					
2N/24E-5CA	45°40.9'	119°50.6'	209	20-45	2	4.1	21.7	NG	0.89			Pomona Basalt
							0.4					
				45-70	7	2.2	40.3	NG	0.88	1.0	C	Selah Tuff
						0.3	1.3					
				70-110	4	3.7	32.3	NG	1.20			Columbia River Basalt
							0.5					
									Average	1.4		
						Dufur						
1S/13E-20DA	45°28.1'	121°11.8'	354	10-50		(3.5)	42.8	41.9	1.5	1.4	C	Columbia River Basalt
							1.5					
				50-135			3.2*					

* Gradient after Spicer (1964)
** Sass and others (1976)
*** Downflow of water in bore hole causes low gradients

Table 2.(cont.)

Location T., R., section	Location Geographic Coordinates		Elev. meters	Depth Interval meters	N	Thermal Conductivity mcal/cmsec°C	Gradient Uncorr. °C/km	Gradient Corr. °C/km	Heat Flow Uncorr. μcal/cm²sec	Heat Flow Corr. μcal/cm²sec	Quality	Lithologic Information
						Baker						
10S/38E-24DC	44°41'	118°01'	1277	25-115	2	5.1	39.9	35.0	2.0	1.8	A	Meta-andesite
						Lebanon						
12S/1W-4DC	44°34'	112°40'	135	30-65	3	3.2	37.1	36.4	1.2	1.2	B	Volcanic Con-
						0.3	1.0					glomerate
						John Day						
13S/31E-27DD	44°24.3'	118°57.7'	1117	40-150	1	6.3	29.8	32.3	1.9	2.0	B	Serpentine
							0.8					
						Drewsey						
21S/35E-11BC	43°45.8'	118°23.2'	1200	10-50		4.0	76.7	73.6	3.1	2.9	B	Rhyolite
							2.7	2.8				
21S/35E-11CAB	43°45.7'	118°23.1'	1295	20-55			41.1	66.4			B	Rhyolite
							1.0	1.9				
				55-100		4.0	49.6	68.4	2.0	2.7	B	Rhyolite
							0.4	0.4				
							Average		2.8			
						Glass Buttes						
23S/23E-27C	43°33'	119°56'	1450	40-200		>2.3	203.4		4.6		C	Obsidian and
							2.3					Rhyolite
				200-220			43.2*					
							1.3					
23S/23E-18C				10-27.5	3	2.7	133.7	NG	3.6			
						0.1	17.0					
				27.5-35	1	1.8	185.3	NG	3.3			
							18.2					
				35-62.5	3	2.2	133.1	NG	2.9			
						0.1	5.8					
							Average		3.3		B	

Table 2.(cont.)

Location T., R., section	Location Geographic Coordinates		Elev. meters	Depth Interval meters	N	Thermal Conductivity mcal/cmsec°C	Gradient Uncorr. °C/km	Gradient Corr. °C/km	Heat Flow Uncorr. μcal/cm²sec	Heat Flow Corr. μcal/cm²sec	Quality	Lithologic Information
24S/22E-2DD				15-60	4	2.4	120.2	NG	2.9		B	
							8.7					
24S/22E-20AA				32.5-60	3	2.5	73.1	NG	1.8		B	
						0.2	13.8					
Coyote Buttes												
27S/30E-13CD	43°13.4'	118°56.5'	1280	25-60		2.3	130.4	119.6	3.0	2.8	B	Tuffs, Claystone and Siltstone
						0.3	2.5	2.4				
				60-130		3.1	61.6	58.4	1.9	1.8		" "
							1.5	1.4				
27S/30E-19DC	43°13'	119°02'		46-108		2.3	131.3	NG	3.0	3.0	B	Tuffs, Claystone and Siltstone
						0.3						
27S/30E-21DD	43°12.5'	118°59.9'	1289	10-35	9	3.1	223.2	NG	(6.9)			" "
						0.2	8.5					
				35-110	19	2.3	132.8	NG	3.05	3.1	A	" "
						0.1	1.0					
27S/30E-26DC	43°11.5'	118°57.8'	1340	10-57.2		2.3	117.9	130.3	2.7	3.0	B	" "
						0.3	1.4					
27S/30E-27AC	43°12.0'	118°59.0'	1320	10-65		2.3	160.0	162.8	3.7	3.7	B	" "
						0.3	1.8					
				65-75		3.1	55.0*		(1.7)			" "
							2.9					
27S/30E-36DBC	43°10.7'	118°57.0'	1258	10-45	4	2.6	73.1	NG	1.9	1.9	B	" "
							1.3					
27S/30E-36CC				10-67.5	3	2.3	88.4	NG	2.0		B	
						0.1						
29S/31E - 1	43°05'	118°49'	1262	56.4-64	4	2.2	89.0	NG	2.0			
						0.2	1.0					
				40-91	4	2.2	96.0	NG	2.1			
						0.2	0.6					
							Best Value		2.0**			
29S/31E - 3	43°05'	118°51'	1260	57.9-62.5	4	2.4	65.0	NG	1.5			
						0.1	2.0					
				89.3-92	4	2.2	83.0	NG	1.8			
						0.1	3.0					
				60-100	8	2.3	74.2	NG	1.7			
						0.1	0.8					
							Best Value		1.7**			

Table 2.(cont.)

Location T., R., section	Location Geographic Coordinates		Elev. meters	Depth Interval meters	N	Thermal Conductivity mcal/cmsec°C	Gradient Uncorr. °C/km	Gradient Corr. °C/km	Heat Flow Uncorr. μcal/cm²sec	Heat Flow Corr.	Quality	Lithologic Information
						Tiller						
32S/2W-4CA	42°49.0'	122°56.0'	937	105-215	8	7.03	20.5	20.9	1.44	1.46	A	Chlorite Schis
						0.41	0.4	0.4	0.10			
						Thomas Creek						
37S/18E-14BB	42°22'	120°33'	1804	30-75	1	2.2	136.0		3.0		C	
37S/18E-27DA	42°20'	120°35'	1750	10-20		(2.2)	108.0		2.4		C	
37S/19E-19CD	42°20'	120°31'	1827	10-20		(2.2)	124.0		2.7		C	
37S/19E-30AB	42°20'	120°31'	1827	15-40	1	2.2	83.4	72.5	1.86			Tuff
							1.2	1.0				
37S/19E-30DB	42°20'	120°31'	1814	30-55	1	2.2	83.3	76.0	1.83			Tuff
							2.6	2.3				
				55-105	10	3.0	47.6	44.0	1.43	1.6	B	Basalt
							0.8	0.7				
				105-135	1	2.1	75.1	70.0	1.65			Tuff
							1.3	1.2				
						White Horse Ranch						
36S/37E-2DD	42°26.2'	118°07.0'	1280	10-30		2.3	147.4	NG	3.4		C	Tuffs, Claystone Siltstone
						0.5	6.9					
				30-40			47.0***					
						Trout Creek						
37S/36E-28AB	42°17.8'	118°16.9'	1366	10-25		2.3	130.6	NG	3.0		C	Tuffs, Claystone Siltstone
						0.5	13.7					
38S/37E-23CC	42°15.3'	118°20.5'	1430	10-50		2.3	88.5	NG	2.0		C	" "
						0.5	3.9					
38S/37E-24BA	42°15.8'	118°19.2'	1430	10-100		2.3	83.9	NG	1.9		C	" "
						0.5	1.2					
38S/37E-25AC	42°15.8'	118°19.2'	1425	31-151		2.3	67.8	NG	1.6		C	" "
						0.5	6.1					
39S/37E-2CC	42°11'	118°20.7'	1430	10-110		2.3	139.4	NG	3.2		C	" "
						0.5	1.7					
39S/37E-17BB	42°14'	118°24.4'	1420	37-128		2.3	81.0	NG	1.9		C	" "
						0.5						
						Fields						
39S/34E-13	42°14'	118°40'	1494	20-370	24	3.60	61.2	59.9	2.20	2.26	A	Owyhee Basalt
						0.05	0.4	0.3	0.04			

Arlington

Four of the wells on Table 2 are in the general area of Arlington, Oregon. Although continuous core was available from all four and there tends to be a correlation of the geothermal gradient with lithology, as shown in the table, the correlation of heat-flow values is not what would be expected from the thermal conductivity values obtained on core samples. The resulting calculated heat-flow values from the different intervals differ in some cases by as much as 50 percent. In general, the heat-flow values seem to increase with depth in the wells from low to more typical regional values (1.5 - 1.6 HFU), suggesting that some phenomenon is lowering the heat flow near the surface. Perhaps there is regional water flow toward the Columbia at shallow depths that transfers the heat from the highlands around Arlington to the Columbia River, and these wells are passing below the aquifer or aquifers. The best value in the area is greater than 1.2 HFU and possibly as high as 1.7 HFU. In any event, because of the disagreement in heat-flow values, a low reliability is placed on these data.

Dufur

The heat-flow value near Dufur, Oregon (well 1S/13E-20DA) was obtained from temperature measurements above the water table and from an estimate of the thermal conductivity of the Columbia River Group basalt. Thermal conductivity measurements from Arlington and in the Washington port of the Columbia River Plateau (Sass and others, 1971; Blackwell, 1974) were used to estimate the thermal conductivity for the well as 3.5 ± 0.5 mcal per cm sec °C. Below the water table at 50 m (164 feet), downflow is present to the bottom of the well and very low gradient is obtained. The calculated value corrected for terrain is about 1.4 HFU.

Baker

The well measured at Baker was at a dam site, so the topographic correction was quite large. The well was drilled into pre-Cenozoic meta-andesite. The calculated heat-flow value is 1.8 HFU.

Lebanon

The measurement at Lebanon was obtained in a core hole drilled at a power plant site. The rocks cut by the well are volcanic conglomerates of the Western Cascades. The terrain correction is moderate; and although the hole is fairly shallow, the heat-flow value, corrected for terrain, of 1.2 HFU is considered reliable.

John Day

The hole near John Day was drilled into Late Triassic serpentinite. The thermal conductivity of the serpentinite is based on measurements of samples of the cuttings and an assumed porosity of 5 percent. The terrain-corrected heat flow at that site is 2.0 HFU.

Drewsey

The heat-flow value near Drewsey, in east-central Oregon, is based on two wells drilled in a mineral prospect. The thermal conductivity is estimated from measurements of welded tuffs in the Harney basin only a few kilometers to the west of the Drewsey area. These welded tuffs have a very uniform bulk thermal conductivity; and *in situ* thermal conductivity, with an estimated porosity of 10 percent, is 4 mcal per cm sec °C. The best heat-flow value, 2.8 HFU, a mean of hole 11BC and the 55- to 100-m (180- to 330 foot) interval in hole 11CAB, is anomalously high. The need for more work in this area is indicated.

Glass Buttes

Glass Buttes (Figure 1) are located on the Brothers fault zone and are interpreted by Walker and others (1967) to be a complex of silicic vents and volcanic domes. Extensive hydrothermal alteration has

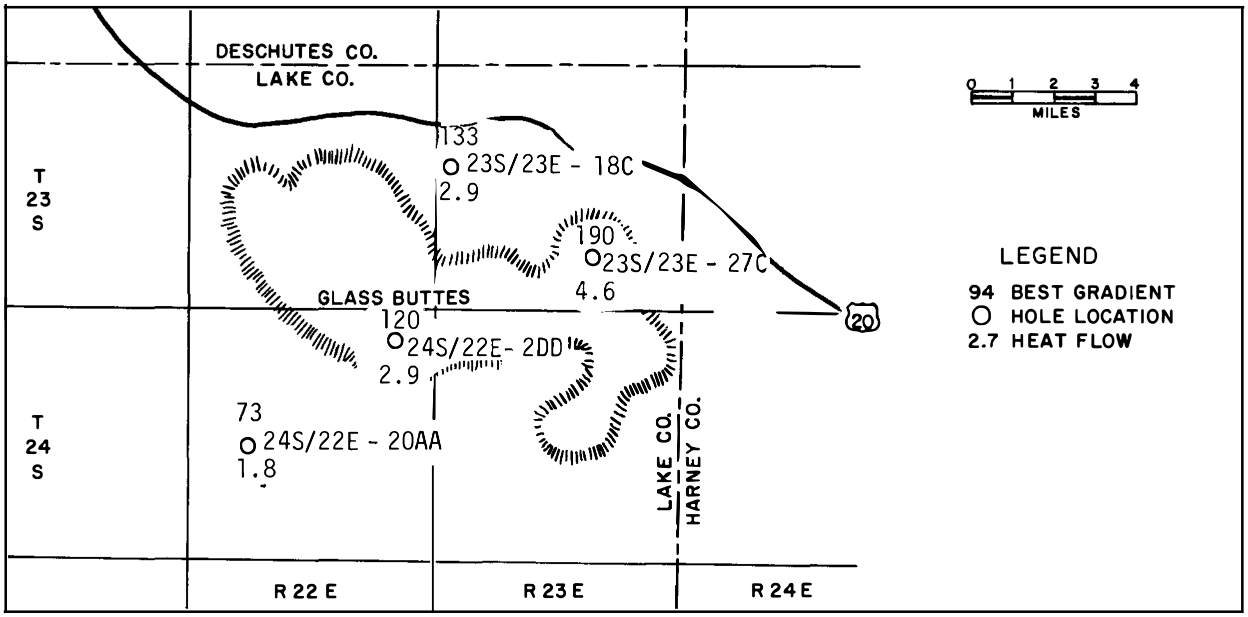


Figure 1. Map of Glass Buttes anomaly.

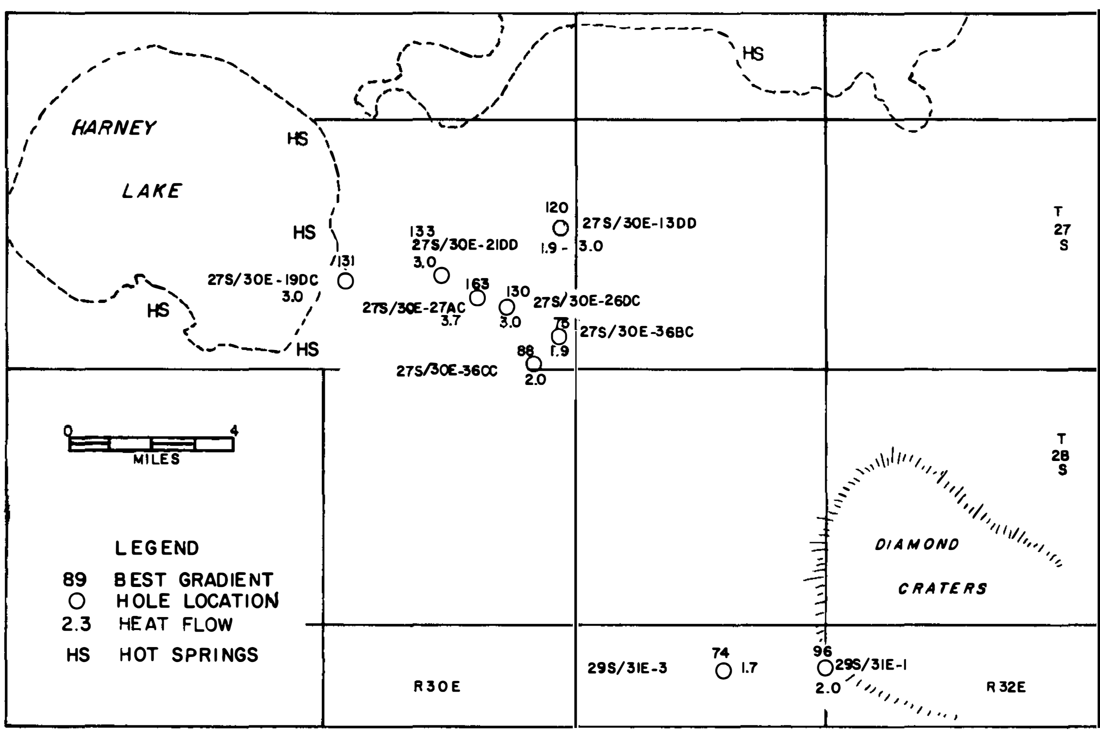


Figure 2. Map of Coyote Buttes anomaly.

produced an opalite zone containing disseminated mercury mineralization. There are no thermal springs in the area. The heat-flow values are based on the well at 23S/23E-27C, which has a water temperature of 48°C at a depth of 220 m (720 feet), and two shallower holes drilled in 1975. The geothermal data on these three holes and another to the south of Glass Buttes are listed in Table 2. It is possible that water circulating at 48°C, as measured in 23S/23E-27C, is causing the geothermal anomaly; however, the fairly extensive high heat flow, as shown on Figure 1, suggests that additional evaluation of this particular area is justified. Further supportive evidence of the existence of a geothermal system in the area was given by Hull (1976). He reports that an electrical resistivity survey made at Glass Buttes shows an area of very low resistance, less than 5 ohm m, underlying a near-surface layer of higher resistance, exceeding 300 ohm m, that generally coincides with the outline of the silicic volcanic rocks. The geothermal, geologic, and geophysical data are favorable and imply that the area is an attractive geothermal prospect.

Coyote Buttes

Six holes were measured in the vicinity of Coyote Buttes in the southern part of the Harney Basin (Figure 2). This area is also located on the Brothers fault zone. The holes had been originally drilled for mineral exploration. They show a generally high range of about 73° to 160°C per km for the reliable gradients. Several of the wells showed two or more distinct segments of geothermal gradient. In well 27S/30E-27AC, the low values of gradient below 65 m (215 feet) appear to be associated with water downflow in the well below the water table. For the other wells it seems likely that variations in lithology cause the variations in geothermal gradient. Thermal conductivity measurements were made on cutting samples from wells 27S/30E-21DD and 27S/30E-36BC and on hand samples from outcrops. These measurements indicate a variation of *in situ* thermal conductivity of from about 2.3 to 3.1 mcal per cm sec °C for an assumed porosity of 30 percent. Unfortunately, none of the samples from wells in which distinct segments of gradient were observed came from the depths characteristic of the different gradients. In the absence of more detailed information, the lowest conductivity was assumed to be associated with the highest gradients. Heat-flow values so calculated range from 3.0 to 1.9 HFU in a single hole (27S/30E-13CD). No matter what assumptions are made in calculating the heat-flow values, there is definitely a thermal anomaly present in the area. Several nearby hot springs west of this area near Harney Lake also indicate a presence of a geothermal system in the area. It appears that the heat-flow values average 3.0 HFU except for the most southerly value, which is 1.9 HFU.

In 1975, the Oregon Department of Geology and Mineral Industries drilled hole 27S/30E-36CC at the south end of the Coyote Buttes anomaly as part of its drilling program along the Brothers fault zone (Bowen and others, 1976). Thermal conductivity measurements of the core samples indicated a heat-flow value of 2.0 HFU, verifying the 1.9 HFU observed in hole 27S/30E-36BC and the apparent change in heat-flow values in the southerly direction. Figure 2 shows the hole locations and includes two of the gradient and heat-flow values reported by Sass and others (1976) near Diamond Craters.

In view of the thermal manifestations, the very high geothermal gradients, and the high heat-flow values, additional exploration seems to be warranted in the Coyote Buttes area.

Tiller

One value was obtained in a mineral prospect near Tiller in southwestern Oregon. This well was drilled in chlorite schist, part of the Klamath Mountains geologic province. Eight measurements of thermal conductivity were made on core samples from the hole. Although the topography is very steep in the vicinity, the terrain correction is quite modest because the various effects cancel out. The calculated value is 1.46 HFU.

Thomas Creek

Several holes were measured in the Thomas Creek area near Lakeview (Figure 3). These holes were originally drilled for mineral exploration. Holes 37S/19E-30AB and -30DB are located at the site of the White King mine. The data for these two holes were averaged to determine the heat flow. There is a poor

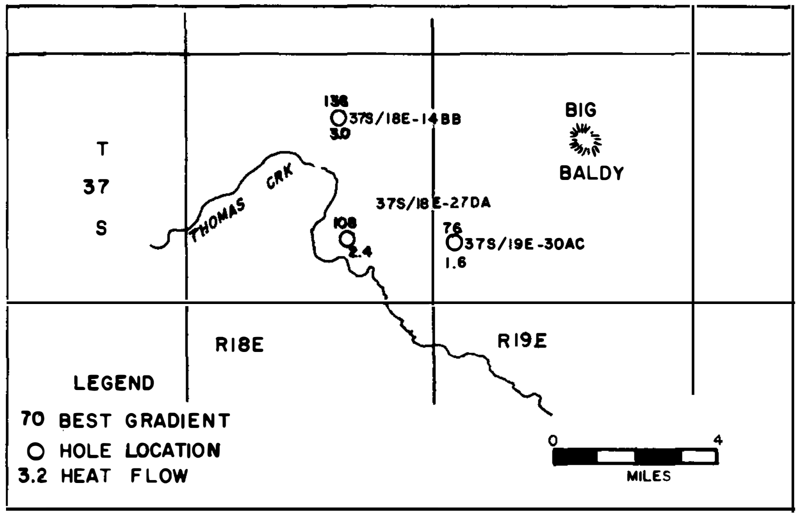


Figure 3. Map of Thomas Creek anomaly.

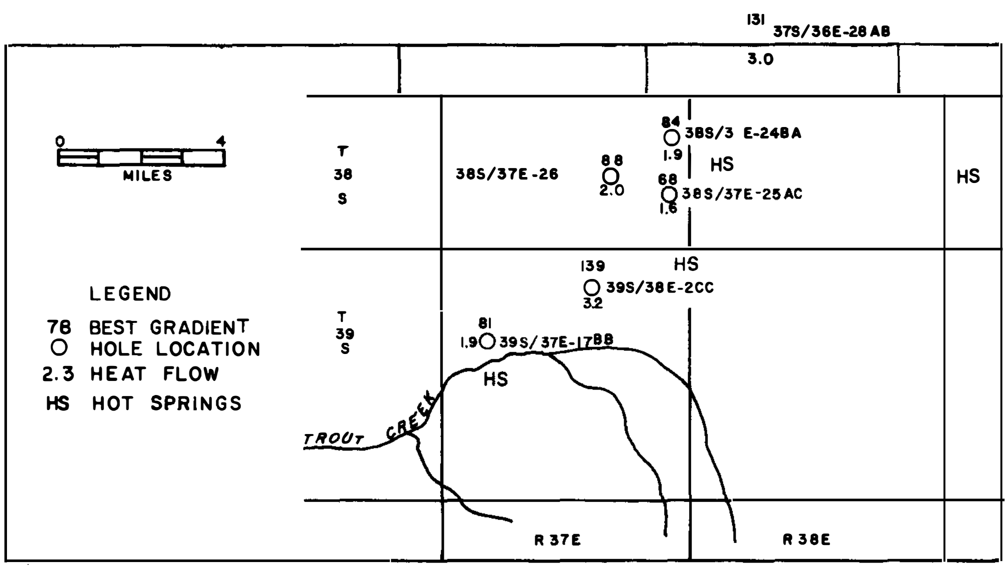


Figure 4. Map of Trout Creek anomaly.

correlation between thermal conductivity and gradient in these wells. The best value of heat flow is taken to be a combination of data from all four intervals from the two holes. This heat flow is 1.6 HFU.

Temperature gradients in all the wells outside section 30 showed considerably higher gradients. Thermal conductivity measurements were made on one sample of cuttings from the hole in section 14 (Table 2). Even with the low value of thermal conductivity observed, the heat flow is 3 HFU because of the very high geothermal gradient. The holes with a high geothermal gradient are also very shallow, but there is definite evidence of a geothermal anomaly in the area, and some additional work to investigate the implications of these higher geothermal gradients might be justified.

White Horse Ranch

A shallow hole drilled as part of a uranium exploration program showed a high gradient and heat flow when measured during this study.

Trout Creek

Several holes were logged in the vicinity of the Trout Creek Mountains in southeastern Oregon (Figure 4). These holes all penetrate the Miocene tuffs, siltstone, and claystone typical of southeastern Oregon. The holes logged range in depth from 50 to 150 m (164 to 490 feet) and the gradients range from 68 to 139.4°C per km. Most of these wells show only a single segment of gradient, although well 39S/37E-17BB does have a low gradient below the water table, which is attributed to water flow below the water table. An estimated thermal conductivity value of 2.3 mcal per cm sec °C is used for the sediments in this area. This value is essentially that found by Sass and others (1976) for values of valley sediments in southeastern Oregon and is typical of the lower range of values found in the Harney Basin and Western Snake River Basin areas. Two of these heat-flow values are anomalous; more work in this area is recommended.

Fields

The heat-flow measurement was obtained in a deep mineral exploration test at Steens Mountain, southwest of Fields (39S/34E-13). The average geothermal gradient to a depth of 370 m (1,215 feet) is about 60°C per km. The calculated heat-flow value is 2.26 HFU, significantly above the lowest regional values of 1.5 HFU. This is the most reliable value obtained in the Miocene basalt of southeastern Oregon. We lack sufficient heat-flow data from the local area to evaluate its significance. More information would be useful in assessing the background regional heat flow for southeastern Oregon.

DEEP WELL DATA FROM THE WESTERN SNAKE RIVER BASIN

The Western Snake River Basin presents a more complete heat-flow pattern than do other regions of the State, and for this reason it is treated as a separate section of the report. The numerous deep holes in the area have made it possible to obtain a relatively high density of geothermal data (see Table 3). To verify thermal trends indicated by data from the predrilled holes, the Oregon Department of Geology and Mineral Industries drilled five deep holes. The information obtained resulted in outlining three specific areas of anomalously high heat flow in the Western Snake River Basin.

The Western Snake River Basin occupies the west limb of the Snake River downwarp, a large structural trough extending from Yellowstone Park, across Idaho, into eastern Oregon, and terminating against the Blue Mountains. The local structural pattern of the area, shown on Figure 5, is a regional northeasterly dip. The faults are based mainly on geophysical evidence from Bowen and Blackwell (1975) in their report on the geology and geothermal manifestations of the Cow Hollow area.

The basin is underlain by a thick sequence of late Tertiary volcanic and sedimentary rocks. Throughout most of the region where the geothermal data have been gathered for this report, the surficial rocks are tuffaceous claystone and siltstone, with lesser amounts of tuff and intercalated lava flows of the Idaho Group.

Table 3. Geothermal data for drill holes in the Western Snake River Basin

Locality	T., R., sec.	N lat.	W long.	Elevation meters	Depth interval meters	Gradient uncor. °C/km	Gradient cor. °C/km	Thermal conduct. K(N) 10^{-3}cal/cmsec°C	Heat flow uncor. 10^{-6}cal/cm^{2}sec	Heat flow cor. 10^{-6}cal/cm^{2}sec	Quality
Adams Ranch	14S/43E-13AA	44°21	117°24'	1170	30-280	32.3 0.3		5.4(1)	1.7		B
Huntington	15S/45E-7BA	44°16'	117°15'	854	30-170	61.9 2.4		2.8	1.7		C
Willow Creek	15S/42E-14BC	44°16'	117°33'	814	10-30	71.4 1.3		2.8	2.0		C
					30-140	33.2* 2.0					
					140-150	77.					
	16S/43E-7D	44°12'	117°30'	850	15-65	48.8 7.3		2.8	1.4		C
					65-115	18.0* 5.1					
	16S/43E-10DB	44°11'	117°26'	758	30-115	71.2 1.5	NG	2.8	2.0		B
	16S/43E-13DD	44°10'	117°24'	768	50-130	51.5 0.5	NG	-	-		
					130-170	94.7 2.7	NG	2.8	2.7		B
	16S/43E-15DA	44°10'	117°26'	758	25-105	38.6 0.7	NG	-	-		
					105-230	70.5 0.3	NG	2.8	2.0		B
	16S/43E-23DD	44°09'	117°25'	749	40-110	61.8 2.2	NG	-	-		
					110-170	99.5 1.3	NG	2.8	2.8		B
	17S/43E-9CB	44°06'	117°27'	866	10-35	134.2 12.0		2.8	3.8		C
	17S/44E-11DC	44°06'	117°17'	719	10-370	94.4 2.2		2.8	2.6		B
	17S/44E-31BB	43°59'	117°20'	829	15-70	85.7 2.2		2.8	2.4		B

* Low due to water flow in bore hole.

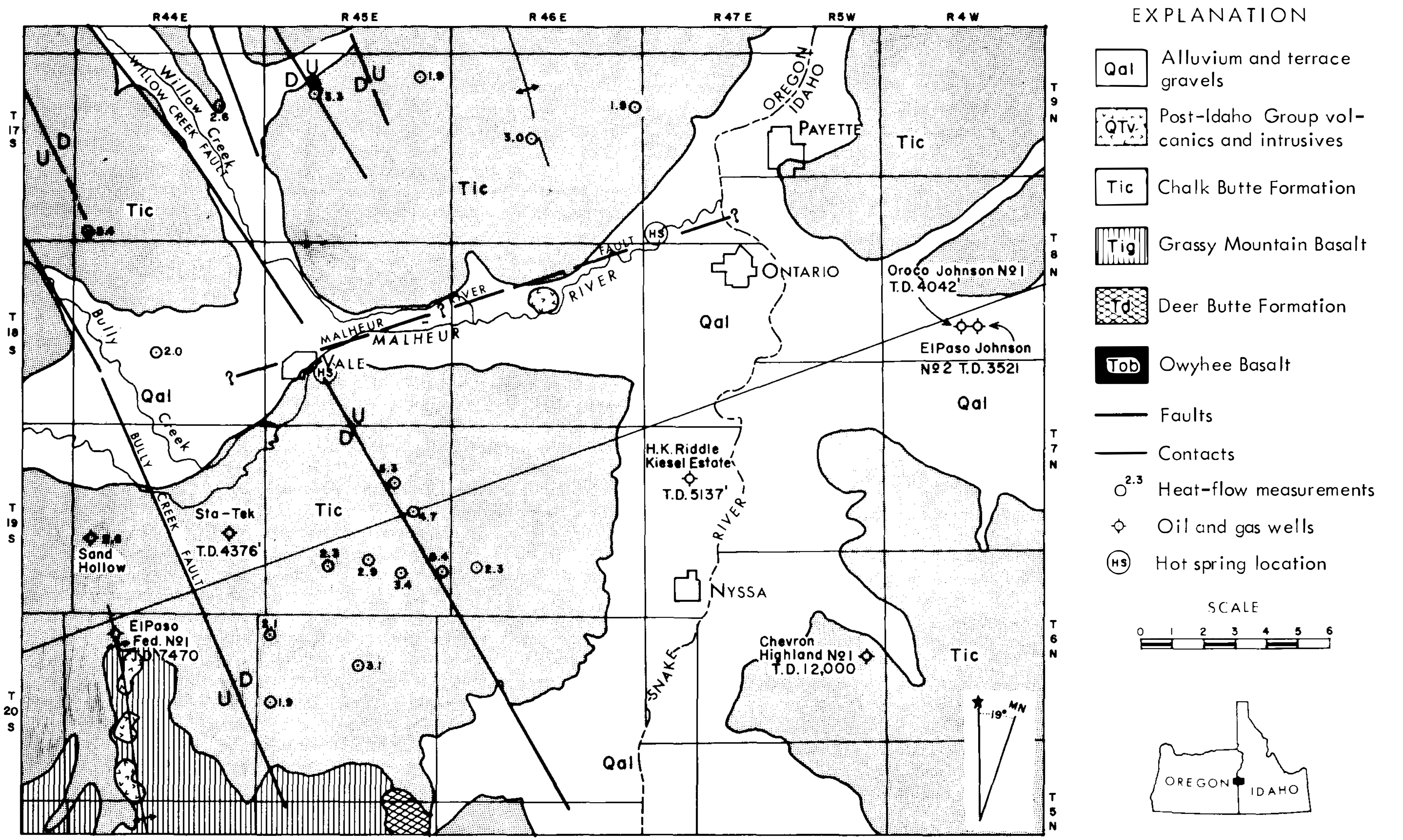
***Van Ostrand, 1938 **Bowen, 1972 NG=Negligible

Table 3.(cont.)

Locality	T., R., sec.	N lat.	W long.	Elevation meters	Depth interval meters	Gradient uncor. °C/km	Gradient cor. °C/km	Thermal conduct. K (N) 10^{-3}cal/cmsec°C	Heat flow uncor. $\cdot 10^{-6}$cal/cm^{2}sec	Heat flow cor.	Quality
S. Fk.	17S/45E-2DA	44°07'	117°10'	814	50-125	82.0	NG	2.5(4)	2.05	2.1	A
Jacobsen						1.1		0.1			
Gulch	17S/45E-8AA	44°07'	117°14'	721	30-60	87.3	NG	3.0	2.6	2.6	A
	17S/46E-13AA	44°06'	117°02'	732	50-150	76.5	NG	2.5(4)	1.9	1.9	A
						0.3		0.1			
	17S/46E-16CA	44°05'	117°06'	762	25-140	115.4	NG	2.5	2.9	2.9	A
						0.7					
Hunter	18S/41E-35AB	43°47'	117°38'	896	30-45	44.0		2.8	1.2		C
						6.9					
Willow Creek	18S/44E-21BA	43°59'	117°20'	760	25-85	66.8		2.8	1.9		B
						1.1					
Cow Hollow	19S/44E-9DD	43°56'	117°20'	701	35-160	71.5	NG	3.0	2.1	2.1	B
						0.5***					
	19S/44E-19	43°54'	117°22'	777	31-395	87.3	NG	3.0	2.6	2.6	B
	19S/45E-11CC	43°55'	117°10'	835	30-65	185.7	176.1	3.0	5.6	5.3	A
						1.6	1.6				
	19S/45E-14DC	43°54'	117°10'	910	20-145	175.2	158.3	3.0	5.3	4.7	A
						1.1	0.8				
	19S/45E-22DB	43°53'	117°11'	843	30-115	110.4	98.9	3.05	3.4	3.0	A
						0.3	0.3	0.13			
	19S/45E-25BB	43°53'	117°09'	813	30-70	232.6	213.6	2.98	6.9	6.4	A
						7.1	6.4	0.05			
	19S/45E-26BD	43°52'	117°10'	822	30-175	119.3	114.0	3.0	3.6	3.4	A
						0.6	0.5				
	19S/45E-28BD	43°52'	117°13'	872	10-90	70.8	76.5	3.0	2.1	2.3	A
						1.5	1.5				
	19S/46E-30BB	43°54'	117°08'	879	20-150	92.6	99.5	3.0	2.8	3.0	A
						0.2	0.2				
	20S/45E-6CC	43°51'	117°15'	823	20-135	73.6	69.8	3.0	2.2	2.1	A
						0.6	0.6				
	20S/45E-10BC	43°50'	117°12'	780	30-135	114.8	104.0	3.0	3.4	3.1	A
						1.6	1.5				
	20S/45E-18AB	43°50'	117°15'	849	10-40	71.9	63.2	3.0	2.1	1.9	B
						3.8	3.3				

Table 3.(cont.)

Locality	T., R., sec.	N lat.	W long.	Elevation meters	Depth interval meters	Gradient uncor. °C/km	Gradient cor. °C/km	Thermal conduct. K(N) 10^{-3}cal/cmsec°C	Heat flow uncor. 10^{-6}cal/cm^{2}sec	Heat flow cor. 10^{-6}cal/cm^{2}sec	Quality
Grassy Mountain	21S/43E-36DD	43°41'	117°23'	995	10-75	53.5 0.5		2.8	1.5		B
	21S-44E-28BC	43°42'	117°20'	1000	10-30	105.2 0.5		2.8	2.9		B
Harper	21S/42E-11CC	43°46'	117°32'	1073	65-140	111.7 1.2		2.8	2.9		B
	21S/42E-27	43°43'	117°33'	1100	10-20	37		2.8	1.0		C
Mitchell Butte	21S/46E-7BB	43°45'	117°09'	866	15-70	108.2 8.6		2.8	3.0		C
Oxbow Basin	23S/44E-5BB	43°36'	117°22'	915	26-148	107.0** 15.5		2.8	3.0		B



Geology adapted from Newton and Corcoran (1963) Magnetic and gravity data (1974) from Koenen

Figure 5. Generalized geologic map of the Western Snake River Basin showing heat-flow measurements and hot-spring and well locations.

Underlying the Idaho Group, at depths of 1.5 to 1.8 km (5,000 to 6,000 feet) at the eastern edge of the area, and cropping out at the surface to the west, is the Owyhee Basalt, a prominent section of basalt flows and interbedded tuffs. The presence of these basalt flows beneath impermeable rocks forms the ideal combination of reservoir and cap rock. The presence of heat is manifest at or near the surface by hot springs and warm-water wells.

The three heat-flow anomalies, the scattered high heat-flow measurements from individual bore holes, and the continuation of the thermal trend into Idaho (Bowen and Blackwell, 1975; Brott, Blackwell, and Mitchell, 1977) indicate the Western Snake River Basin is a major geothermal province, similar in some ways to the Imperial Valley geothermal province.

Deep-Hole Drilling Program

The Oregon Department of Geology and Mineral Industries drilled five deep holes near Vale, Oregon, in the Western Snake River Basin, to focus on areas of high heat flow indicated by data derived from pre-drilled holes in this region. Holes ranging in depth from 62 to 152 m (200 to 500 feet) were drilled to explore the three anomalies: Cow Hollow, Willow Creek, and South Fork Jacobsen Gulch. The holes are designated on Table 3 as follows: 19S/46E-30BB, 17S/45E-8AA, 17S/45E-2DA, 17S/46E-16CA, and 17S/46E-13AA.

Drilling was done with a truck-mounted rotary rig using a combination of air-rotary, down-hole hammer, and coring techniques. The rock units encountered were poorly consolidated claystone and siltstone of the Idaho Group of Pliocene age and altered basalt of Miocene age. The claystone and siltstone were drilled primarily with air-rotary equipment using water and soap injection to aid in removal of drill cuttings. Penetration rates for the four holes drilled primarily with air rotary were 18.6, 15.2, 13.7, and 14 m per hour (61, 50, 45, and 46 feet per hour, respectively). A carbide insert bit was used in the sedimentary rocks to obtain 10.16-cm (4-inch) diameter cores for subsequent laboratory measurements of thermal conductivity.

The harder altered basalt was drilled mainly with a 15.2-cm (6-inch) diameter down-hole hammer at a penetration rate of about 8 m (25 feet) per hour. The basalt was cored with a 10.16-cm (4-inch) I. D. diamond bit. Core recovery in both the sedimentary units and the basalt was essentially 100 percent except for a single unsuccessful attempt at coring the basalt with the carbide insert bit.

The overall direct cost of the drilling including mobilization, demobilization, and all materials was $13.55 per m ($4.13 per foot) drilled.

Holes were completed by inserting a water-filled and bottom-capped 2.54-cm (1-inch) diameter polyvinyl chloride (PVC) pipe to total depth and then backfilling the annulus around the PVC pipe with cement, a bentonite slurry, or drill cuttings. Cement was used in hole 17S/45E-8AA, which encountered artesian water. Either bentonite or cuttings were used in the remaining holes from 3 m (10 feet) to bottom with the uppermost 3 m (10 feet) being cemented. Temperature gradients were later measured in the water-filled PVC inner casing. All holes were secured by a padlocked steel cap welded to a length of 15.2-cm (6-inch) diameter steel casing left in the upper portion of each hole.

Periodic temperature gradient measurements were used to check the time required for the holes to reach temperature stability. Holes backfilled with cuttings reached thermal equilibrium within 2 days after drilling and filling. Hole 17S/45E-8AA, filled with cement, had not reached equilibrium 5 days later. The time required for a temperature gradient hole to reach equilibrium is dependent upon a number of variables including drilling technique, casing technique, backfilling material, rock type, permeability, and ground-water conditions. The times noted above should be applied with caution in future work.

The temperature gradient, thermal conductivity, and calculated heat-flow values in the deep holes are summarized in Table 3. The various temperature-depth curves are shown graphically in Figure 6. All of these gradients are linear except for hole 17S/45E-8AA, which encountered warm artesian water at a depth of 32 m (105 feet) as indicated by the change in slope on the graph of this hole. The lithology in the remaining holes is uniform, and the linearity of the temperature gradients indicates that heat flow is essentially conductive over the depth drilled.

The artesian thermal water flowed from hole 17S/45E-8AA at a rate of 10 to 14 gpm, a temperature of 24°C, and a pressure of 5 pounds per square inch. The gradient shown in Table 3 and Figure 6

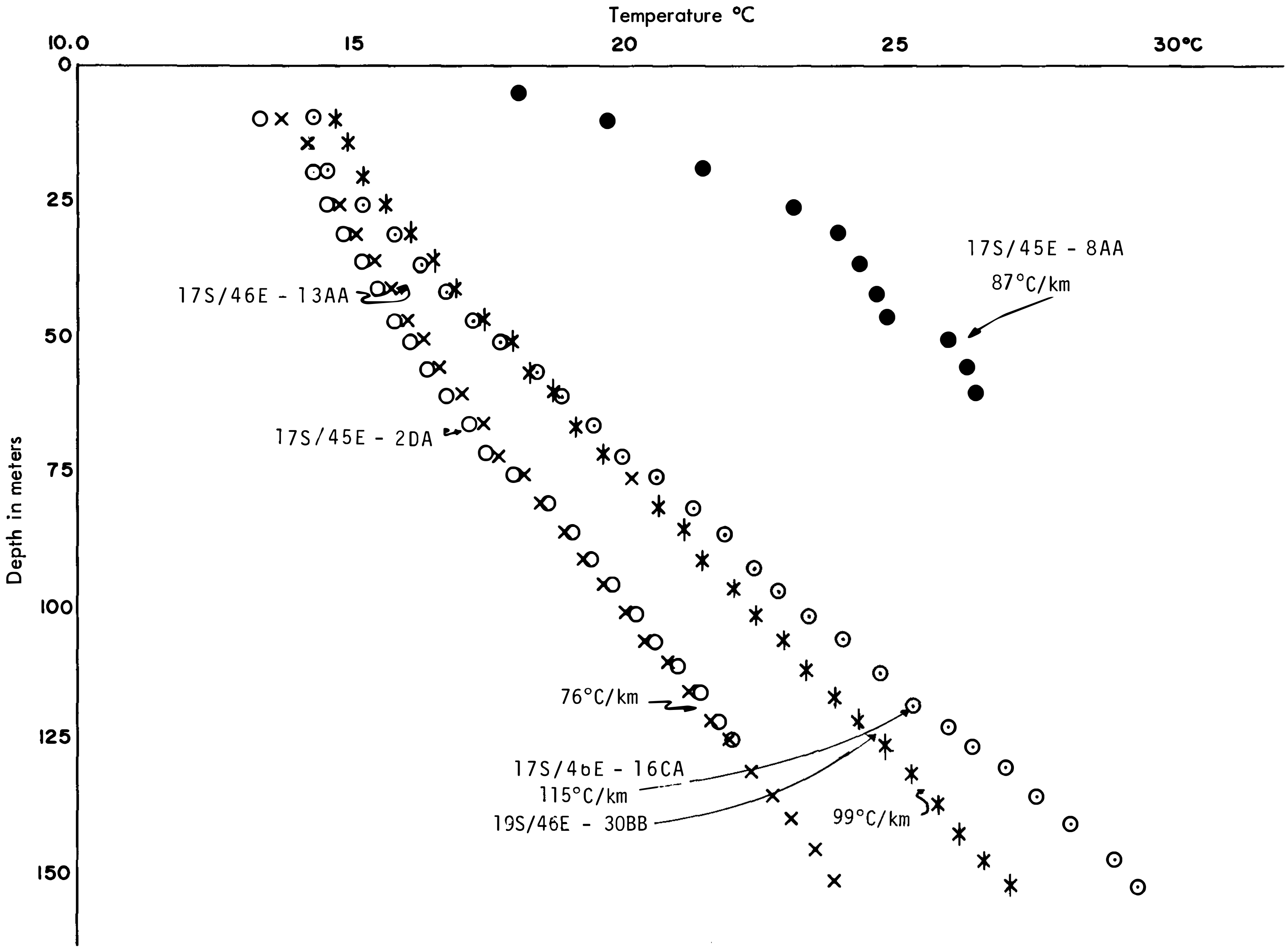


Figure 6. Temperature-depth plots for holes drilled by Oregon Department of Geology and Mineral Industries.

was measured after the hole hod been cemented to stop the flow, although a temperature effect from the worm water is still present as indicated by the high apparent surface temperatures.

The gradients in all of these holes except 17S/46E-13AA appear to be anomalously high, and the results are consistent with earlier gradient measurements in the Vole area. The east-west profile along the South Fork Jacobsen Gulch lies east of predrilled wells with relatively high gradients. Hole 19S/45E-30BB lies 1.6 km (1 mile) east of monitor hole no. 1 and is in the area of the Cow Hollow thermal anomaly.

Heat-Flow Anomalies

Cow Hollow anomaly

The most prominent area of anomalous heat flow encountered in the area during progress of the study is the Cow Hollow anomaly, centered about 13 km (8 miles) southeast of Vale (Figure 7). This anomaly has been discussed by Bowen and Blackwell (1975) and the results are only briefly summarized here.

The Cow Hollow anomaly appears to follow a linear trend at least 8 km (5 miles) long and 5 km (3 miles) wide. Within this zone geothermal gradients range from 71 to 233°C per km and heat-flow values range from 2.1 to 6.4 HFU. The rocks in the area consist of a thick sequence of Tertiary continental sediments and volcanics. Lacustrine sedimentary rocks of the Idaho Group outcrop at the surface and ore underlain by Owyhee Basalt. Geological and geophysical evidence suggests that faulting has brought the Owyhee Basalt into juxtaposition against the Idaho Group sediments, blocking the lateral migration of the hot waters and creating a trap. Leakage from this reservoir along the fault has produced the high heat flow at Cow Hollow. Wells drilled on the upthrown side of the fault into the Owyhee Basalt, estimated to be at a depth of about 2 km (1.2 miles), should encounter geothermal fluids with temperatures of 150° to 200°C.

Willow Creek anomaly

The Willow Creek onomaly is centered about 16 km (10 miles) northwest of Vale (Figure 8). Its relationship to the Cow Hollow anomaly is unknown at the present time. Its presence is indicated by measurements from four water wells with gradients greater than 90°C per km and heat-flow values ranging from 2.0 to 3.8 HFU. This anomaly may be related to the Willow Creek fault zone, discussed in the paper by Bowen and Blackwell (1975); it appears to be lower in amplitude and possibly more restricted in extent than the Cow Hollow anomaly.

South Fork Jacobsen Gulch anomaly

The South Fork Jacobsen Gulch anomaly, situated north of Vole, was discovered by the Department program and may be near another fault system parallel to the Willow Creek fault (see Figure 8).

In this anomaly, two holes about 11 km (7 miles) aport show high heat-flow values. Hole 17S/45E-8AA encountered worm (24°C) water at 32 m (105 feet) in Owyhee Basalt, which crops out just north of the drill hole. The high gradient of 240°C per km observed from the surface to 32 m (105 feet) in 17S/45E-8AA is due to the worm water and probably does not continue below the basalt; only deeper drilling con reveal this. The results from this hole indicate that the heat-flow anomalies in the Western Snoke River Basin are probably related to water circulation in the basalt aquifers, such as the Grassy Mountain and the Owyhee Basalt, and to faulting which may disrupt the basalt aquifers. In areas such as this, high heat-flow values cannot be properly interpreted unless the depth to the aquifer is known so that the temperature within the aquifer con be inferred. The seismic and gravity studies in progress (Couch and others, 1975) will give important data which con be combined with the heat-flow data to interpret the geothermal pattern found here for the Western Snoke River Bosin.

Drill hole 17S/46E-16CA also has heat-flow values above the regional background. It appears possible that the geothermal potential encompassed by the Known Geothermal Resource Area extending southward from the town of Vole may also extend northwest from Vale at least as for as the east-west profile along the South Fork of Jacobsen Gulch.

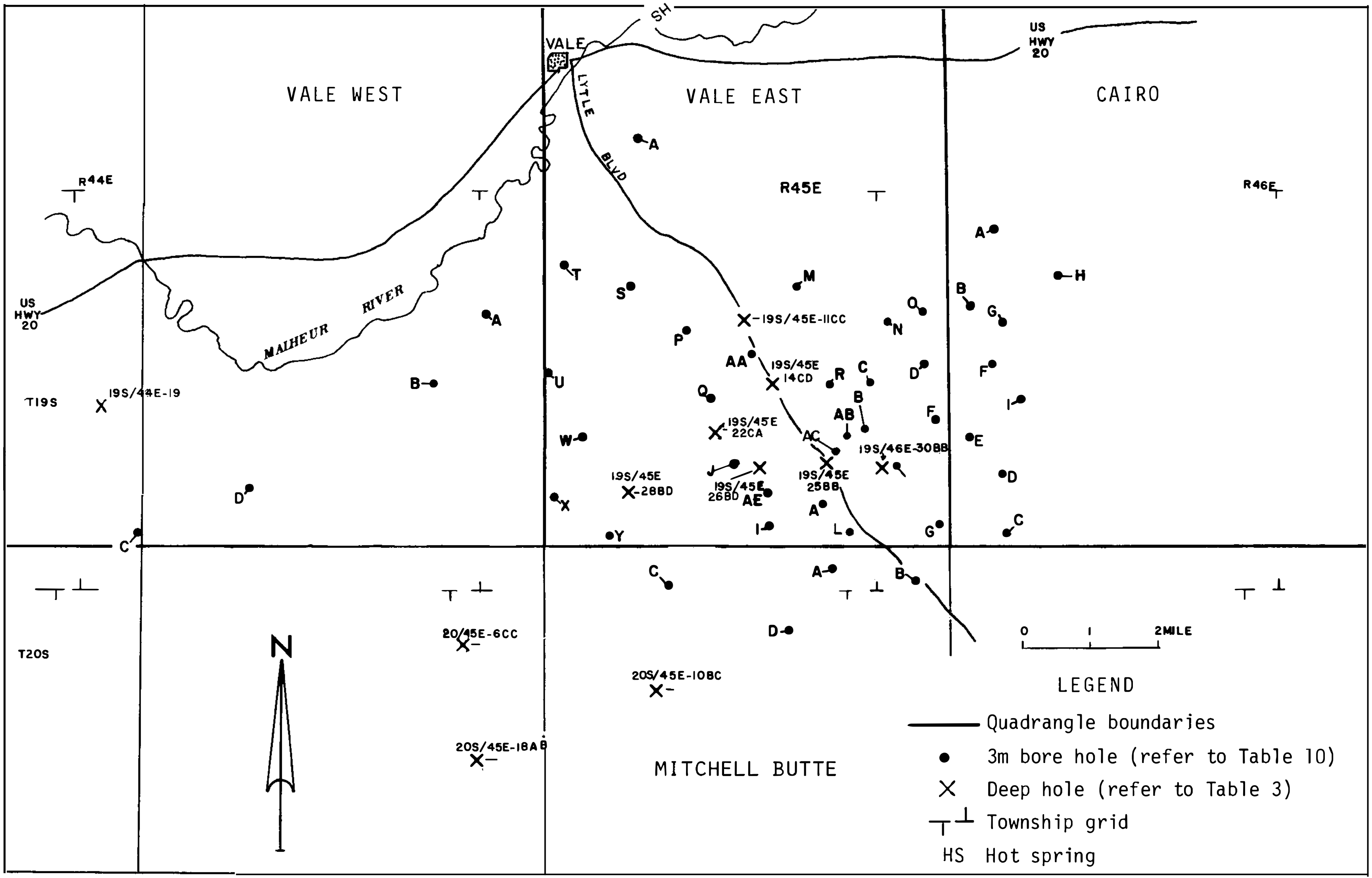


Figure 7. Map of Cow Hollow bore-hole locations.

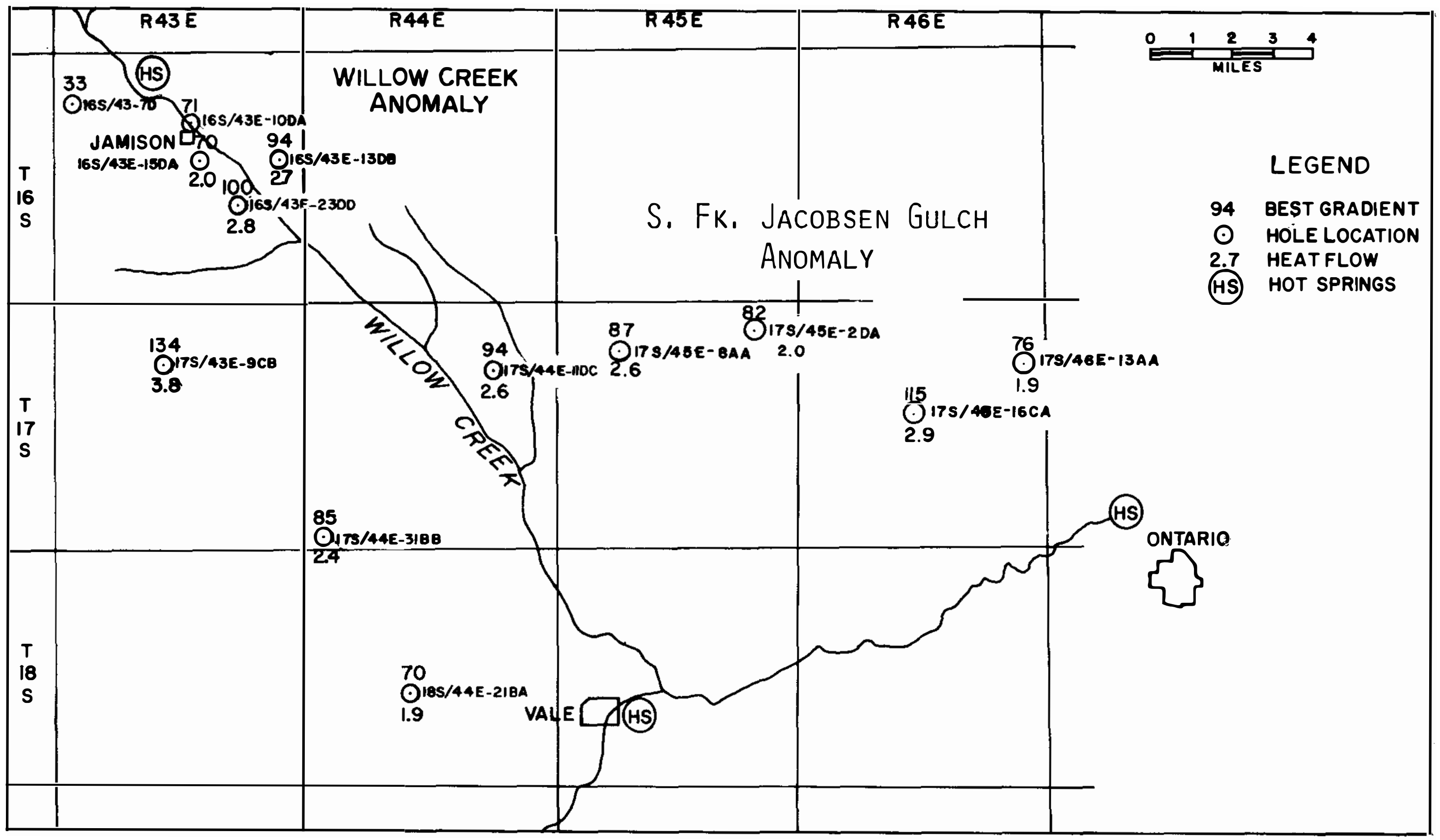


Figure 8. Map of Willow Creek and South Fork Jacobsen Gulch anomalies.

MONITOR WELLS

Methods

One of the goals of this study was to work on methods of identifying geothermal anomalies at the shallow depths, where solar radiation has greater effects on temperature than does geothermal heat flow. At the surface the solar heating component normally amounts to several thousand times the geothermal component, diminishing with depth to a point where the solar component is no longer detectable. Because so little information exists about the near-surface temperatures and the effects of the annual solar heating cycle, the monitor well program was instituted to determine the nature of these variations.

Six monitor well sites in different parts of the State were chosen to sample the effects of various climatic, geographic, and geologic conditions on the shallow temperature field. Well availability and accessibility were also factors in choice of sites. Approximately once a month the temperatures at 1, 2, 3, 5, 7.5, 10, 15, 20, and 25 m (3.3, 7, 10, 16, 25, 33, 49, 66, and 82 feet) were taken in each hole. In all of the wells chosen as monitors, either the water level was below the level to be logged and shown to be constant or the well was cased and set with plastic pipe sealed at the bottom. Where plastic pipe was used, it was filled with water to facilitate measuring. At several sites, however, surface cooling of the water during cold months produced a high gradient which caused convection cells to develop within the bore holes, affecting the accuracy of the measurements. This effect was remedied by bailing the water and taking measurements in air. In order to counteract the effects of the long interval of time required for the probe to reach equilibrium in air, four readings taken at 2-minute intervals were plotted on semilog graph paper and extrapolated to infinite time. This method proved satisfactory in giving the best temperature at a particular depth. An error of 0.5 m (1.6 feet) on the cable markings was discovered in November 1972 after well monitoring began; therefore all measurements prior to that date were taken at 1.5, 2.5, 3.5, etc. m (5, 8, 12, etc. feet) and those after that date were at 1, 2, 3, etc. m (3.3, 7, 10, etc. feet).

Tabulated data for the monitor wells gives dates the wells were logged, mean average air temperature for the month, and temperatures at various depths. Question marks represent readings that depart significantly from a sine curve. Two plots are shown for each monitor well: one for temperature vs depth at different periods of time, and the other for temperature vs time at various depths. Both sets of curves have been smoothed where there are obvious inconsistencies. The effects of convection due to the high gradients developed from surface cooling in the winter time showed up in several of the plots, particularly the 2-m and 5-m (7- and 16-foot) temperature-vs-time plots.

Description of Monitor Well Sites

Monitor 1, Vale, Oregon

Sec. 25, T. 19 S., R. 45 E., (19S/45E-25BB), Malheur County, elev. 813 m (2,667 feet) (Table 4, Figures 9A and 9B). This hole was an abandoned mineral exploration well that was logged to a depth of 70 m (230 feet). Plastic pipe was set at a depth of 26 m (85 feet) and filled with water. This well has the highest gradient of any located during the course of the study (214°C per km; 6.4 HFU with topographic correction). The area is on the west flank of the Western Snake River Basin. Rocks at the surface and to a depth of 800 to 1,000 m (2,600 to 3,300 feet) are tuffaceous claystone and siltstone with minor sandy and conglomeratic interbeds. Mean annual ground-surface temperature in the well area is about 13°C. The U. S. Weather Bureau reports the average monthly temperature is between -2° and +24°C. This wide variation is reflected in the shallow readings, with the 1-m (3.3-foot) readings changing nearly 20°C and the 2-m (7-foot) readings changing more than 12°C. Temperature variations are significantly damped at 10 m (33 feet), and at 20 m (66 feet) the variations probably reflect measurement errors rather than true variations.

Table 4. Data from monitor well 1, Vale

Date Logged	Mean Monthly Air Temp.	1½m	2½m	3½m	4½m	5½m	10½m	15½m	20½m	25½m
9/7/72	14.5			15.97		14.69	15.43			
9/26/72	14.5	18.76	18.05	16.41	15.91	15.06	15.65	16.75	17.61	18.31
10/3/72	11.17	18.38	18.33	16.96	15.66	15.11	15.64	16.73	17.67	18.15
10/10/72	11.17	18.25	17.78	16.65	15.48	15.10	15.68	16.84	17.72	18.25
10/15/72	11.17	17.61	17.74	16.92	15.73	15.22	15.77	16.76	17.68	18.17
11/1/72	4.83	15.40	16.18	16.35	15.99	15.31	15.69	16.56	17.53	18.17
11/16/72	4.83	14.88	15.69	16.04		15.36	15.87	16.79	17.75	18.24

Date Logged	Mean Monthly Air Temp.	1m	2m	3m	4m	5m	7½m	10m	15m	20m	25m
11/16/72	4.83	14.40	15.28	15.84		15.57		15.77	16.69	17.64	18.24
11/29/72	4.83	11.62	13.00	14.03	14.87	15.25		15.68	16.55	17.56	18.10
(air) 12/20/73	-6.00	9.60	12.57	14.15	14.98	15.33	15.32	15.69	16.64		
(oil) 12/20/73	-6.00	10.88	11.96	13.47	14.45	15.06	15.35	15.73	16.65	17.55	18.17
1/4/73	-2.33	9.63	12.39	13.69	14.61	15.17	15.53	15.77	16.70	17.58	18.26
1/23/73	-2.33	7.78	10.49	12.55	13.14	13.92	15.39	15.73	16.58	17.49	18.07
2/15/73	0.5	9.03	10.43	11.53	13.91	14.31	15.55	15.76	16.68	17.58	18.19

Temperatures in ^{o}C

Table 4.(cont.)

Date Logged	Mean monthly Air Temp.	1m	2m	3m	4m	5m	7½m	10m	15m	20m	25m
2/20/73	0.5	3.76	8.60	10.69	12.77	13.77	15.46	15.71	16.57	17.52	18.11
3/13/73	7.39	7.50	10.27	12.16	13.80	14.78	15.51	15.82	16.68	17.65	18.70
4/3/73	9.56	5.84	8.04	9.91	11.81	13.64	15.41	15.76	(16.10)	17.65	18.43
(oil) 4/25/73	9.56	9.98	10.09	11.16	12.32	13.69	15.34	15.72	16.62	17.56	18.17
5/16/73	16.33	15.23	11.07	11.59	12.63	13.48	15.55	15.75	16.60	17.57	18.15
6/5/73	21.06	16.68	13.84	12.20	12.66	13.61	15.26	15.84	16.66	17.54	18.11
6/26/73	21.06	19.24	15.03	13.15	13.25	13.98	15.39	15.78	16.65	17.58	18.23
7/18/73	23.22	23.07	16.21	13.78	13.71	14.15	15.43	15.85	16.65	17.61	18.24
8/10/73	23.83	23.45	18.94	15.26	14.41	14.29	15.44	15.71	16.68	17.64	18.23
9/10/73	14.5	22.05	20.32	17.35	15.72	14.84	15.33	15.77	16.67	17.62	18.22

Table 5. Data from monitor well 2, Warren

Date Logged	Mean Monthly Air temp.	1½m	2½m	3½m	4½m	5½m	6½m	7½m	8½m	9½m	10½m	15.4m
8/10/72	21.11			10.75		9.66					10.3	10.05
9/15/72	15.00	14.74	12.48	10.85	10.09	9.81	9.79	9.86	9.93	9.98	10.02	10.05
10/22/72	11.28	12.38	12.40	11.44	10.55	10.07	9.90	9.89	9.92	9.96	10.00	10.05
11/15/72	7.94	11.27	11.42	11.39		10.24					9.99	10.04

Date Logged	Mean Monthly Air temp.	1m	2m	3m	4m	5m	6m	7½m	10m	15m
11/15/72	7.94	10.88	11.35	11.41		10.49			9.98	10.04
12/2/72	1.94	10.46	10.79	10.99	11.00	10.57	10.19		9.98	10.04
12/11/72	1.94	9.18	9.93	10.68	10.73	10.62		9.98	9.97	10.04
12/17/72	1.94	8.64	9.67	10.39	10.55	10.60	10.25	10.00	9.98	10.04
1/12/72	2.8	8.27	8.77	9.37	9.97	10.16		10.06	9.98	10.03
1/29/72	2.8	7.91	8.45	8.77	9.62	10.03		10.10	9.99	10.03
2/14/73	5.17	5.84	8.18	9.8	10.39	10.47		10.13	10.00	10.03
3/5/73	8.78	7.09	7.81	9.18	10.04	10.36		10.16	10.02	10.03
3/21/73	8.78	7.30	8.11	9.17	9.93	10.29				
4/30/73	8.06	9.34	8.66	8.98	9.56	9.98		10.16	10.05	10.03
5/19/73	14.94	11.53	9.34	9.23	9.58	9.88		10.19	10.11	10.08
6/18/73	16.5	12.09	9.99	9.52	9.63	9.90		10.11	10.08	10.11
7/17/73	20.39	13.66	10.64	9.76	9.78	10.01		10.05	10.07	10.03
8/14/73	21.11	14.56	12.03	10.54	9.99	9.89		10.03	10.07	10.04
10/23/73	11.28	12.19	12.17	11.37	10.69	10.26		10.02		10.04
12/19/73	1.94	8.99	9.07	10.15	10.32	10.39		10.01	10.04	10.00

Table 6. Data from monitor well 3, Arlington

Date Logged	Mean Monthly Air Temp.	1m	2m	3m	4m	5m	7½m	10m	15m	20m	25m
2/23/73	3.9		8.27	11.23	13.21	14.46	15.34	15.14	14.96	15.24	15.50
4/4/73	9.83	9.23	9.61	10.87	12.37	13.44	15.20	15.29	15.15	15.39	15.64
4/26/73	9.83	12.98	10.96	11.12	12.10	12.65	15.01	15.25	15.21	15.38	15.65
5/22/73	17.89	15.62	13.19	12.48	12.94	13.70	15.03	15.29	15.25	15.57	15.78
6/1/73	21.61	15.27	13.48	12.92	13.15	13.63	14.73	15.11	15.31	15.49	15.73
6/19/73	21.61	17.07	14.57	13.61	13.57	13.86	14.76	15.22	15.62	15.89	
8/1/73	25.0	21.77	17.42	15.72	14.65	14.31	14.52	14.99	14.87	15.51	
8/19/73	25.0	18.50	18.50	15.43	15.09	14.57	14.46	14.95	15.39	15.35	15.86
9/4/73	17.06	19.85	19.19	17.21	15.71	15.03	14.53	14.96	15.45	15.58	15.83
10/15/73	11.17	16.81	18.49	17.48	16.62	15.88	14.82	14.86	15.37	15.61	
1/18/74		(8.85)	10.73	13.71	15.04	15.35	15.47	15.14	15.33	15.52	

Table 7. Data from monitor well 4, Baker

Date Logged	Mean Monthly Air Temp.	1m	2m	3m	4m	5m	7½m	10m	15m	20m	25m
12/21/72	-5.44	3.23	7.46	9.31	10.55	11.32	10.91	10.71	10.79	10.98	
1/6/73	-5.00	2.97	7.22	9.37	10.67	11.09	10.90	10.73	10.78	10.91	
1/24/73	-5.00	1.74	6.72	8.97	10.13	10.82	10.85	10.75	10.79	10.97	11.11
2/8/73	0.17	1.77	5.24	7.26	8.78	10.21	10.73	10.74	10.79	10.96	11.13
2/21/73	0.17	1.90	4.95	7.06	8.49	10.07	10.67	10.73	10.79	10.98	11.10
3/14/73	6.00	4.56	5.79	7.11	8.33	9.79	10.52	10.68	10.79	10.98	11.10
4/4/73	5.78	6.50	6.34	7.21	8.16	9.35	10.46	10.64	10.74	10.97	11.10
4/26/73	5.78	9.13	7.38	9.85	8.27	9.52	10.34	10.57	10.79	10.98	11.10
5/18/73	13.67	15.35	8.07	8.02	8.50	9.59	10.20	10.52	10.78	10.99	11.10
6/6/73	16.67	16.21	10.47	9.03	8.94	9.60	10.19	10.52	10.77	11.00	11.10
7/5/73	19.72	20.17	13.51	11.04	10.18	10.08	10.26	10.52	10.80	11.01	11.13
7/18/73	19.72	21.72	13.77	11.55	10.56	10.11	10.32	10.50	10.80	11.02	11.13
8/9/73	20.78	21.35	15.09	12.72	11.38	10.60	10.41	10.52	10.80	11.02	11.13
9/5/73	12.17	17.75	15.43	13.80	12.51	11.26	10.51	10.57	10.80	11.02	11.12

Table 8. Data from monitor well 5, Dufur

Date Logged	Mean Monthly Air Temp.	1m	2m	3m	4m	5m	7½m	10m	15m	20m	25m
12/22/72	-2.94	8.36	10.09	11.32	12.35	12.75	12.89	12.97	13.26	13.55	13.88
1/11/73	0.22	5.14	8.72	10.81	12.33	13.02	13.20	13.31	13.56	13.76	14.02
1/25/73	0.22	6.80	8.76	11.70	12.35	12.73	12.95	13.07	13.44	13.70	13.99
2/9/73	2.5	5.30	8.69	10.62	12.80	13.11	13.08	13.16	13.66	13.87	14.10
2/26/73	2.5	8.28	9.38	10.58	12.40	13.00	12.92	12.94	13.39	13.67	13.96
3/15/73	7.0	8.83	9.90	10.98	12.54	13.08	12.98	13.05	13.76	14.25	14.28
4/5/73	6.67	11.07	10.37	11.35	12.94	13.06	13.11	13.00	13.76	13.84	14.03
4/27/73	6.67	14.07	13.74	11.13	11.58	12.59	12.78	12.98	13.72	13.77	14.08
6/1/73	16.5	15.94	12.82	12.70	13.12	13.12	13.12	13.24	13.97	13.92	
6/19/73	16.5	16.78	13.93	12.93	13.06	13.10	13.09	13.19	13.77	13.91	
7/9/73	19.94	21.29	16.31	14.09	13.27	13.20	13.23	13.22	13.77	13.90	
8/1/73	20.22	22.51	17.21	15.23	13.73	12.72	13.18	13.26	13.77	13.85	
9/4/73	13.44	18.00	18.41	16.71	14.24	13.55	12.49	13.35	13.65	13.84	14.05
11/1/73	5.28	12.06	15.06	15.43	15.08	14.27	13.19	13.35	13.74	13.91	14.06

Table 9. Data from monitor well 6, Burns

Date Logged	Mean Monthly Air Temp.	1m	2m	3m	4m	5m	7½m	10m	15m	20m	25m
2/19/73	-0.72	6.44	7.22	9.38	10.63	11.25	12.38	12.58	13.42	13.77	14.07
3/12/73	5.33	6.74	7.77	8.75	9.72	11.10	12.39	12.53	13.33	13.76	14.07
4/2/73	4.72	6.81	7.76	7.75	9.96	11.33	12.40	12.59	13.37	13.76	14.06
4/24/73	4.72	7.15	8.26	9.27	10.18	11.34	12.38	12.63	13.34	13.77	14.06
5/16/73	12.61	11.47	8.20	9.27	10.56	11.29	12.35	12.83	13.44	13.74	14.07
6/4/73	16.78	14.35	9.50	9.47	10.38	11.17	12.39	12.83	13.43	13.76	14.05
6/28/73	16.78	16.87	11.42	10.47	11.04	11.80	13.03	13.18	13.56	13.79	14.17
7/17/73	19.61	20.20	13.27	10.92	11.09	11.38	12.11	12.56	13.44	13.81	14.10
8/8/73	20.06	19.72	14.46	11.77	11.21	11.40	12.20	12.58	13.45	13.79	14.10
8/21/73	20.06	20.31	15.76	12.54	11.37	11.33	12.30	12.56	13.42	13.78	14.09
9/12/73	11.17	18.40	16.07	13.19	11.87	11.64	12.29	12.57	13.46	13.78	14.10

Table 10. Data from shallow holes, Cow Hollow

Location	Elevation (m)	Lapse Corr.	10/15/72		5/8/73		6/25/73		9/7/73	
			1m	3m	1m	3m	1m	3m	1m	3m
VE - A (Vale east)	768	-.26	17.49	16.87	12.18	11.54			22.13	16.72
VE - B	913	+.61	17.79	16.91	11.72		18.80	12.76	22.90	16.99
VE - C	925	+.68	17.41	16.13	12.17		19.39	12.66	23.14	16.00
VE - D	841	+.18	17.87	16.85	12.46	11.44	19.54	12.80	23.07	16.68
VE - E	878	+.40	14.40	16.29	11.61	11.92	20.41	12.93	23.75	16.00
VE - F	823	+.07	16.40	16.18	12.67	(11.88)	19.25	13.02	22.50	16.12
VE - G	832	+.13	17.79	18.05	13.09	11.71	20.78	13.17	23.88	17.23
VE - H	811	.00	16.90	16.68	11.81	(11.07)	16.70	13.48	21.33	16.26
VE - I	872	+.37	16.21	15.86	10.99	11.05	16.75	12.25	21.08	15.52
VE - J	830	+.11	16.01	16.22	11.62	11.33	17.92	12.47	21.37	15.70
VE - K	811	.00					18.77	13.52	22.96	17.44
VE - L	780	-.19					18.73	13.67	22.68	17.68
VE - M	884	+.44					17.94	12.24	22.46	16.12
VE - N	872	+.37					17.26	11.54	20.99	14.17
VE - O	835	+.14					19.76	13.96	23.68	18.09
VE - P	881	+.42					17.92	12.12	18.76	16.02
VE - Q	860	+.29					18.20	12.28	18.70	15.91
VE - R	963	+.91					17.25	11.80	17.78	15.03
VE - S	835	+.14					17.57	12.67	21.44	16.29
VE - T	719	-.55					17.94			
VE - U	771	-.24					18.31	12.78	22.70	16.60

Table 10. (cont.)

Location	Elevation	Lapse Corr.	10/15/72 1m	10/15/72 3m	5/8/73 1m	5/8/73 3m	6/25/73 1m	6/25/73 3m	9/7/73 1m	9/7/73 3m
VE - V	850	+.23					17.22	12.62	21.69	16.66
VE - W	832	+.13					18.48	12.60	22.88	16.79
VE - X	823	+.07					18.00	12.28	21.99	16.12
VE - Y	890	+.47					18.20	12.71	22.02	16.26
VE - AA	847	+.22							21.53	16.41
VE - AB	902	+.55							22.65	16.59
VE - AC	835	+.14							22.77	17.34
VE - AD	844	+.20							22.41	16.69
VE - AE	832	+.13							22.17	16.00
VW - A (Vale west)	713	-.59					17.57	12.46	20.62	16.35
VW - B	725	-.52					17.63	12.55	21.53	15.52
VW - D	722	-.53							20.60	15.39
C - A (Cairo)	780	-.19					18.66	12.64	22.47	15.78
C - B	869	+.35					17.17	11.46	21.13	15.26
C - C	793	-.46					19.94		22.90	
C - D	790	-.13					19.56	12.61	22.47	16.01
C - E	786	-.15					18.82	12.71	22.01	16.69
C - F	835	+.14					19.61	13.09	23.45	16.98
C - G	866	+.33					19.08	12.70	22.94	16.80
C - H	853	+.25					18.82	12.64	22.21	16.54
C - I	805	-.04					19.63	12.70		

Table 10. (cont.)

Location	Elevation	Lapse Corr.	10/15/72 1m	10/15/72 3m	5/8/73 1m	5/8/73 3m	6/25/73 1m	6/25/73 3m	9/7/73 1m	9/7/73 3m
MB - A (Mitchell Butte)	814	+.02					18.15	13.14	22.29	16.41
MB - B	762	-.29					18.66	13.06	22.24	16.43
MB - C	921	+.66					17.97	12.61	21.73	16.74
MB - D	855	+.26					19.08	13.49	23.07	16.96
MB - E	808	-.02					18.78	13.83	22.62	

Monitor 2, Warren, Oregon

Sec. 11, T. 4 N., R. 2 W., (4N/2W-11AC) Columbia County, elev. 146 m (480 feet) (Table 5, Figures 10A and 10B). This well was drilled by the Oregon Department of Geology and Mineral Industries to 17 m (56 feet). Sealed plastic casing was set to total depth. The well is in an area of very low heat flow and has a geothermal gradient of about 10°C per km. The rock type is a deeply weathered laterized basalt. Average annual ground-surface temperature near the well is about 10°C, with the monthly temperatures for the region averaging between 2° and 20°C. As the well site is located in a forested area the monthly average temperatures are moderated over the regional average. This minimal variation is reflected in the subsurface, which at 1 m (3.3 feet) has a total variation of nearly 9°C. At 2 m (7 feet) the annual variation is 4°C; at 5 m (16 feet) the annual variation is less than 1°C.

Monitor 3, Arlington, Oregon

Sec. 36, T. 3 N., R. 21 E., (3N/21E-36BB), Gilliam County, elev. 226 m (740 feet) (Table 6, Figures 11A and 11B). This well was drilled and cased with plastic pipe to 125 m (410 feet) as a foundation test for an electric power generating plant. The area is a part of the Umatilla Plateau. The rocks encountered in the bore hole were tuffaceous lacustrine sediments of the Selah Formation to a depth of 110 m (360 feet) underlain by Columbia River Group basalt. Geothermal gradient in the bore hole is about 62°C per km. The site is located on a sage-covered flat, average ground-surface temperature is about 14°C, and monthly averages range between 0° and +24°C. Annual temperature variation at 2 m (7 feet) is about 11°C, at 5 m (16 feet) it is damped to 3°C, and at 10 m (33 feet) it is less than 1°C.

Monitor 4, Baker, Oregon

Sec. 13, T. 9 S., R. 39 E., (9S/39E-13AB), Baker County, elev. 1,067 m (3,500 feet) (Table 7, Figures 12A and 12B). This hole, drilled as a water well to 72 m (236 feet), is cased to total depth. Water level stands at 7 m (23 feet). No change was detected in water level during the time it was logged. The site is located in alluvium in the Baker Valley, at the foot of Elkhorn Ridge. At present and during the recent past the area has been an open field. Average around-surface temperature is about 10°C with monthly average variation between -4°C and +22°C. At a depth of 2 m (7 feet) the yearly range is about 10°C; at 5 m (16 feet) it is 2°C, and at 10 m (33 feet) it is 0.25°C.

Monitor 5, Dufur, Oregon

Sec. 20, T. 1 S., R. 13 E., (1S/13E-20DA), Wasco County, elev. 354 m (1,160 feet) (Table 8, Figures 13A and 13B). This hole was drilled and cased as a water well to 135 m (445 feet). Standing water level was at 55 m (180 feet), so all measurements were made in air. The well has a geothermal gradient of 54°C per km to the water table, where it decreased to about 3°C per km to total depth. The low gradient in the bottom part of the hole is due to downflow of water in the hole from one aquifer to another. The well is drilled in basalt near the edge of an alluvium-filled valley. Average annual ground-surface temperature is about 13°C, with monthly average variations between 0°C and 20°C. At 2 m (7 feet) the yearly range is about 10°C; at 5 m (16 feet) it is 2°C, and at 10 m (33 feet) it is less than 0.5°C.

Monitor 6, Burns, Oregon

Sec. 13, T. 27 S., R. 30 E., (27S/30E-13DD) Harney County, elev. 1,274 m (4,180 feet) (Table 9, Figure 14A and 14B). The mineral exploration well had been drilled to 130 m (426 feet). Plastic casing sealed at the bottom was set to 25 m (82 feet). Standing water level is 20 m (66 feet). The upper 70 m (230 feet) shows a gradient of 120°C per km; below that depth the gradient is about 70°C per km. The gradient difference may reflect the local geologic conditions in which semiconsolidated lacustrine tuffaceous sediments near the surface overlie a dense welded tuff. The site is located in sage-covered rolling hills. The average annual ground-surface temperature is about 10°C, with monthly average variations between -4°C and +21°C. A good curve was not obtained at this site because it was not logged for a sufficient period and

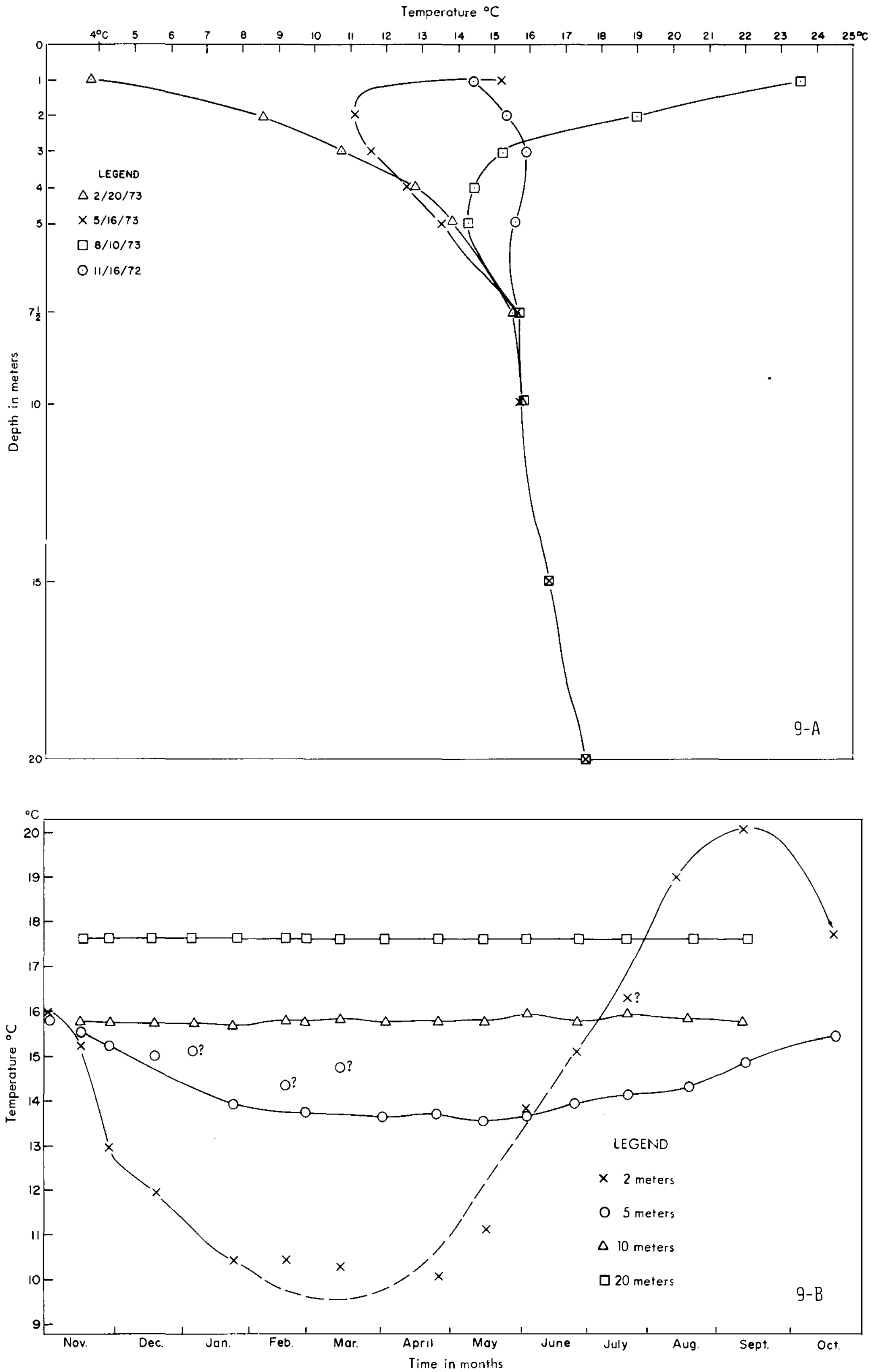


Figure 9. Vale, monitor 1 - plots of data.
A - temperature vs depth; B - temperature vs time.

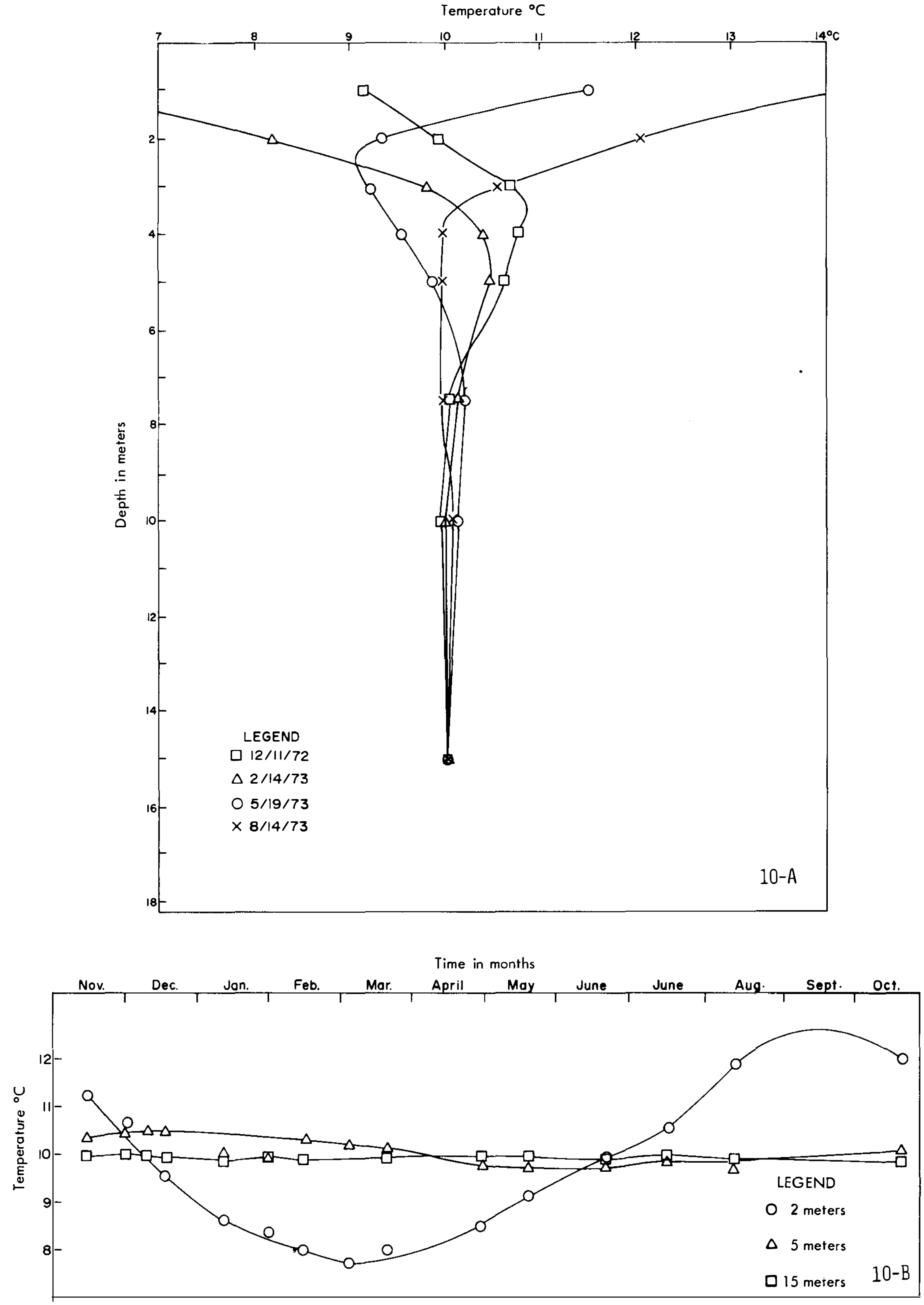


Figure 10. Warren, monitor 2 - plots of data.
A - temperature vs depth; B - temperature vs time.

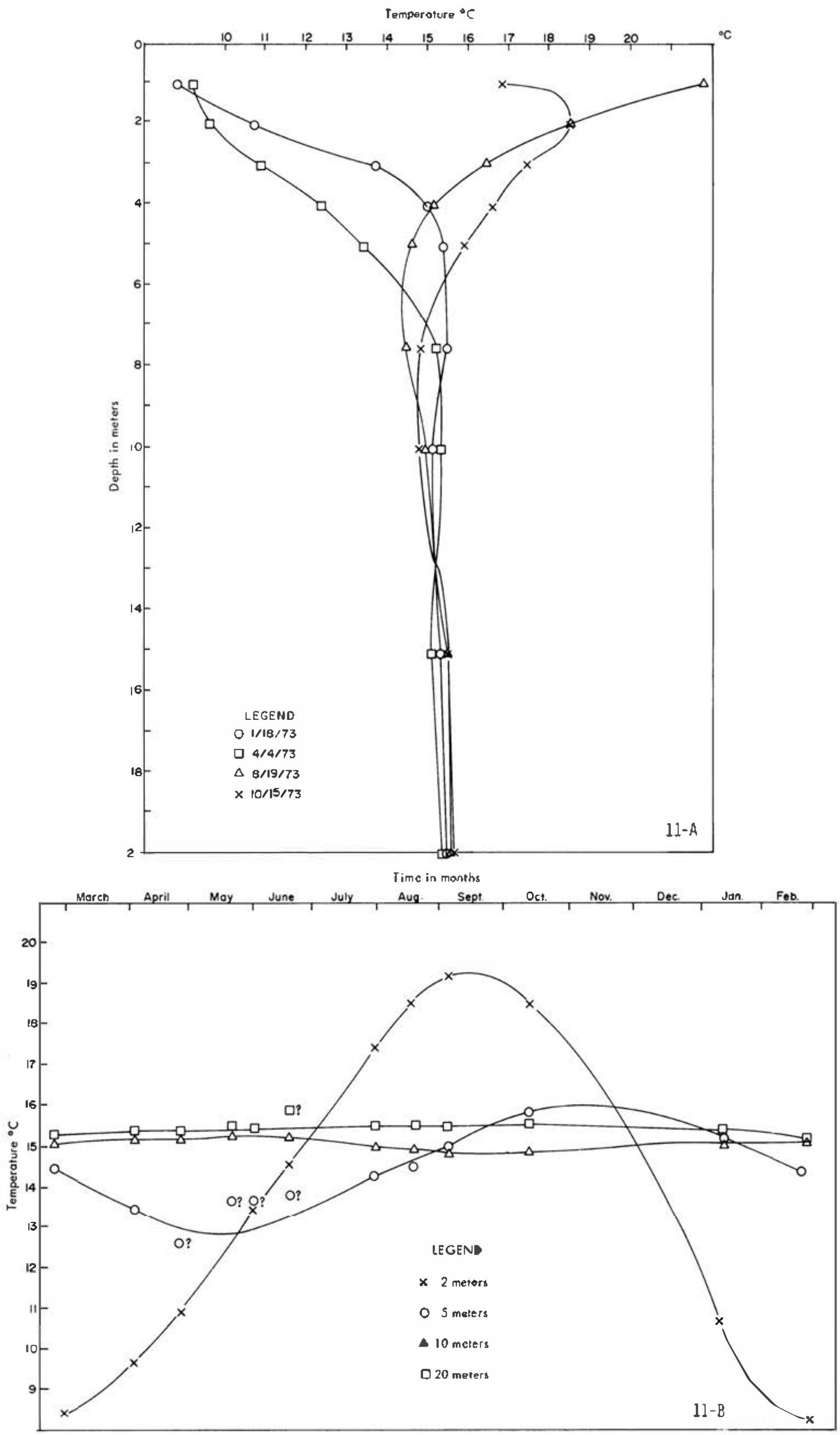


Figure 11. Arlington, monitor 3 - plots of data.
A - temperature vs depth; B - temperature vs time.

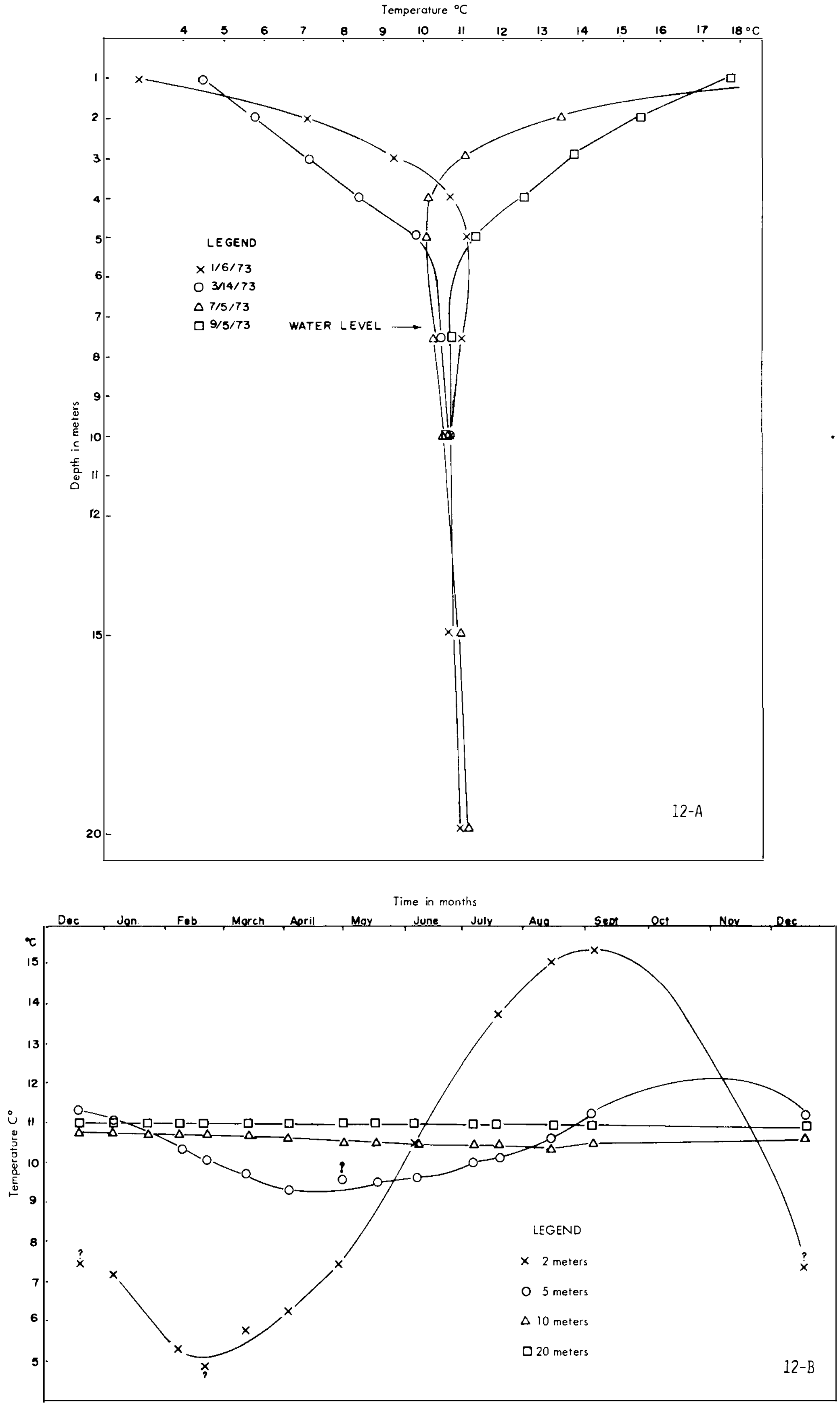


Figure 12. Baker, monitor 4 - plots of data.
A - temperature vs depth; B - temperature vs time.

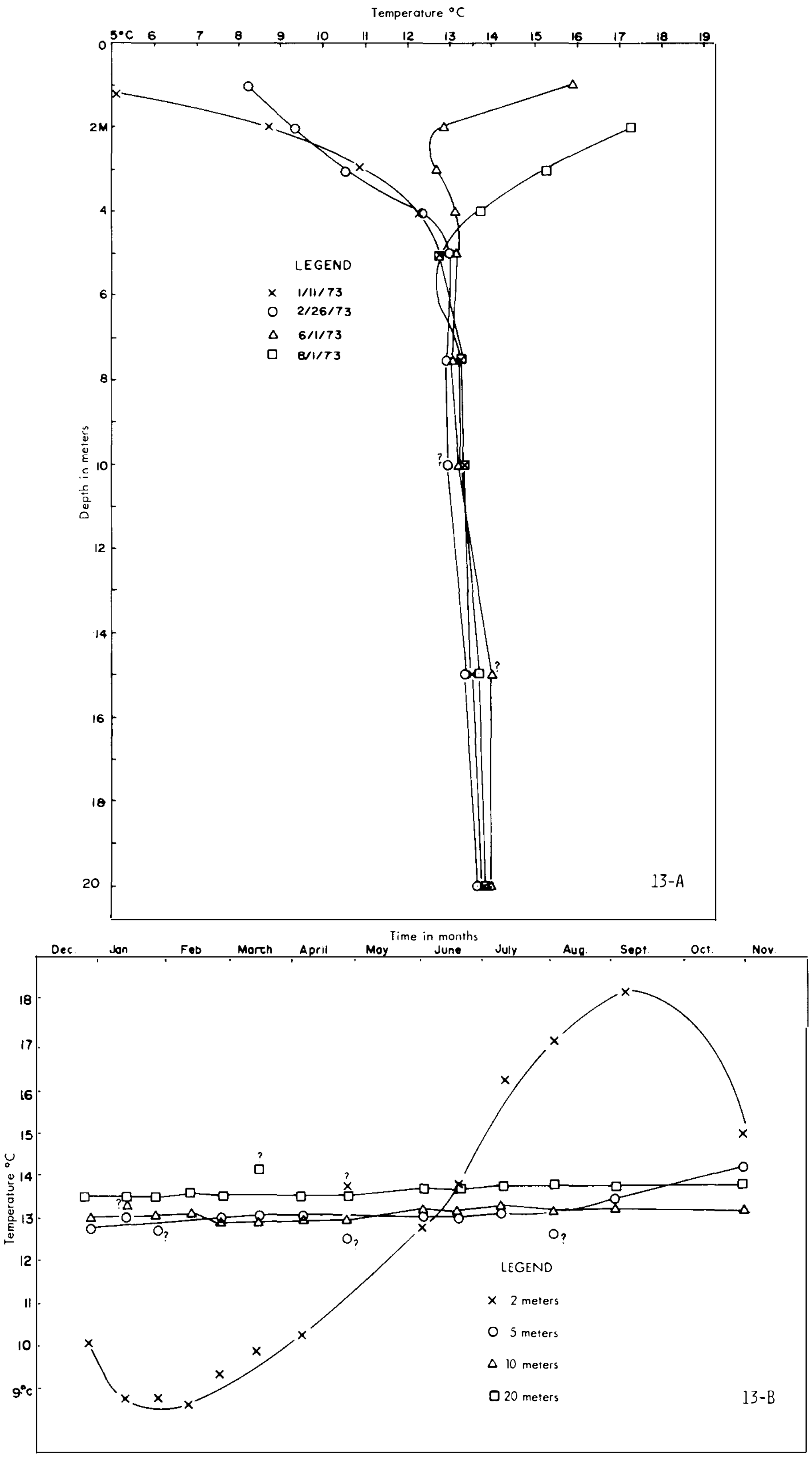
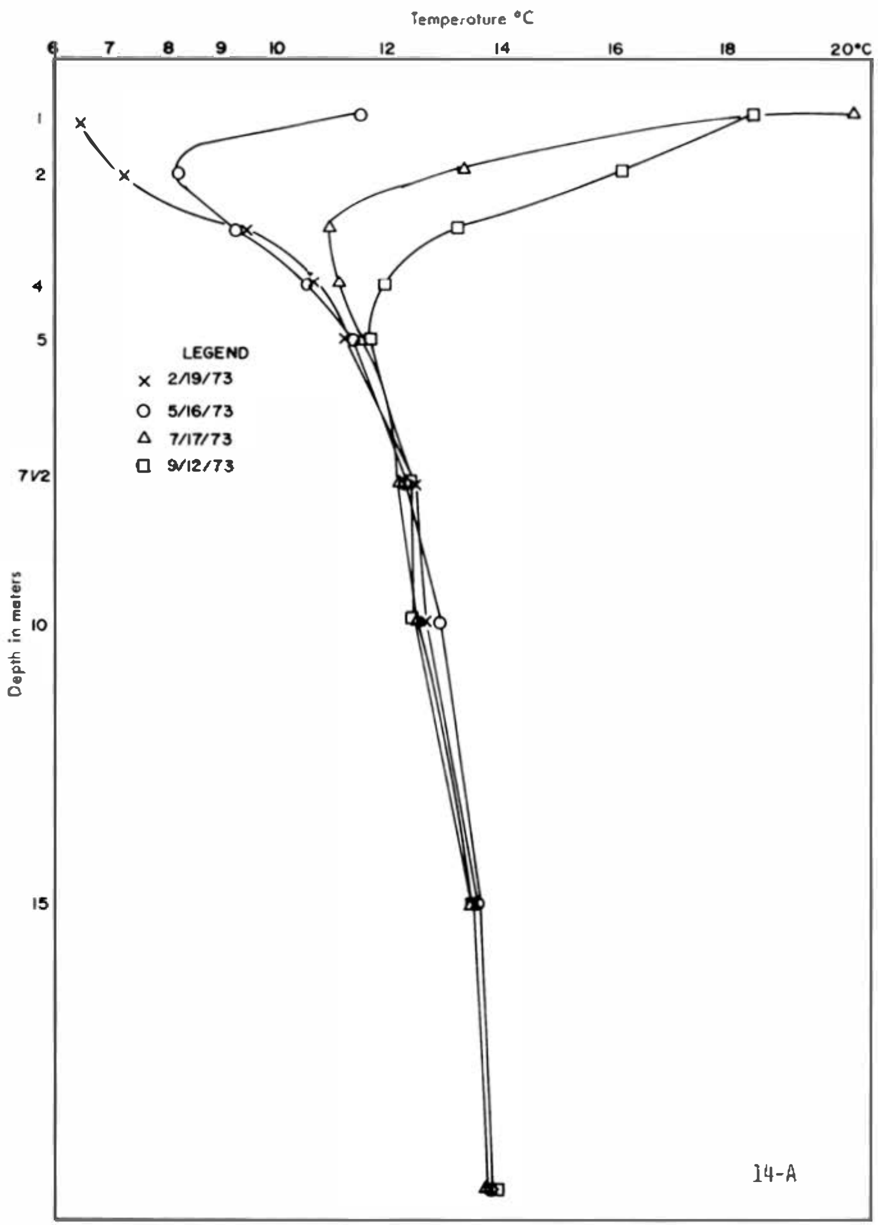


Figure 13. Dufur, monitor 5 - plots of data.
A - temperature vs depth; B - temperature vs time.



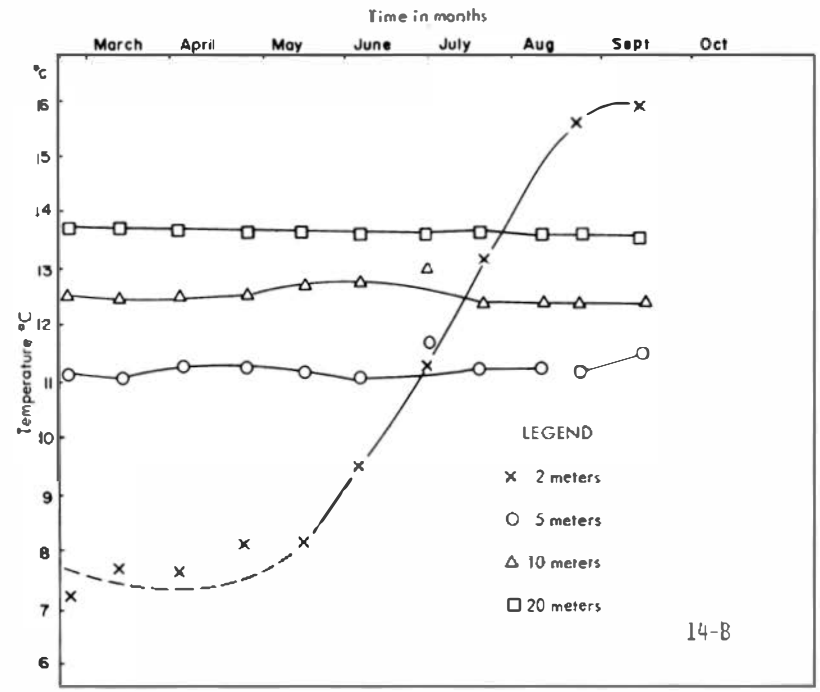


Figure 14. Burns, monitor 6 - plots of data.
A - temperature vs depth; B - temperature vs time.

because convection of water in the plastic pipe altered shallow gradients. At 2 m (7 feet) the annual variation appears to be about 9°C. At 5 m (16 feet) records show a change of about 0.5°C, but this may reflect convective temperature disturbances rather than true temperatures. At 20 m (66 feet) the well was extremely stable, with changes of 0.05°C (within measurement error) observed.

SHALLOW WELL PROGRAM

In the summers of 1972 and 1973, shallow holes were drilled near the Cow Hollow anomaly near Vale in southeastern Oregon. This phase of the study was an experiment to see if geothermal anomalies could be identified by temperature measurements from bore holes drilled only 2 or 3 m (7 or 10 feet) deep. Since the cost of geothermal exploration by heat-flow studies is related directly to drill-hole depth, it was believed the use of shallow holes to obtain preliminary data might reduce exploration costs considerably.

The holes were drilled with a Minuteman power auger and cased with 2.54-cm (1-inch) plastic pipe to insure successful re-entry. The pipe was capped at the bottom and filled with water. The water was used in order to speed readings with the temperature gear. This procedure was satisfactory during the summer; but in the winter the extreme temperature contrasts produced convection, resulting in inaccurate readings. Experiments showed that convection could be stopped and satisfactory results obtained by replacing the water with air or viscous liquid. A more detailed discussion of convection-temperature relationship is given by Sammel (1968).

The temperatures at shallow depths in the earth are affected by a number of variables. The most important of these are annual air temperature variations, elevation, ground cover, slope direction, slope inclination, and ground-water motion. The object of this study was to analyze or ovoid the effect of these various parameters to learn whether significant data about heat flow from the interior could be obtained in such shallow holes. In 2- to 3-m (7- to 10-foot) holes, a large annual variation in solar radiation is the predominant effect. However, studies by Poley and von Stevenick (1970) and by Geertsma (1971) suggest that relatively large temperature differences near the surface (1°C or more) might be caused by variations in terrestrial heat flow by a factor of 2 or more, given favorable near-surface thermal parameters. It was felt, however, that variables affecting temperatures in 2- to 3-m (7- to 10-foot) drill holes might be analyzed with enough precision to identify anomalies of the order of magnitude predicted by Poley and van Stevenick. Thus data from shallow drill holes might be sufficient to point out targets for deeper geothermal exploration drill holes.

There are several major advantages in testing shallow-hole exploration techniques in the Vale area: 1) The sparse ground cover makes it unnecessary to correct for vegetation contrasts. As Poley and van Stevenick (1970) show, vegetation can have a very significant effect. 2) The moderate slope of the ground (less than 10°) eliminates the necessity for correcting for slope inclination and orientation. 3) The moderate topography requires only minor correction for elevation variation. 4) The low rainfall and relatively impermeable shallow layers negate problems with ground-water movement.

These advantages, together with the presence of a number of deep drill holes with significant variation in heat flow for comparison with shallow-hole results, influenced the selection of the Vale area for evaluating the usefulness of the shallow-hole data.

The results of the measurements for a number of shallow holes in the Cow Hollow anomaly area near Vale, Oregon, are listed in Table 10. Locations of holes are shown in Figure 15. Data shown in the table include identification of the hole, elevation of the hole, lapse correction applied, and temperature data at 1 m and 3 m (3.3 and 10 feet) after application of the lapse correction. Temperatures in parentheses are averages of oscillating readings and are not reliable. The only correction that was applied to the data was for elevation. The correction factor was based on an assumed change of temperature of -6°C per km (temperature increases with decrease in elevation). Thus the extrapolated ground-surface temperature of a well at an elevation of 1,000 m (3,300 feet) would be expected to be 6°C colder than that in a surface temperature of a well at sea level if the elevation difference were the only factor affecting surface temperatures. For shallow wells, lapse corrections were applied in order to correct mean annual surface temperature to a common elevation (in the table shown, temperatures of all of the holes are reduced to a common elevation

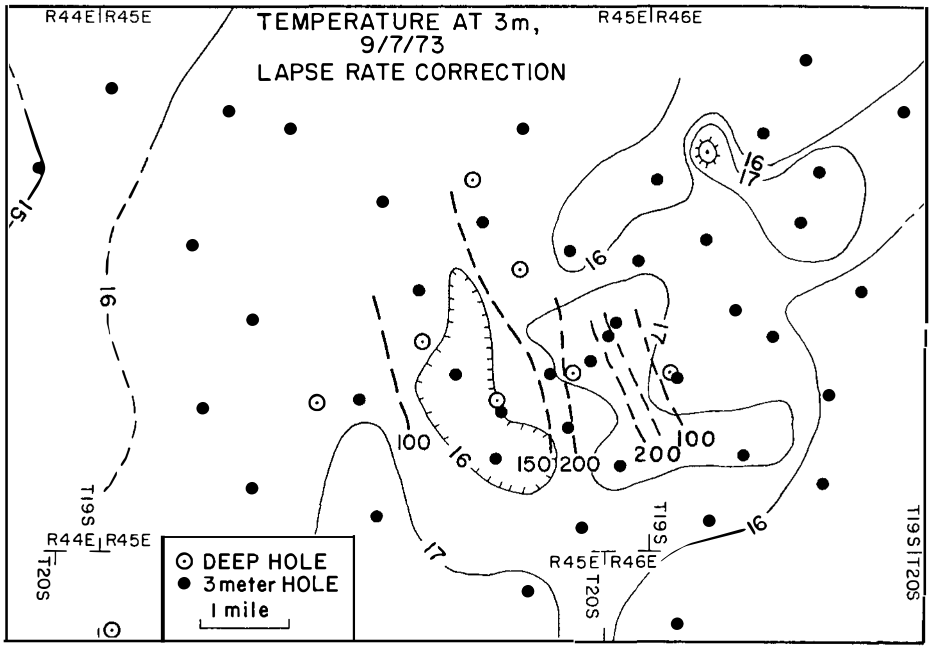


Figure 15. Map of area south of Vale showing contours of temperatures at a depth of 3 meters and locations of all holes drilled for this study. Dashed lines are contours of equal gradient determined from the deep wells.

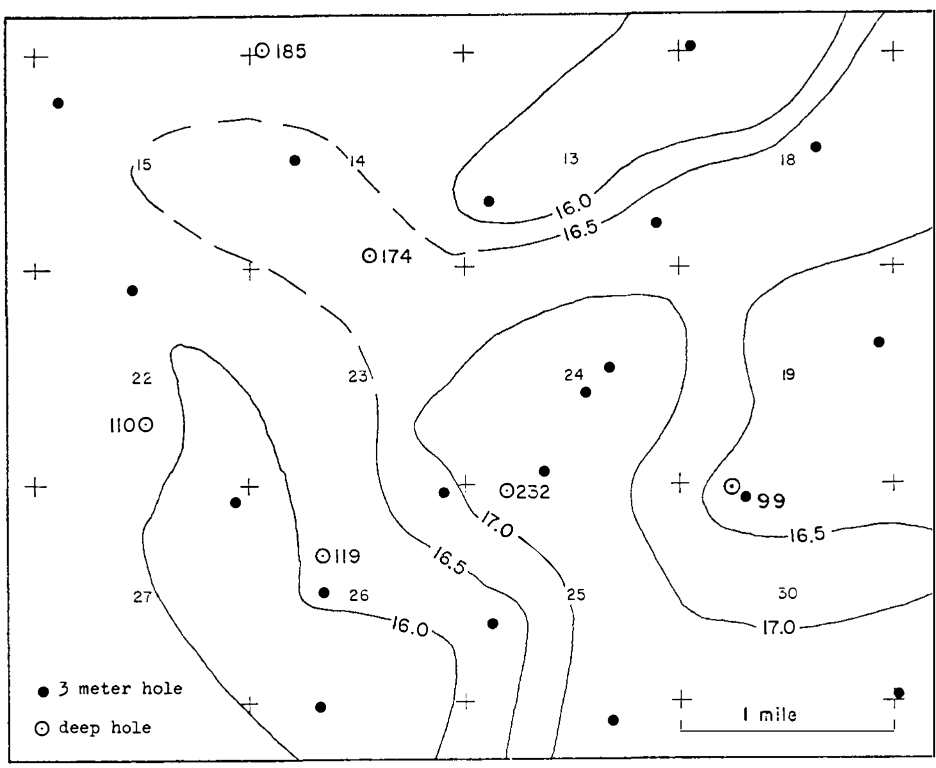


Figure 16. Detailed contour map of temperatures at 3-meter depth, Cow Hollow anomaly area. Locations and observed geothermal gradients for the deeper wells are also shown.

of 811 m (2,660 feet)). Measurements for an individual group of holes were made over a period of one day or, at most, a few days so that the drift in temperatures at various depths due to the solar radiation effect would be minimal. In cases where the temperature measurements span several days, measurements were made in at least one well every day so that drift corrections could be applied, if necessary, to reduce the data to a common day. There has been no attempt to match the temperature data from the different times of measurement using a theoretical temperature-versus-date curve, although in the future we hope to do this for comparison purposes. The current data are significant only in relative terms.

Results from drill holes in the Vale area are shown in Figures 15 and 16. Data shown are the logging of September 7, 1973, corrected for lapse rate and contoured for 3 m (10 feet) values; the locations of the deep drill holes; and the geothermal gradients observed in the deep drill holes. The holes were all drilled in siltstones in the Chalk Butte Formation, where the thermal conductivity, which is directly proportional to heat flow, does not vary laterally among the deeper drill holes. The gradient observed in the deeper holes varies by a factor of 2.5, and a linear zone of very high gradients occurs along the center of the maps. The trend of the geothermal anomaly is approximately NW-SE along the Willow Creek fault zone (Bowen and others, 1975).

The details of the contour maps of temperature measurements vary according to measurement period, depth, and type of reduction applied; however, the basic pattern remains quite stable. Figure 15 covers an area including all 3-m (10-foot) holes drilled south of Vale, while Figure 16 covers in more detail a smaller area around the known geothermal anomaly. Section corners and section numbers are shown in Figure 16. In general, temperature range at 3 m (10 feet) is about 2°C, although three holes have 3-m (10-foot) temperatures below 15.5°C. Temperature variations are generally smooth and can be contoured at 0.5°C intervals (Figure 15). In the detailed map (Figure 16) there might be a correlation between temperature and geothermal gradient, with about 1.5°C change in surface temperature corresponding to a factor of 2 change in heat flow. The 17°C isotherm outside this detailed area does not seem to correlate as well to the geothermal anomaly, however.

Deep hole 19S/46E-30CC was put down where 3-m (10-foot) readings indicated the highest temperature areas. Results of this deep drilling, however, gave heat-flow measurements of less than half the heat flow found a mile west, where 3-m (10-foot) temperature readings were slightly less than at the above drill site (see Figure 16). On the basis of this one deep hole on a shallow anomaly, it appears that shallow temperature measurement is not a satisfactory exploration method.

The general conclusion of our shallow-well study is that use of a much larger rig to drill holes 20 to 30 m (66 to 100 feet) deep would be more cost effective.

SUMMARY AND CONCLUSIONS

The different aspects of this initial heat-flow survey in Oregon have been described in this paper. Two main purposes of the study, to develop information on the subsurface temperature conditions of Oregon and to experiment with different concepts and techniques of obtaining this information, have, we believe, been fulfilled. As a result of this study, knowledge of the geothermal resources in Oregon has been increased beyond that presented by Van Ostrand (1938), Peterson and Groh (1967), and Bowen (1972). Geothermal gradient measurements have been made in 86 holes ranging from 20 to 380 m (66 to 1,250 feet). In 71 of these holes sufficient information has been gathered to make the heat-flow calculations included in Tables 2 and 3. The data obtained from the 6 monitor wells and the 47 shallow wells are useful information on the near-surface thermal conditions under a variety of geologic and climatic conditions. Anomalies identified at Cow Hollow, Willow Creek, Jacobsen Gulch, Coyote Buttes, Glass Buttes, and Thomas Creek may prove, with more study and drilling, to be important energy sources.

Synthesis of this gradient and heat-flow information shows that in much of southeastern Oregon background heat-flow values are about 2.3 HFU but that there are many areas of anomalous heat flow with values in excess of 2.5-3.0 HFU. The background heat-flow values are about normal for the Basin and Range physiographic province of the western United States, which includes most of eastern Oregon, southern Idaho, western Utah, and all of Nevada. Geothermal potential of this region is high because within the last 5 to 10 m.y. the region has been subjected to extensive tectonism, volcanism, and magmatic intrusions.

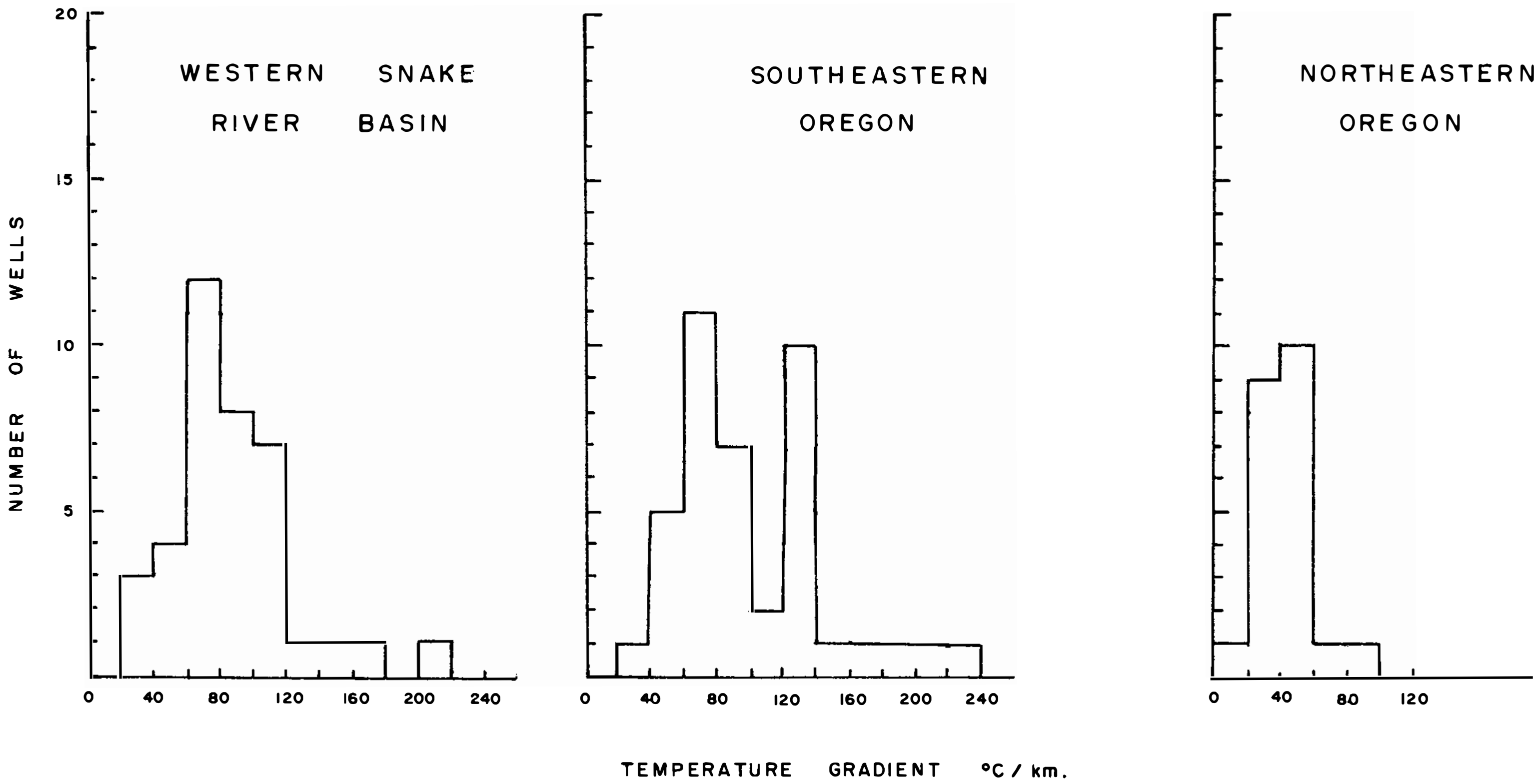


Figure 17. Histograms of geothermal gradients for Western Snake River Basin, southeastern Oregon, and northeastern Oregon.

These processes have caused transfer of much thermal energy from deep-seated sources toward the surface.

Figure 17 is a histogram summarizing geothermal gradients in Oregon east of the Cascade Range where most of the data presented herein were collected. Where more than one geothermal gradient has been observed in a hole, the different gradients have been plotted individually, so that the total number of data points plotted from 90 drill holes is 101. Separate histograms are given for northeastern Oregon, the Western Snake River Basin, and southeastern Oregon, excluding the Western Snake River Basin.

Twenty-two temperature gradient segments in northeastern Oregon range from 14.3 to 90.1°C per km with a median value of 41.2°C per km, excluding some very low gradients caused by water flow in the drill holes. The mean of seven heat-flow values is 1.54 HFU.

Thirty-eight gradients measured in the Western Snake River Basin range from 32.3 to 213.6°C per km with a median value of 79.5°C per km, although the arithmetic mean is 89.6°C per km because of the relatively large number of values exceeding 100°C per km. The arithmetic mean heat flow for the Western Snake River Basin, based on 33 somples of variable quality, is 2.69 HFU.

In southeastern Oregon outside of the Western Snake River Basin temperature gradients range from 30.0 to 232.2°C per km with a median of 88.4°C per km for 37 values measured during this investigation. The mean gradient is 104.1°C per km, and the mean heat flow for 24 holes is 2.64 HFU. The majority of the holes used to calculate the median and mean values described above were predrilled holes such as water wells and mineral exploration holes; and as they were sited in a random manner with respect to possible geothermal resources, the data should be relatively unbiased. There is, however, considerable variation in the quality of these data and they represent a small sample population so that more work will be required to establish reliable values of heat flow for the various geologic provinces in Oregon.

The average geothermal gradient in southeastern Oregon is two to three times the world average for two reasons: most of the lacustrine deposits and basalts in southeastern Oregon have relatively low thermal conductivity and, therefore, a higher geothermal gradient for a given heat flow than do typical crystalline rocks (such as granite) or denser sedimentary rocks (such as shale, limestone, or sandstone); and the heat flow in southeastern Oregon is high. Results of this study imply that temperatures from 50°C to 150°C are found at depths of 1 km (0.6 miles) throughout southeastern Oregon; and if suitable traps and circulation systems are present, temperatures of 150°C to 200°C may occur.

REFERENCES

Blackwell, D. D., 1969, Heat flow determinations in the northwestern United States: Jour. Geophys. Res., v. 74, p. 992-1007.

________, 1971, The thermol structure of the continental crust, *in* The structure and physical properties of the earth's crust: Am. Geophys. Union, Geophys. Mono. Ser., v. 14.

________, 1974, Terrestrial heat flow and its implications on the location of geothermal reservoirs in Washington, *in* Energy resources of Washington: Washington Dept. of Natural Resources, Div. of Geol. and Earth Resources, I. C. 50, p. 24-33.

Bodvarsson, G., Couch, R. W., MacFarlane, W. T., Tank, R. W., and Whitsett, R. M., 1974, Telluric current exploration for geothermal anomalies in Oregon: Ore Bin, v. 36, no. 6, p. 93-107, 6 figs., 1 table.

Bowen, R. G., 1972, Geothermal gradient studies in Oregon: Ore Bin, v. 34, no. 4, p. 68-71.

________, 1975, Geothermal gradient data, State of Oregon: Oregon Dept. of Geol. and Mineral Indus. Open-file Rept. 0-75-3, 133 p.

Bowen, R. G., and Blackwell, D. D., 1973, Progress report on geothermal measurements in Oregon: Ore Bin, v. 35, no. 1, p. 6-7.

________, 1975, The Cow Hollow geothermal anomaly, Malheur County, Oregon: Ore Bin, v. 37, no. 7, p. 109-121.

Bowen, R. G., Blackwell, D. D., ond Hull, D. A., 1975, Geothermal studies and exploration in Oregon: Final draft to U.S. Bureau of Mines: Oregon Dept. Geol. and Mineral Indus. Open-file Rept. 0-75-7. 65 p.

Bowen, R. G., Blackwell, D. D., Hull, D. A., and Peterson, N. V. , 1976, Progress report on heat-flow study of the Brother's fault zone, central Oregon: Ore Bin, v. 38, no. 3, p. 39-46, 2 figs., 1 table.

Brott, C. A., Blackwell, D. D., and Mitchell, J. C., 1976, Heat-flow study of the Snake River Plain region, Idaho: Idaho Dept. Water Resources Water Info. Bull. 30, part 8, 195 p.

Combs, J., and Muffler, L. J. P., 1973, Exploration for geothermal resources, *in* Kruger, P., and Otte, C., eds., Geothermal energy-resources, production, stimulation: Stanford, California, Stanford Univ. Press, p. 95-128.

Couch, R., French, W., Gemperle, M., and Johnson, A., 1975, Geophysical measurements in the Vale, Oregon geothermal resource area: Ore Bin, v. 37, no. 8, p. 125-129, 3 figs.

Geertsma, J., 1971, Finite-element analysis of shallow temperature anomalies: Geophys. Prospecting, v. 19, no. 4, p. 662-681.

Hull, D., 1975, Geothermal studies in the Vale area, Malheur County, Oregon: Ore Bin, v. 37, no. 6, p. 104-106, 1 fig., 2 tables.

________, 1976, Electrical resistivity survey and evaluation of the Glass Buttes geothermal anomaly: Oregon Dept. Geol. and Mineral Indus. Open-file Rept. 0-76-1, 18 p.

Peterson, N. V., and Groh, E. A., 1967, Geothermal potential of the Klamath Falls area, Oregon: a preliminary study: Ore Bin, v. 29, no. 11, p. 209-231, 2 plates, 10 figs., 2 tables.

Poley, J. P. H., and van Stevenick, J., 1970, Geothermal prospecting - delineation of shallow salt-domes and surface faults by temperature measurements at a depth of approximately 2 meters: Geophys. Prospecting, v. 18, Supplement, p. 666-700.

Roy, R. F., Decker, E. R., Blackwell, D. D., and Birch, F., 1968, Heat flow in the United States: Jour. Geophys. Res., v. 73, no. 16, p. 5207-5221.

Sammel, E. A., 1968, Convective flow and its effects on temperatures: Geophysics, v. 33, no. 6, p. 1004-1011.

Sass, J. H., Galanis, S. D., Jr., Munroe, R. J., and Urban, T. C., 1976, Heat-flow data from south-eastern Oregon: U.S. Geol. Survey Open-file Rept. 76-217, 52 p., 19 figs., 4 tables.

Sass, J. H., Lachenbruch, A. H., Munroe, R. J., Green, G. W., and Moses, T. H., Jr., 1971, Heat flow in the western United States: Jour. Geophys. Res., v. 76, no. 26, p. 6376-6413.

Spicer, H. C., 1964, A compilation of deep-earth temperature data, U. S. A. 1910-1945: U. S. Geol. Survey Open-file Rept. 147, 74 p.

Van Orstrand, C. E., 1938, Temperatures in the lava beds of east-central and south-central Oregon: Am. Jour. Sci., 5th ser., v. 35, no. 205, p. 22-46.

Walker, G. W., 1974, Some implications of late Cenozoic volcanism to geothermal potential in the high lava plains of south-central Oregon: Ore Bin, v. 36, no. 7, p. 109-119, 2 figs., 1 table.

Walker, G. W., Peterson, N. V., and Greene, R. C., 1967, Reconnaissance geologic map of the east half of the Crescent quadrangle, Lake, Deschutes, and Crook Counties, Oregon: U. S. Geol. Survey Map I-493.

GLOSSARY OF TERMS USED IN THIS REPORT

Anomaly: Deviation from the common or departure from the normal. In mineral exploration an anomaly means a higher than normal concentration of whatever substance is being sought. For geothermal exploration an anomaly is generally considered to exist when either heat flow or geothermal gradient is twice the normal value.

Calorie: Unit of heat in the cgs system. The quantity of heat required to raise the temperature of one gram of water from 15° to 16° on the Celsius (centigrade) scale.

Conduction: (K) The transfer of heat by passing heat energy from adjacent molecules, similar to the manner by which electricity is conducted along a wire. The transfer of heat through rock by excitation of adjacent molecules. A measurement of conductivity is the heat transferred in 1 second through a layer of the substance 1 cm thick, the difference in temperature between these faces being 1 degree Celsius (centigrade).

Convection: The transfer of heat by moving the mass of material, as when steam or hot water is carried in a pipe. In a geothermal convection system hot water or steam travels upward and, because of its lighter weight and greater buoyancy, displaces the cooler water which sinks toward the bottom of the system.

Crust: The outermost layer of the rocks that make up the structure of the earth. Crust varies in thickness in oceanic areas from 5 to 20 km and under continents from 20 to 100 km. It is underlain by the mantle.

Flux: The flow: the geothermal flux is the continual flow of heat energy from within the earth; the solar flux is the flow of solar energy or radiation from the sun.

Fumarole: A natural orifice from which high-temperature gaseous fumes are emitted. In most cases water vapor far exceeds all other constituents, which often include carbon dioxide and sulfurous gases. Fumaroles commonly occur in volcanic areas.

Geothermal gradient (G): The increase of temperature with penetration in the earth normally expressed in °C per km. The world average rate of increase of temperature with depth is approximately 30°C per km. In geothermal work the term temperature gradient is often used interchangeably with geothermal gradient.

Heat flow (Q) and (HFU): The transfer of heat by any means from one area to another. In geothermal work it is the transfer of heat energy from within the earth to space. It is the product of geothermal gradient (G) and rock conductivity (K) expressed in mcal per cm^2 per sec. Heat flow is sometimes expressed as watts per m^2: 1 HFU = 4.19×10^{-2} W per m^2.

HFU: A heat-flow unit as described above.

Hot spring: A naturally discharging spring with water at a temperature around 10°C greater than normal ground waters in the area.

Log: A record of measurements; a temperature log is a record of temperatures at various depths.

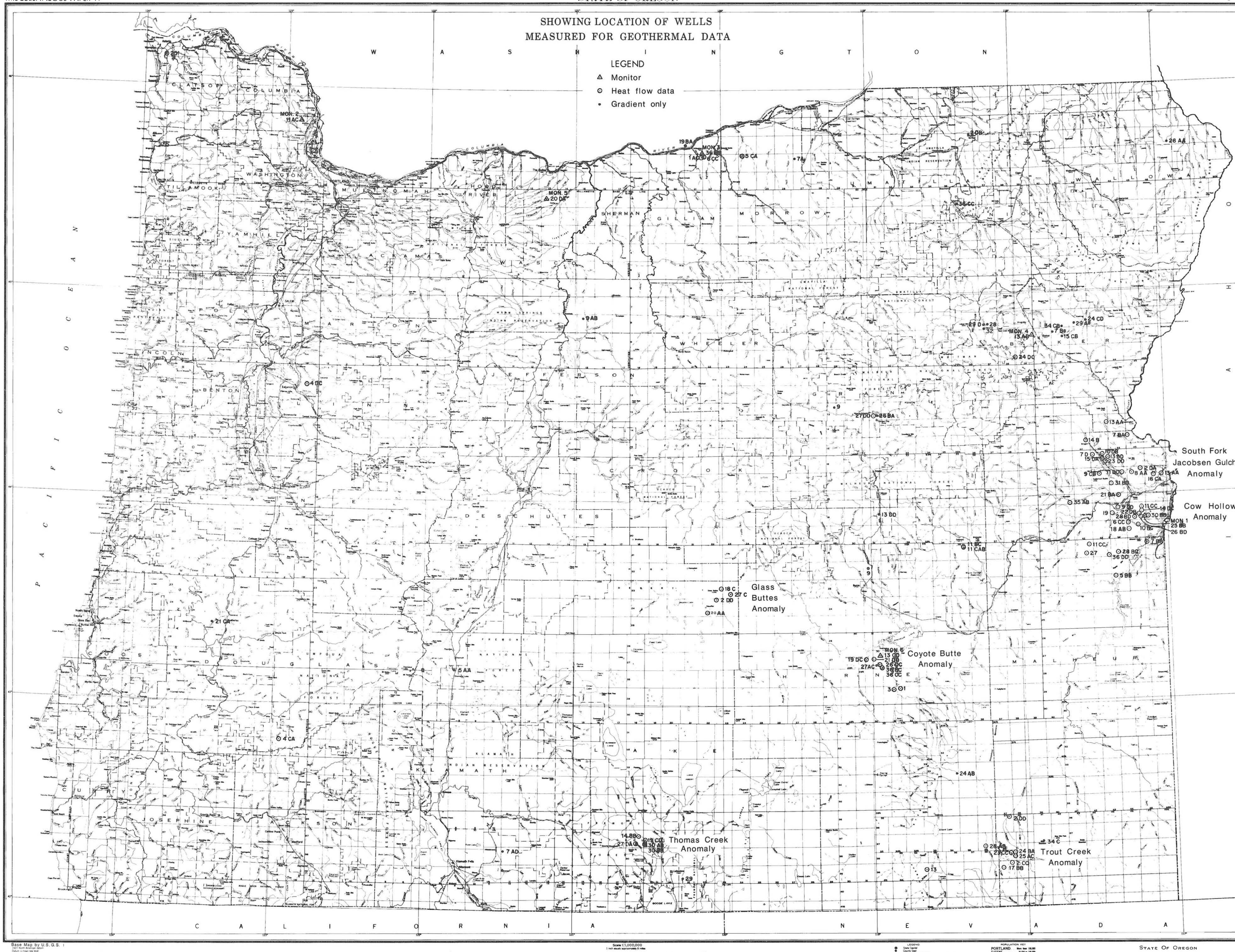
Mantle: That segment of the layered structure of the earth that underlies the crust.

Piezometric level: An imaginary surface that coincides everywhere with the static level of the water in the aquifer.

Radiation: The transmission of energy or light in the form of electromagnetic waves or discrete particles. All solar energy travels to the earth by radiation.

Telluric currents: Natural electric currents that flow on or near the earth's surface. Methods have been developed for using these currents to make electrical resistivity surveys.

Temperature gradient (G): The rate of increase of temperature. In geothermal studies, the term is used interchangeably with geothermal gradient and is expressed in the same units, °C per km.



STATE OF OREGON
DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES
RALPH S. MASON, STATE GEOLOGIST