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DRAFT FINAL REPORT

GEOTHERMAL STUDIES AND EXPLORATION IN OREGON

OREGON DEPARTMENT OF GEOLOGY AND MINERAL INDUSTRIES

SUPPORTED BY U.S. BUREAU OF MINES
CONTRACT NO. S0122129

By

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1975

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ABSTRACT

This report presents a compendium of geothermal data on the State of Oregon gathered under U.S. Bureau of Mines Study Contract S0122129. Included in the study are data from six monitor wells located in areas with differing geographic, geologic, and climatic conditions. Temperatures were recorded at depths ranging from 1 to 25 meters for periods of time sufficiently long to show the patterns of seasonal variations. Graphs from these six locations show changes in temperature with depth and changes of temperature with time. A total of 140 shallow (3-8 meter) holes were drilled to show the shallow-temperature field over an anomaly identified by deeper (62-152 meter) drilling. Shallow-temperature conditions are also shown for several areas in southeastern Oregon. Eighty geothermal gradients were measured in pre-drilled holes. Thirty-one heat-flow determinations are reported, including those from five bore holes drilled as a part of the study. Geothermal data gathered has so far resulted in the identification of six areas of anomalously high heat flow. Further studies are underway on several of these anomalies. Data in the report are presented in the form of text, graphs, tables, and maps.

GEOTHERMAL STUDIES AND EXPLORATION IN OREGON

INTRODUCTION

Study goals

In 1972, the Oregon Department of Geology and Mineral Industries began a study to locate geothermal resources utilizing various heat-flow techniques. During the period of this study, ending June 30, 1975, several previously unknown areas of high heat flow and geothermal potential were identified. In addition, a better understanding of regional heat-flow patterns was obtained and a comprehensive set of data on shallow-temperature fields was developed in several parts of the State.

This report summarizes the nature of the work done, presents the data gathered, and discusses the findings. It also lists published articles and open-file reports that have already presented some of the results of this study.

Gathering the data for this study involved four types of activities:

1. Pre-drilled bore holes were located and temperatures logged; data gathered through October 1974 was placed on open file as Department Open-File Report 0-75-3.
2. Six monitor wells situated in a wide range of climatic and geologic environments, were located, cased, and logged for annual temperature change.
3. 140 shallow bore holes ranging from 3 to 8 meters were drilled in widely scattered locations in eastern Oregon to determine their shallow-temperature conditions.
4. Five bore holes were drilled from 62 to 152 meters in depth to verify trends found in the shallow holes and to confirm trends picked up from other phases of the study.

Development of methods

After the inception of the program, it became necessary, or desirable, to modify some of the methods for accomplishing the goals. For example, we purchased a set of temperature-logging equipment since none was available for rent as had been anticipated. Later, experience showed that logging with high-quality portable equipment was much preferable to implanting permanent instrumentation in the monitor holes as originally intended. A third change in the program was in the method of siting the five holes for deep drilling. An early concept was to site the deep bore holes from information obtained by drilling many shallow holes. As the study progressed, we found that pre-drilled bore holes (water wells and exploration holes) provided far better information than shallow holes. For this reason, and because of delays in obtaining permits to drill on Federal land, the information that was developed from pre-drilled holes was the basis for locating all but one of the bore-hole sites.

As an addition to this study, financial support of $2,000 was provided the Geophysical Research Group, Department of Oceanography, Oregon State University, to obtain telluric current data. Because telluric currents are strongly affected by the Earth's thermal field, this work was complimentary to the overall goals of the program and resulted in publication of an east-west profile across the State (see No. 7 of papers listed below).

Progress of study

As the study progressed and information relating to specific facets of the program was gathered, progress reports were issued from time to time. One of these reports (See No. 1 below) listed gradients and heat flow for several of the pre-drilled bore holes, the most interesting of which was the Cow Hollow anomaly discussed in the next section. The progress reports on the study are as follows:

1. Bowen, R.G., Blackwell, D.D., 1973, Progress report on geothermal measurements in Oregon: Ore Bin, Vol. 35, No. 1, p. 6-7.
2. Blackwell, D.D., Bowen, R.G., 1973, Heat flow and Cenozoic tectonic history of the northwestern United States: Cordilleran Section Meeting, Geological Society of America, Portland, Oregon, March 1973 (Abstract).
3. Bowen, R.G., Blackwell, D.D., 1973, Heat flow in the State of Oregon: Fall Annual Meeting American Geophysical Union, San Francisco, Calif., December 1973 (Abstract).
4. Bowen, R.G., 1974, Oregon geothermal study program: Oregon Academy of Science, Eugene, February 23, 1974 (Abstract).
5. Fisher, Deborah, 1974, An estimate of southeast Oregon's geothermal potential: Fall Annual Meeting American Geophysical Union, San Francisco, Calif., December 1974 (Abstract).
6. Oregon Department of Geology and Mineral Industries Open File Report 0-75-3, Geothermal Gradient Data.
7. Bodvarsson, G., Couch, R.W., Mac Farlane, W.T., Tank, R. W. and Whitsett, R.M. 1974, Telluric current exploration for geothermal anomalies in Oregon: Ore Bin Vol. 36, no. 6, p. 93-107.
8. Bowen, R.G. and Blackwell, D.D., 1975, The Cow Hollow geothermal anomaly: Ore Bin, Vol. 37, no. 7, p. 109-121.
9. Blackwell, D.D. and Bowen, R.G., 1975, Geothermal measurements in the Western Snake River Plain, Oregon: (in preparation)

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 Fisher helped immeasurably in the gathering, reduction, and intrepretation of data. Alan Preissler served as principal field assistant for 2 years, doing an excellent job of whatever task assigned. The success achieved in locating and in measuring gradients in pre-drilled 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.

Mr. Walter Lewis, Bureau of Mines Contracting Officer, was very helpful, particularly in working as liaison with other Federal agencies.

GEOTHERMAL ANOMALIES

Several areas have been located where temperature gradients appear to exceed, by a factor of at least 0.5, what is considered to be the normal gradient for tuffaceous sediments in the region —60°C/km. The anomalous areas, shown on Plate 1 are as follows:

Cow Hollow anomaly (Figure 1)

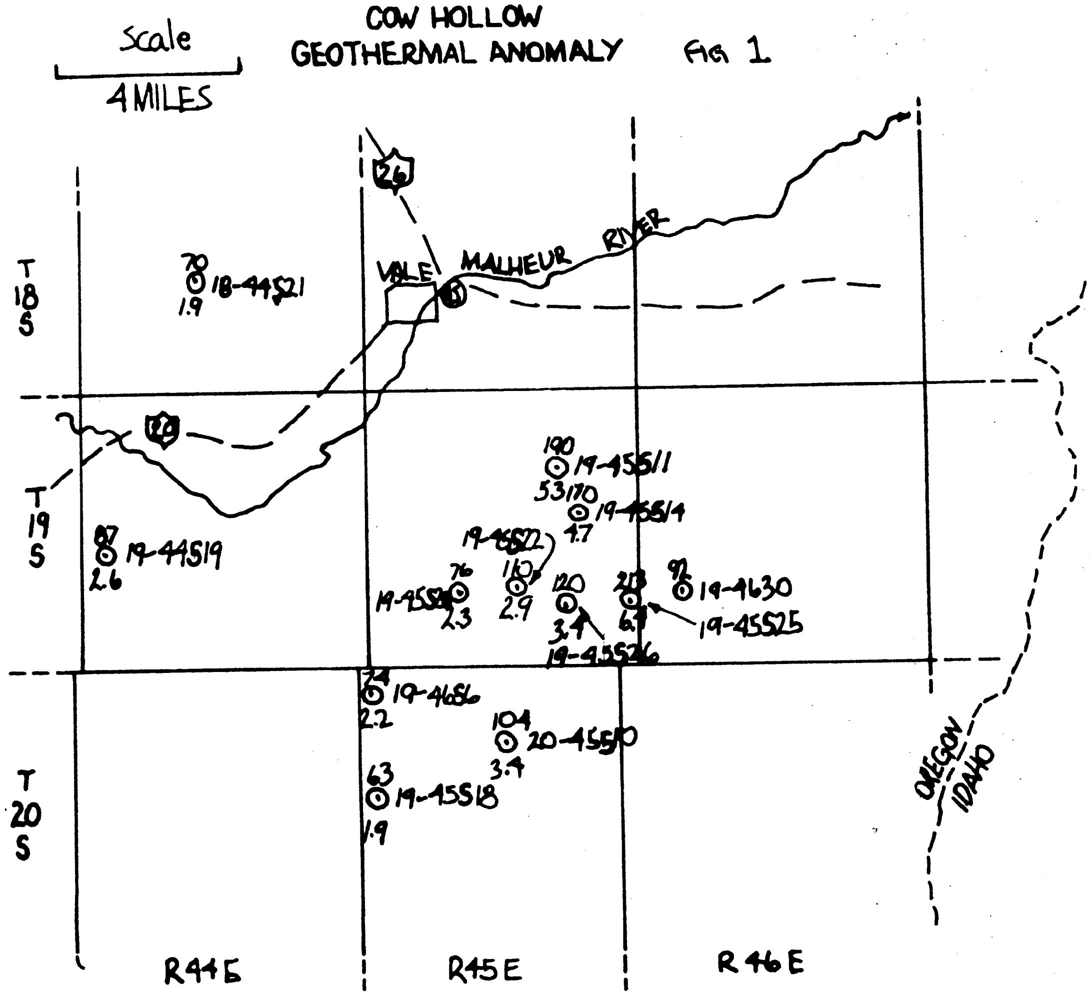
A report on the Cow Hollow anomaly, prepared for the July, 1975 Ore Bin, is included in the appendix, but a summary is presented here.

The Cow Hollow anomaly, covering an area of at least 18 square miles, is located about 7 miles southeast of Vale, Oregon. Within the area, heat-flow values range between 2.3 and 6.4, from slightly above to more than three times normal for the region. The anomaly appears to be on a fault zone paralleling the general regional structural trend of the Snake River Downwarp. The faulting is believed to have displaced permeable reservoir rocks against impermable lacustrine sediments causing a structural trap and preventing further migration of the geothermal fluids. The anomaly is believed to reflect the presence of an accumulation of these fluids.

Willow Creek anomaly (Figure 2)

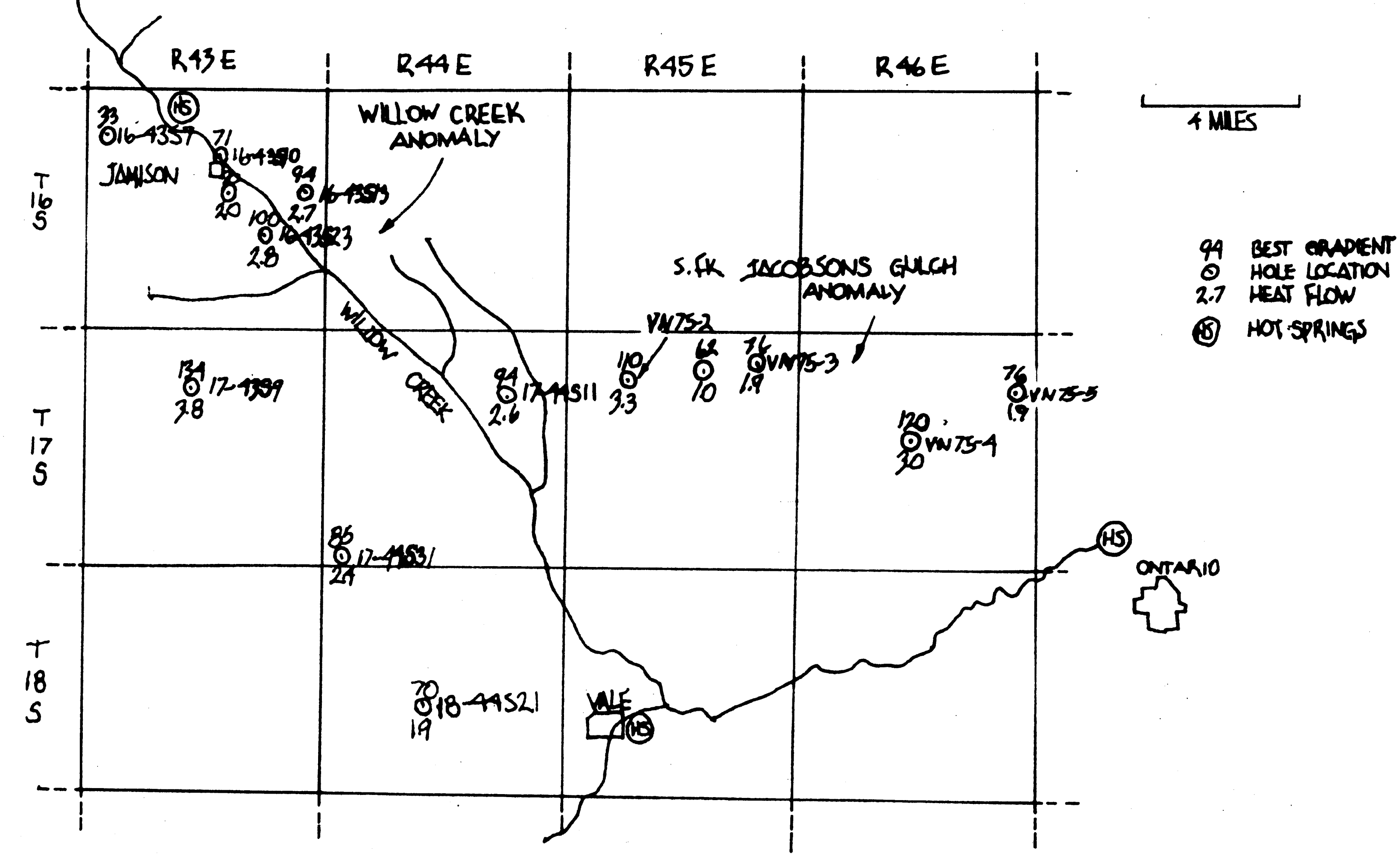
The Willow Creek anomaly is centered about 10 miles northwest of Vale and is possibly a continuation of the Cow Hollow anomaly, southeast of Vale. Its presence is manifested by measurements in four water wells with gradients greater than 90°C/km. Heat-flow values range from 2 to 3.8 HFU. The value of 3.8 in bore hole 17-43S9 is considered less reliable than the other values because the hole is only 35 meters deep. This anomaly is probably associated with the Willow Creek fault zone reported in the paper on the Cow Hollow anomaly. Table 10 gives the geothermal data for this region.

COW HOLLOW
GEOTHERMAL ANOMALY Fig 1



WILLOW CR. - SOUTH FK. JACOBSON GULCH GEOTHERMAL ANOMALIES

FIG 2



Jacobsen Gulch anomaly (Figure 2)

The Jacobsen Gulch anomaly was located by the DOGAMI drilling program and may be an extension of the Willow Creek anomaly to the west. In this anomaly two bore holes about 7 miles apart show high readings. Hole 17-45S8 encountered warm (24°C) water at 105 feet, which probably indicates the presence of heat transfer by convection rather than conduction and makes the value of this heat-flow reading of questionable value. The bore holes drilled farther east, all in impermeable sediments, showed no signs of convection, indicating that the heat-flow measurements are reliable. Table 11 gives the geothermal data for this region.

Trout Creek anomaly (Figure 3)

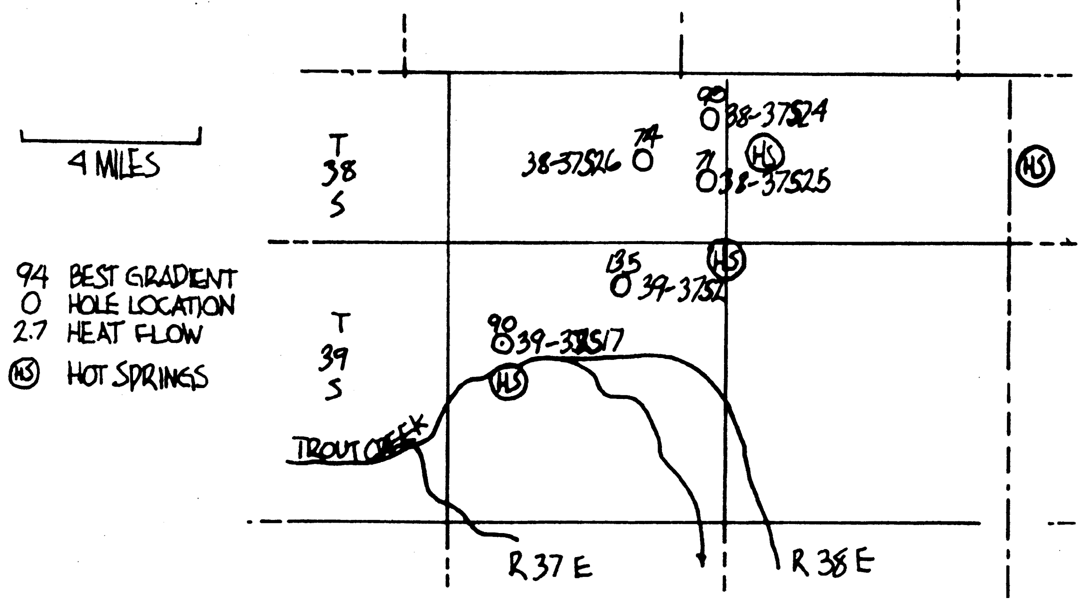
The Trout Creek anomaly was located in bores drilled during a uranium exploration program in the region. The holes logged ranged in depth from 50 to 150 meters. Several near-by warm springs also indicate the presence of heat in this region. Table 9 lists the geothermal data for this region.

Coyote Buttes anomaly (Figure 4)

At the Coyote Buttes anomaly, five bore holes, also drilled for a uranium exploration program, have gradients of 120°C/km and greater. There are several hot springs nearby at or near Harney Lake. Temperature gradients in the bore holes indicate that the heat source continues under the hills to the east of the Lake. This trend is located on the Brothers fault zone (described by Walker, 1974). Since cuttings or cores were not available from this site, no heat-flow determinations were made; however, the lithology is very similar to the other lacustrine tuffaceous sediments in east-central Oregon which have shown conductivities in the range of 2.6 to 2.8. Thus, heat-flow values in the Coyote Butte anomaly range between 3.1 and 4.2 HFU. Table 9 gives a listing of geothermal data for this region.

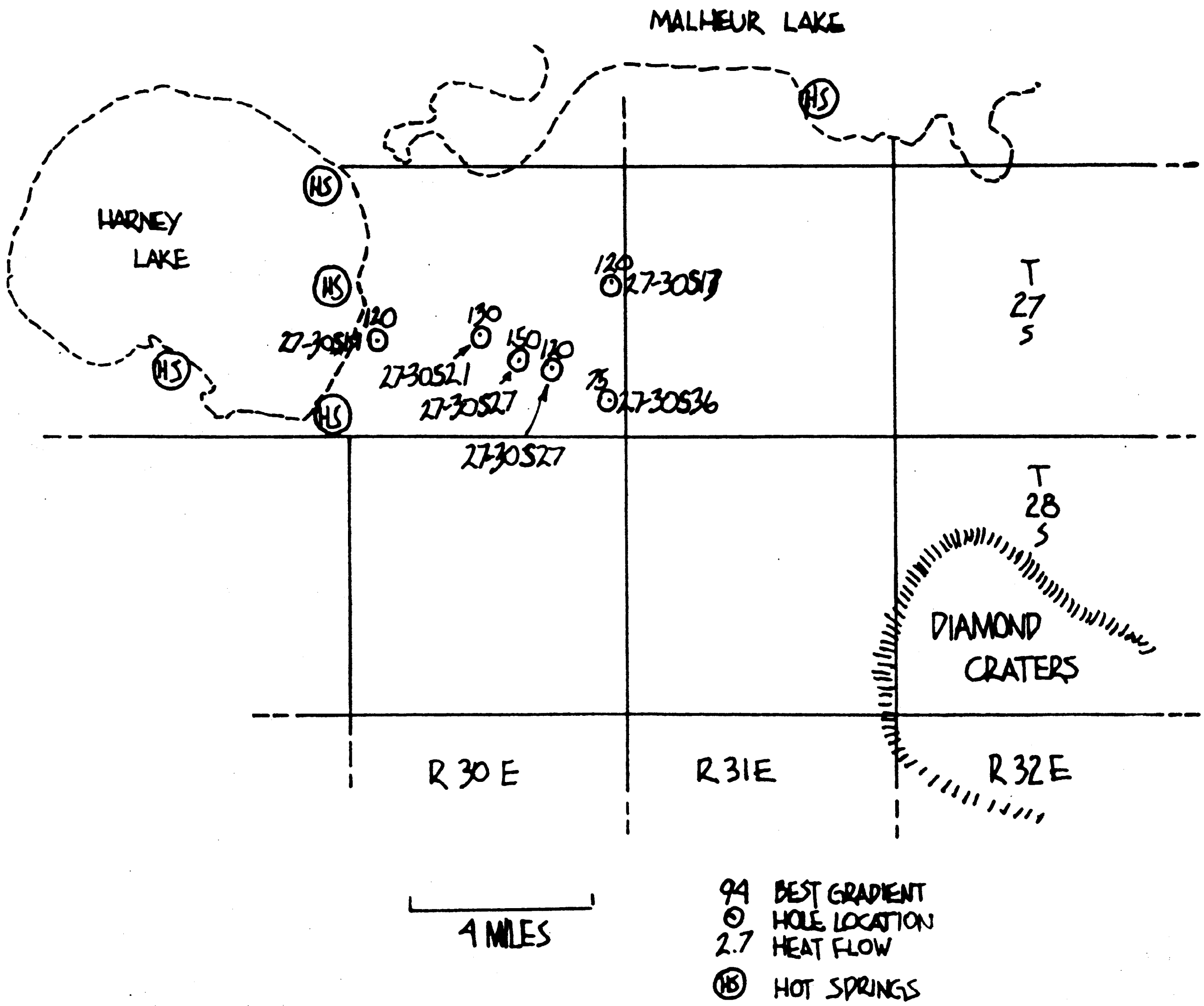
TROUT CREEK
GEOTHERMAL ANOMALY

FIG 3



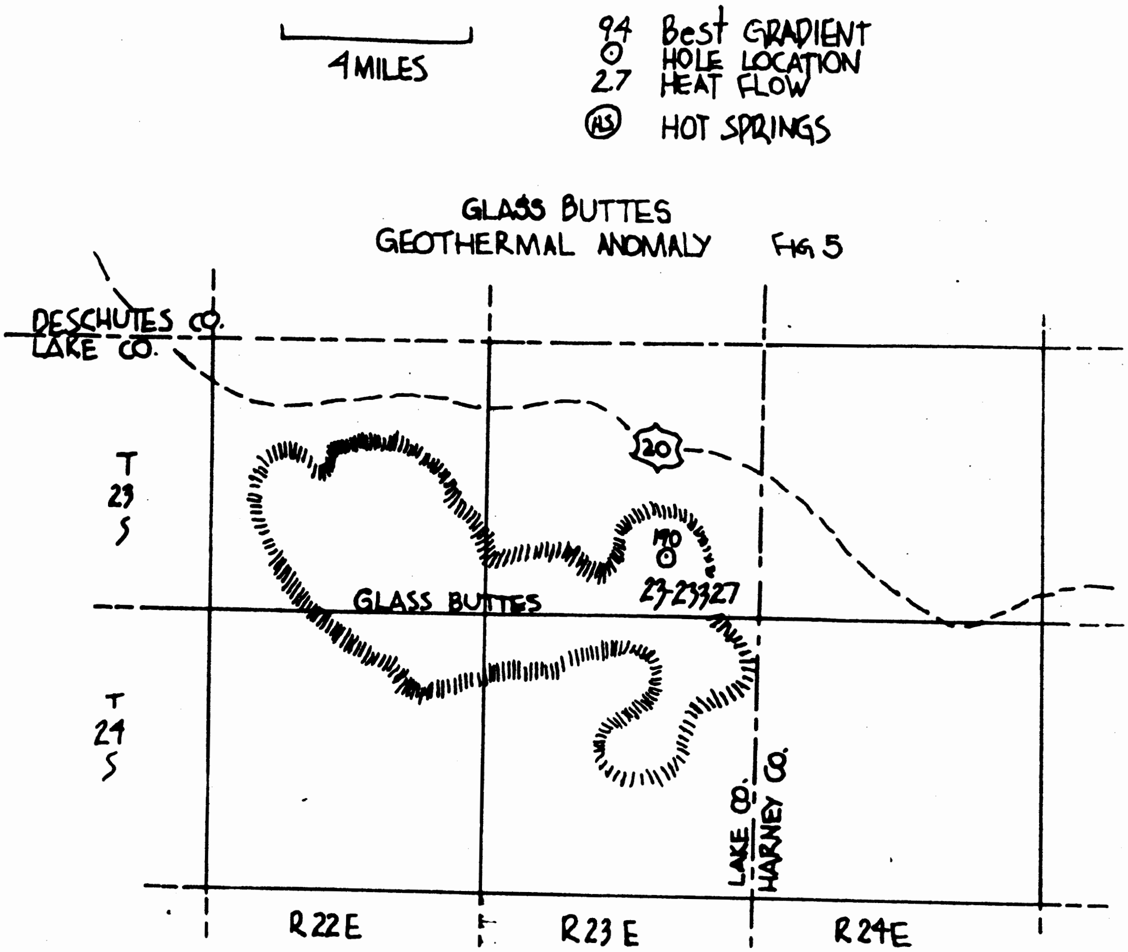
COYOTE BUTTE
GEOTHERMAL ANOMALY

FIG 4



Glass Buttes anomaly Figure 5)

The Glass Buttes anomaly was located by logging a pre-drilled water well. The area, also located on the Brothers fault zone, is interpreted by Walker, Peterson, and Green (1967) to be a complex of silicic volcanic vents and domes. Extensive hydrothermal alteration has produced an opalite zone containing disseminated mercury mineralization. There are no thermal springs in the area, but the well has water at 48°C (118°F) at a depth of 220 meters and an average gradient of 190°C/Km. This high gradient combined with the location of the Buttes on the Brothers fault zone appear to make the area an attractive geothermal prospect.


4 MILES
94 Best GRADIENT
HOLE LOCATION
27 HEAT FLOW
HOT SPRINGS
GLASS BUTTES
GEOTHERMAL ANOMALY
FIG 5
DESCHUTES CO.
LAKE CO.
20
T
23
S
T
24
S
GLASS BUTTES
23-23-27
LAKE CO.
HARNEY CO.
R22E
R23 E
R24E

MONITOR WELLS

Methods

One of the goals of this study was to work on methods of identifying geothermal anomalies at shallow depths where solar radiation has greater effects on temperature of rock than does geothermal heat flow. At the surface the solar heating component can amount to several thousand times the geothermal component, diminishing with depth to a point where it no longer is 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 as an adjunct to the geothermal study program.

Six monitor wells in different parts of the State were chosen to sample the effects of various climatic, geographic, and geologic conditions on heat flow. Well availability and accessibility were also facotrs in choice of sites. Approximately once a month the temperatures at 1, 2, 3, 5, 7½, 10, 15, 20 and 25 meters were taken in each hole. In all of the wells chosen for 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 the more rapid taking of measurements. At several sites, however, surface cooling of water during cold months produced a high gradient which caused convection and affected the acurracy of the measurements. This was remedied by bailing out 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 log graph paper and interpolated to infinite time. This method proved satisfactory in giving the best temperature at a particular depth. An error of ½ meter on the cable markings was discovered in November 1972 after well monitoring began; therefore all measurements prior to that date were taken at 1½, 2½, 3½, etc. meters and those after that date were at 1, 2, 3, etc. meters.

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 and are believed to be inaccurate. Two plots are shown for each monitor well: one for temperature vs depth at different periods of time and the other 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-meter and 5-meter temperature vs time plots.

Descriptions of monitor well sites

Monitor 1, Vale, Oregon: Sec 25, T 19 S, R 45 E, Malheur County, elev. 2667 feet (813 M) (Table 1, Figure 6). This was an abandoned mineral exploration well that was relocated and logged to a depth of 70 meters. Plastic pipe was set to a depth of 26 meters and filled with water. This well has the highest gradient of any located during the course of the study (214° C/km; HFU 6.4 with topographic correction). Geologically the area is on the west flank of the Snake River Basin. Rocks at the surface and presumably to a depth of about 800 to 1000 meters are tuffaceous claystone, siltstone, and minor sandy and conglomeritic interbeds. Mean annual surface temperature in the well area is about 13°C. The U.S.

Weather Bureau reports the average monthly temperature to range between -2° and +24°C. This wide variation is reflected in the shallow readings, with the 1-meter readings changing nearly 20° and the 2-meter readings changing more than 12°. Temperature variations are significantly damped by 10 meters, and by 20 meters they probably reflect reading errors more than true variation.

Monitor 2, Warren Oregon: Sec 11, T 4 N, R 2 W, Columbia County, elev. 480 feet (146 M) (Table 2, Figure 7). This well was drilled by the Department of Geology and Mineral Industries to 17 meters and a sealed plastic casing was set to T.D. The well is in an area of very low heat flow and has a geothermal gradient about 10°C/km. The rock type is deeply weathered basalt that has become laterized. Average annual temperature in the vicinity of the well appears to be about 10°C with the monthly temperatures for the region averaging between 2° and 20°. 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 meter has a total variation of nearly 9°; at 2 meters it varies 4° and at 5 meters it varies less than 1°.

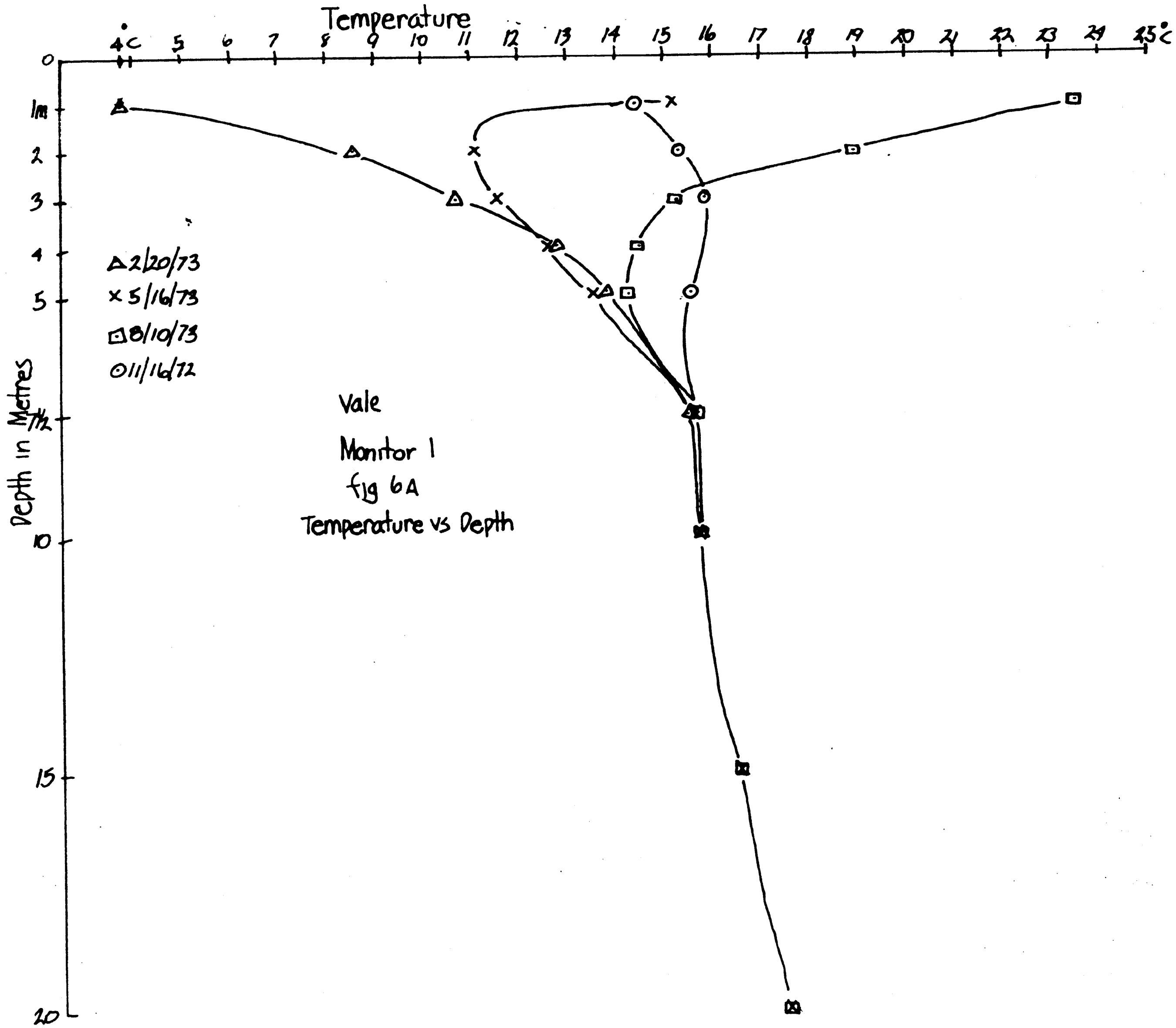
Monitor 3, Arlington, Oregon: Sec 1, T 2 N, R 21 E, Gilliam County, elev. 740 feet (226 M) (Table 3, Figure 8). This well was drilled and cased with plastic pipe to a depth of 125 meters as a foundation test for an electric power generating plat. Regionally the area is a part of the Umatilla Plateau. The rocks encountered in the bore hole were tuffaceous lacustrine sediments of the Selah Formation to a depth of 110 meters overlying Columbia River Basalt. The geothermal gradient in the bore hole is about 62°C/km. The site is located on a sage-covered flat, average surface temperature is about 14°C, and monthly averages range between 0° and 24°C.

Annual variation at a depth of 2 meters is about 11°, at 5 meters it is damped to 3°, and at 10 meters it is less than 1°.

Monitor 4, Baker, Oregon: Sec 13, T 9 S, R 39 E, Baker County, elev. 3500 feet (1067 M) (Table 4, Figure 9). This hole was drilled to 72 meters as a water well. It is cased to total depth, and the water level stands at 7 meters. No change was detected in the water level during the time it was logged. The site is located in alluvium in the Baker Valley, at the foot of the Elkhorn Mountains. At present and during the recent past the area has been an open field. Average surface temperature is about 10°C with monthly average variation between -4° and 22°C. At a depth of 2 meters the yearly range is about 10°, at 5 meters it is 2° and at 10 meters it is 0.25°.

Monitor 5, Dufur, Oregon: Sec 20, T 1 S, R 13 E, Wasco County, elev. 1160 feet (354 M) (Table 5, Figure 10). Drilled and cased as a water well to 135 meters. Standing water level was at 55 meters so all measurements were made in air. The well has a geothermal gradient of 54°C/km to the water table where it decreased to about 3°C/km to total depth. The bottom part of the hole represents convective heat transfer. The well is drilled in basalt near the edge of an alluvial filled valley. Average annual temperature is about 13°C with monthly average variations between 0° and 20°C. At a depth of 2 meters the yearly range is about 10°, at 5 meters it is 2°, and at 10 meters it is less than 0.5°.

Monitor 6, Burns, Oregon: Sec 13, T 27 S, R 30 E, Harney County, elev. 4180 feet (1274 M) (Table 6, Figure 11). Drilled for mineral exploration to a depth of 130 meters. A plastic casing sealed at the bottom is set to 25 meters. Standing water level reported at 20 meters. The upper 70 meters of this hole shows a gradient of 120°C/km, and about 70°C/km


Temperature
4°C 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25°C
0
1m
2
3
4
5
7½
10
15
20
Depth in Metres
△ 2/20/73
× 5/16/73
⊡ 8/10/73
⊙ 11/16/72
Vale
Monitor 1
fig 6A
Temperature vs Depth

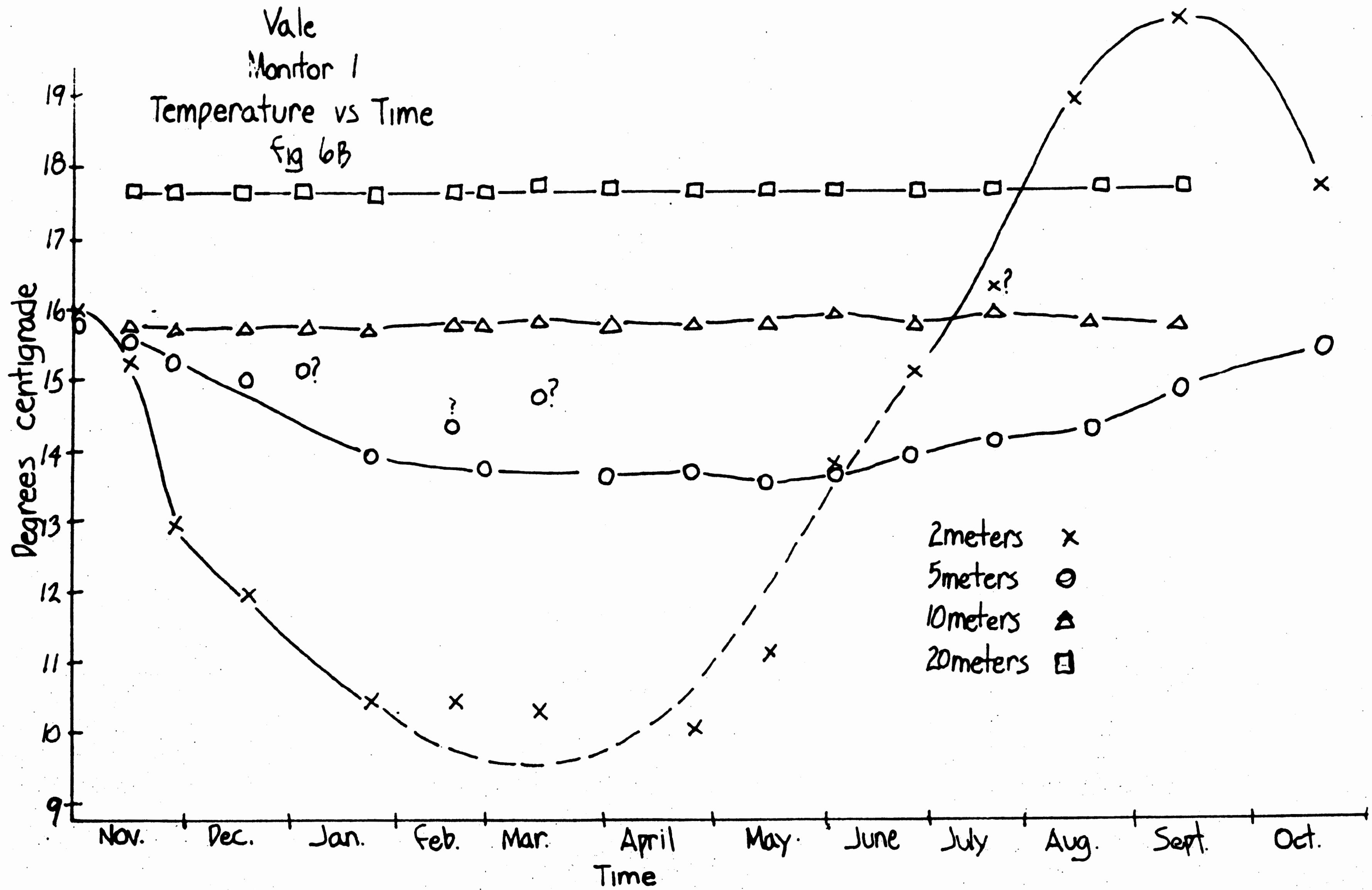

Vale
Monitor 1
Temperature vs Time
fig 6B
Degrees centigrade
19
18
17
16
15
14
13
12
11
10
9
Nov.
Dec.
Jan.
Feb.
Mar.
April
May
June
July
Aug.
Sept.
Oct.
Time
2meters ×
5meters o
10meters △
20meters □

Table 1. Data from monitor well 1, Vale

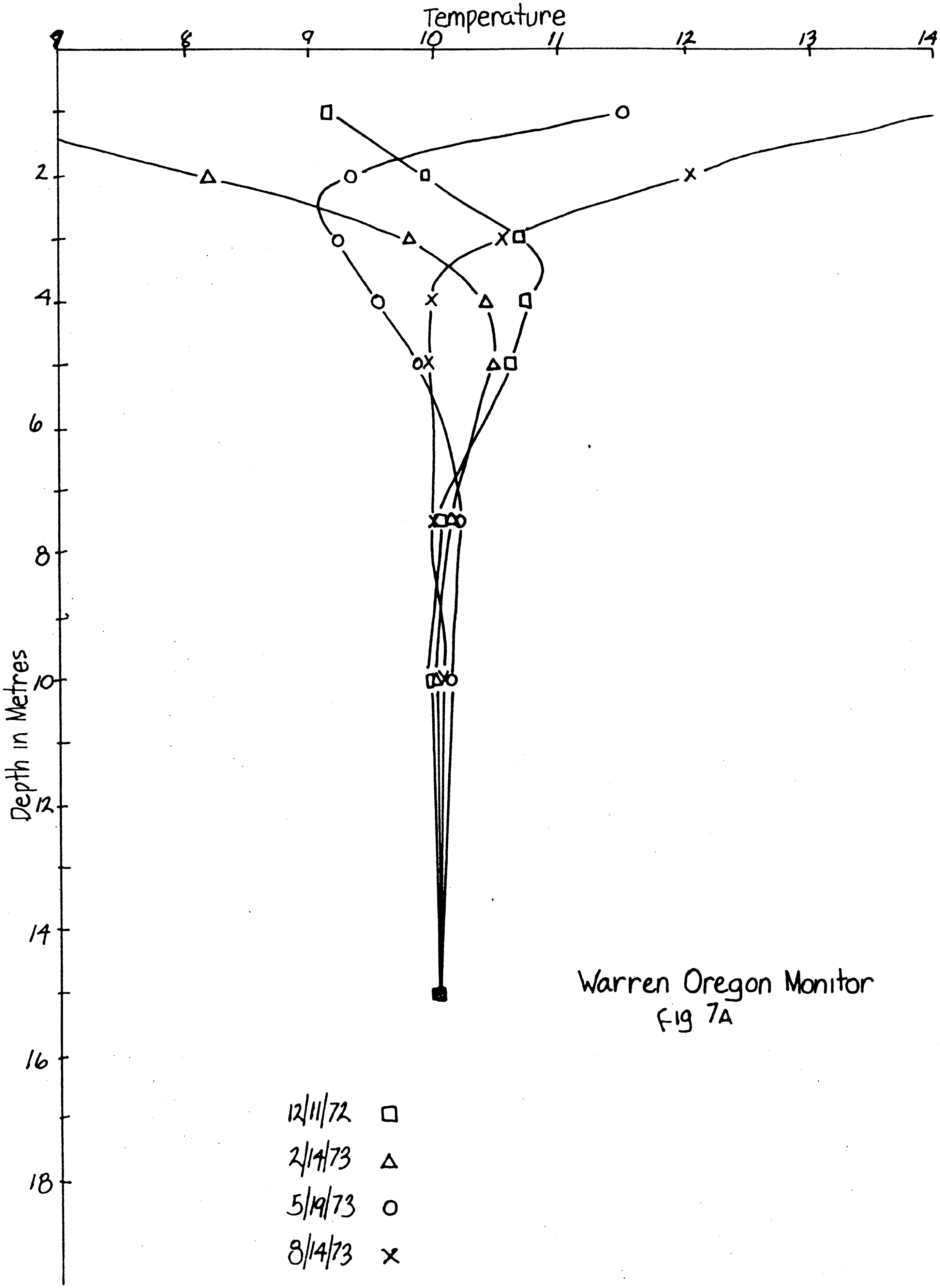
Date Logged	Mean Monthly Air Temp.	1½m	2½m	3½m	4½m	5½m	10½m	15½m	20½m	25½m
9/7/72	14.5			15.97		14.69	15.43			
9/26/72	14.5	18.76	18.05	16.41	15.91	15.06	15.65	16.75	17.61	18.31
10/3/72	11.17	18.38	18.33	16.96	15.66	15.11	15.64	16.73	17.67	18.15
10/10/72	11.17	18.25	17.78	16.65	15.48	15.10	15.68	16.84	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 °C

Monitor well 1, Vale: page 2

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



Warren Oregon Monitor
Fig 7A

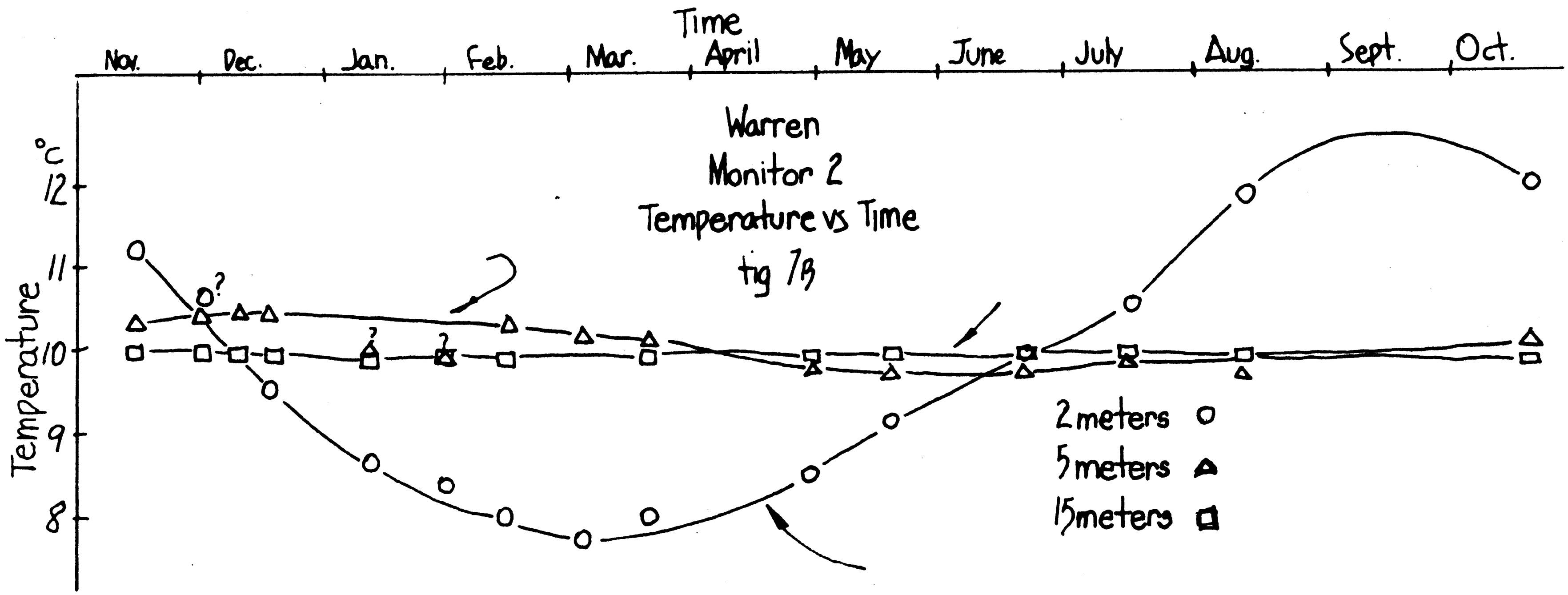

Time
Nov.
Dec.
Jan.
Feb.
Mar.
April
May
June
July
Aug.
Sept.
Oct.
Warren
Monitor 2
Temperature vs Time
fig 7B
°C
12
11
10
9
8
Temperature
2 meters
5 meters
15 meters

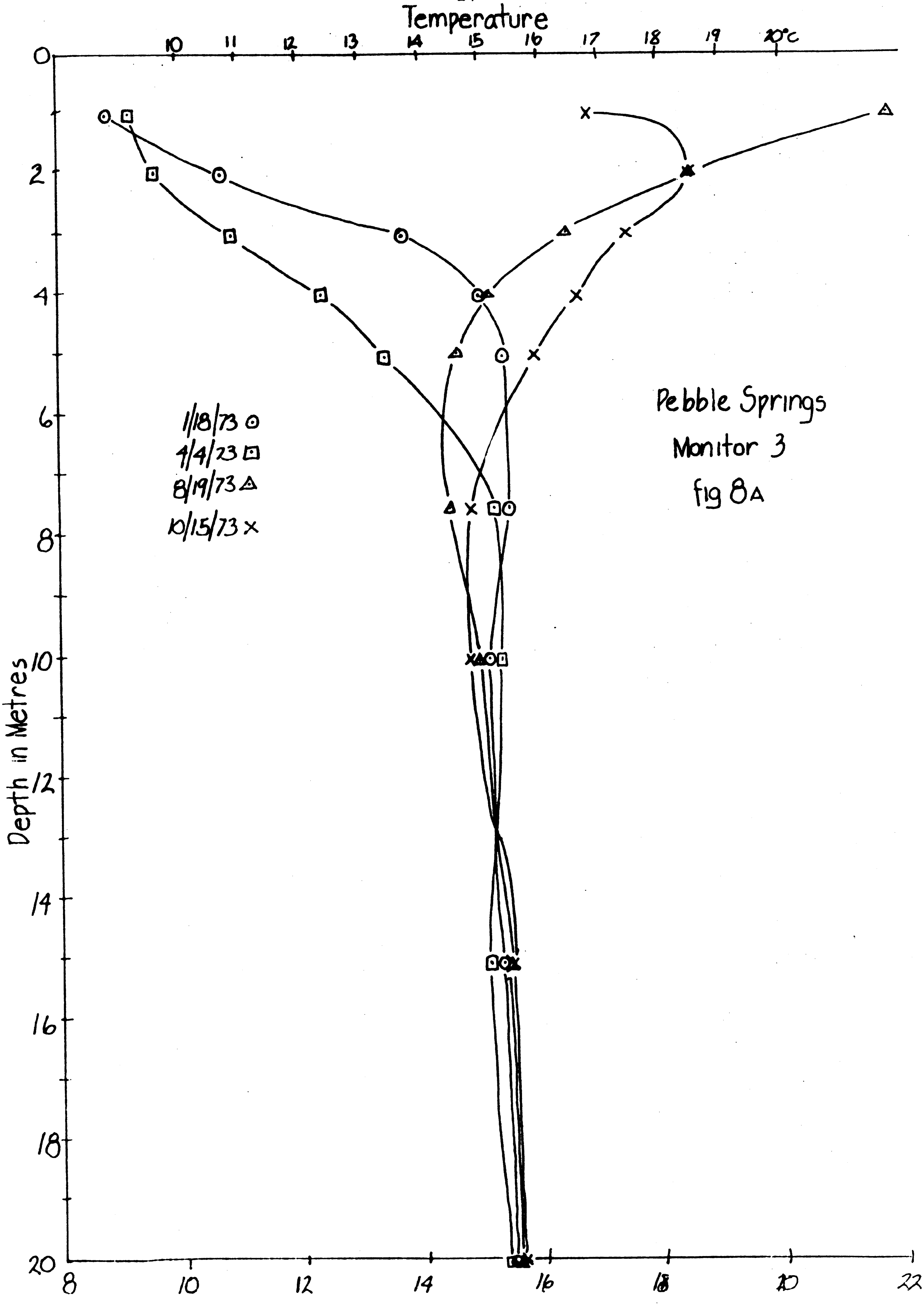
Table 2. Data from monitor well 2, Warren

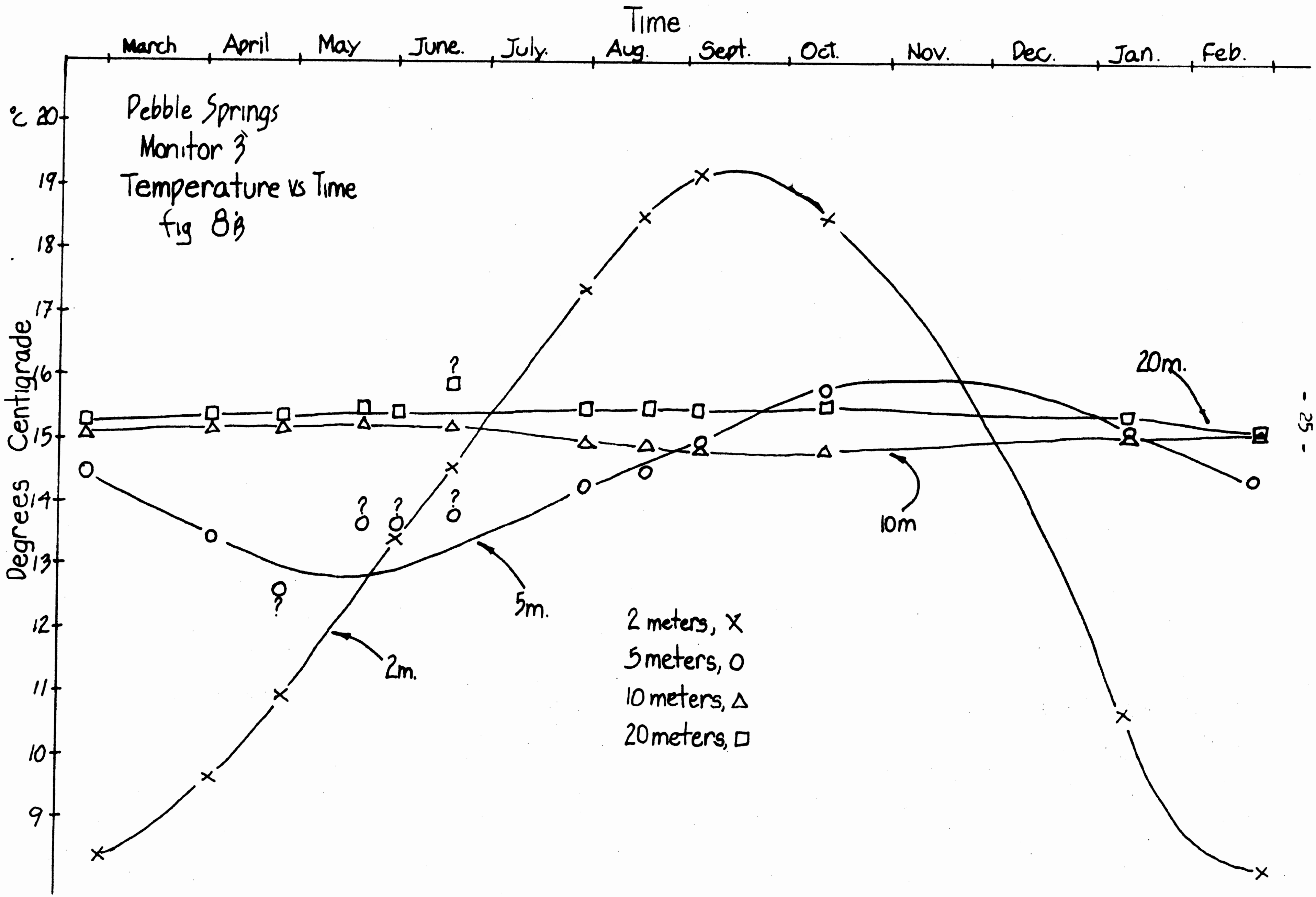
Date Logged	Mean Monthly Air temp.	1½m	2½m	3½m	4½m	5½m	6½m	7½m	8½m	9½m	10½m	15.4m
8/10/72	21.11			10.75		9.66					10.3	10.05
9/15/72	15.00	14.74	12.48	10.85	10.09	9.81	9.79	9.86	9.93	9.98	10.02	10.05
10/22/72	11.28	12.38	12.40	11.44	10.55	10.07	9.90	9.89	9.92	9.96	10.00	10.05
11/15/72	7.94	11.27	11.42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

Monitor well 2, Warren: page 2

Date Logged	Mean Monthly Air Temp.	1m	2m	3m	4m	5m	7½m	10m	15m
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


Temperature
10
11
12
13
14
15
16
17
18
19
20°C
0
2
4
6
8
10
12
14
16
18
20
Depth in Metres
8
10
12
14
16
18
20
22
1/18/73 ⊙
4/4/73 ⊡
8/19/73 △
10/15/73 ×
Pebble Springs
Monitor 3
fig 8A



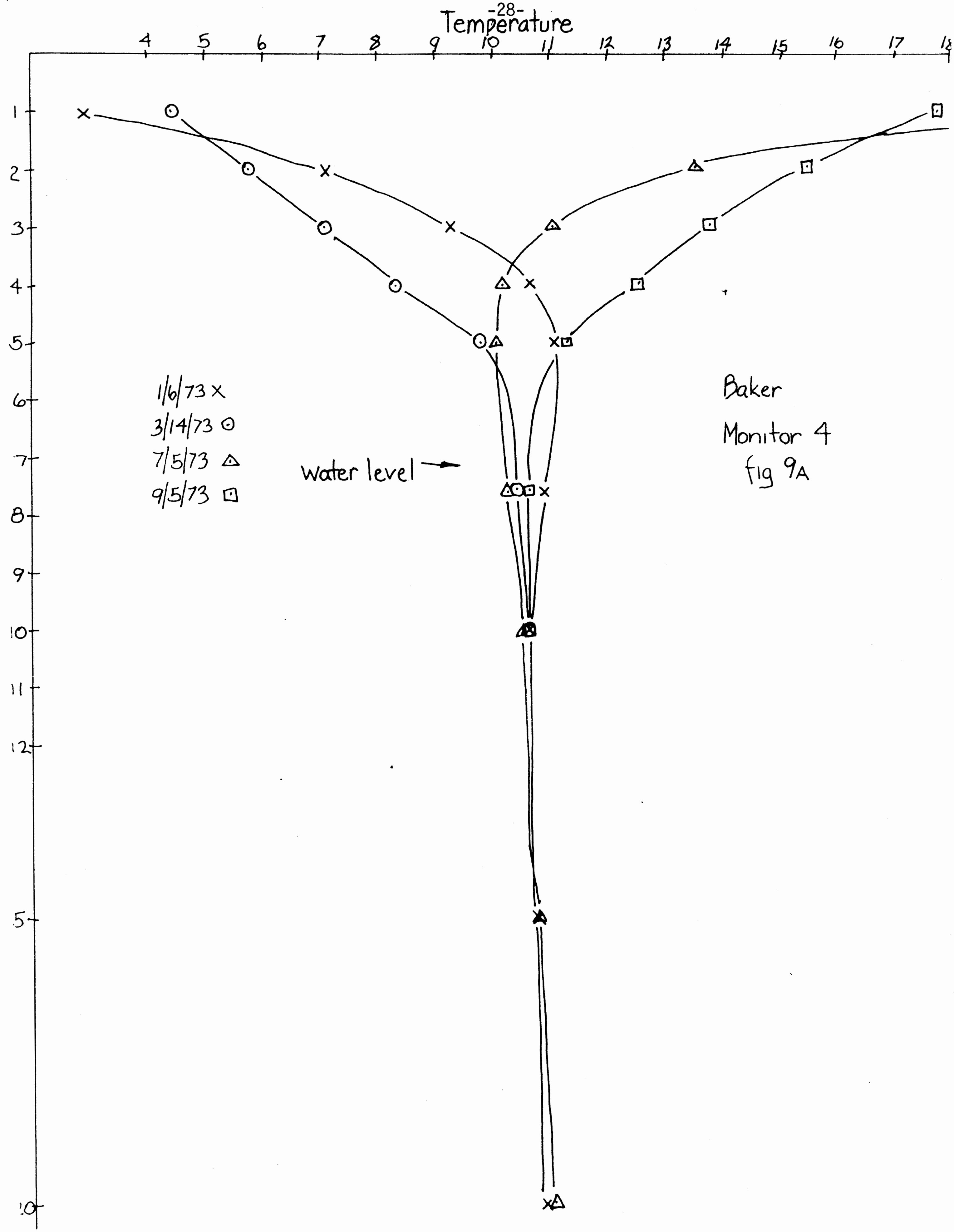
Time
March
April
May
June.
July.
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
Pebble Springs
Monitor 3
Temperature vs Time
fig 8B
°C 20
19
18
17
16
15
14
13
12
11
10
9
Degrees Centigrade
20m.
10m
5m.
2m.
2 meters, X
5 meters, O
10 meters, △
20 meters, □

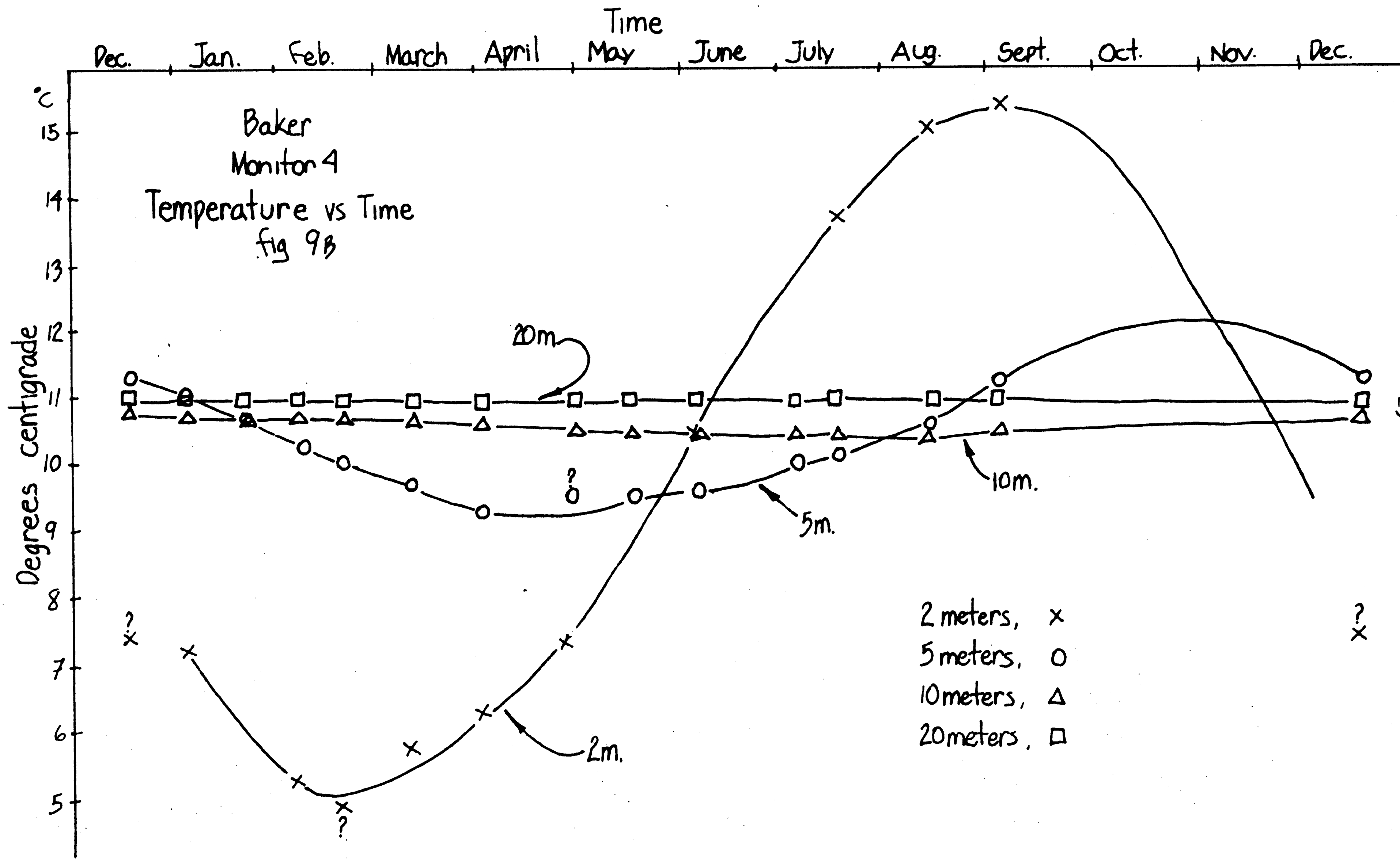
Table 3. Data from monitor well 3, Pebble Springs

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	

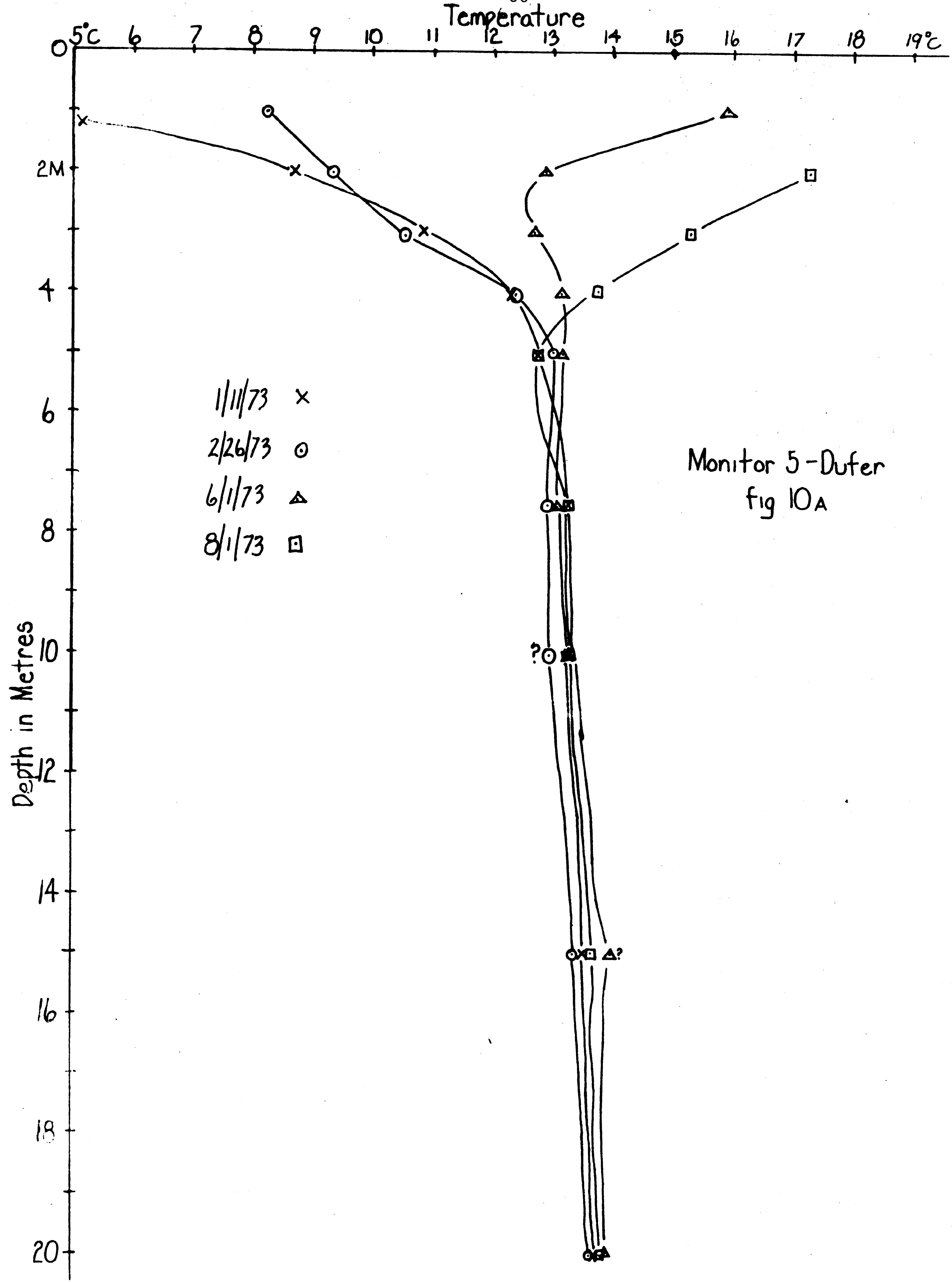
Table 4. Data from monitor well 4, Baker

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


Temperature
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
1
2
3
4
5
6
7
8
9
10
11
12
5
20
1/6/73 X
3/14/73 ⊙
7/5/73 △
9/5/73 ⊡
water level
Baker
Monitor 4
fig 9A



Time
Dec.
Jan.
Feb.
March
April
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
°C
15
14
13
12
11
10
9
8
7
6
5
Degrees centigrade
Baker
Monitor 4
Temperature vs Time
fig 9B
20m
10m.
5m.
2m.
2 meters, x
5 meters, o
10 meters, Δ
20 meters, □


Temperature
0 5°C 6 7 8 9 10 11 12 13 14 15 16 17 18 19°C
Depth in Metres
2M
4
6
8
10
12
14
16
18
20
1/11/73 ×
2/26/73 ⊙
6/1/73 △
8/1/73 ⊡
Monitor 5-Dufer
fig 10A

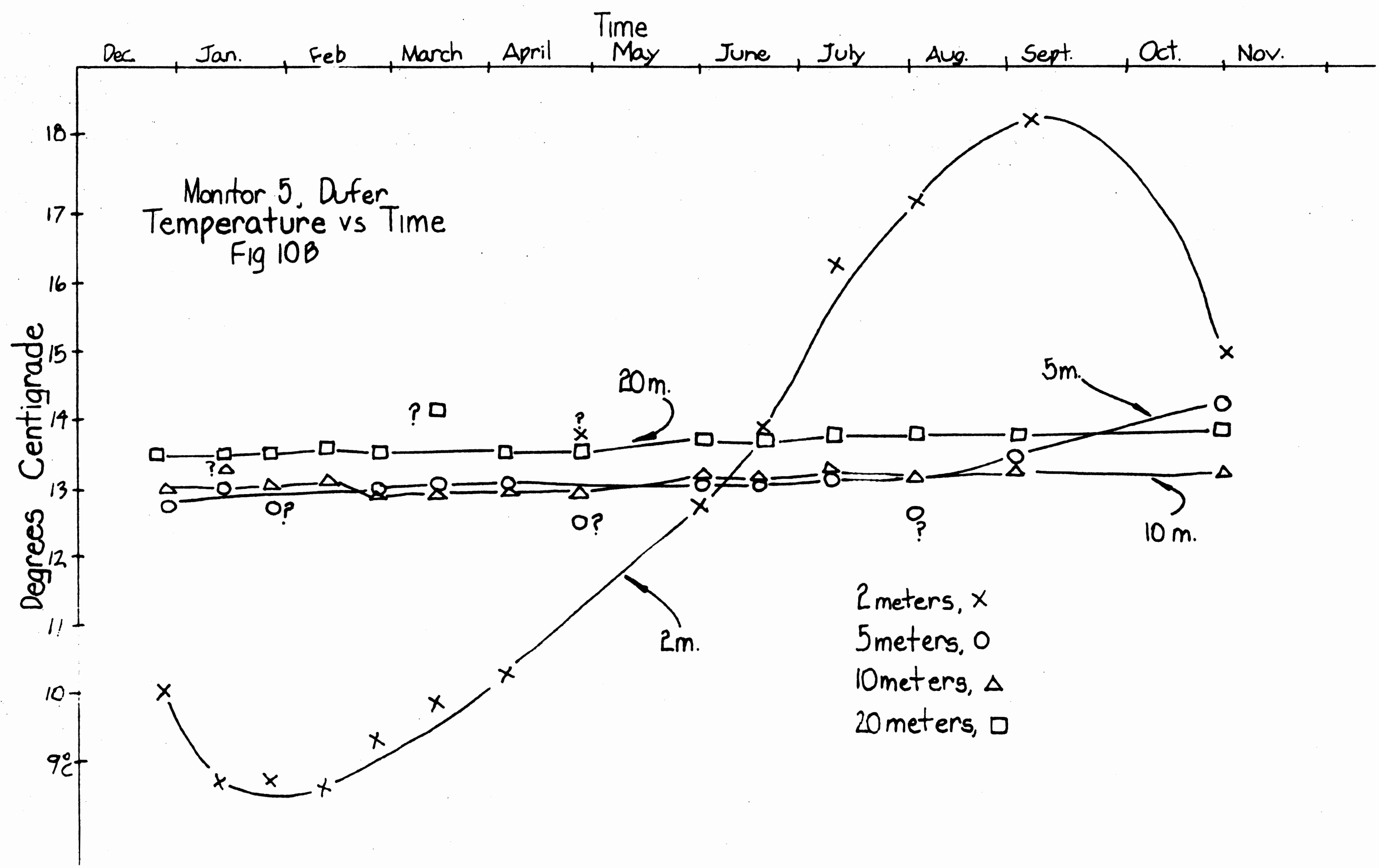
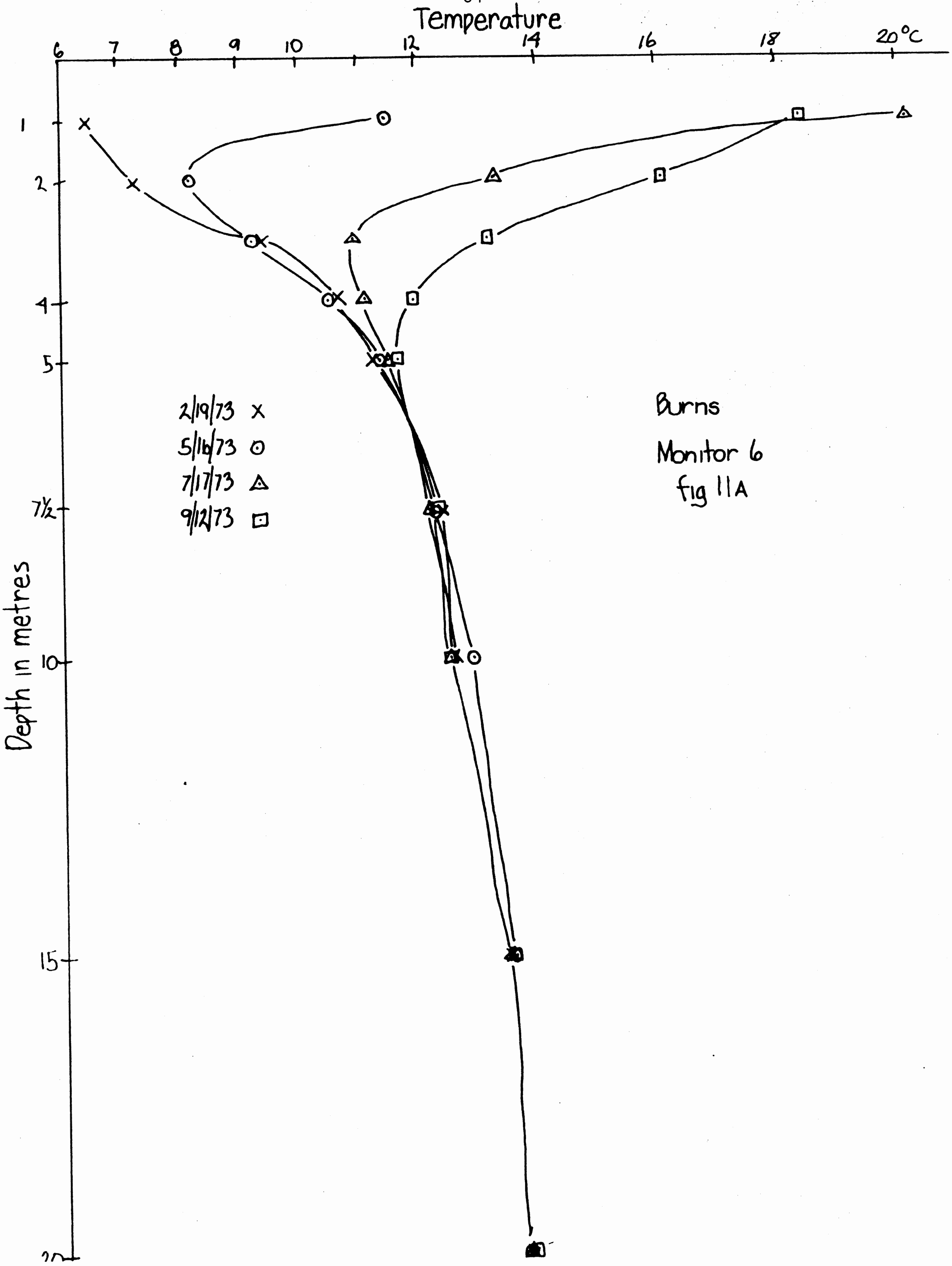

Monitor 5, Dufer
Temperature vs Time
Fig 10B
Time
Dec.
Jan.
Feb
March
April
May
June
July
Aug.
Sept.
Oct.
Nov.
Degrees Centigrade
18
17
16
15
14
13
12
11
10
9°C
20m.
5m.
10 m.
2m.
2 meters, x
5 meters, o
10 meters, △
20 meters, □

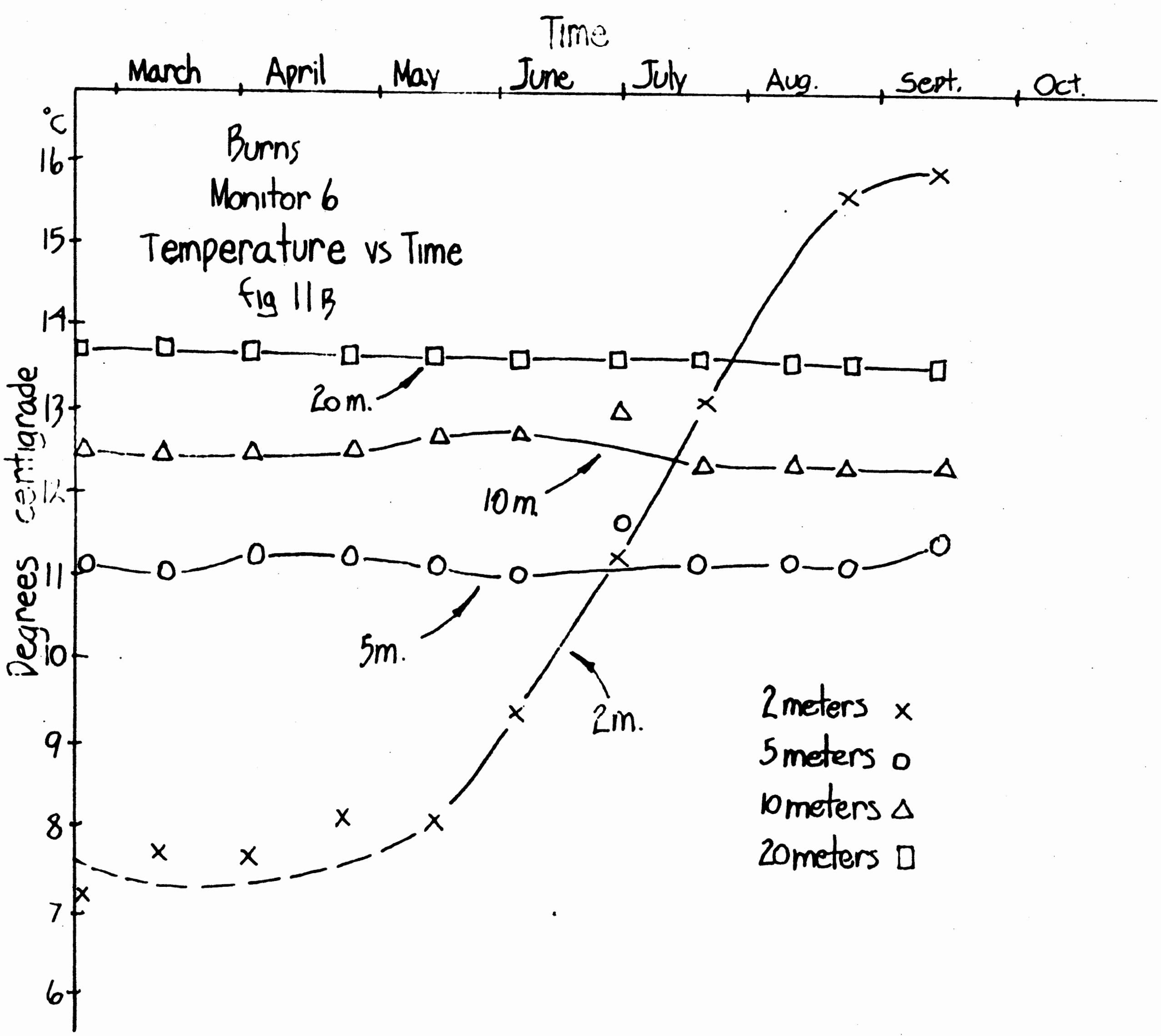
Table 5. Data from monitor well 5, Dufur

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 6. 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


Temperature
6
7
8
9
10
12
14
16
18
20°C
1
2
4
5
7½
10
15
Depth in metres
2/19/73 X
5/16/73 ⊙
7/17/73 △
9/12/73 ⊡
Burns
Monitor 6
fig 11A


Time
March
April
May
June
July
Aug.
Sept.
Oct.
°C
Burns
Monitor 6
Temperature vs Time
Fig 11B
16
15
14
13
12
11
10
9
8
7
6
Degrees centigrade
20m.
10m.
5m.
2m.
2 meters x
5 meters o
10 meters △
20 meters □

below that depth. The gradient difference may reflect the local geologic conditions in which semi-consolidated lacustrine tuffaceous sediments near the surface overlie a dense welded tuff. The site is located in sage-covered rolling hills. The average annual temperature is about 10°, with monthly average variations between -4° and +21°C. A good curve was not obtained at this site because it was not logged for a sufficient period and because convection of the water in the plastic pipe upset the shallow gradients. At a depth of 2 meters the annual variation appears to be about 9°. At 5 meters records show a change of only about ½°, but this may reflect the temperature disturbances due to convection rather than true temperatures. By 20 meters the well showed extreme stability with changes of only 0.05°.

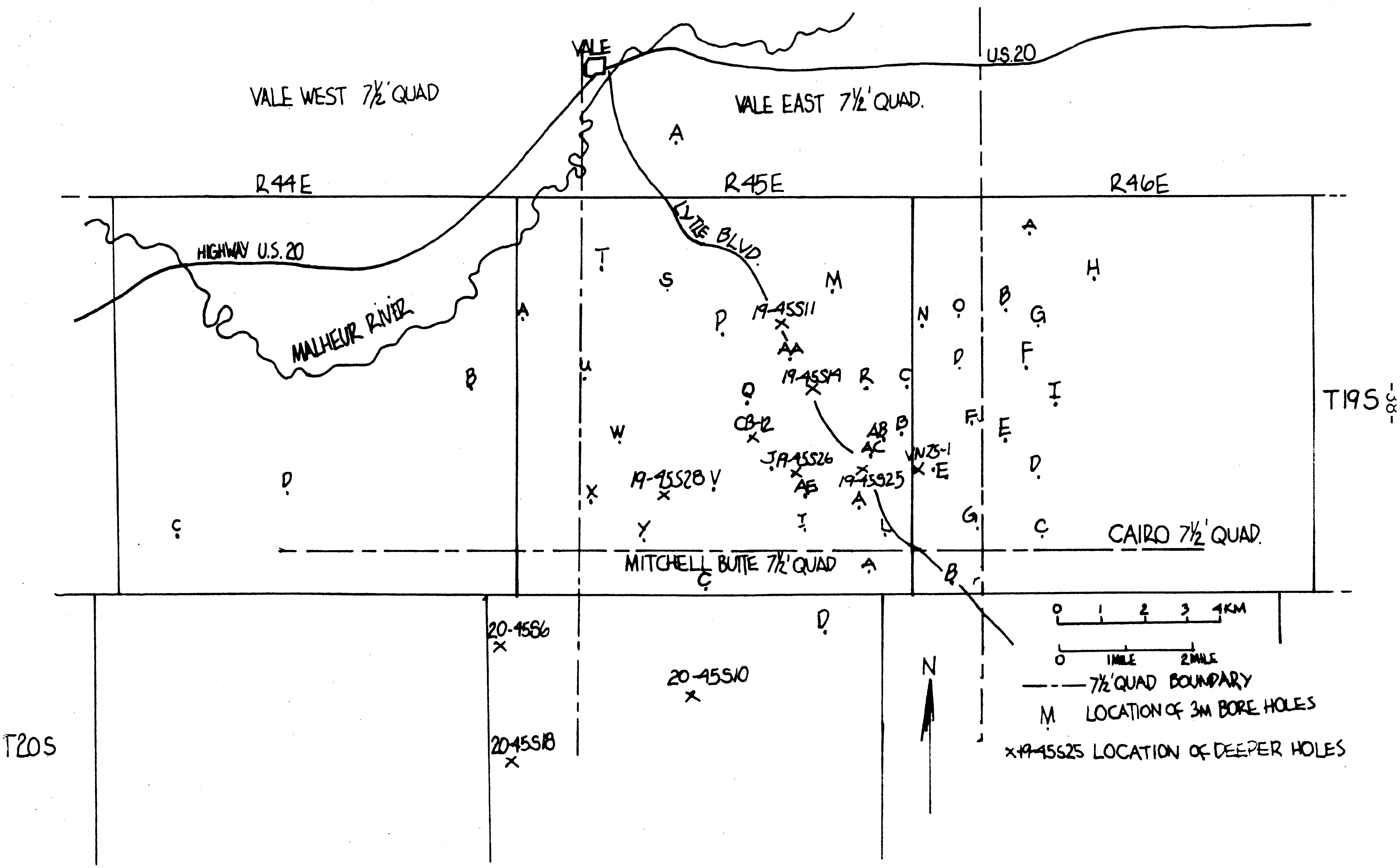
SHALLOW WELL PROGRAM

The goal of this phase of the study was to see if geothermal anomalies could be identified by temperature measurements from bore holes drilled only 2 or 3 meters deep. The results of this study are still unclear as the analysis of the date gathered has not been completed. From what has been learned thus far it appears that the method has promise, but the gathering and working up of the data to make useful comparison is so time consuming that drilling the holes to a depth where they are out of the effects of solar heating is more worth-while. This study has fallen into two divisions, the first is the intensive examination of the geothermal anomaly in the Cow Hollow area, and the second is the reconnaissance drilling in other parts of eastern Oregon. In the Cow Hollow area (Figure 12) 48 holes were drilled to a depth of at least 3 meters, but some as deep as 8 meters. During the reconnaissance drilling 92 holes were drilled to a depth of 3 to 7 meters in various areas in eastern Oregon. These areas are shown on Plate I.

The holes were drilled with a Mobil Minuteman power auger and when completed were cased with plastic pipe, capped at the bottom, and filled with water. A cap was also placed at the top of the pipe to ensure successful re-entry. Temperature measurements were then made in the drill holes after the upsetting effects of drilling had diminished and the holes had stabilized. In practice we found that a relatively experienced crew was able to drill between one and two shallow holes a day. Nearly all holes were drilled in tuffaceous sediments, with a few in alluvium. Because of the abrasiveness of the tuffaceous sediments, bit wear was high and life of the augers was short. Frequent moves contributed to making this program relatively costly per foot of hole drilled.

COW HOLLOW BORE HOLE LOCATION

FIG. 12



To derive useful information from temperature measurements taken within the zone of annual temperature changes requires the awareness of several variables, aside from annual air temperature changes. Also important is the elevation, ground cover, direction and inclination of the slope, ground-water movements, and cultural changes. The object of this study was to analyze or avoid these effects in order to see if significant data about the heat flow could be obtained from shallow holes. Temperature variations due to annual air temperature changes could be accounted for either by using monitor wells to record these changes, or by taking all measurements in the areas to be compared within an interval of one or two days.

Since temperature decreases with an increase in elevation, a "lapse correction" for elevation was applied to the data. The correction factor used was $-3^{\circ}C/km$. For the shallow wells, the lapse correction was applied in order to correct the mean annual surface temperatures to a common elevation (in Table 7 the mean elevation used was 1000 meters). Measurements for an individual group of holes were made over a period of one day, or at most a few days, so that the temerature drift would be minimal. Where the temperature measurements spanned several days, measurements were made in at least one well every day so that drift corrections could be applied and the data reduced to a common day. There has been no attempt to match the temperature data from the different areas by using a theoretical temperature-versus-date curve. At the present time the data are only significant when compared to the local group of drill holes.

The shallow-hole data from Cow Hollow shown in Table 7 gives the results of measurements taken at different times. Table 7 also gives the elevation and lapse correction used in preparing a comparison of the data.

[illegible] from Shallow Holes, Cow Hollow

Location	Elevation	Lapse	10/15/72		5/8/73		6/25/73		9/7/73	
			1m	3m	1m	3m	1m	3m	1m	3m
VE - A	768	-0.72	17.49	16.87	12.18	11.54			22.13	16.72
VE - B	913	-0.26	17.79	16.91	11.72		18.80	12.76	22.90	16.99
VE - C	925	-0.23	17.41	16.13	12.17		19.39	12.66	23.14	16.00
VE - D	841	-0.48	17.87	16.85	12.46	11.44	19.54	12.80	23.07	16.68
VE - E	878	-0.37	14.40	16.29	11.61	11.92	20.41	12.93	23.75	16.00
VE - F	823	-0.53	16.40	16.18	12.67	(11.88)	19.25	13.02	22.50	16.12
VE - G	832	-0.50	17.79	18.05	13.09	11.71	20.78	13.17	23.88	17.23
VE - H	811	-0.57	16.90	16.68	11.81	(11.07)	16.70	13.48	21.33	16.26
VE - I	872	-0.38	16.21	15.86	10.99	11.05	16.75	12.25	21.08	15.52
VE - J	830	-0.51	16.01	16.22	11.62	11.33	17.92	12.47	21.37	15.70
VE - K	811	-0.57					18.77	13.52	22.96	17.44
VE - L	780	-0.66					18.73	13.67	22.68	17.68
VE - M	884	-0.35					17.94	12.24	22.46	16.12
VE - N	872	-0.38					17.26	11.54	20.99	14.17
VE - O	835	-0.50					19.76	13.96	23.68	18.09
VE - P	881	-0.36					17.92	12.12	18.76	16.02
VE - Q	860	-0.42					18.20	12.28	18.70	15.91
VE - R	963	-0.11					17.25	11.80	17.78	15.03
VE - S	835	-0.50					17.57	12.67	21.44	16.29
VE - T	719	-0.84					17.94			
VE - U	771	-0.69					18.31	12.78	22.70	16.60

Shallow holes, Cow Hollow: page 2

Location	Elevation	Lapse	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	-0.45					17.22	12.62	21.69	16.66
VE - W	832	-0.50					18.48	12.60	22.88	16.79
VE - X	823	-0.53					18.00	12.28	21.99	16.12
VE - Y	890	-0.53					18.20	12.71	22.02	16.26
VE - AA	847	-0.46							21.53	16.41
VE - AB	902	-0.29							22.65	16.59
VE - AC	835	-0.50							22.77	17.34
VE - AD	844	-0.47							22.41	16.69
VE - AE	832	-0.50							22.17	16.00
VW - A	713	-0.86					17.57	12.46	20.62	16.35
VW - B	725	-0.83					17.63	12.55	21.53	15.52
VW - D	722	-0.83							20.60	15.39
C - A (Cairo)	780	-0.66					18.66	12.64	22.47	15.78
C - B	869	-0.39					17.17	11.46	21.13	15.26
C - C	793	-0.62					19.94		22.90	
C - D	790	-0.63					19.56	12.61	22.47	16.01
C - E	786	-0.64					18.82	12.71	22.01	16.69
C - F	835	-0.50					19.61	13.09	23.45	16.98
C - G	866	-0.40					19.08	12.70	22.94	16.80
C - H	853	-0.44					18.82	12.64	22.21	16.54

Location	Elevation	Lapse	10/15/72		5/8/73		6/25/73		9/7/73	
			1m	3m	1m	3m	1m	3m	1m	3m
MB - A	814	-0.56					18.15	13.14	22.29	16.41
MB - B	762	-0.71					18.66	13.06	22.24	16.43
MB - C	921	-0.24					17.97	12.61	21.73	16.74
MB - D	855	-0.44					19.08	13.49	23.07	16.96
MB - E	808	-0.58					18.78	13.83	22.62	
C - I	805	-0.59					19.63	12.70		

Thus far the correlation between the temperatures found in the shallow holes and the heat flow as determined from the deeper holes has not been resolved. Blackwell and Bowen are continuing to work on the data and intend to publish a study of the area in the near future using the data gathered under this contract.

The information on the other shallow holes drilled under this study are listed in Table 8. This listing gives location, elevation, lapse correction, date holes were logged, and temperatures at various depths. The general areas where these holes are located are also shown on Plate 1.

Table 8. Data from scattered shallow holes

Shallow Hole Information ---

Temperatures in °C; Elevation in meters; Lapse correction to 1000m elevation; numbers in paren. indicated depth at which temperature was taken.

Location		Elevation	Lapse	Date	1m	2m	3m (depths logged)	4m	5m	6m	7½m
Radium Hot Springs											
SW¼NE¼ sec 28 T7S R39E	H1	1009	+0.0	12/5/72	8.12	10.60	13.34	15.16			
SW¼NE¼ sec 28 T7S R39E	H_2	1009	+0.0	12/5/72	10.14	12.87	15.87	17.40	18.15		
SW¼NE¼ sec 28 T7S R39E	H_3	1009	+0.0	12/5/72	6.40	7.52	8.33	9.14	9.77		
SW¼NE¼ sec 28 T7S R39E	H_6	1009	+0.0	12/5/72	6.87	10.50	11.60	12.04	12.61		
Malheur County											
SE¼SW¼ sec 36 T17S R45E	MHA_1	744	-0.77	8/24/72			14.495	13.90 (3.7m)			
SE¼SW¼ sec 36 T17S R45E	MHA_2	744	-0.77	8/24/72			14.235	13.73 (3.8m)			
SE¼NE¼ sec 36 T17S R45E	MHB_1	756	-0.73	8/24/72			14.82	14.245			
SE¼NE¼ sec 36 T17S R45E	MHB_2	756	-0.73	8/24/72			15.075	14.49	14.505	14.53	14.60
NE¼NE¼ sec 36 T17S R45E	MHC_1	768	-0.70	8/24/72			14.745	14.325	14.360	14.42	15.54
NE¼NE¼ sec 36 T17S R45E	MHC_2	768	-0.70	8/24/72			14.90	14.292			
NW¼NE¼ sec 15 T17S R45E	MHD_1	878	-0.37	9/6/72	20.46	16.31	14.04	13.14	12.99		
NW¼NE¼ sec 15 T17S R45E	MHD_2	878	-0.37	9/6/72	19.59	16.14	14.10	13.30	13.15		
SW¼SW¼ sec 15 T17S R45E	MHE_1	951	-0.15	9/6/72	19.76	16.57	14.70	12.89	12.61		
SW¼SW¼ sec 15 T17S R45E	MHF_1	936	-0.19	9/6/72		19.15	14.57	13.04	12.67		
SE¼SW¼ sec 36 T16S R45E	MHG_1	892	-0.32	9/6/72	20.04	17.03	14.51	13.39	13.15	13.18	13.28
SW¼SW¼ sec 36 T16S R45E	MHH_1	865	-0.41	9/6/72	22.97	19.68	16.91	15.51	14.91		
SE¼NW¼ sec 36 T16S R45E	MHI_1	913	-0.26	9/6/72	22.49	19.35	16.34	14.37			

Scattered shallow holes: page 2

					1m	2m	3m	4m	5m	6m	7½m
SW¼SW¼ sec 36 T17S R43E	JaA_1	796	-0.61	10/14/72	17.03	16.97	15.58	14.61	14.13	14.11	14.19
SW¼SE¼ sec 36 T17S R43E	JaB_1	803	-0.59	10/14/72	17.47	17.34	15.80	14.64	14.07	13.98	13.99
NE¼NE¼ sec 36 T16S R44E	JaC_1	786	-0.64	10/10/72	17.36	16.68	14.93	14.18	14.16	14.23	14.29
NW¼NE¼ sec 36 T16S R44E	JaD_1	767	-0.70	10/10/72	17.66	17.21	15.29	14.17	13.74	13.76	13.81
SW¼NW¼ sec 36 T16S R44E	JaE_1	741	-0.78	10/10.72	16.62	16.07	14.49	13.68	13.34		
SE¼SEP sec 26 T17S R44E	(Farm)	725	-0.83	9/30/72	17.32	16.49	15.20	13.99	13.10		12.83 (8½m
SE¼SW¼ sec 36 T17S R45E	MHA	744	-0.77	9/10/73	22.29	18.65	15.66	14.36			
Double Mountain											
SW¼NW¼ sec 5 T20S R44E	DMA	744	-0.77	8/18/73	22.22	16.93	14.34				
SE¼NE¼ sec 20 T20S R44E	DMB	917	-0.25	8/18/73	22.62	17.67	15.71(2.5m)				
SEPNE¼ sec 23 T20S R44E	DMC	951	-0.15	8/19/73	21.80	17.62	14.91				
NE¼NE¼ sec 12 T20S R44E	DMD	832	-0.50	8/18/73	22.01	18.07	15.33				
Kane Spring Gulch											
SE¼SE¼ sec 7 T20S R44E	KSGS	774	-0.68	8/18/73	24.24	19.17					
NE¼SE¼ sec 30 T20S R44E	KSGB	811	-0.57	8/18/73	21.30	16.30					
Adrian 7½ min. Quadrangle											
SW¼SE¼ sec 16 T21S R46E	AdA_1	799	-0.60	8/23/72			16.685				
SW¼SE¼ sec 16 T21S R46E	AdA_2	799	-0.60	8/23/72			17.415				
SW¼SE¼ sec 16 T21S R46E	AdA_3	799	-0.60	8/23/72			16.125				
SW¼SE¼ sec 16 T21S R46E	AdA_4	805	-0.59	8/23/72			15.43				
SW¼SE¼ sec 16 T21S R46E	AdA5	811	-0.57	8/23/72			16.36	14.595	13.785		
E½SE¼ sec 16 T21S R46E	AdB_1	771	-0.69	8/23/72			16.925				

Scattered shallow holes: Page 3

					1m	2m	3m	4m	5m	6m	
NE¼SE¼ sec 16 T21S R46E	AdB_2	771	−0.69	8/23/72			16.885				
NE¼SE¼ sec 16 T21S R46E	AdB_3	771	−0.69	8/23/72			17.765				
NE¼SE¼ sec 16 T21S R46E	AdB_4	770	−0.69	8/23/72			16.885				
NE¼SE¼ sec 16 T21S R46E	AdB_5	771	−0.69	8/23/72			16.63	14.92	14.08	13.95	
SE¼SW¼ sec 16 T21S R46E	AdC_1	831	−0.51	8/23/72			16.095	14.60	14.035		
SE¼SW¼ sec 16 T21S R46E	AdC_2	831	−0.51	8/23/72			15.965	14.28	13.78		
SW¼SE¼ sec 16 T21S R46E	AdA_5	811	−0.57	9/7/72		20.03	17.05	14.88	13.97	13.83	
NE¼SE¼ sec 16 T21S R46E	AdB5	771	−0.69	9/7/72		21.14	17.46	15.64	14.60	14.15	13.98 (7M)
SW¼SE¼ sec 16 T21S R46E	AdA	805	−0.59	9/8/73	22.52	19.46	16.84				
NE¼SE¼ sec 16 T21S R46E	AdB	771	−0.69	9/8/73	24.70	22.38	18.52				
SE¼SW¼ sec 16 T21S R46E	AdC	831	−0.51	9/8/73	23.68	20.75	17.62				
East Silver Creek											
NW¼SE¼ sec 21 T23S R26E	B-A	1295	+0.89	8/21/73		14.66	12.42				
NW¼NW¼ sec 34 T23S R25E	B-B	1356	+1.07	8/22/73	17.74	13.93	11.74				
NE¼NW¼ sec 33 T23S R26E	B-E	1329	+0.99	8/22/73	18.04	14.37	11.93	10.70			
NW¼NW¼ sec 18 T23S R26E	B-F	1329	+0.99	8/21/73	19.76	16.32					
SE¼SE¼ sec 1 T23S R26E	B-G	1311	+0.93	8/21/73	18.51	15.29	12.92				
NW¼NE¼ sec 1 T23S R26E	B-H	1311	+0.93	8/21/73	20.42	16.43	13.60	11.49			
Camp Harney											
NW¼SE¼ sec 32 T24S R32½E	CH-A	1253	+0.76	8/20/73	18.94	14.20	11.47	10.37			
NW¼SE¼ sec 32 T24S R32½E	CH-B	1253	+0.76	8/20/73	20.77	16.42	12.89	11.15			

Scattered shallow holes: Page 4

								1m	2m	3m	4m
NW¼NE¼ sec 22	T24S	R32½E	CH-C	1254	+0.76	8/20/73		19.16	15.02	11.90	10.49
SE¼SE¼ sec 21	T24S	R32½E	CH-D	1253	+0.76	8/20/73		20.23	16.03	12.69	11.91 (3.9m)
NW¼NW¼ sec 11	T25S	R32½E	CH-E	1250	+0.75	8/20/73		18.85	13.99	11.42	
Christmas Lake											
NW¼SW¼ sec 33	T26S	R20E	CL-C	1311	+0.93	8/22/73		17.06	12.29	10.15	9.66 (3.9m)
NW¼SW¼ sec 28	T26S	R20E	CL-D	1311	+0.93	8/22/73		19.80	11.61	10.86 (2.77m)	
SE¼SE¼ sec 26	T26S	R19E	CL-E	1311	+0.93	8/22/73		19.29	10.54	9.98	
Wagontire											
NW¼SW¼ sec 10	T26S	R25E	W-A	1433	+1.30	8/22/73		18.65	14.03	11.87	10.56
NW¼NE¼ sec 28	T27S	R25E	W-B	1402	+1.21	8/22/73		17.36	13.17	11.02	
NW¼SE¼ sec 22	T26S	R25E	W-C	1341	+1.02	8/22/73		18.09	14.11	11.62	10.47
SW¼NE¼ sec 21	T26S	R24E	W-D	14194	+1.48	8/22/73		18.90	14.21	11.22	9.94
SE¼NE¼ sec 28	T26S	R25E	W-E	1341	+1.02	8/22/73		18.18	14.18	11.23	9.61
Silver Lake											
SE¼SW¼ sec 11	T28S	R15E	SL-A	1341	+1.02	8/23/73		21.09	16.25	13.09 (2.95m)	
NW¼SE¼ sec 15	T28S	R15E	SL-B	1326	+0.98	8/23/73		15.82	11.97	10.04	9.25
SE¼SE¼ sec 5	T28S	R16E	SL-D	1332	+1.00	8/23/73		16.85	12.24	9.60	8.87
NE¼NE¼ sec 9	T28S	R16E	SL-E	1323	+0.97	8/23/73		15.07	11.24	9.08	8.52
NE¼NE¼ sec 8	T28S	R15E	SL-F	1341	+1.02	8/23/73		18.15	13.30	11.05	9.97
NE¼NE¼ sec 9	T28S	R15E	SL-G	1326	+0.98	8/23/73		15.26	11.47	9.05	8.21

Scattered shallow holes: Page 5

							1m	2m	3m	4m
Paisley										
NW¼NW¼ sec 5	T30S	R17E	P-A	1302	+0.91	8/23/73	22.34	17.57	14.42	12.72
SE¼SE¼ sec 14	T30S	R17E	P-B	1302	+0.91	8/23/73	18.40	13.78	11.35	10.95
NW¼SE¼ sec 11	T30S	R17E	P-C	1302	+0.91	8/23/73	21.68	17.16	14.19	12.45
SE¼SW¼ sec 2	T30S	R17E	P-D	1302	+0.91	8/23/73	18.56	14.62	11.90	
SE¼SE¼ sec 12	T30S	R17E	P-E	1302	+0.91	8/23/73	22.30	16.78	14.43	13.06
NE¼NE¼ sec 10	T29S	R23E	P-F	1308	+0.92	8/23/73	15.83	11.81	9.70	9.25
SE¼SW¼ sec 15	T29S	R23E	P-G	1308	+0.92	8/22/73	15.95	12.05	10.28	9.93
NE¼SW¼ sec 21	T30S	R23E	P-H	1308	+0.92	8/22/73	19.20	15.07	13.51	12.61
SW¼SW¼ sec 33	T29S	R23E	P-I	1308	+0.92	8/22/73	17.36	14.15	11.79	10.73
SE¼SE¼ sec 1	T30S	R22E	P-J	1308	+0.92	8/22/73	19.68	14.97	12.93	12.20 (3.8m)
Coleman Point										
NW¼NE¼ sec 17	T36S	R18E	CP-A	1594	+1.78	8/24/73	14.81	10.56	8.23	7.37
NW¼NE¼ sec 19	T36S	R18E	CP-B	1634	+1.90	8/24/73	12.19	9.48	7.69	6.85
NE¼NE¼ sec 24	T36S	R17E	CP-C	1634	+1.90	8/24/73	15.31	12.49	10.47	9.42 (3.92m)
NE¼SE¼ sec 19	T36S	R18E	CP-D	1634	+1.90	8/24/73	15.40	11.99	9.72	8.53
NE¼NE¼ sec 8	T36S	R17E	CP-E	1682	+2.05	8/24/73	13.93	10.55	8.02	6.83
Cox Flat										
NW¼NE¼ sec 34	T37E	R18E	CF-A	1698	+2.09	8/24/73	14.25	11.45	9.36	8.47 (3.8m)
NW¼NE¼ sec 16	T37S	R18E	CF-B	1728	+2.18	8/24/73	13.01	10.05	8.42	7.56
SW¼NE¼ sec 15	T37S	R18E	CF-C	1737	+2.21	8/24/73	17.94	14.26	11.46	9.78

Scattered shallow holes: Page 6

	Elev.	Lapse	Date					
Baker								
				3m	4m	5m	10m	11m
T 9S R40E (2630 Auburn Ave)	1045	-0.14	11/5/72	9.83	11.39	11.49	11.63	11.65
Baker								
T9S R40E 16 (940 Campbell Ave)	1045	-0.14	no date	11.96		11.49	11.33	
Baker								
				1m	2m	3m	4m	
SE¼SW¼ sec 10 T9S R41E VR-1			7/5/73	17.17	12.30	10.90	10.66	
SE¼SE¼ sec 18 T9S R41E VF-2			7/5/73	16.86	12.33	10.81	10.44	

PRE-DRILLED HOLES

In addition to the holes of varying depth which were drilled during the present investigation, we undertook a concentrated program of locating and measuring temperature gradients in pre-drilled holes such as abandoned water wells, mineral exploration holes, and petroleum wells. Measurement of pre-drilled holes represents the most efficient means of rapidly securing temperature gradient information over a large area. To date 81 holes have been measured throughout Oregon (see Plate 1). The bulk of the holes lie in southeastern Oregon where water wells are more abundant.

The gradients measured in pre-drilled holes have been periodically published or placed in open file (Bowen, 1972 and Bowen and Blackwell, 1973, and Bowen, 1975).

The results to date are tabulated in Table 9. Detailed temperature logs for each of these holes are available for inspection at the various offices of the Department of Geology and Mineral Industries. Hole numbers represent location by section, township, and range, eg., hole number 1-13-S-20 is located in section 20 of township 1 south, range 13 east. Unless otherwise noted, all holes are south and east of the Willamette meridian and base line.

The quality of the temperature gradients tabulated in Table 9 is highly variable. The pre-drilled holes utilized in this program are mainly water wells exceeding six inches in diameter and holes of this type are subject to water movement within the well or the aquifer. These currents distort the temperature patterns and make the calculated average gradients semi-qualitative at best. Most of the gradients are probably accurate to

Table 9. Temperature gradients in pre-drilled holes

Hole no.	North Latitude	West Longitude	Depth interval, Meters	Collar elevation, Meters	Average gradient °C/km
3N-21-S19	45°44'	120°14'	25 - 70	120	52.0
3N-21-S36	45°42'	120°09'	15 - 145	232	45.3
3N-47-S26	45°42	116°54'	15 - 65		23.0
2N-21-S 1	45°41'	120°08'	15 - 130	226	59.4
2N-22-S 6	45°41'	120°07'	15 - 130	241	46.1
2N-24-S 5	45°41'	119°51'	15 - 115	206	31.7
2N-27-S 7	45°40'	119°29'	30 - 305	313	64.2
1 -13-S20	45°28'	121°12'	15 - 55	354	41.7
1 -35-S36	45°25'	120°08'	15 - 130		24.5
8 -15- S9	44°51'	120°54'	15 - 155	914	32.4
8 -37-S28	44°51'	118°11'	20 - 100		8.5
8 -37-S29	44°51'	118°12'	20 - 118		11.3
8 -37-S32	44°50'	118°13'	20 - 85		2.6
8 -41-S34	44°50'	117°41'	15 - 130		42.7
8 -42-S24	44°51'	117°31'	15 - 70		30.4
8 -42-S29	44°50'	117°36'	15 - 45		12.3
9 -39-S13	44°47'	117°53'	15 - 72.5		32.3
9 -41-S7	44°47'	117°44'	15 - 25		48.0
10-38-S24	44°41'	118°01'	25 - 115	1,277	39.9
12-01W-S4	44°34'	122°49'	15 - 67.5	131	32.0
13-29-S15	44°27'	119°13'	15 - 150		34.1
13-31-S26	44°24'	118°56'	20 - 70		39.0
13-31-S27	44°24'	118°58'	15 - 150		34.8
16-43-S7	44°12'	117°30'	15 - 115		33.4
17-45-S3	44°07'	117°12'	15 - 180		61.6
19-31-S13	43°55'	118°57'	20 - 240		25.9
21-35-S11a	43°45'	118°23'	15 - 100		48.8
21-35-S11b	43°45'	118°23'	15 - 50		72.0
21-42-S27	43°43'	117°33'	10 - 20		37.0
21-46-S7	43°45'	117°09'	15 - 70		108.2
22-21-S9 (?)	43°40'	120°12'	15 - 40		58.8
23-23-S27	43°33'	119°56'	15 - 220		177.4
25-6W-S21	43°23'	123°25'	15 - 90		8.9
27-30-S13	43°14'	118°57'	15 - 130		85.0
27-30-S19	43°13'	119°02'	46.6-107.6		131.0
27-30-S21	43°13'	119°00'	15 - 110		152.2
27-30-S26	43°12'	118°58'	15 - 57.2		115.6
27-30-S27	43°12'	118°59'	15 - 75		142.5
27-30-S36	43°11'	118°57'	15 - 47.3		71.8
28- 8-S5	43°10'	121°48'	15 - 75		-5.3
32-2W-S4	42°49'	122°56'	15 - 215		15.3
37-18-S14	42°22'	120°33'	15 - 75		133.7

Table 9. (cont'd)

Hole no.	North Latitude	West Longitude	Depth interval, Meters	Collar elevation, Meters	Average gradient °C/km
37-18-S27	42°20'	120°35'	10 - 20		107.5
37-19-S30a	42°20'	102°31'	15 - 135		69.6
37-19-S30b	42°20'	120°31'	10 - 20		124.5
37-19-S30c	42°20'	120°31'	15 - 40		82.0
38-37-S24	42°16'	118°19'	15 - 100		81.4
38-37-S25	42°15'	118°19'	30.5-150.9		70.6
38-37-S26	42°15'	118°20'	15 - 50		84.6
39-21S29	42°10'	120°16'	15 - 40		38.8
39-34-S2	42°14'	42°41'	20 - 380		60.3
39-37-S2	42°11'	42°20'	15 - 110		79.5
39-37-S17a	42°14'	42°23'	36.6-128.0		81.0
39-37-S17b	42°14'	42°23'	30.5-105.8		139.4

plus or minus 20 percent of the figure given in the table but it is not possible to calculate statistically valid accuracy limits on these measurements. The individual temperature measurements are precise to plus or minus 0.05°C and are likely accurate to plus or minus 0.1°C. The depth intervals used for the average gradient calculations were selected to avoid diurnal and seasonal near-surface temperature fluctuations, but in a few cases the measured temperatures were probably affected by moving groundwater caused by active irrigation.

The gradients shown in Table 9 should be utilized with caution as heat flow is also dependent upon rock conductivity. 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 0.0025 to 0.004 calories/cm sec°C. In practice in southeastern Oregon, most of the tuffaceous sediments have conductivities ranging from 0.0028 to 0.0032. This means that in general, gradients, although not comparable, can yield useful information on the relative heat flow of different bore holes. However, in other parts of the State where bedrock geology is not so consistent, comparisons should be made with great care.

Because of the availability of many pre-drilled holes from mineral exploration and unused water wells, and because the gradients and heat flow data indicate the region has significant geothermal potential, much of the study was concentrated in the Western Snake River Basin. Table 10 gives a listing of all of the geothermal data that has been obtained from the pre-drilled wells in that region.

Table 10. Geothermal data for pre-drilled holes in the Western Snake River Basin

Locality	Hole no.	N Lat	W Long	Elevation meters	Depth Interval Meters	G °C/km	G* °C/km	K 10^{-3}cal/cmsec°C	Q 10^{-6}cal/cm^{2}sec	Q*	
Adams Ranch	14-43S13	44°21'	117°24'	1170	30-280	32.3 0.3					A
Huntington	15-45S7	44°16'	117°15'	854	30-170	61.9 2.4		2.8	1.7		C
Willow Creek	15-42S14	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.					
	16-43S10	44°11'	117°26'	758	30-115	71.2 0.5	NG	2.8	2.0		B
	16-43S13	44°10'	117°24'	768	50-130	51.5 0.5	NG				
					130-170	94.7 2.7	NG	2.8	2.7		B
	16-43S15	44°10'	117°26'	758	25-105	38.6 0.7	NG	-	-		
					105-230	70.5 0.3	NG	2.8	2.0		B
	16-43S23	44°09'	117°25'	749	40-110	61.8 2.2	NG	-	-		
					110-170	99.5 1.3	NG	2.8	2.8		B
	17-43S9	44°06'	117°27'	866	10-35	134.2 12.0		2.8	3.8		C
	17-44S11	44°06'	117°17'	719	-370	94.4 2.2		2.8	2.6		B
	17-44S31	43°59'	117°20'	829	15-70	85.7 2.2		2.8	2.4		B
	18-44S21	43°59'	117°20'	760	25-85	66.8 1.1		2.8	1.9		B
Hunter	18-41S35	43°47'	117°38'		30-45	44.0 6.9		2.8	1.2		C

Table 10. Geothermal data for pre-drilled holes in the Western Snake River Basin (cont'd)

Locality	Hole No.	N Lat	W Long	Elevation meters	Depth Interval Meters	G °C/km	G* °C/km	K 10^{-3}cal/cmsec°C	Q 10^{-6}	Q* cal/cm²sec	
Cow Hollow	19-45S11	43°55'	117°10'	835	30-65	185.7 1.6	176.1 1.6	3.0	5.6	5.3	A
	19-45S14	43°54'	117°10'	910	20-145	175.2 1.1	158.3 0.8	3.0	5.3	4.7	A
	19-45S22	43°53'	117°11'	843	30-115	110.4 0.3		3.05 0.13		2.9	A
	19-45S25	43°53'	117°09'	813	30-70	232.6 7.1	213.6 6.4	2.98 0.05	6.9	6.4	A
	19-45S26	43°52'	117°10'	822	30-175	119.3 0.6	114.0 0.5	3.0	3.6	3.4	A
	19-45S28			872	10-90	70.8 1.5	76.5 1.5	3.0	2.1	2.3	A
	19-44S9				35-160	71.5 0.5		3.0		2.1	B
	19-44S19			777	31-395	87.3*		3.0	2.6		B
	20-45S6	43°51'	117°15'	823	20-135	73.6 0.6	69.8 0.6	3.0	2.2	2.1	A
	20-45S10	43°50'	117°12'	780	30-135	114.8 1.6	104.0 1.5	3.0	3.4	3.1	A
	20-45S18			849	10-40	71.9 3.8	63.2 3.3	3.0	2.1	1.9	B
Grassy Mtn.	21-43S36	43°41'	117°23'	995	10-75	53.5 0.5		3.0	1.6		B
	21-44S28	43°42'	117°20'	1000	10-30	105.2 0.5		3.0	3.2		B
Harper	21-42S11				65-140	111.7 1.2		3.0	3.4		B
Oxbow Basin	23-44S5				26-148	107.0** 15.5		3.0	3.2		B

*Van Ostrand, 1938 **Bowen, 1972 NC - Not calculated, NG - Neglible

G* and Q* indicate wells in which topographic corrections have been made.

DEEP BORE HOLES

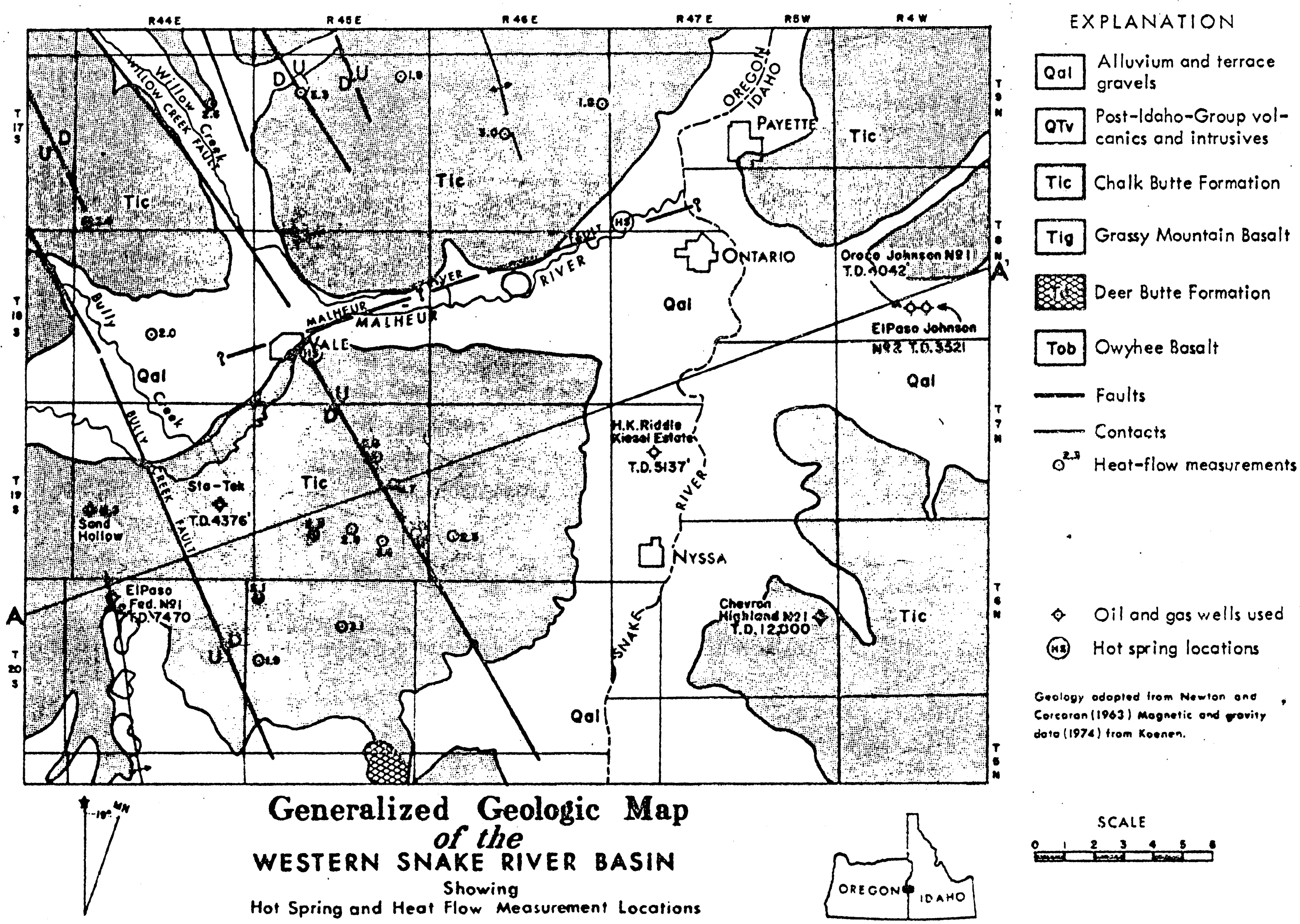
The final phase of the current geothermal study consisted of drilling five holes to depths ranging from 62-152 meters (203 to 500 feet). The purposes of the deeper drilling were (1) to study heat flow in areas where previous temperature-gradient measurements in pre-drilled wells had indicated abnormally high gradients and (2) to further evaluate the validity and utility of the gradients in the shallow holes.

The deep holes were drilled near Vale in northern Malheur County as shown on Figure 13. The holes were drilled 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 probable Pliocene or 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 4 holes drilled primarily with air rotary were 61, 50, 45, and 46 feet per hour. A carbide insert bit was used in the sedimentary rocks to obtain 4-inch diameter cores for subsequent laboratory measurements of thermal conductivity.

The harder altered basalt was drilled mainly with a 6-inch diameter down-hole hammer at a penetration rate of about 25 feet per hour. The basalt was cored with a 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 $4.13 per foot drilled.

FIGURE 13



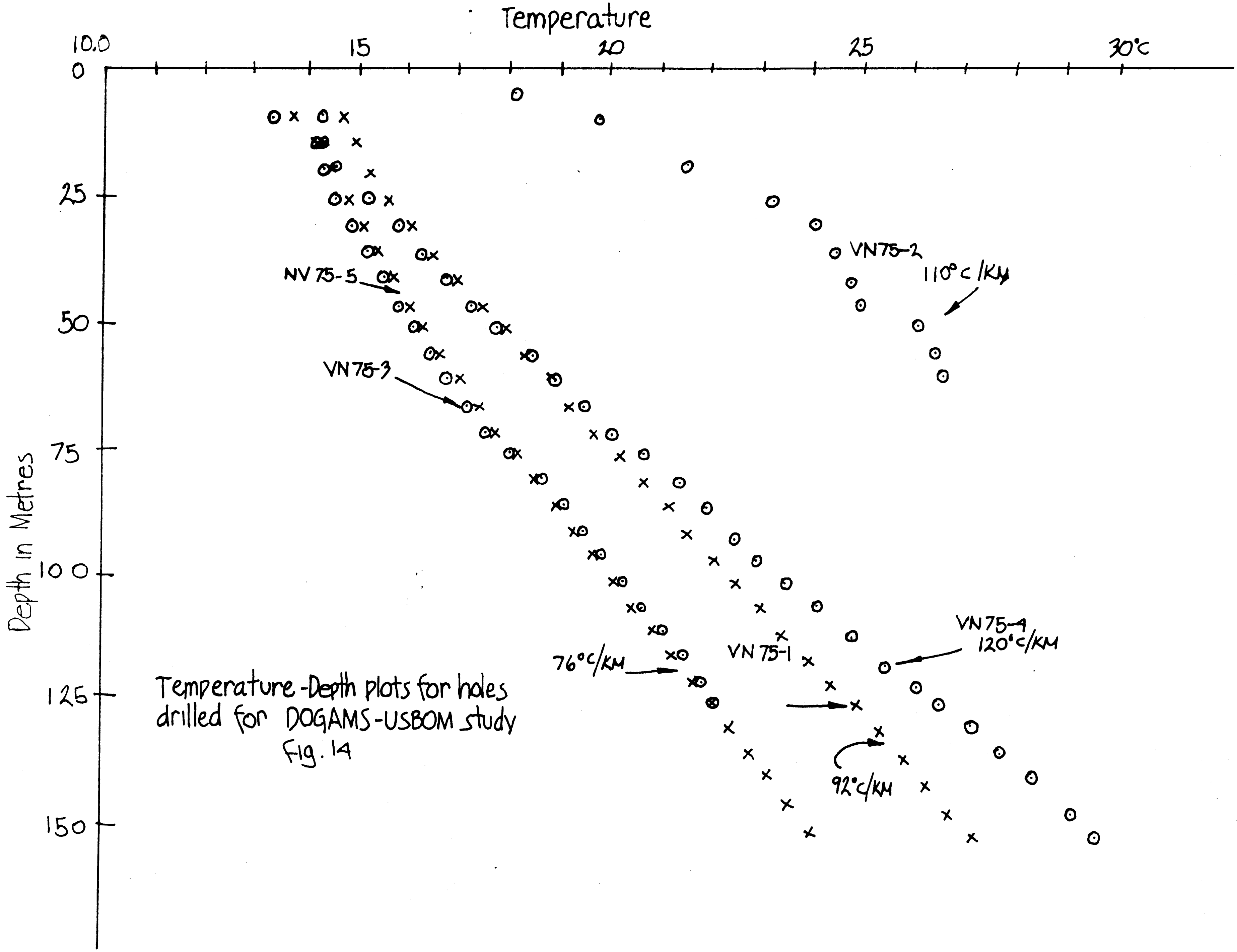
Generalized Geologic Map
of the
WESTERN SNAKE RIVER BASIN
Showing
Hot Spring and Heat Flow Measurement Locations

Holes were completed by inserting a water-filled and bottom-capped 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 75-2 which encountered artesian water. Either bentonite or cuttings were used in the remaining holes from 10 feet to bottom with the uppermost 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 6-inch steel casing left in the upper portion of each hole.

We plan to monitor the holes for a period of about 1 year to test for the effects of irrigation on near-surface temperature gradients.

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 VN-75-2, which was 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, rock porosity, and ground-water conditions. The times noted above should be applied with caution in future work.

The temperature gradients, thermal conductivity and calculated heat flow values in the deep holes are summarized in Table 11. The various gradients are shown graphically in Figure 14. All of these gradients are linear except for hole VN-75-2 which encountered warm artesian water at a depth of 105 feet as indicated by the change in slope on the graph of this hole. The lithology in the remaining holes is uniform throughout,



Temperature-Depth plots for holes drilled for DOGAMS-USBOM study
Fig. 14

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 VN-75-2 at a rate of 10 to 14 gpm, a temperature of 24°C (75°F) and a pressure of 5 pounds per aquare inch. The gradient shown in Table 11 and Figure 14 was measured after the hole had been cemented to stop the flow.

The gradients in all of these holes appear to be anomalously high and the results are consistent with earlier gradient measurements in the Vale area. The east-west profile represented by holes VN-75-2, 3, 4 and 5 lies east of pre-drilled wells with relatively high gradients. Hole VN-75-1 lies 1 mile east of monitor hole no. 1 and is in the area of the Cow Hollow thermal anomaly discussed above. It appears that the geothermal potential encompassed by the Known Geothermal Resource Area extending southward from the town of Vale may also extend northward from Vale at least as far as the east-west profile of holes VN-75-5.

Table 11. Geothermal data from holes drilled in Vale area by Oregon Department of Geology and Mineral Industries

Hole No.	North Latitude	West Longitude	Depth Interval	Elevation	Lithology	Average Gradient	Thermal Conductivity mcal/cmsec°C	Heat Flow**** microcal/cm^2sec
VN-75-1	43°54'	117°08'	20-150 m	879 m	siltstone	91.4° C/km	2.53	2.3
VN-75-2	44°07'	117°14'	30-60	721	claystone & basalt	110 **	2.54 3.0 ***	3.3 **
VN-75-3	44°07'	117°10'	50-125*	814	siltstone	76	2.54	1.9
VN-75-4	44°05'	117°06'	25-150	762	siltstone	120	2.53	3.0
VN-75-5	44°06'	117°02'	50-150	732	siltstone	76	2.53	1.9

* Hole VN-75-3 was drilled to 152 meters but a casing problem limited the gradient measurements to a depth of 125 meters.

** The average gradient and heat flow as shown reflects the existence of shallow thermal water in the vicinity of the hole.

*** Estimated

**** Topographic corrects not applied

CONCLUSIONS

As the result of this study, the knowledge of geothermal resources in Oregon has been greatly increased beyond that presented by Van Ostrans (1938), Peterson and Groh (1967), and Bowen (1972). During this study, 80 geothermal gradients were measured and the gradients released from pre-drilled wells. A total of 31 heat-flow determinations have been published. They are included here in Tables 10 and 11. The data obtained from the six monitor wells and the 92 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 and Glass Buttes may prove, with more study and drilling, to be important energy sources. The identification of the Cow Hollow anomaly has already lead to the classification of this area as a KGRA. It is anticipated that the bonus bids for Cow Hollow lease tracts will more than cover the Government's entire cost of this study.

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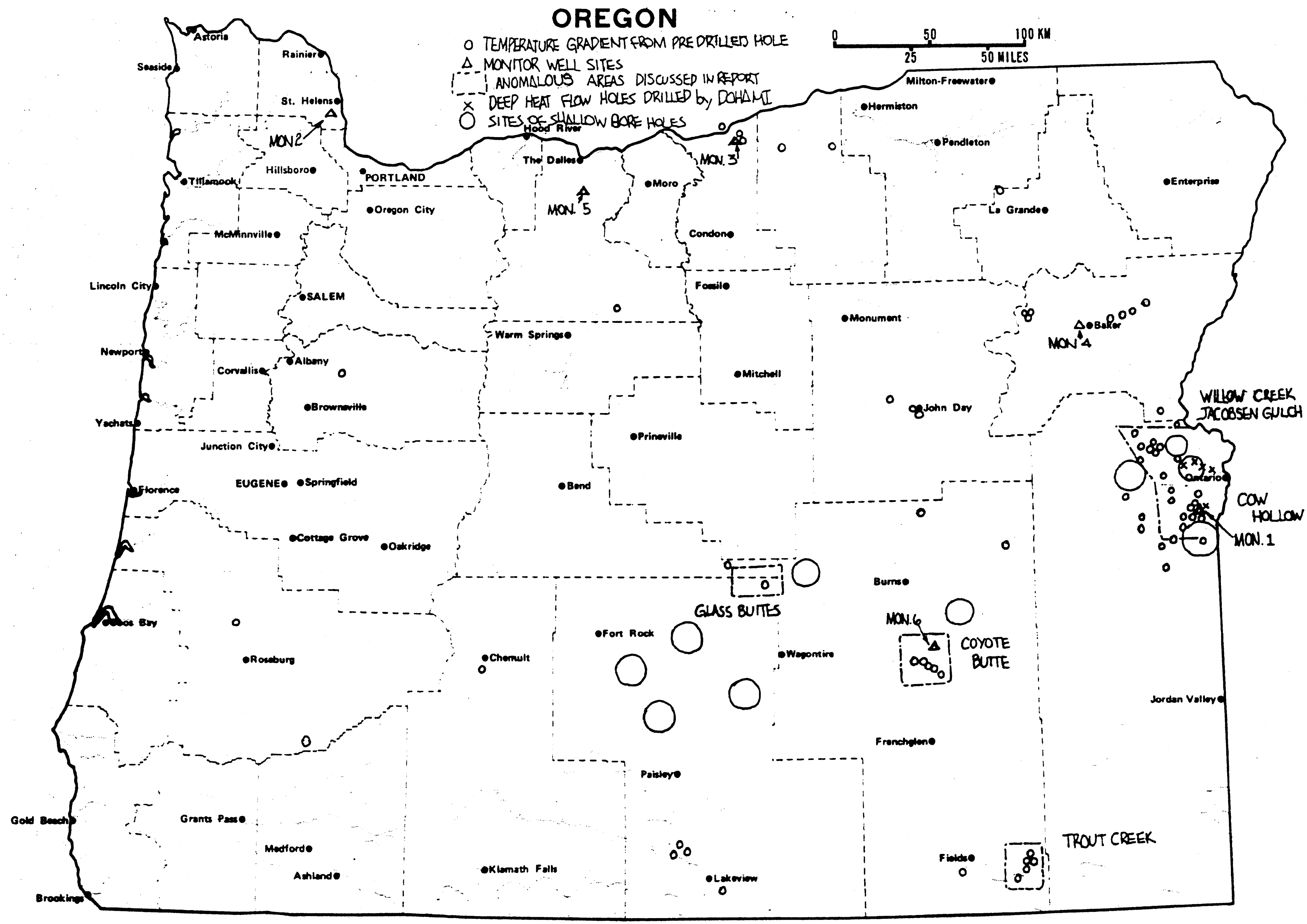
OREGON
TEMPERATURE GRADIENT FROM PREDRILLED HOLE
MONITOR WELL SITES
ANOMALOUS AREAS DISCUSSED IN REPORT
DEEP HEAT FLOW HOLES DRILLED by DOHAMI
SITES OF SHALLOW BORE HOLES
0 50 100 KM
25 50 MILES
Astoria
Seaside
Rainier
St. Helens
MON 2
Tillamook
Hillsboro
PORTLAND
Hood River
The Dalles
MON. 5
Moro
MON. 3
Hermiston
Milton-Freewater
Pendleton
Enterprise
La Grande
Oregon City
McMinnville
Condon
Lincoln City
SALEM
Fossil
Monument
Baker
MON 4
Warm Springs
Newport
Albany
Corvallis
Mitchell
Brownsville
John Day
Yachats
WILLOW CREEK
JACOBSEN GULCH
Prineville
Junction City
EUGENE
Springfield
Florence
Bend
Ontario
COW HOLLOW
MON. 1
Cottage Grove
Oakridge
Burns
GLASS BUTTES
Coos Bay
MON. 6
COYOTE BUTTE
Fort Rock
Wagontire
Roseburg
Chemult
Jordan Valley
Frenchglen
Paisley
Gold Beach
Grants Pass
Medford
TROUT CREEK
Ashland
Klamath Falls
Fields
Lakeview
Brookings

APPENDIX

1. The Cow Hollow Geothermal Anomaly, Malheur County, Oregon, by R.G. Bowen and D.D. Blackwell: The ORE BIN, vol. 37, no. 7 p. 109-121, 1975.

2. Telluric Current Exploration for Geothermal Anomalies in Oregon, by Gunnar Bodvarsson, Richard W. Couch, William T. MacFarlane, Rex W. Tank, and Robert M. Whitsett: The ORE BIN, vol. 36, no. 6, p. 93-107, 1974.

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The ORE BIN
Volume 36, No. 6
June 1974

TELLURIC CURRENT EXPLORATION FOR GEOTHERMAL ANOMALIES IN OREGON

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This study was supported in part by the U.S. Bureau of Mines grant No. SO122129 to the Oregon Department of Geology and Mineral Industries. Because of its timely interest, the article is being published in The ORE BIN rather than in a more technical journal in order to make the information immediately available to those involved in geothermal exploration in Oregon and elsewhere.

Introduction

A reconnaissance telluric current* exploration program for geothermal anomalies in southern and eastern Oregon was initiated in 1971 by the Geophysics Group at Oregon State University. During 1971 and 1972, observational data were obtained from a total of 19 field stations. The program concentrated on the Klamath Falls area, where 10 stations were occupied, and on a profile including a total of 9 stations extending from Siletz at the Pacific Coast to the area around Vale in the extreme eastern part of the state. The locations of the stations are shown in Figures 5 and 6. The principal purpose of this program was to test instrumentation, field procedure, data processing methods, and the general applicability of the telluric current method in reconnaissance exploration for geothermal resources. The results obtained are to be applied to improve all aspects of our methodology and to prepare for a more substantial effort in this field.

The field procedure applied on the present program deviates from the standard telluric method in that the telluric data obtained at the field stations are compared with the magnetic field recorded at a fixed base station. Our method is therefore a variant of the standard magneto-telluric method,

* Natural electric currents that flow on or near the earth's surface in large sheets. Methods have been developed for using these currents to make resistivity surveys.

but since we are mainly interested in large-scale lateral variations of the earth's conductivity, we have preferred to refer to the method as a telluric rather than magneto-telluric method.

Rationale for the Telluric Current Method

Regional reconnaissance exploration for geothermal resources is concerned with the initial detection and recognition of geothermal anomalies of economic interest. An elementary investigation (Bodvarsson, 1966) of resource energetics shows that the heat capacity of rock is such that in terms of electrical energy it is realistic to expect that very roughly about 1 kwhr can be generated per cubic meter of resource volume. This estimate is based on the assumption of the conditions in known fluid-phase, high-temperature geothermal systems where base temperatures of the order of 250°C are encountered and by using a recovery factor of 10 percent. Hence, the generation of 250 Mw at base-load condition for 50 years would require a resource volume of not less than 100 cubic kilometers. This volume could, for example, have the shape of a disk with a diameter of 8 km and thickness of 2 km. Invariably such a reservoir would be surrounded by a thermal halo of considerable extent and the total associated thermal anomaly could extend over areas of several hundred square kilometers and downward into the deeper crust. The exploration targets are, therefore, quite extensive features.

Most of the important known geothermal resources are leaky in the sense that they generate thermal surface manifestations such as hot springs and conspicuous thermal rock alteration. The high temperature character can be recognized on the basis of the physical and chemical characteristics of the surface display. In general, the leaky resources are easily recognized, and there is little need for sophisticated reconnaissance type exploration work.

There is, however, considerable evidence that geothermal systems of great economic potential may be totally concealed and display no surface leakage at all (Bodvarsson, 1961, 1970). In fact, geothermal fluids have a tendency to chemically seal outlets and thereby contribute to the eradication of surface manifestations (Bodvarsson, 1961). Resources of this type can be detected only with the help of more elaborate techniques, such as thermal and electrical exploration methods.

The thermal methods involve regional temperature probing or heat-flow mapping with the help of temperature data from very shallow boreholes. Large geothermal resources within drillable depths are invariably associated with conspicuous surface heat-flow anomalies and can therefore be recognized in regional heat-flow maps of sufficiently detailed nature.

The application of the electrical methods is based on the fact that the formations within geothermal systems have a low electrical resistivity (Bodvarsson, 1970). Values in the range of 1 to 10 Ωm have been observed within many high-temperature geothermal reservoirs. This is the consequence of high temperatures and high mineral content of reservoir interstitial waters.

The resistivity contrast between the hot formations and the surrounding country rock quite often involves factors ranging from 10 to 100. Most major geothermal systems are associated with large-scale electrical resistivity anomalies, and this is especially true with the fluid phase systems. Electrical methods are therefore important tools in geothermal exploration work.

Electrical exploration methods fall into two categories, those based (1) on controlled artificial current source fields, and (2) on natural current fields provided by magnetic micropulsations and other ULF natural activity. The second class of methods, which includes the telluric and magneto-telluric methods, has a considerable advantage in reconnaissance type exploration work involving exploration targets of relatively large dimensions and depths of more than 1 or 2 kilometers. The artificial current sources in such circumstances would require a considerable amount of equipment and field effort. The advantage of the second class of methods is obtained at the cost of less resolving power and greater ambiquity in interpretation, but since target dimensions and resistivity contrasts are unusually large, this disadvantage is not considered to be too important.

For the present purpose, the natural field electrical methods have a certain economic advantage over the thermal methods. Heat-flow mapping is based on the measurement of the vertical flow of heat, which usually has to be derived from temperature and heat conductivity data obtained from shallow boreholes. The minimum depth of such boreholes is 10 to 20 meters, and the selection of drilling locations has to be carried out with considerable care. The field effort required at each station to obtain one or two hours of telluric records is considerably smaller. Moreover, since the telluric currents are horizontal, each telluric station can sample a larger formation volume than the corresponding heat-flow station. In a given area it should therefore be possible to obtain useful reconnaissance type data with the help of fewer telluric field stations than thermal stations. It is clear that carefully measured heat-flow data can be more accurate and have a greater resolution than telluric data, but in reconnaissance type geothermal exploration work the economic advantage of the telluric method appears to outweight this disadvantage. These are the main reasons for selecting the telluric method for our work in Oregon.

In this study it was considered of advantage to install a fixed magnetic base station, rather than to rely on a telluric electrical field base station. The magnetic data allow us to obtain absolute conductivity values. The magnetic base station was installed at Corvallis, Oregon, some 280 km north of the Klamath Falls area. Investigations of micropulsation activity in southern California (Benioff, 1960) have indicated that the micropulsation field at moderate latitudes does not vary appreciably over such distances. On the other hand, the field stations at Vale in eastern Oregon are located almost 500 km from the base station, and the general magnetic coherency cannot be expected to be as good, although individual magnetic events with a good coherency appear to exist.

Expected Resolution

It is important to raise the question as to the overall quality of the exploratory information which can be expected from a telluric current field program of the type described above. Unfortunately, the information content of the observational field data depends to a considerable extent on the local conditions at the individual field stations. Moreover, the theory of telluric currents in electrically non-homogeneous geological structures is a matter of great complexity and not much work of practical relevance has been devoted to the subject. We therefore limit ourselves to the following quite superficial remarks.

For the present purpose, the earth can be assumed to be a semi-infinite perfect reflector of the magnetic field generated by the oscillating ionospheric currents. The penetration of the induced telluric currents is limited by the skin effect which is measured by the skin depth, that is, the depth at which the current amplitude has been attenuated to $1/e = 0.37$ of its surface value (Keller and Frischknecht, 1966, p. 213). Relevant values of the skin depth for homogeneous isotropic half-spaces at various resistivities and at periods from 10 to 50 seconds are given in Figure 1.

Approximately 2/3 of the telluric current flows in the horizontal region above the skin depth. Hence, this depth gives a fairly good measure of the thickness of the formations sampled by the telluric currents and the associated electrical field. Assuming perfect source current conditions and a homogeneous half-space, the above described telluric method will give the true resistivity of the half-space regardless of the frequency. In a layered

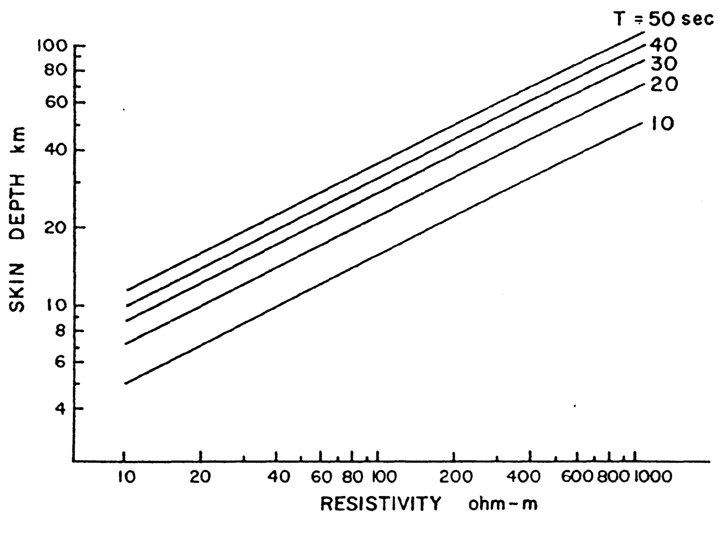


Figure 1. Data on the skin depth in a homogeneous half-space.

half-space, the method gives a certain weighted average of the vertical resistivity distribution in the region where the bulk of the telluric current flows. Obviously, the averaging is biased toward the shallower sections.

The telluric current pattern is distorted by lateral inhomogeneities and anisotropicities which commonly occur in the field. The conditions in the local region between and around the field electrodes are of primary importance, particularly where the electrodes have been placed within a local low resistivity anomaly. The electrical field readings are then abnormally low and the station yields an apparent resistivity value which can be grossly in error. Substantial apparent anisotropies may also be introduced by purely local conditions. Clearly, difficulties of this kind are common to all electrical methods using conductive contacts. The principal precautions against serious errors of this type are (1) to select the field stations with care to avoid local zones of low resistivity and anisotropicity, and (2) to scrutinize all conspicuously low and anisotropic apparent resistivity values by repeated measurements at several stations in the local area. This is of particular importance for the present project since the low resistivity anomalies are the primary exploration targets.

Directional and density inhomogeneities in the overhead ionospheric currents are further sources of errors. Usually, the interpretation of telluric and magneto-telluric data is based on the assumption of uniform and unidirectional source currents. Deviations from this idealized model lower the quality of the observational material and are perhaps the main cause of the often excessive scattering of observational magneto-telluric resistivity data. As indicated above, this matter is of particular concern with regard to the present project since such difficulties are likely to be enhanced by the distance between the magnetic base station and the electrical field stations. To minimize this effect, it is important to obtain field records for sufficiently long periods of time and to edit the data by rejecting sections with low magnetic-telluric coherency.

Instrumentation and Field Procedure

The instrumentation used on the present project consists of two separate parts, (1) the magnetic base station at Corvallis, and (2) the portable telluric field equipment. Block diagrams of the two systems are shown in Figures 2 and 3. The magnetic data aquisition system was provided by the Boeing Company, Seattle, Washington. A description of the magnetic sensors has been given by McNicol and Johnson (1964).

In brief, the magnetic sensors consist of three mumetal-cored induction coils each with 4.8×10^5 turns of wire. The diameter of the cores is 1 inch. The three coils were buried in the ground at the World Wide Standard Seismic Network Station at Corvallis, where the associated electronic equipment was housed, and were placed along three local orthogonal axes, geographic north, east and vertical. The station crystal clock provided an

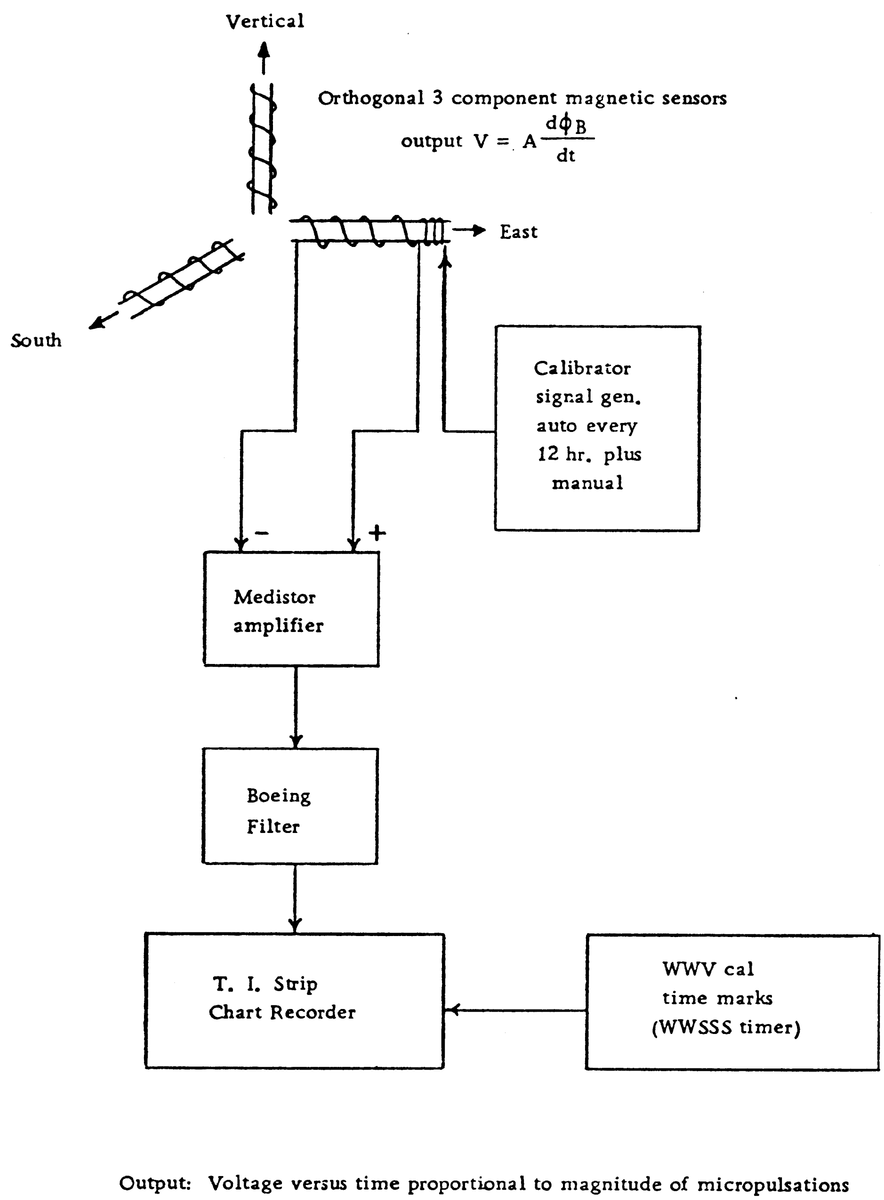
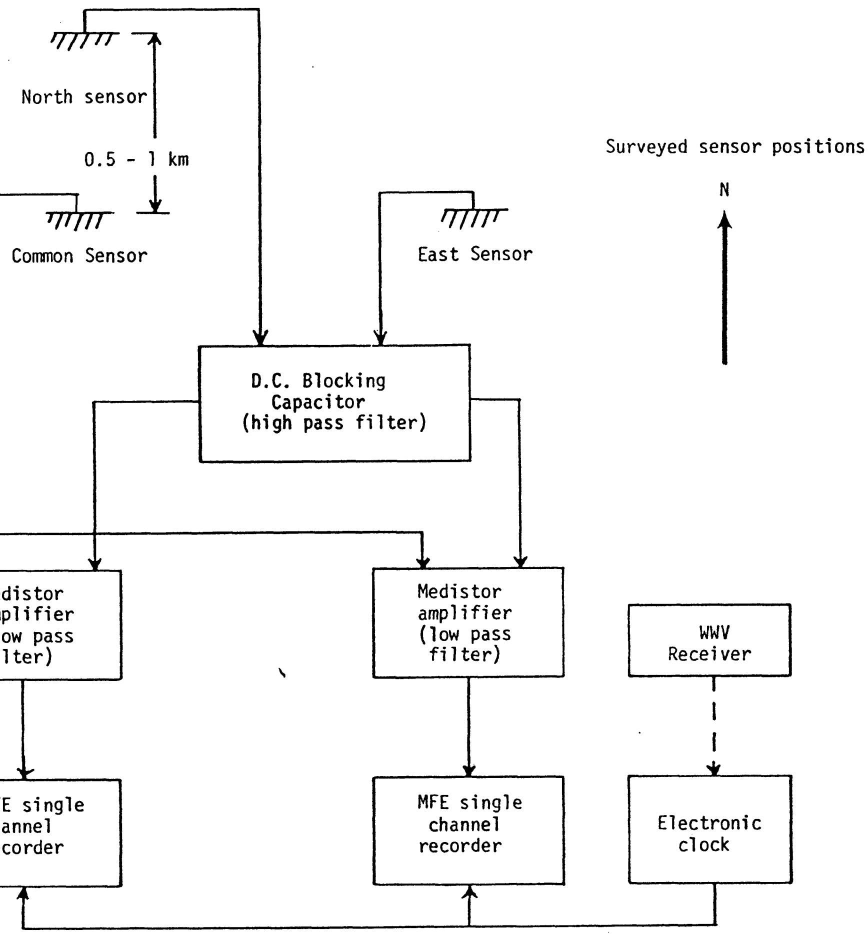


Figure 2. Magnetic data-acquisition system.



Output: Voltage versus time, each absolutely calibrated usually expressed mv/km

Figure 3. Telluric data-acquisition system.

absolute time reference. The amplified magnetic signals were recorded on Texas Instrument strip chart recorders. The magnetic system was calibrated by using an artificial oscillating magnetic field.

The telluric sensors, which consisted of three lead metal probes inserted into the ground at the individual field stations, formed an orthogonal L-shaped array where one arm pointed north and the other east. The length of the arms ranged from 200 to 500 meters, depending on local conditions. Each probe consisted of a piece of metallic lead plate 5 mm thick, 600 mm wide, and 1,000 mm long, rolled up into a tube 200 mm in diameter, and buried in the ground. Local D.C. fields were blocked out with a non-polar 20-micro farad capacitor. The output signals were amplified and recorded on a four-track strip-chart recorder. Each field station was occupied for a time sufficient to provide 1 to 2 hours of telluric field data.

Observational Data

A comparison of the individual telluric field records with simultaneous orthogonal magnetic base station records shows that the coherency generally varies considerably over the record length. In most pairs of simultaneous records, there were, however, individual wave packets or events in the 10- to 50-second period band which showed a good coherency and which could be considered likely to furnish representative values of the electromagnetic impedance ratio. It was, therefore, decided to base the data processing on such wave packets only and to apply the simple individual event method of Berdichevsky and Brunelli (1959) to obtain the impedance ratios at the various frequencies. The method has also been described by Keller and Frischknecht (1966, p. 246).

Usually, between 5 and 10 events could be processed for each pair of orthogonal field components. The impedance ratios obtained were then applied to derive an apparent resistivity with the help of the well-known basic equation for magneto-telluric investigations (see Keller and Frischknecht, 1966, p. 217),

$$\rho_a = (\mu_o T/2\pi)\ (E/B)^2 \qquad (1)$$

where ρ_a is the apparent resistivity, T is the period, $\mu_o = 4\pi \times 10^{-7}$ is the permeability of free space, E the amplitude of the horizontal electrical field, and B the amplitude of the orthogonal horizontal magnetic field, both amplitudes measured at the ground surface, all in MKSA units.

Many geological formations exhibit a substantial anisotropy, that is, the apparent resistivity depends on the direction in which the fields are measured. In the following, we therefore use the subscripts n and e for north-south and east-west, respectively, and refer to ρ_{an} as the apparent resistivity value based on E_n/B_e and to ρ_{ae} as the value based on E_e/B_n.

An illustration of the results is obtained by plotting the apparent resistivities derived from the individual component pairs against the event periods. Typical plots of this kind are given in Figure 4, which shows the processed apparent resistivity data from the Corvallis base station (12) and from South Klamath Hills (6) in the Klamath Falls region.

As indicated by the examples in Figure 4, the apparent resistivity data exhibit a considerable irregular scattering, which in most cases covers a relative range from 1 to 3; that is, the highest values are about three times as large as the lowest. At most stations, the maximums are observed in the 20- to 30-second period band.

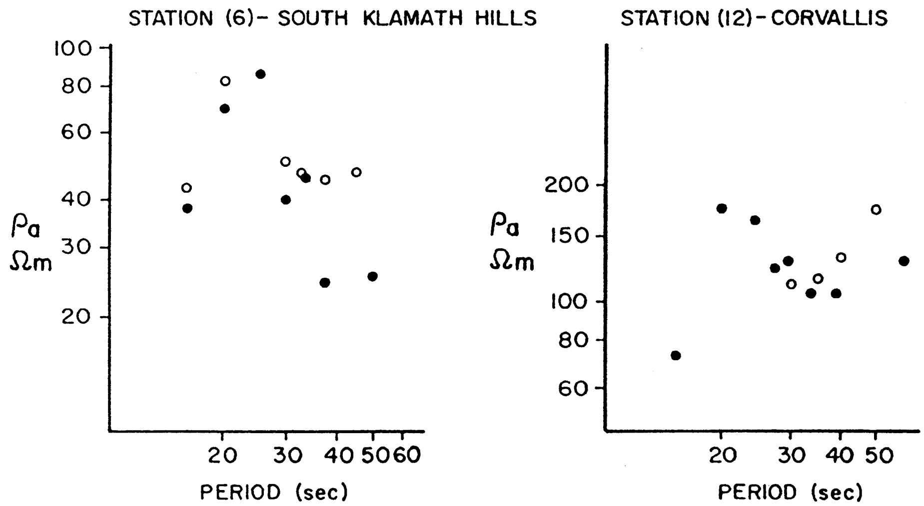


Figure 4. Apparent resistivities versus period for stations (6) and (12). Full circles represent ρ_{an}, the north-south resistivities, and the open circles ρ_{ae}, the east-west resistivities.

Scattering of this kind is frequently encountered in magneto-telluric work, and along the lines discussed above, we point out that the following causes may contribute to this situation: (I) Non-uniform source current fields; (II) enhanced non-coherency due to the distances between the magnetic base station and the individual field stations; (III) numerical errors introduced by the individual event analysis method; and (IV) instrumental errors. Obviously, all errors in the observed impedance ratios are enhanced by the squaring of the impedance ratio in equations (1).

At this juncture, it appears that the non-uniformities under (I) are a substantial cause of the scattering. Since the results obtained at the Corvallis base station exhibit a similar character as the other field stations, the distance factor mentioned under (II) does not appear to be a primary cause. We have still to evaluate the influence of the data-processing method listed under (III). The maximums observed in the 20- to 30-second band may partially be instrumental.

Preliminary Numerical Results

In view of the character of the observational material and since we are mainly interested in a fairly large-scale average resistivity at each station, there is at this time not much incentive to attempt a more elaborate interpretation of the present data. In our present analysis, we therefore rely on the simple procedure of taking averages over the apparent resistivity values observed in the 10- to 50-second period band for each direction at the individual stations. This procedure yields two values, $\bar{\rho}_{an}$ and $\bar{\rho}_{ae}$, for each station. The first is the averaged apparent resistivity in the north-south direction, and the second is the value for the east-west direction. These data are listed in columns (1) and (2) in Table 1. Moreover, the table also lists in column (3) the averages for the two directions. Since the penetration of telluric currents depends on the skin depth, the trend of the apparent resistivities with increasing periods gives a certain indication about the downward trend of the resistivity. This information is given in the last column of Table 1. The averaged resistivity from column (3) in Table 1 is plotted on the maps in Figures 5 and 6.

Data Evaluation and Discussion

A preliminary review of the data given in Table 1 and shown in Figures 5 and 6 can be summarized as follows. We will focus our attention on the averaged apparent resistivity data in column (3) of Table 1.

(1) Data from a total of 19 field stations are available. The average values given in column (3) of Table 1 vary from a low of 15 to a high of 360, that is, by a factor of 24. The variability is one order of magnitude greater than the scattering of the data at the individual stations.

(2) Six of the ten data obtained in the Klamath Falls area are well below 100 Ωm. With one exception, these are the lowest values observed on our project. This is of primary interest since Klamath Falls is an area of known geothermal activity (Peterson and McIntyre, 1970). Stations (6) and (7) which yield values of 60 and 40 Ωm, respectively, are close to geothermal surface manifestations. Moreover, stations (1), (3), and (9) to the northwest and north yield low values, particularly station (1). Since the Klamath Falls area is the only area with known geothermal display investigated by us, we conclude that our results exhibit an encouraging correlation with geothermal activity. Nevertheless, we have to emphasize that other non-thermal factors may also be involved, and in this respect we point out that there is an abrupt decrease in the observed resistivity from station (5) to station (6). Since the distance between these two stations is only 7 km, we surmise that local geological factors are of some importance.

Table 1. Average apparent resistivities for the 10- to 50-second period band

Station	Name	(1) North-south resistivities, $\bar{\rho}_{an}$	(2) East-west resistivities, $\bar{\rho}_{ae}$	(3) Average (1) and (2) (rounded off)	(4) Downward trend
Klamath Falls area					
(1)	Lake of the Woods	10 Ωm	20 Ωm	15 Ωm	D
(2)	Miess Lake	210	260	240	I
(3)	Indian Springs Flat	100	40	70	D
(4)	Lake Miller	40	420	230	U
(5)	Tulane	280	330	310	I
(6)	S. Klamath Hills	50	70	60	D
(7)	Noble	40	30	40	D
(8)	Nuss Lake	30	240	140	D
(9)	Swan Lake	10	130	70	D
(10)	Scranz	30	120	80	U
West-East profile					
(11)	Siletz	110	100	110	I
(12)	Corvallis	130	130	130	U
(13)	Sweet Home	120	200	160	I
(14)	Sisters	330	360	350	D
(15)	Hampton	140	130	140	U
(16)	Harney Basin	360		360	D
(17)	Vale-Negro Rock	40	10	25	D
(18)	Vale-E. Cow Hollow	70	330	200	D
(19)	Vale-Alkali Flats	220	170	200	U
Column average		120	170	150	

D - decreases; I - increases; U - uncertain

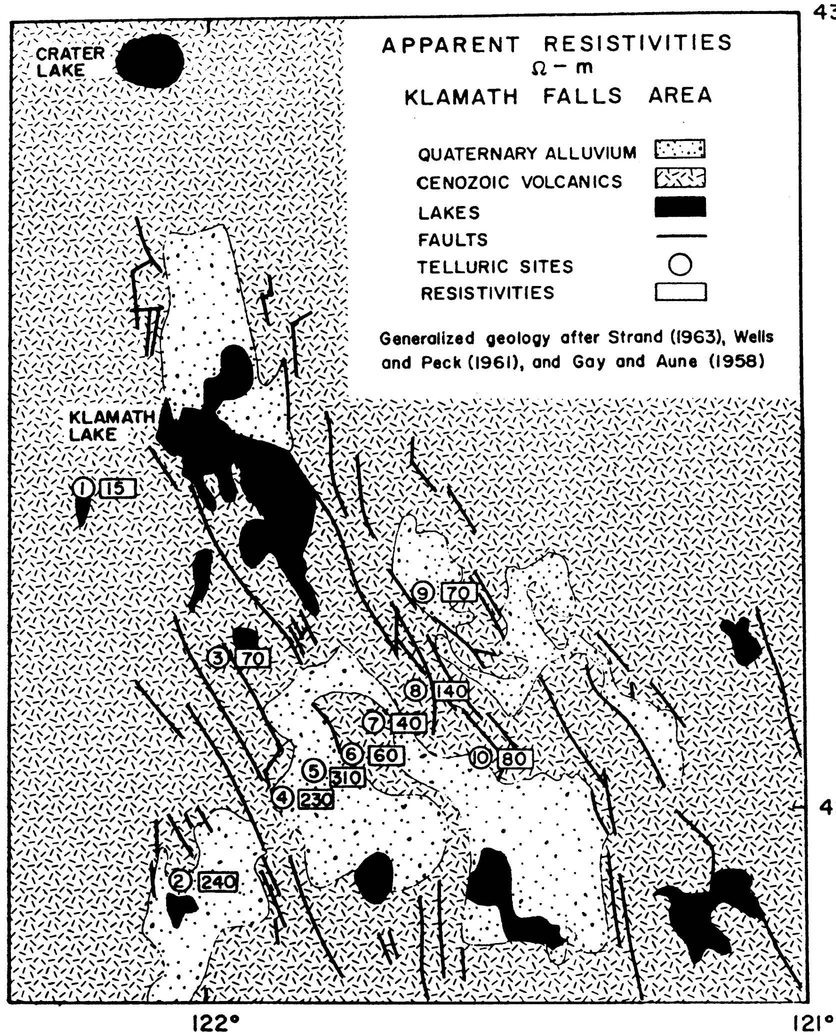


Figure 5. Average apparent resistivities in the Klamath Falls area listed in column (3) of Table 1.

(3) On the other hand, the resistivity values obtained so far in Klamath Falls are considerably above values observed by D.C. resistivity methods in known high-temperature geothermal areas (Banwell, 1970). The present data are, therefore, not indicative of typical high-temperature conditions there. The data are, however, too few to draw definite conclusions.

(4) The very low values observed at stations (1) and (17) are of particular interest although they cannot be correlated with any known

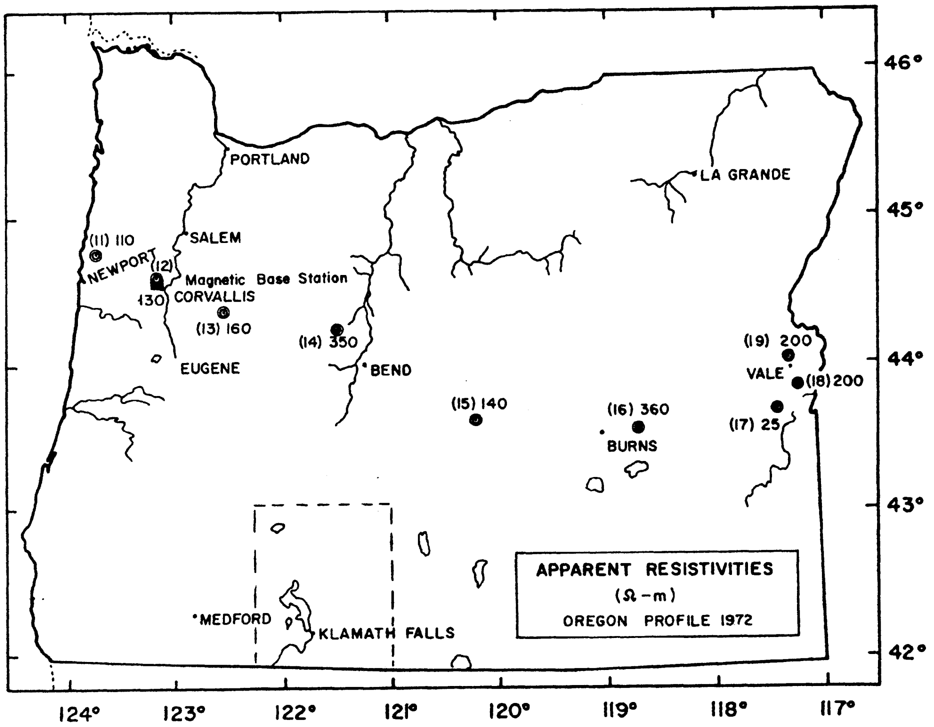


Figure 6. Average apparent resistivities on the profile from Siletz to Vale listed in column (3) of Table 1. The figure in brackets is the station number. The dashed line outlines the area of Figure 5.

local thermal surface display. A further investigation is definitely warranted.

(5) At ten of the stations the apparent resistivity decreases with increasing depth. In particular, this is true of the stations with low values and is very probably of significance with regard to geothermal anomalies.

(6) Six of the stations exhibit a very pronounced anisotropy involving ratios up to 10. There is little doubt that local effects at the station sites are important causes of some of the high ratios. On the other hand, it is noted that generally the east-west resistivities are higher than the north-south values. This appears to be a reasonable result since the general geological strike in the Klamath Falls and Vale areas is not far from being north-south.

(7) Because of the sparsity of stations along the Siletz-Vale profile, we are unable to comment on the distribution of apparent resistivities along the profile. It appears reasonable that relatively low values are observed in the coastal region and in the Willamette Valley. The values observed

east of the Cascades are typical of values observed in mafic Tertiary volcanics (Bodvarsson, 1950).

(8) We conclude that, in spite of obvious shortcomings, our preliminary results indicate that the telluric method applied has a potential of becoming a reconnaissance tool of significant interest in the exploration for geothermal resources.

Acknowledgments

This work was supported by the National Science Foundation under Grant GA-25896. We are also indebted to the Boeing Company, Seattle, WA; Weyerhauser Company, Tacoma, WA; Pacific Power and Light Company, Portland, OR; and the Oregon Department of Geology and Mineral Industries, Portland, OR, under Bureau of Mines grant SO 122129, for partial support of our work. N. V. Peterson, Oregon Department of Geology and Mineral Industries, provided valuable guidance in selecting field stations.

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* * * * *

WASTE RECYCLING FILM AVAILABLE FROM MINES BUREAU

The recycling of urban and industrial waste is the subject of "Wealth out of Waste," a 16mm film now available from the U.S. Bureau of Mines.

The film shows why waste disposal has become a national problem and details the technology, including Bureau-developed processes, which can separate the refuse into reusable components for manufacture into new products or for use in energy production.

Prints of the 27-minute sound and color film are available on free, short-term loan to schools, civic, professional, business, and scientific organizations interested in resource development and conservation. Write Motion Pictures, Bureau of Mines, 4800 Forbes Avenue, Pittsburgh, Pa., 15213. Borrowers should state they have a 16mm sound projector and an experienced operator; they will be responsible for return postage and for any damage to the print beyond normal wear.

* * * * *

POTENTIAL-HAZARDS MAP OF MOUNT RAINIER PUBLISHED

"Potential hazards from future eruptions of Mount Rainier, Washington," by Dwight R. Crandell is a map with descriptive text that shows by color and pattern the distribution of mudflows and tephra (airborne volcanic debris) and the varying degrees of risk to human life in those areas in the event of a volcanic eruption. The map, at a scale of 1:125,000, and text are on a single sheet designated as Miscellaneous Geologic Investigations Map I-836. The publication is for sale by the U.S. Geological Survey Distribution Section, Federal Center, Denver, Colorado, 80225 for 75 cents.

* * * * *

PROSPECTING WORKSHOP OFFERED

Clackamas Community College is sponsoring a Prospecting Workshop in Room B-104 on the evening of August 23 at 7:00 p.m. An all-day field trip will be held on August 24 in the Quartzville area. Both the lecture and field trip will be led by Jerry Gray of the Department staff. Tuition for the workshop is $12.00 and pre-registration is recommended. Additional information may be obtained by calling 656-2631, ext. 311.

* * * * *

FIRST VOLUME OF OREGON LAKES INVENTORY PRINTED

"Lakes of Oregon, Volume 1, Clatsop, Columbia, and Tillamook Counties" by R. B. Sanderson, M. V. Shulters, and D. A. Curtiss, has been issued as an open-file report by the U.S. Geological Survey in cooperation with the Oregon State Engineer. The 95-page, bound booklet describes 33 lakes in the three counties. Each lake is briefly described as to location, size, use, water temperature, and other pertinent characteristics, and is illustrated with an aerial photograph and a map showing shape and depth. Volume 1 is the beginning of a much-needed inventory of Oregon Lakes that will be a very useful reference. The volume is printed in limited supply. Information concerning its availability can be obtained from the U.S. Geological Survey Water Resources Division in Portland or from the Oregon State Engineer's office in Salem.

* * * * *

JOHN ALLEN RETIRES FROM PORTLAND STATE UNIVERSITY

Dr. John Eliot Allen has retired from the faculty of Portland State University after 17 years as head of the Earth Sciences Department and a long career that had considerable influence on geological education and research.

Dr. Allen had stepped down as chairman and head of the Earth Sciences Department at PSU last year, continuing to teach during the recently ended school year. He has a long list of publications both in the scientific journals and in materials written for the layman. He received his bachelor and master's degrees from the U of O and his doctorate from the University of California, Berkeley. Between 1939 and 1944 he was a geologist with Oregon Department of Geology and Mineral Industries. He is succeeded as head of the Department by Dr. Richard E. Thoms, who joined the Earth Sciences Department staff in 1964.

* * * * *

State of Oregon
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and Mineral Industries
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The ORE BIN
Volume 37, No. 7
July 1975

THE COW HOLLOW GEOTHERMAL ANOMALY, MALHEUR COUNTY, OREGON

R. G. Bowen* and D. D. Blackwell**

During the past four years, the Oregon Department of Geology and Mineral Industries has been conducting a regional study, sponsored by the U.S. Bureau of Mines with grant No. S0122129, on the geothermal potential of eastern Oregon. In the course of the study, an area of anomalously high heat flow was discovered a few miles southeast of Vale, Malheur County, in an area known locally as Cow Hollow (see Figure 1, p. 116-117). The anomaly, which covers an area at least 6 miles by 3 miles, gives heat-flow values ranging from slightly greater to more than three times greater than normal for this region.

In 1973, Bowen and Blackwell (Ore Bin, 1973) reported geothermal gradient and heat-flow values for the Cow Hollow area (at that time referred to as the Chalk Butte area). In 1974, when Federal lands in Oregon were opened for geothermal leasing and multiple filings were made in Cow Hollow, the area, which is entirely under Federal ownership, was established as a Known Geothermal Resource Area (KGRA). A sale of geothermal leases in Cow Hollow has been scheduled by the U.S. Bureau of Land Management for September 25, 1975.

Since publication of the early geothermal information on Cow Hollow, The Oregon Department of Geology and Mineral Industries has gathered additional geological and geophysical data for the area, has drilled 24 shallow (3 to 4 meter) temperature holes, and has published results (Hull, 1975) on a deeper drilling in the area. This summary of the geologic interpretations and geophysical data is published as a preliminary report in order to make the information available for those working to develop the geothermal resources of the area. A future report (Blackwell and Bowen, in prep.) will describe in more detail the heat flow and shallow temperature data together with the geological and geophysical information.

Although the authors accept responsibility for the geologic concepts outlined in this paper, they wish to acknowledge the help given them by Department staff, including V. C. Newton, R. E. Corcoran, Alan Preissler, Deborah Fisher, and Donald Hull.

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Previous Geologic and Geophysical Studies

A geologic map and report on the Mitchell Butte quadrangle, which includes the Cow Hollow area, was prepared by Corcoran and others (1962). A report by Newton and Corcoran (1963) on the western Snake River Basin details the subsurface conditions in the region. A geologic map by Kittleman and others (1967) covers the Owyhee Region south and west of the Cow Hollow area. A reconnaissance surface magnetic map of the area has been prepared by Brott and Blackwell (SMU, unpublished data), and gravity and magnetic maps have been prepared by K. H. Koenen, consulting geophysicist, Portland.

Geology

Stratigraphy

The Cow Hollow area (see Figure 1) lies in the northeastern part of the Mitchell Butte 30' quadrangle and southern parts of the Jamieson and Moores Hollow quadrangles. The area is underlain by a thick sequence of late Tertiary continental sedimentary and volcanic rocks. Quaternary alluvium and terrace gravels mask the Tertiary units in the valleys of the Snake River, Malheur River, and Willow Creek. The youngest Tertiary rocks belong to the Idaho Group of Pliocene age. Originally described as one unit by Cope (1883), the Idaho Group has been divided by Corcoran and others (1962) into three formations: two lacustrine units, the Chalk Butte and the Kern Basin Formations, separated by the Grassy Mountain Basalt.

The Chalk Butte Formation, the uppermost member of the Idaho Group, is composed of tuffaceous claystone and siltstone with lesser amounts of tuff, conglomerate, ash beds, and fresh-water limestone. Thickness of the formation, estimated from well data to the east and west, ranges from 2,500 to 3,500 feet. The Grassy Mountain Basalt, which underlies the Chalk Butte Formation, is reported by Corcoran and others (1962) to be 500 to 1,000 feet thick. Beneath the Grassy Mountain Basalt is the Kern Basin Formation composed of tuffaceous claystone, siltstone, sandstone, and, less commonly conglomerate. The Kern Basin Formation is not exposed in the area, but at its type locality, about 20 miles to the south, it is 750 feet thick.

Underlying the Kern Basin Formation, with apparent unconformity, is the Deer Butte Formation of late Miocene age. The Deer Butte is composed chiefly of lacustrine and fluviatile tuffaceous siltstone and shale but also includes prominent beds of well-cemented conglomerate and sandstone. Measured sections of the Deer Butte Formation elsewhere in the Mitchell Butte quadrangle have a maximum thickness of 1,248 feet.

The Owyhee Basalt, which underlies the Deer Butte sediments, is a very widespread and prominent section consisting of basalt flows and interbedded tuff. It is middle Miocene in age and can be traced southwestward to the Steens Basalt and northwestward to the Columbia River Basalt.

Under the Owyhee Basalt is the Sucker Creek Formation, named by Corcoran and others, 1962. It crops out extensively in the southern part of the Mitchell Butte quadrangle, where it consists mostly of tuffaceous sediments with interbedded rhyolitic and felsitic volcanics in the upper part and basalt flows in the lower part.

Intrusions and associated flows of Tertiary-Quaternary age occupy small areas in the southwestern part of the map area.

Structural geology

Regionally, the structural position of the area is on the west limb of the western Snake River Basin, which is a part of the Snake River downwarp, a large structural trough extending from Yellowstone Park across southern Idaho and into eastern Oregon. The Idaho part of the western Snake River Basin appears to be a large graben, as high-angle faults parallel the general trend of the basin along its northeastern and southwestern edges (Hill, 1963). The bounding faults mapped in Idaho have not been identified in Oregon, however. Corcoran and others (1962) show no faults or structures except the regional northeasterly dip in the Cow Hollow area.

From the data gathered as a part of this study, the authors interpret a major northwest-trending fault zone transecting the Cow Hollow area and believe the geothermal manifestation and high heat-flow anomaly reflect leakage along this fault. The magnetic and gravity mapping appear to corroborate this thesis. The authors have named this the Willow Creek fault after the Willow Creek valley northwest of Vale. Evidence for the Willow Creek fault is mainly from physiographic expression and geophysical measurements. Displacement of lithologic units has not been found and amount of throw has not been determined. The strongest physiographic expression of the fault is the lineament formed by Willow Creek valley extending for 30 miles in a nearly straight line to the northwest of Vale. Southeast of Vale the trend continues but is less conspicuous. The presence of Vale Hot Spring on the fault, several reported warm-water wells in the Willow Creek area, and the high heat flow to the southeast along the zone are additional evidence for the fault.

Lawrence (in press) describes a series of right lateral tear fault zones, one of which he calls the Vale Zone. This zone, consisting of several linear segments, includes Willow Creek and portions of the Snake River in Idaho. The Vale Zone includes what we have called the Willow Creek fault in this paper.

A parallel fault zone, named the Bully Creek fault, lies about 6 miles to the west. Physiographic evidence is similar to the Willow Creek fault but the trends are not as prominent. To the north, Owyhee Basalt has been uplifted on the west side of the Bully Creek fault trend, indicating that the area between the Willow Creek and Bully Creek faults is a graben. Electric logs from the Sta-Tex "Russell well" east of the Bully Creek fault and from the El Paso "Federal well" west of the fault indicate the western block is uplifted, corroborating the interpretation of a graben between the two faults.

A third fault, appproximately perpendicular to the Willow Creek fault, here called the Malheur River fault, is believed to parallel the course of the Malheur River northeast of Vale. Its existence is interpreted largely from geophysical mapping by Koenen, but there is also a strong physiographic expression of a fault at this location. Vale Hot Spring appears to be located on the intersection of the Willow Creek and the Malheur River faults. Rinehart Butte and Vale Butte, situated just east of Vale, are believed by the authors to represent silicified remnants of hot springs that have maintained their topographic expression through resistance to erosion. Corcoran and others (1962) believe the two buttes represent topographic highs in the pre-Idaho terrain and that sediments of the Idaho Group were deposited around these ancient highs.

Geophysical evidence for the Willow Creek fault comes from a ground magnetic profile made in 1973 (Brott and Blackwell, SMU, unpublished data). This information shows a magnetic high along the eastern side of the fault zone to the southeast of Vale. Gravity and magnetic data of the Vale KGRA by Koenen are included on Figure 1. These patterns show strong northwest trends with gravity and magnetic highs on the east side of the zone, consistent with the northwest fault trends as proposed here for the Bully Creek and Willow Creek fault zones. The accompanying cross section (Figure 2) shows this relationship. Koenen (oral communication, 1975) believes the gravity and magnetic maps indicate a series of intrusives along a northwest-trending fault zone.

Geothermal Systems

Heat-flow information

Measuring variations in the rate of heat escaping from within the earth and flowing toward the surface is one of the best methods of prospecting for geothermal resources, and it was the method used for this study. Other geophysical methods, such as electrical and seismic, provide indirect evidence of conditions related to geothermal energy accumulation and help to support the heat-flow data. Detailed information on the mechanics of heat-flow acquisition and reduction is given by Roy and others (1968).

High heat flow always indicates the presence of a geothermal accumulation, but temperature, depth, or size of the accumulation must be obtained by other exploration tools. A high-level anomaly may prove to be only warm geothermal waters at a relatively shallow depth, whereas a lower-level anomaly may represent fluids of very high temperature at greater depths. Although other geophysical and geochemical methods in conjunction with geologic investigations can be used for depth estimates along with the heat-flow data, it is necessary to sample formation fluids by drilling in order to determine reservoir characteristics.

Basically, heat flow is the product of the geothermal gradient (rate of increase of temperature with depth) and the conductivity of the rocks (rate of passage of heat through the rocks). 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 1.4 HFU. In areas of Tertiary volcanic rocks, such as eastern Oregon and Idaho, average heat flow is closer to 2 HFU (Blackwell, 1969).

The map, Figure 1, shows some of the heat-flow values in the western Snake River Basin gathered as a part of this study as well as data previously published (Bowen, 1972; Bowen and Blackwell, in Ore Bin, 1973), including five recently drilled holes (Hull, 1975), with additional unpublished geothermal data. The Cow Hollow anomaly is represented by the concentration of data along the Willow Creek fault where gradients range from 76° to 214°C/km and heat-flow values from 2.3 to 6.4 HFU. All of the bore holes, which range in depth from 65 to 395 meters, are in the Chalk Butte Formation. One of the new drill holes, about 1 mile east of the highest heat-flow value, has a heat flow of only 2.3 HFU. Thus the geothermal anomaly appears to be elongated in a northwest direction and is asymmetric, with the sharpest drop in heat flow to the east. The anomaly also appears to be related to leakage along the Willow Creek fault, and suggests that the fault dips to the west, consistent with a down-to-the-west normal fault.

The heat-flow values on the remainder of the map range from 1.9 to 4.6 but the data are too sparse for any conclusions about the presence or absence of other anomalies. The average gradient for 20 wells in the western Snake River Basin, excluding the ones in the geothermal anomaly, is 81°C/km (4.4°F/100 ft.) with a range of 44° to 112°C/km. Table 1 lists all geothermal data used as a part of this paper.

Geothermal possibilities

For a geothermal deposit to be economically viable, three reservoir conditions must exist. 1) There must be sufficient heat, since the amount of heat in the fluids determines the use and the value of the deposit. For example, temperatures of 200°C (392°F) or greater are suitable for electric power production; temperatures of 150°C (302°F) to 250°C have potential value for heating and process uses; and temperatures below 150°C can be applied to space heating or lower-grade process uses. 2) There must be a sufficient volume of geothermal fluid in the reservoir to produce the necessary quantities of heat energy for 30 to 50 years. Either this volume of fluid must be present in storage or suitable hydrologic conditions must exist to allow recharge. To meet such requirements, reservoir rocks must be sufficiently porous to hold fluids and sufficiently permeable to allow the fluids to migrate from the reservoir rocks to the bore holes. 3) The system must

Table 1. Geothermal data used for Cow Hollow-western Snake River Basin study

Location	Hole No.	N. Lat.	W. Long.	Elev. meters	Depth interval meters	Gradient °C/km	Topo Cor.* Grad. °C/km	K 10^{-3}cal/cm sec. °C	Q 10^{-6}cal/cm^2 sec.	Cor.* Q 10^{-6}cal/cm^2 sec.	Qual.**	Lithology
Willow Creek	17-44S11	44°06'	117°17'	719	-370	94.4		2.8	2.6		B	Siltstone
	17-44S31	43°59'	117°20'	829	15-70	85.7		2.8	2.4		B	Siltstone
South Fork Jacobsen Gulch	VN-75-2	44°07'	117°14'	721	30-60	110		3.0***	3.3		B	Basalt
	VN-75-3	44°07'	117°10'	814	50-150	76		2.54	1.9		A	Siltstone
	VN-75-4	44°05'	117°06'	762	30-150	120		2.53	3.0		A	Siltstone
	VN-75-5	44°06'	117°02'	732	60-150	76		2.53	1.9		A	Siltstone
Bully Creek	18-44S21	43°59'	117°20'	760	25-85	66.8		2.8	1.9		B	
Sand Hollow	19-44S19			777	31-395	87.3****		3.0***	2.6		B	
Cow Hollow	19-45S11	43°55'	117°10'	835	30-65	185.7	176.1	3.0	5.6	5.3	A	Siltstone
	19-45S14	43°54'	117°10'	910	20-145	175.2	158.3	3.0	5.3	4.7	A	Siltstone
	19-45S22	43°53'	117°11'	843	30-115	110.4		3.05		2.9	A	Siltstone
	19-45S25	43°53'	117°09'	813	30-70	232.6	213.6	3.0	6.9	6.4	A	Siltstone
	19-45S26	43°52'	117°10'	822	30-175	119.3	114.0	3.0	3.6	3.4	A	Siltstone
	19-45S28	43°53'	117°13'	872	10-90	70.8	76.5	3.0	2.1	2.3	A	Siltstone
	20-45S6	43°51'	117°15'	823	20-135	73.6	69.8	3.0	2.2	2.1	A	Siltstone
	20-45S10	43°50'	117°12'	780	30-135	114.8	104.0	3.0	3.4	3.1	A	Siltstone
	20-45S18	43°50'	117°16'	849	10-40	71.9	63.2	3.0	2.1	1.9	B	Siltstone
	VN-75-1	43°54'	117°08'	879	25-150	91.4		2.53	2.3		A	Siltstone

*Topographic correction
** Quality: A = ± 10%; B = ± 25%
*** Estimated K
****Van Ostrand, 1938

be confined in some way by a relatively impermeable barrier to the migration of the fluids so that a trap is formed, thereby allowing the fluids to accumulate.

High heat flow, defined by bore-hole data, signifies a concentration of heat at depth in the Cow Hollow area. In addition, temperatures of hot springs surrounding Cow Hollow indicate a regional accumulation of heat at depth. Thermal springs at Vale to the north have a temperature of 98°C (208°F), and several springs along the Owyhee River to the south have temperatures up to 77°C (171°F). The chemical constituents in the thermal springs at Mitchell Butte have been analyzed by Mariner and others (1974), who estimate minimal reservoir temperatures of 72°C (162°F).

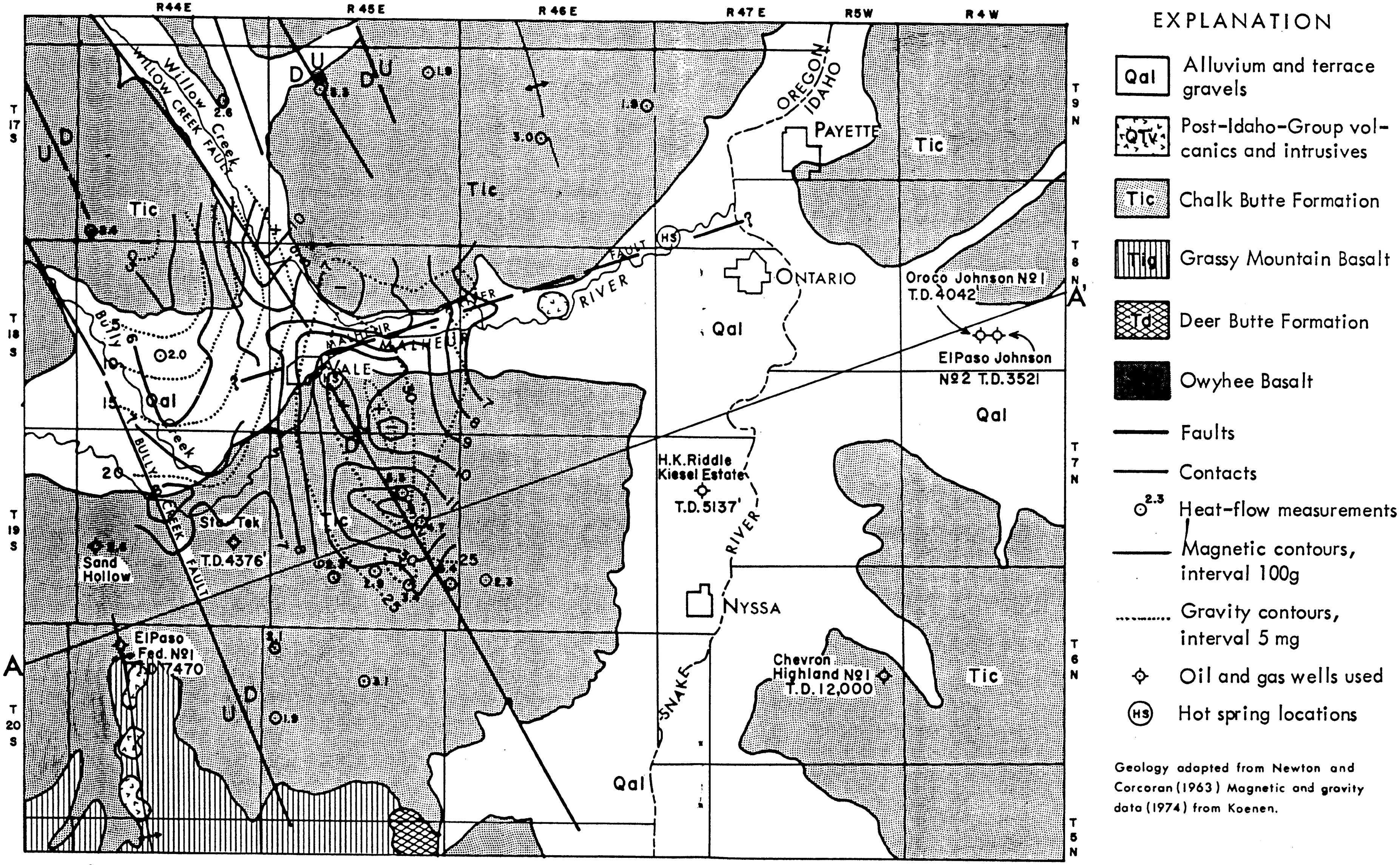
The authors believe the subsurface geologic conditions in the Cow Hollow area are favorable for the presence of a reservoir and trap. Using data from deep oil and gas exploration wells drilled in the western Snake River Basin (Newton and Corcoran, 1963), a cross section has been constructed for the Cow Hollow area to show the geologic sequence and the potential reservoirs (Figure 2). The two basalt flows of this area, the Grassy Mountain Basalt and the Owyhee Basalt, should make excellent geothermal reservoirs as they have sufficient inter-flow permeability to allow the storage and movement of major quantities of fluids. The few thin sands in the sedimentary units (Newton and Corcoran, 1963) may form minor reservoirs.

Another potential reservoir is the silicic rocks of the Sucker Creek Formation. These rocks, called the Idavada Volcanics farther to the east along the southern margin of the Snake River Basin, are a major warm artesian aquifer sequence (Ralston and Chapman, 1968).

Because of its great extent and thickness, making more water available for storage and recharge, the Owyhee Basalt is probably the best potential reservoir. This thick, multiple-flow sequence of fine-grained to porphyritic basalt has been down-warped and buried to depths of several thousand feet in the Snake River Basin and has undoubtedly been subjected to a great deal of heating through the period of late Tertiary and early Quaternary volcanic activity. This heat energy would be transferred to the accumulated ground water in storage in the basalt. Because of the greater mobility and lower density of hot water and steam, the geothermal fluids would tend to migrate updip to the nearest barrier, where they would accumulate. The steam, if present, would tend to concentrate in the upper part of the permeable zones and the hot water in the lower, similar to the layering of steam and water in a man-made boiler or to the layering of oil and gas in a petroleum reservoir.

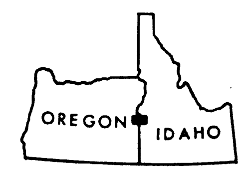
In the region of this study, the most common type of barrier would be a fault zone where the impermeable tuffaceous sediments are faulted against the truncated edges of the basalt flows. Another type of trap might occur where lava flows and tuffaceous sediments interfinger. In the Cow Hollow area, a trap may have been formed where the west side of the Willow Creek fault has moved down, bringing the Idaho Group sediments into juxtaposition

FIGURE 1



Generalized Geologic Map *of the* WESTERN SNAKE RIVER BASIN

Showing
Hot Spring and Heat Flow Measurement Locations



against the truncated edge of the Grassy Mountain and Owyhee Basalts (Figure 2).

Estimate of depths and temperatures

Information on the depths and thicknesses of the shallower rock units in the western Snake River Basin were compiled by Newton and Corcoran (1963). Until recently, there has been little information on the deeper subsurface stratigraphy, but in 1973 a deep oil and gas test well was drilled by Standard Oil Company of California, "Highland," about 14 miles east of Cow Hollow, near Parma, Idaho. This well, drilled to a total depth of nearly 12,000 feet, passed through the Owyhee Basalt and into underlying siliceous volcanics, lacustrine sediments, and interbedded basalts, a sequence that may correlate with the Sucker Creek Formation in the Mitchell Butte quadrangle. It is reported that the Standard "Highland" well encountered high temperatures in the Owyhee Basalt and underlying rocks. In this well, the top of the Grassy Mountain Basalt was at a depth of 3,800 feet (-1,153 msl) and the Owyhee Basalt at 6,720 feet (-4,073 msl). Newton and Corcoran (1963,Plate 3) show a depth to basalt of 3,820 feet (-1,643 msl) in the Oroco Oil and Gas Kiesel No. 1 well, which is about 8 miles east of Cow Hollow and is believed to be in a deeper part of the Basin.

From the general structural pattern for the area as outlined by Corcoran and others (1962), the authors infer that the Chalk Butte Formation is about 1,500 feet thinner in the Cow Hollow area than in the Oroco-Kiesel well to the east. If this is true, then the Grassy Mountain Basalt is at a depth of about 2,500 feet (+100 to -200 msl), and the Owyhee Basalt is at about 5,500 to 6,000 feet (-2,800 to -3,300 msl). These relationships are shown schematically in Figure 2.

Under some conditions it appears to be possible to predict subsurface temperatures using the near-surface gradients. In the western Snake River Basin, the average geothermal gradient is 81°C/km (4.4°F/100 ft.) with most of the observed gradients between 65° and 100°C/km. The lithologies, and therefore also thermal conductivities, in which the measurements were made are relatively uniform so that gradients are directly comparable. Assuming that heat flow is by conduction and remains constant with depth, the temperature in the various stratigraphic units can be predicted if the depth is known. If the depth to the Grassy Mountain Basalt is in the range of 1 to 1.5 km (3,300 to 4,500 ft.), the temperature would be on the order of 120°C ± 30° (248°F±50°). If the top of the Owyhee Basalt is on the order of 2 km (6,600 feet), the temperatures would be on the order of 170°C ± 40°. The lower units of the Owyhee Basalt and the underlying silicic rocks could have temperatures correspondingly higher. It is emphasized that these are minimum temperatures based on the projected temperature gradients corresponding to a heat-flow value near the regional average. Since temperatures almost certainly exceeding 200°C occur at depth in porous and

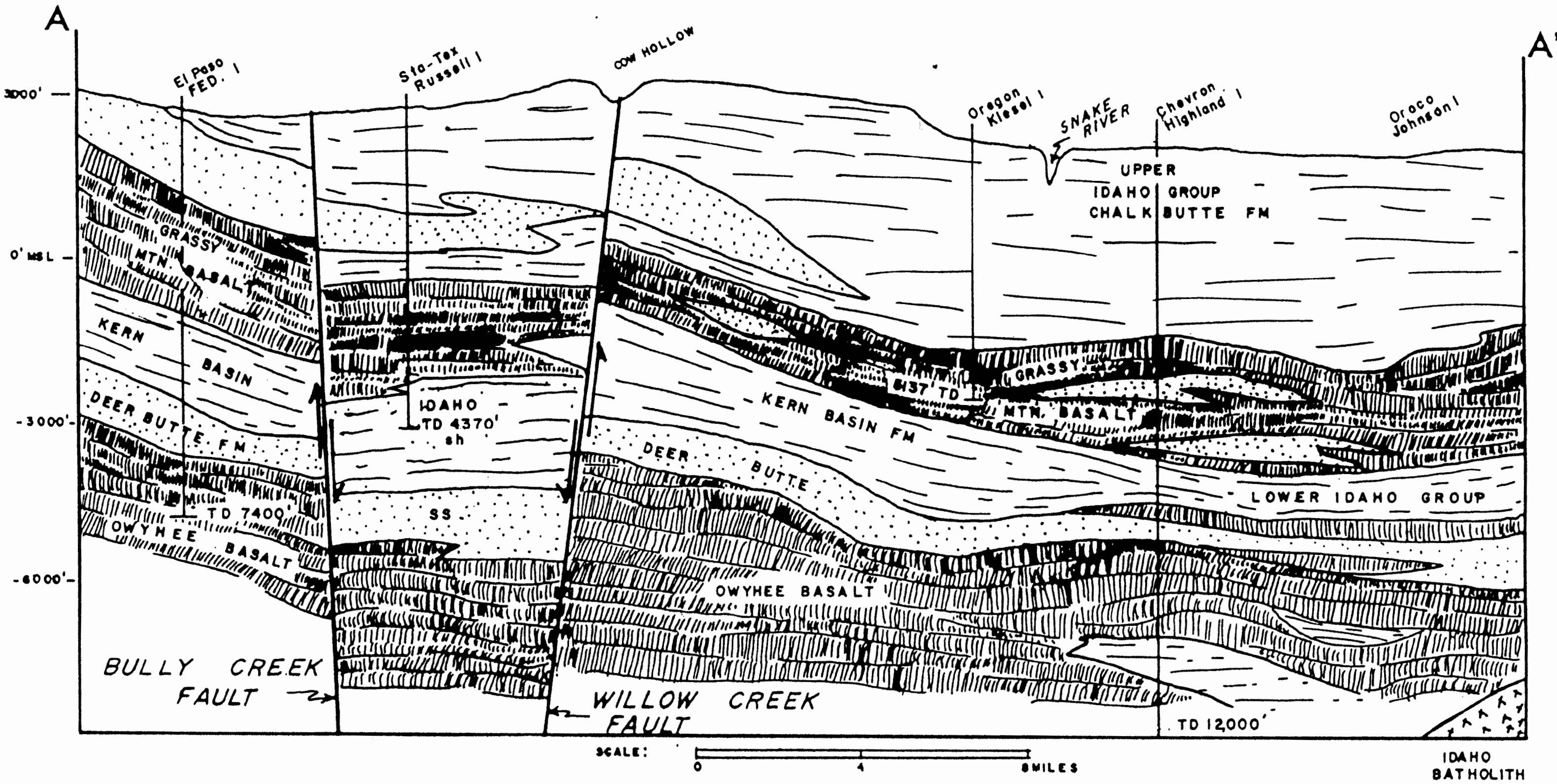


Figure 2. Cross section A-A' (see Figure 1 for location) prepared from oil and gas test-well data.

permeable rocks, fluids with temperatures high enough for commercial power production may leak upwards and occur at much shallower depths as well as regionally at greater depths.

Apparently in the Cow Hollow area such upward leakage is occurring along the Willow Creek fault. The geothermal potential of the anomaly depends on the temperature of the fluids moving along the fault. On the basis of the available data we cannot say how deep the gradients along the fault zone can be extrapolated. If more detailed heat-flow data were available, the anomaly could be compared to type curves for circulation along fault zones (Blackwell, 1974), and the depth of water circulation along the fault, the dip of the fault, and the temperature along the fault might be determined or limits on the parameters estimated. With the data that are available, it appears that the depth of circulation must be 2 km or more (based on the breadth of the anomaly), and the dip of the fault must be 60° or more to the southwest (based on the asymmetry of the anomaly). If circulation along the fault takes place to depths in excess of 2 km, then it must tap fluid at +150°C. Therefore we speculate that the temperatures along the fault at relatively shallow depth (500 to 1,500 m) are on the order of 150°C or more. Of course, the fluid moving upward along the fault zone may be cooling off as it rises so that temperatures at shallow depth may be less than at greater depths. If this condition exists, production testing of the wells in the fault zone should show an increase in temperature as the hotter fluids from the deeper portions of the reservoir displace the cooler ones.

Conclusions

Our studies and those of our colleagues in Idaho indictate that the western Snake River Basin is a major geothermal province, similar in some ways to the Imperial Valley Geothermal Province. Deep drilling should encounter high temperature fluids in permeable rocks below 2 km and at shallower depths where permeability has developed, as along faults and fracture zones. The Cow Hollow area seems to have the necessary conditions for a high-temperature geothermal reservoir: high heat flow, permeable rocks at depth, and a barrier to migration or trap.

Prior to drilling a deep exploratory well, more geologic and geophysical work and more detailed structural geologic studies should be done, more heat-flow holes should be drilled, and additional gravity and magnetic surveys should be done. In addition, some geochemical electrical resistivity, and seismic studies should be made to further define the anomaly. After these more definitive investigations are made, the only sure method of determining if geothermal fluids exist in commercial quantities is to drill enough wells to define the base temperature and production capabilities of the reservoir.

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REICHHOLD ENERGY CORPORATION TO DRILL FOR GAS

The Department issued State Permit No. 65 to Reichhold Energy Corporation, Tacoma, Washington, on June 26, 1975 for the drilling of a 5,000-foot exploratory hole in Tillamook County. The test hole is to be drilled in the NE$\frac{1}{4}$, NE$\frac{1}{4}$ sec. 22, T. 2 S., R. 10 W., Tillamook County. Reichhold officials announced intent to drill several wildcat holes in western Oregon this year. The API number for the test well is 36-057-00004.

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GEOTHERMAL DRILLING LAW REVISED

Oregon Legislature passed House Bill 2040 in May 1975; Governor Straub signed it into law June 30, 1975. The new statute is summarized as follows:

"Geothermal resources" are defined as natural heat of the earth, energy, in whatever form, below the surface of the earth.

"Prospect wells" are defined as geophysical test wells, seismic shot holes, mineral exploration drilling, core drillings, or temperature gradient drillings which are less than 500 feet in depth.

"Geothermal wells" are defined as any excavation greater than 500 feet in depth made for discovery or production of geothermal resources. Wells producing fluids less than 250°F bottom-hole temperature and less than 2,000 feet in depth are excluded.

Bonds for geothermal wells were set at $10,000 per well and a blanket bond of $5,000 is required for prospect well applications. Bonding of prospect wells was not required in the original law.

House Bill 2040 places authority for geothermal drilling solely with the State of Oregon Department of Geology and Mineral Industries. Conflicts of jurisdiction between state agencies appear to be removed by House Bill 2040. The revised law should encourage an increase in geothermal exploration in Oregon.

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GEOTHERMAL TEST WELL IN UTAH SHOWS PROMISE

The first successful geothermal test well in Utah has been announced by the U.S. Geological Survey. The test is located in the Roosevelt Hot Springs KGRA on a tract leased by Phillips Petroleum Co. The test well, completed to a depth of 2,728 feet, showed in excess of 200,000 pounds per hour mass flow rate at a temperature of over 400°.

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GEOTHERMAL DRILLING IN OREGON

Deep Test Holes:

Organization	Date	County	Status
Gulf Oil Co.-U.S.	Sept. 7, 1973	Lake	Abandoned hole at a depth of 5,440'
Magma Energy, Inc.	July 25, 1974	Union	Abandoned hole at a depth of 2,730'

Thermal Gradient Holes:

Organization	Date	County	Status
Thermal Power Co.	Feb. 1975	Klamath	Completed
Dept. Geol. & Min. Indus.	July 1972	Malheur	Completed
Union Oil Co.	Dec. 1974	Malheur	Completed
Gulf Research	July 1974	Lake	Active
U.S. Geological Survey	Aug. 1974	Klamath	Completed
Geothermal Surveys, Inc.	Feb. 1975	Malheur	Active
AMAX Exploration	March 1975	Union	Active
AMAX Exploration	March 1975	Malheur	Active
AMAX Exploration	March 1975	Lake	Active
AMAX Exploration	March 1975	Harney	Active
Phillips Petroleum	April 1975	Malheur	Completed
Dept. Geol. & Min. Indus.	April 1975	Malheur	Active

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METAL MINES HANDBOOKS REPRINTED

The Department's Bulletin 14, Oregon Metal Mines Handbooks, have been reprinted by an out-of-state firm after having been out of print for a considerable number of years. The six publications, each covering a section of the state, list all mines in that area known at the time of the original printing, together with information on general geology.

Information on the reprinted handbooks is available from George Srein, American Trading Co., P. O. Box 1312, Bellevue, WA 98009. The six sections, originally published in 1939 to 1951, are:

A. Baker, Union, and Wallowa Counties
B. Grant, Morrow, and Umatilla Counties
C-1. Coos, Curry, and Douglas Counties
C-II, sec. 1. Josephine County
C-II, sec. 2. Jackson County
D. Northwestern Oregon

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DEPARTMENT PUBLICATIONS GO UP IN PRICE

On July 1, 1975, prices of the more recent Department publications were raised to help meet greatly increased printing costs. The ORE BIN is now $3.00 per year, or 3 years for $8.00. Current subscriptions will continue at the former rate until expiration. For new prices of Bulletins, Geologic Maps, Short Papers, Miscellaneous Papers, Oil and Gas Investigations Series, and other items, see back cover of this and subsequent issues of The ORE BIN, or write to the Department for the latest listing.

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NEW BOARD MEMBER APPOINTED BY GOVERNOR STRAUB

Leeanne G. MacColl (Mrs. E. Kimbark M.) was appointed to the Governing Board of the Oregon Department of Geology and Mineral Industries by Governor Straub on June 28, 1975. She fills the position formerly held by William E. Miller, whose term of office has expired.

Mrs. MacColl is a graduate of Occidental College, Los Angeles, with a major in music and an interest in geology. Since her graduation in 1952 she has been a resident of Portland, where she has been active in a variety of civic affairs. She has been a board member of the Junior Symphony and the Chamber Music Northwest, and is the new president of Friends of Chamber Music. As a member of the League of Women Voters, she has been on the board of the Portland League for 3 years and has served as chairman for committees concerned with environmental problems, transportation, and energy.

Interest in geothermal development began with her visit to the Larderello fields in Italy in 1972. In 1974 she attended the Geothermal Conference at Klamath Falls and since that time has been encouraging this type of energy development in Oregon.

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GRANT COUNTY GEOLOGY TOUR IN AUGUST

On August 14 and 15, Dr. Tom Thayer, geologist with the U.S. Geological Survey and authority on the geology of Grant County, will lead field trips to see the geology of the area. Those who plan to attend must pre-register prior to August 7 so transportation arrangements can be made. Bus fare will be $7.75 per person per day and lunches $1.50. Send name, address, phone number, and fee for bus and lunches to Grant County Extension Office, Box 67, Canyon City, Oregon 97820.

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AVAILABLE PUBLICATIONS

(Please include remittance with order; postage free. All sales are final – no returns. Upon request, a complete list of Department publications, including out-of-print, will be mailed.)

BULLETINS

26.	Soil: Its origin, destruction, preservation, 1944: Twenhofel	$0.45
33.	Bibliography (1st suppl.) geology and mineral resources of Oregon, 1947: Allen	1.00
35.	Geology of Dallas and Valsetz quadrangles, Oregon, rev. 1964: Baldwin	3.00
36.	Papers on Tertiary foraminifera: Cushman, Stewart & Stewart. vol. 1-$1.00; vol. 2-	1.25
39.	Geology and mineralization of Morning mine region, 1948: Allen and Thayer	1.00
44.	Bibliography (2nd suppl.) geology and mineral resources of Oregon, 1953: Steere.	1.00
46.	Ferruginous bauxite deposits, Salem Hills, 1956: Corcoran and Libbey	1.25
49.	Lode mines, Granite mining district, Grant County, Oregon, 1959: Koch	1.00
52.	Chromite in southwestern Oregon, 1961: Ramp	5.00
53.	Bibliography (3rd suppl.) geology and mineral resources of Oregon, 1962: Steere, Owen	3.00
57.	Lunar Geological Field Conf. guidebook, 1965: Peterson and Groh, editors	3.50
60.	Engineering geology of Tualatin Valley region, 1967: Schlicker and Deacon	7.50
61.	Gold and silver in Oregon, 1968: Brooks and Ramp	7.50
62.	Andesite Conference Guidebook, 1968: Dole	3.50
64.	Geology, mineral, and water resources of Oregon, 1969	3.00
65.	Proceedings of the Andesite Conference, 1969: McBirney, editor (photocopy)	10.00
66.	Geology and mineral resources of Klamath and Lake Counties, 1970.	6.50
67.	Bibliography (4th suppl.) geology and mineral industries, 1970: Roberts	3.00
68.	Seventeenth biennial report of the Department, 1968-1970	1.00
69.	Geology of the southwestern Oregon Coast, 1971: Dott	4.00
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71.	Geology of selected lava tubes in the Bend area, 1971: Greeley	2.50
72.	Geology of Mitchell quadrangle, Wheeler County, 1972: Oles and Enlows	3.00
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75.	Geology, mineral resources of Douglas County, 1972: Ramp	3.00
76.	Eighteenth biennial report of the Department, 1970-1972	1.00
77.	Geologic field trips in northern Oregon and southern Washington, 1973.	5.00
78.	Bibliography (5th suppl.) geology and mineral industries, 1973: Roberts and others	3.00
79.	Environmental geology inland Tillamook Clatsop Counties, 1973: Beaulieu.	7.00
80.	Geology and mineral resources of Coos County, 1973: Baldwin and others	6.00
81.	Environmental geology of Lincoln County, 1973: Schlicker and others	9.00
82.	Geol. Hazards of Bull Run Watershed, Mult. Clackamas Counties, 1974: Beaulieu	6.50
83.	Eocene stratigraphy of southwestern Oregon, 1974: Baldwin	4.00
84.	Environmental geology of western Linn Co., 1974: Beaulieu and others.	12.00
85.	Environmental geology of coastal Lane Co., 1974: Schlicker and others	12.00
86.	Nineteenth biennial report of the Department, 1972-1974	1.00
87.	Environmental geology of western Coos and Douglas Counties, Oregon, 1975	in press
88.	Geology and mineral resources of upper Chetco River drainage, 1975: Ramp	in press

GEOLOGIC MAPS

Geologic map of Oregon west of 121st meridian, 1961: Wells and Peck $2.00; mailed –	2.50
Geologic map of Oregon (12" x 9"), 1969: Walker and King	0.25
Geologic map of Albany quadrangle, Oregon, 1953: Allison (from Bulletin 37)	1.00
Geologic map of Galice quadrangle, Oregon, 1953: Wells and Walker	1.50
Geologic map of Lebanon quadrangle, Oregon, 1956: Allison and Felts	1.50
Geologic map of Bend quadrangle, and portion of High Cascade Mtns., 1957: Williams	1.50
GMS-1: Geologic map of the Sparta quadrangle, Oregon, 1962: Prostka	2.00
GMS-2: Geologic map, Mitchell Butte quadrangle, Oregon: 1962	2.00
GMS-3: Preliminary geologic map, Durkee quadrangle, Oregon, 1967: Prostka	2.00
GMS-4: Gravity maps, Oregon onshore & offshore; [set only]: at counter $3.00, mailed	3.50
GMS-5: Geology of the Powers quadrangle, 1971: Baldwin and Hess	2.00
GMS-6: Preliminary report, geology of part of Snake River Canyon, 1974: Vallier.	6.50

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19. Brick and tile industry in Oregon, 1949: Allen and Mason 0.20
21. Lightweight aggregate industry in Oregon, 1951: Mason 0.25
24. The Almeda mine, Josephine County, Oregon, 1967: Libbey 3.00

MISCELLANEOUS PAPERS

1. Description of some Oregon rocks and minerals, 1950: Dole 1.00
2. Oregon mineral deposits map (22 x 34 inches) and key (reprinted 1973): 1.00
4. Rules and regulations for conservation of oil and natural gas (rev. 1962) 1.00
5. Oregon's gold placers (reprints), 1954 . . . . 0.50
6. Oil and gas exploration in Oregon, rev. 1965: Stewart and Newton 3.00
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   (Supplement) Bibliography of theses, 1959 to Dec. 31, 1965: Roberts 0.50
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OIL AND GAS INVESTIGATIONS

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2. Subsurface geology, lower Columbia and Willamette basins, 1969: Newton . . . 3.50
3. Prelim. identifications of foraminifera, General Petroleum Long Bell No. 1 well . . 2.00
4. Prelim. identifications of foraminifera, E. M. Warren Coos Co. 1-7 well: Rau . . 2.00

MISCELLANEOUS PUBLICATIONS

Landforms of Oregon: a physiographic sketch (17" x 22"), 1941 . . . . 0.25
Mining claims (State laws governing quartz and placer claims) 0.50
Oregon base map (22" x 30"). 0.50
Geologic time chart for Oregon, 1961 . . . . free
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