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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 O-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:

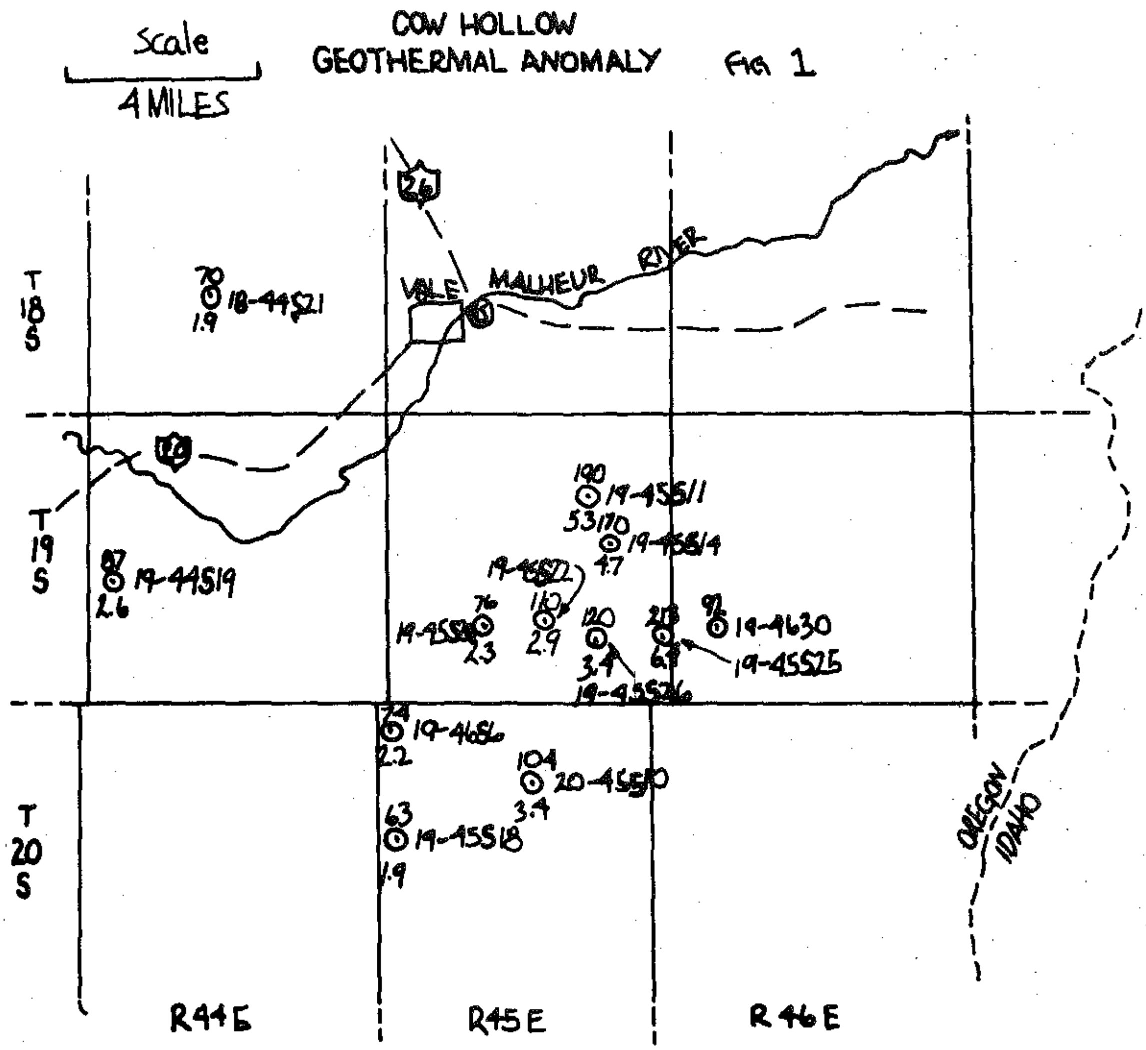
<u>Cow Hollow anomaly</u> (Figure 1)

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.

<u>Willow Creek anomaly</u> (Figure 2)

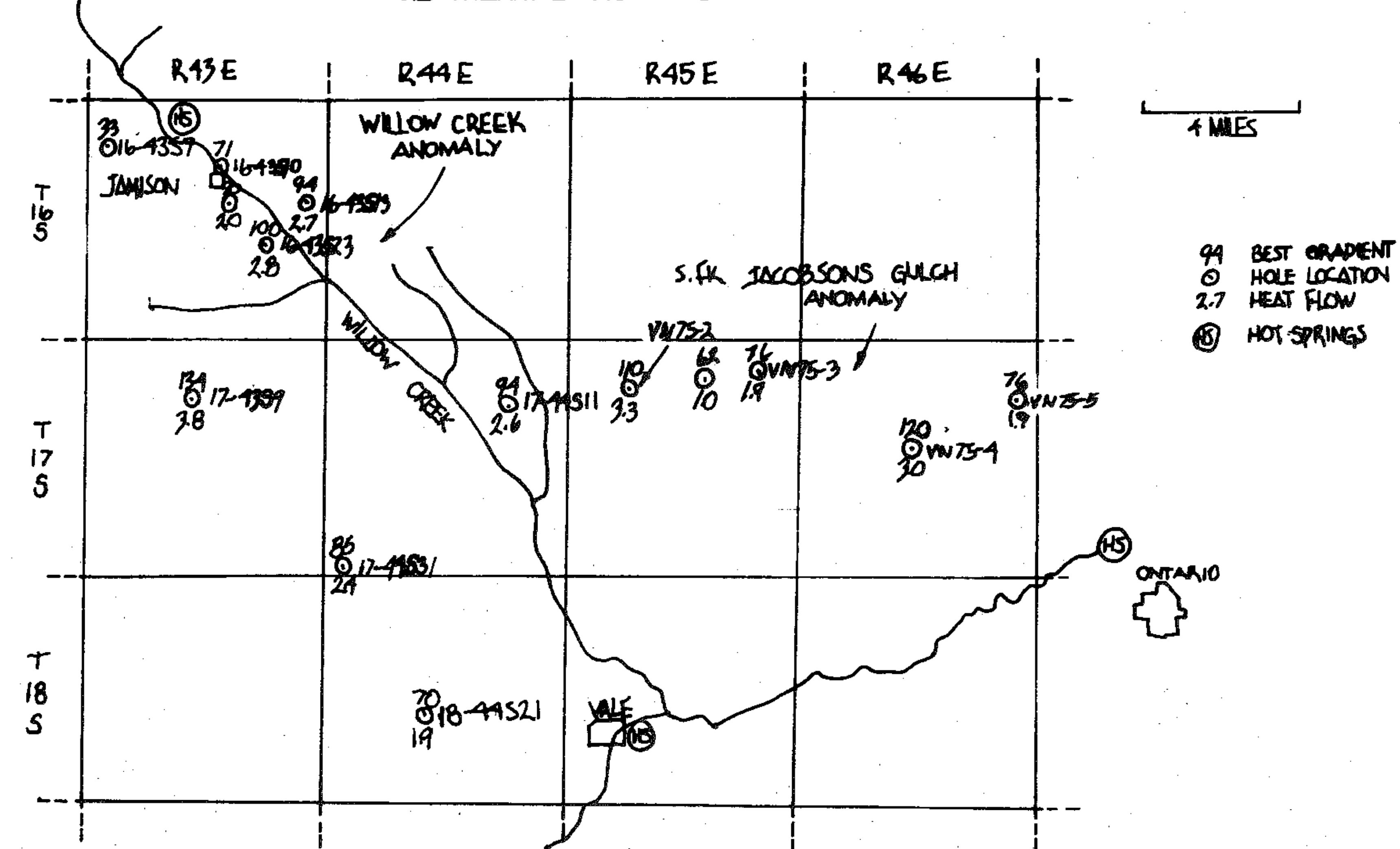
The Willow Creek anomaly is centered about 10 miles northwest of Vale and is possibly a continuation of the Cow Hollow anomaly, southeast of Vale. Its presence is manifested by measurements in four water wells with gradients greater than 90°C/km. Heat-flow values range from 2 to 3.8 HFU. The value of 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.


Scale
4 MILES
COW HOLLOW
GEOTHERMAL ANOMALY
FIG 1
VALE
MALHEUR RIVER
T 18 S
T 19 S
T 20 S
R44E
R45E
R46E
OREGON
IDAHO
18-44S21
19-44S19
19-45S11
19-45S14
19-45S22
19-45S20
19-4630
19-45S25
19-45S26
19-4686
20-45S10
19-45S18

WILLOW CR. - SOUTH FK. JACOBSON GULCH
GEOTHERMAL ANOMALIES

FIG 2

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)

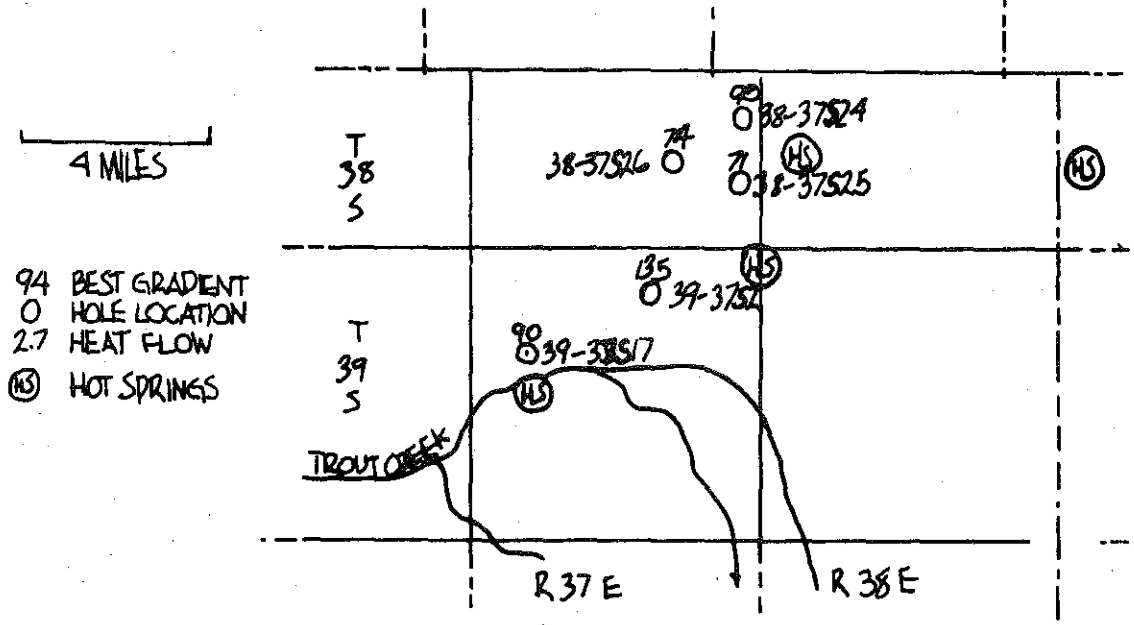
The Trout Creek anomaly was located in bores drilled during a uranium exploration program in the region. The holes logged ranged in depth from 50 to 150 meters. Several near-by warm springs also indicate the presence of heat in this region. Table 9 lists the geothermal data for this region.

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.

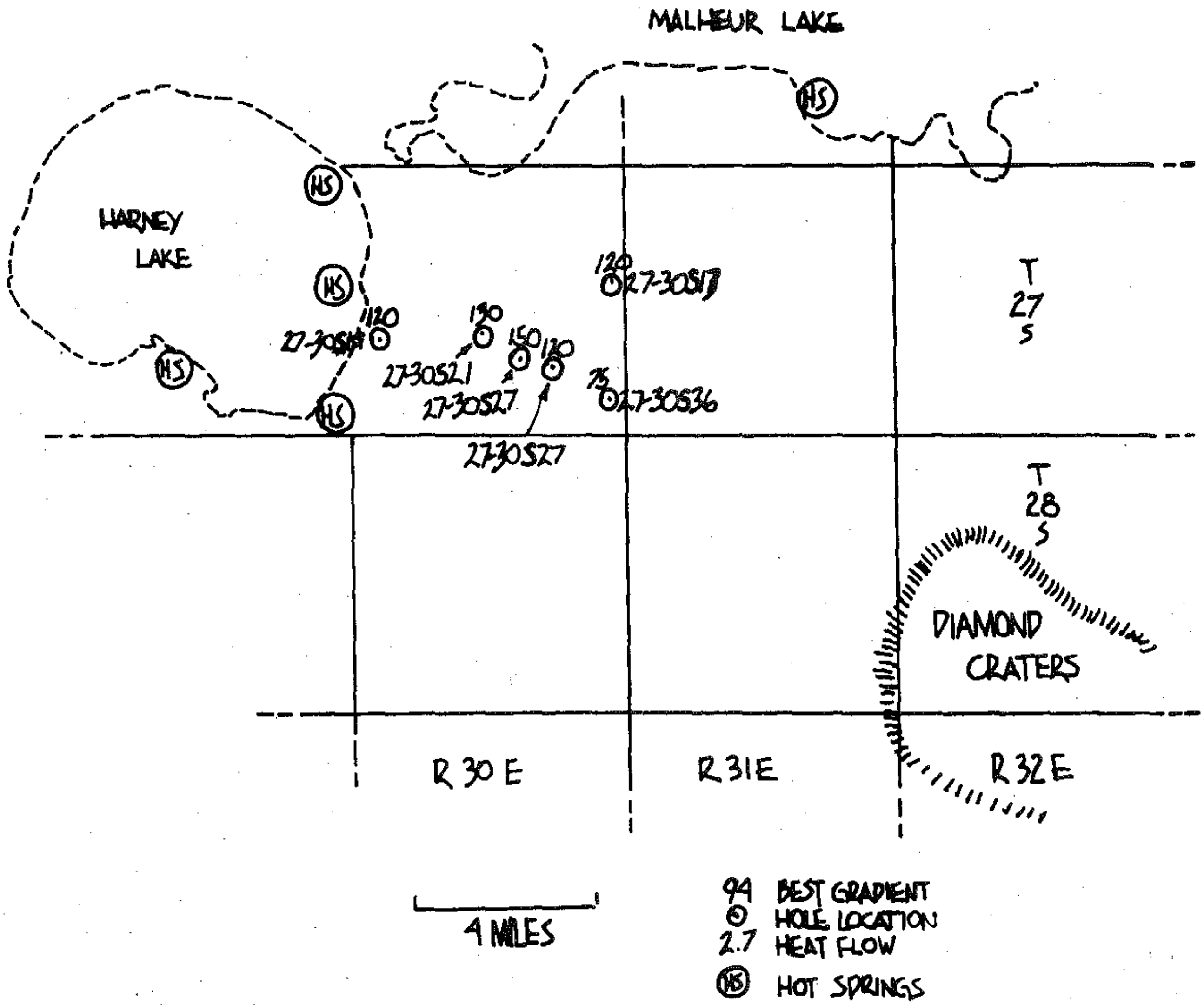
TROUT CREEK
GEOTHERMAL ANOMALY

FIG 3



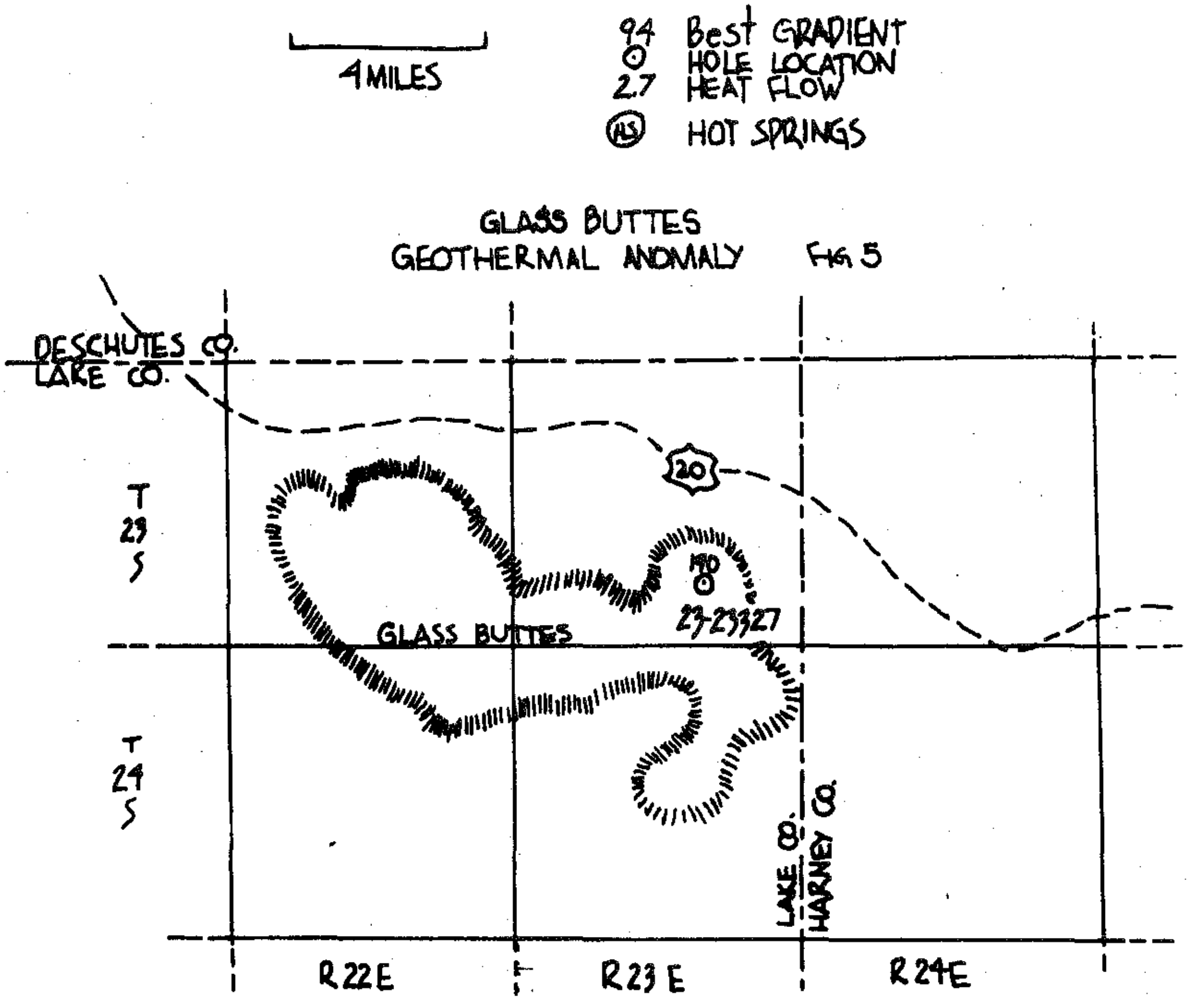
COYOTE BUTTE
GEOTHERMAL ANOMALY

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
2.7 HEAT FLOW
HOT SPRINGS
GLASS BUTTES
GEOTHERMAL ANOMALY Fig 5
DESCHUTES CO.
LAKE CO.
20
T 23 S
T 24 S
GLASS BUTTES
190
23-23S27
LAKE & HARNEY CO.
R22E
R23E
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 $+24^{\circ}C$. 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.

<u>Monitor 2, Warren Oregon:</u> 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 plasticcasing was set to T.D. The well is in an area of very low heat flow and has a geothermal gradient about $10^{\circ}C/km$. The rock type is deeply weathered basalt that has become laterized. Average annual temperature in the vicinity of the well appears to be about $10^{\circ}C$ 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°.

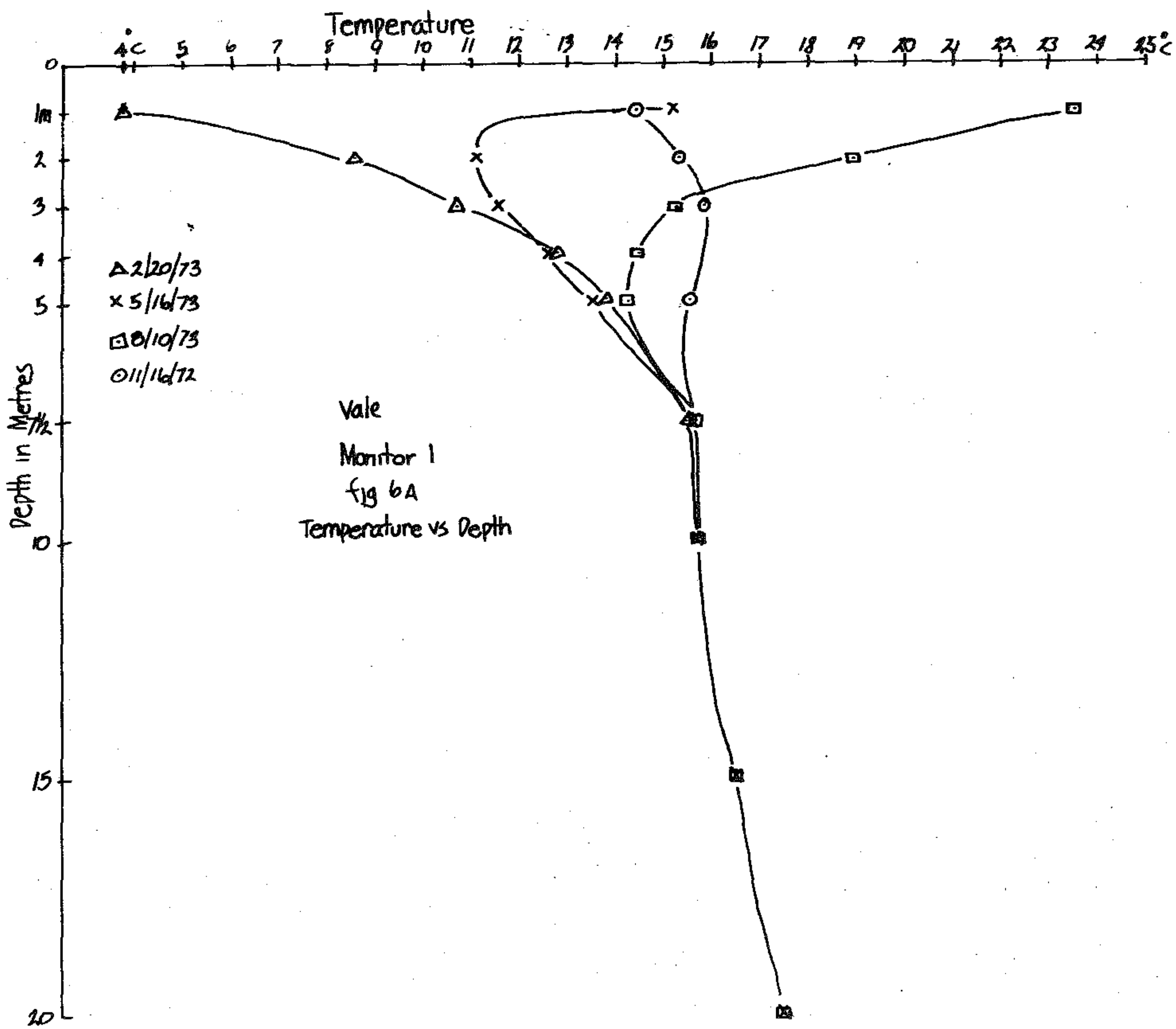
<u>Monitor 3, Arlington, Oregon:</u> Sec 1, T 2 N, R 21 E, Gilliam County, elev. 740 feet (226 M) (Table 3, Figure 8). This well was drilled and cased with plastic pipe to a depth of 125 meters as a foundation test for an electric power generating plat. Regionally the area is a part of the Umatilla Plateau. 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 $62^{\circ}C/km$. The site is located on a sage-covered flat, average surface temperature is about $14^{\circ}C$, and monthly averages range between 0° and $24^{\circ}C$.

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



Vale

Monitor 1

fig 6A

Temperature vs Depth

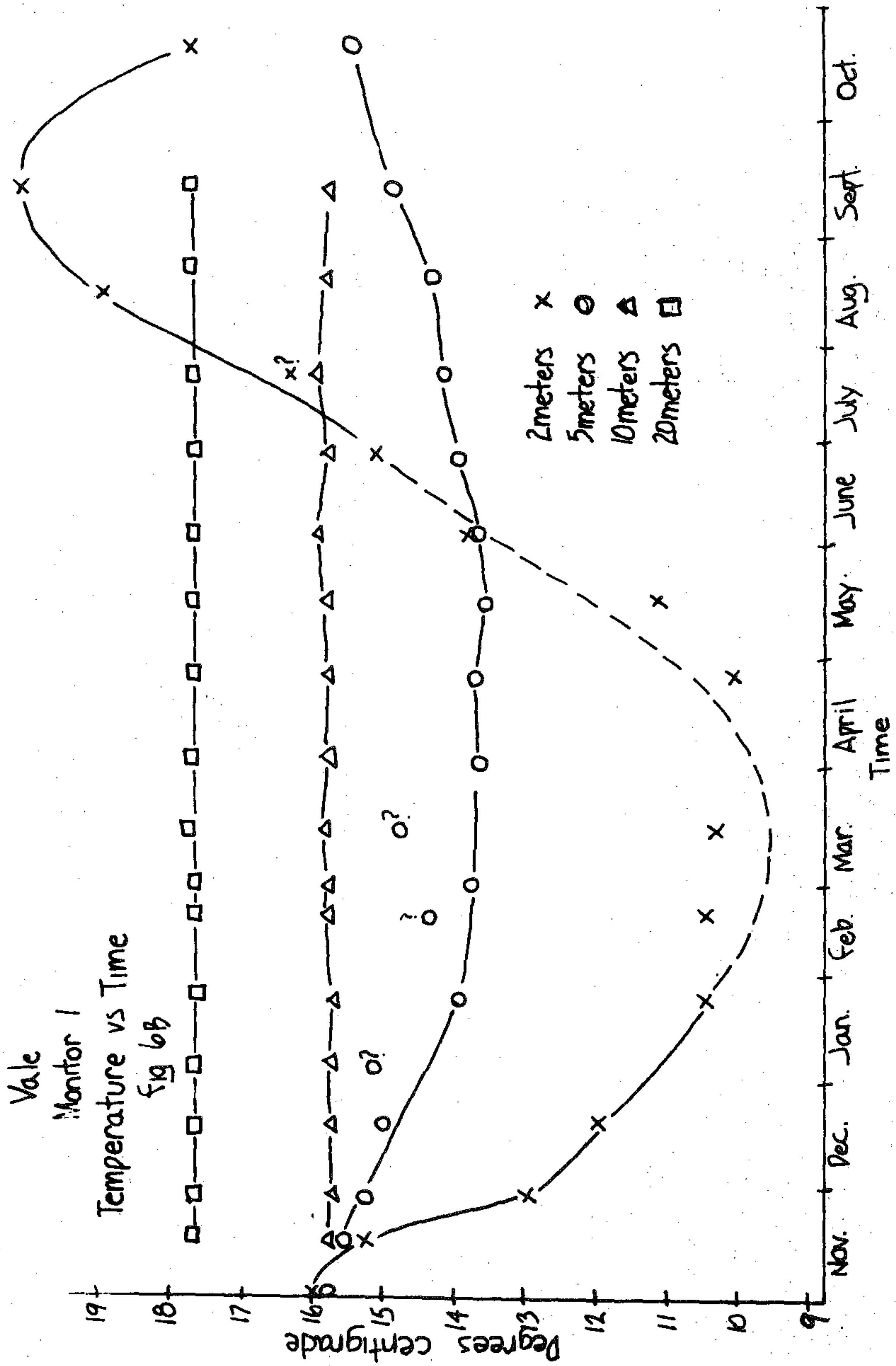

Vale
Monitor 1
Temperature vs Time
Fig 6B
Degrees centigrade
19
18
17
16
15
14
13
12
11
10
9
Nov.
Dec.
Jan.
Feb.
Mar.
April
May
June
July
Aug.
Sept.
Oct.
Time
2meters ×
5meters o
10meters △
20meters □
x?
o?

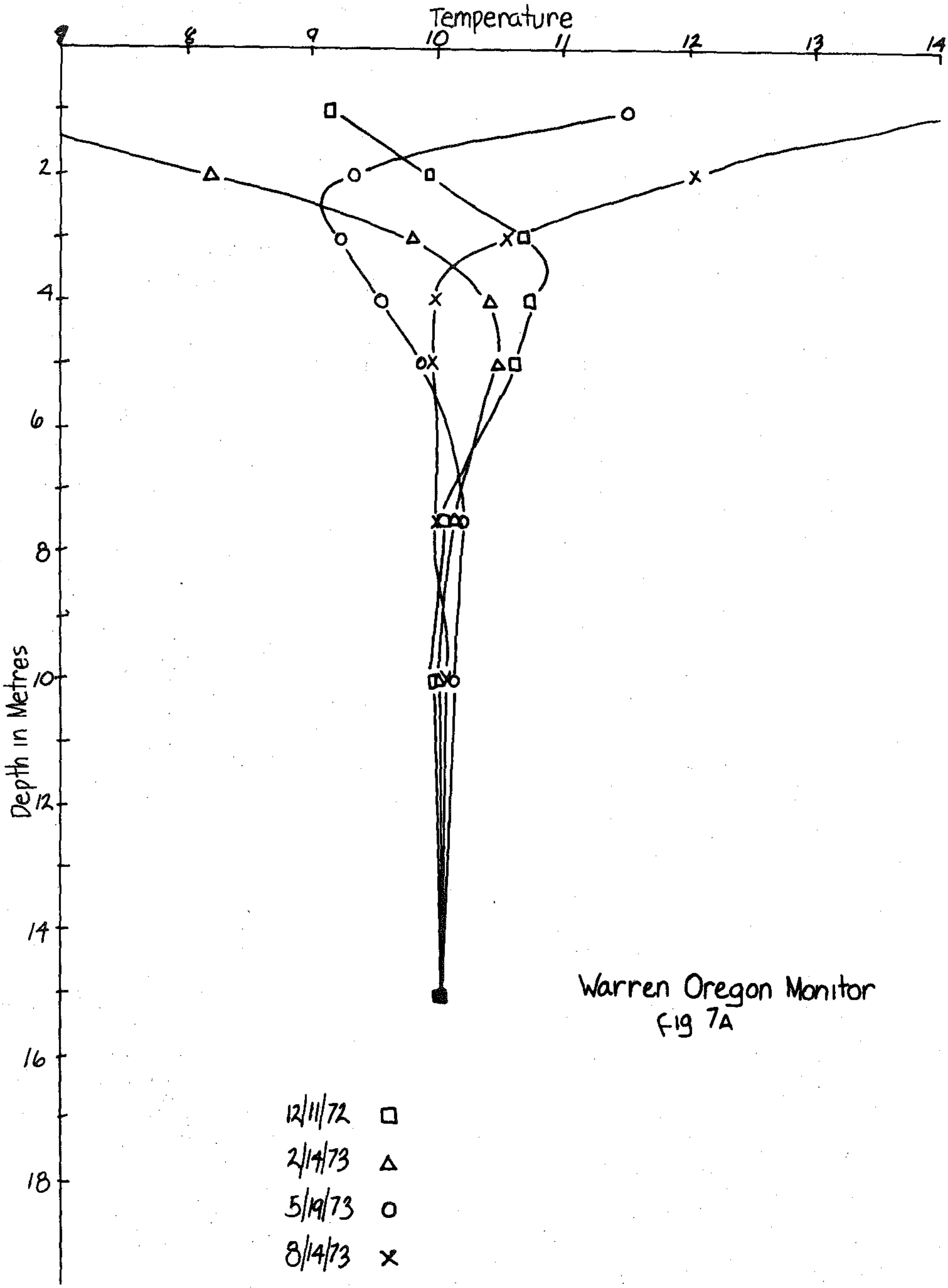
Table 1. Data from monitor well 1, Vale

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

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

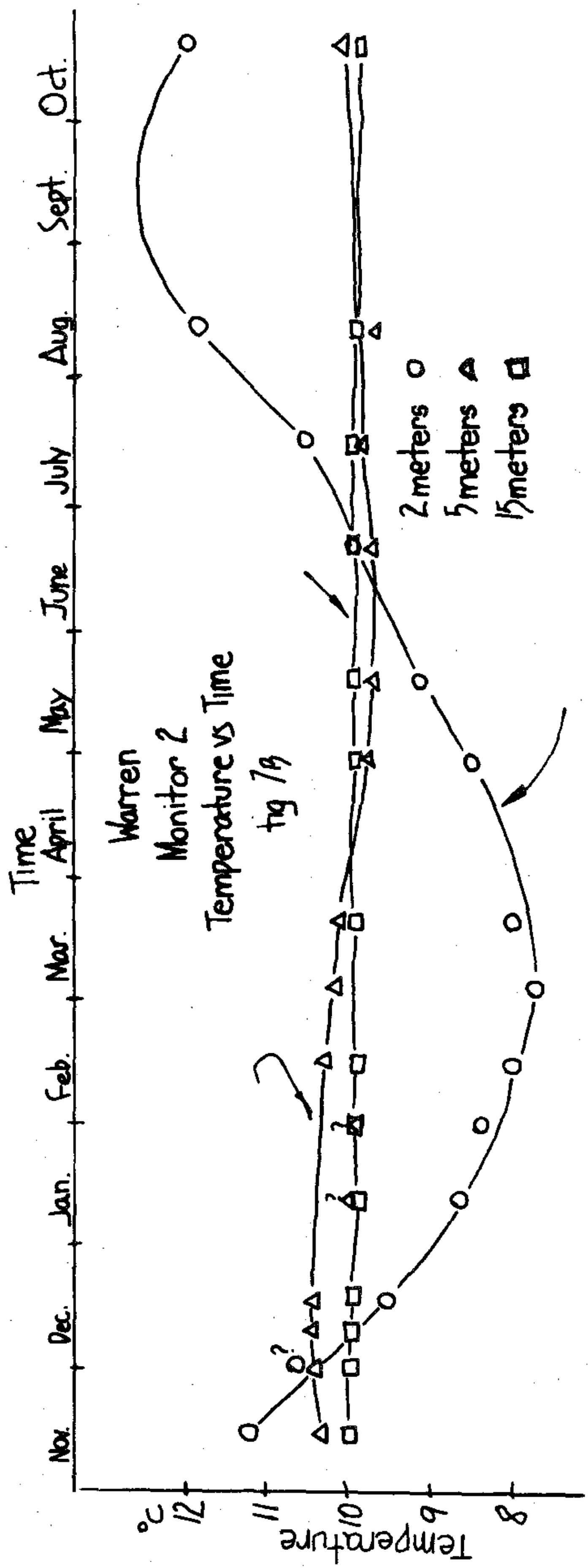

Warren
Monitor 2
Temperature vs Time
fig 7B
Time
Nov.
Dec.
Jan.
Feb.
Mar.
April
May
June
July
Aug.
Sept.
Oct.
Temperature
°C
12
11
10
9
8
2 meters
5 meters
15 meters

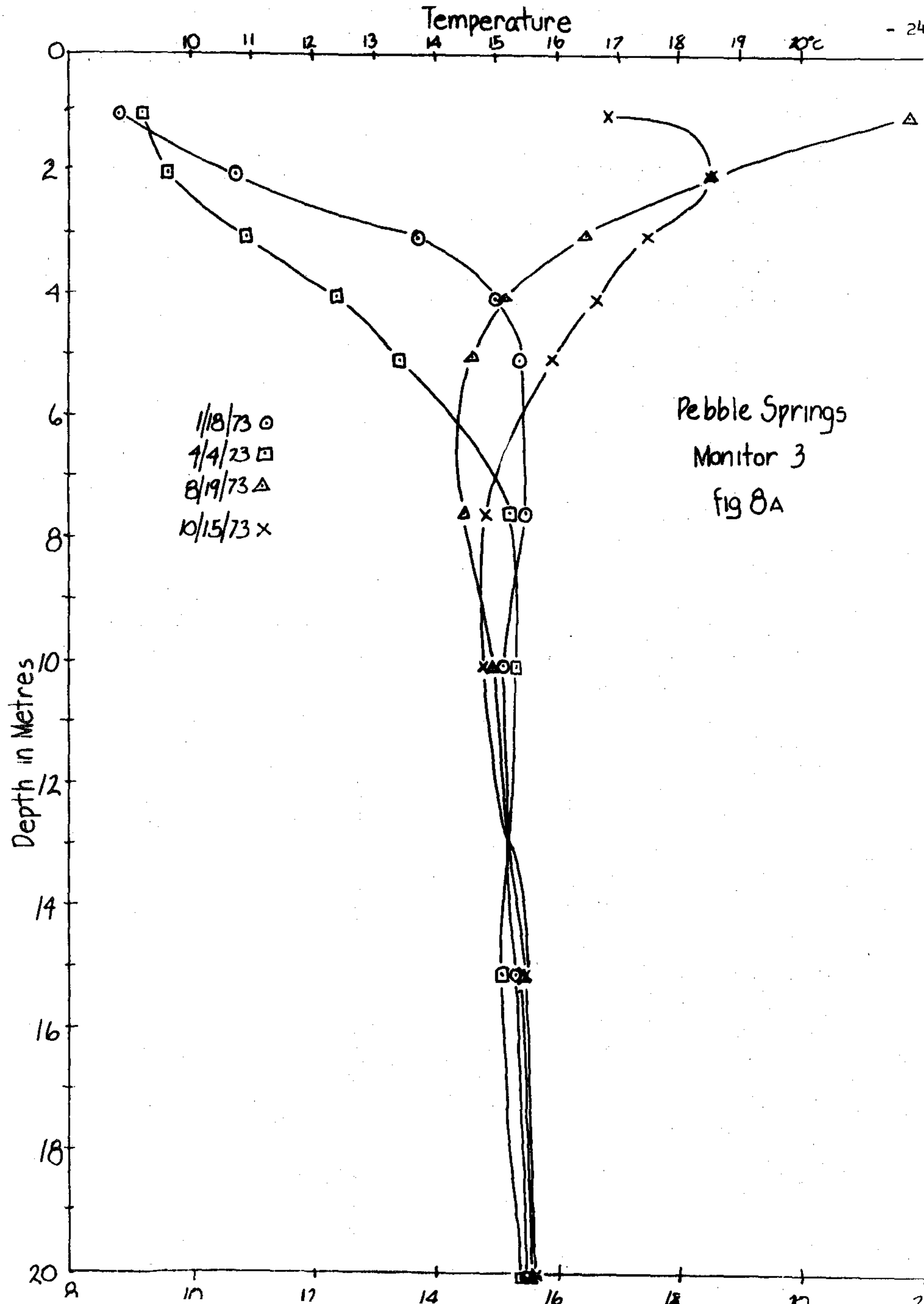
Table 2. Data from monitor well 2, Warren

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
1/18/73 ⊙
4/4/23 ⊡
8/19/73 △
10/15/73 ×
Pebble Springs
Monitor 3
fig 8A

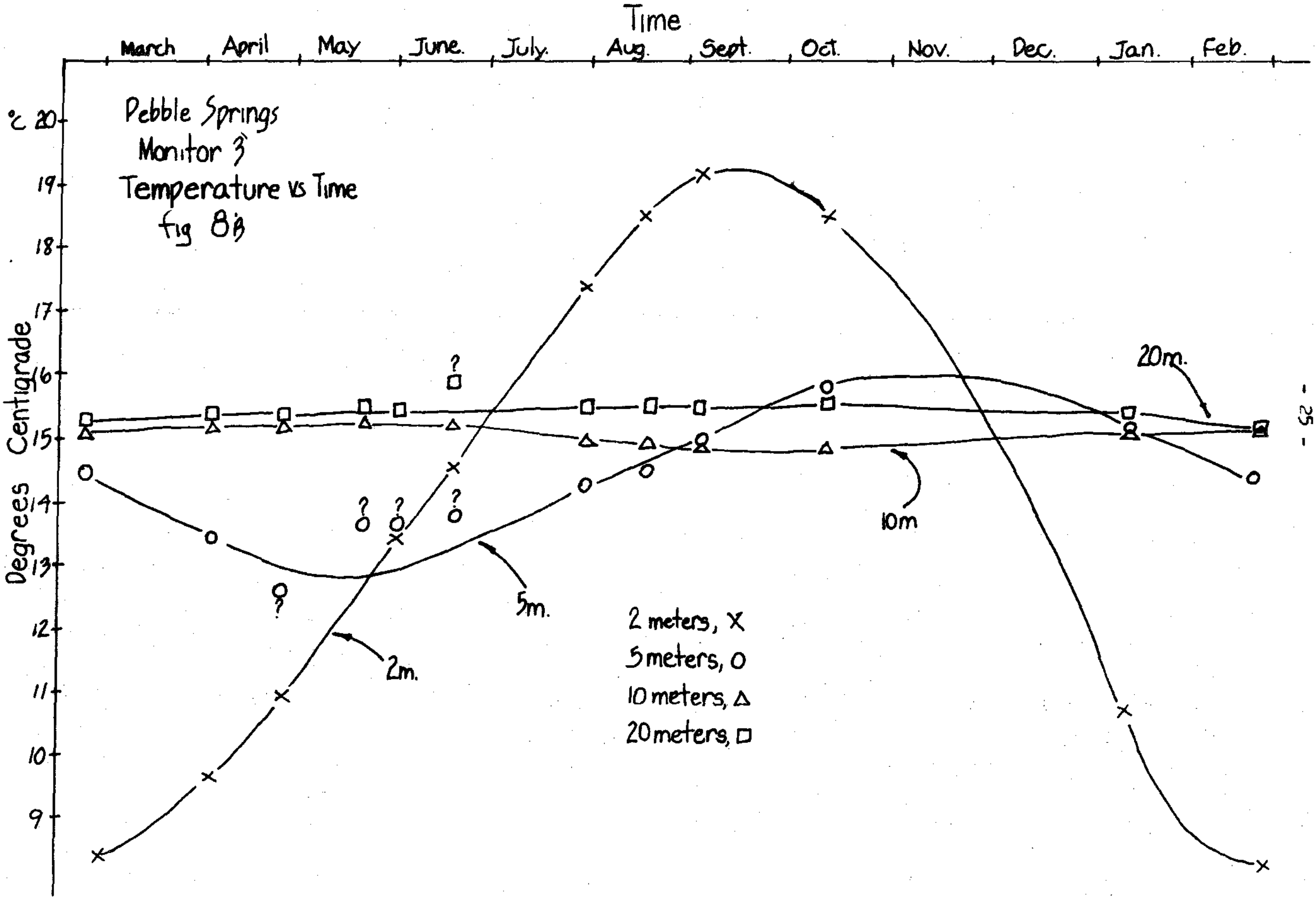
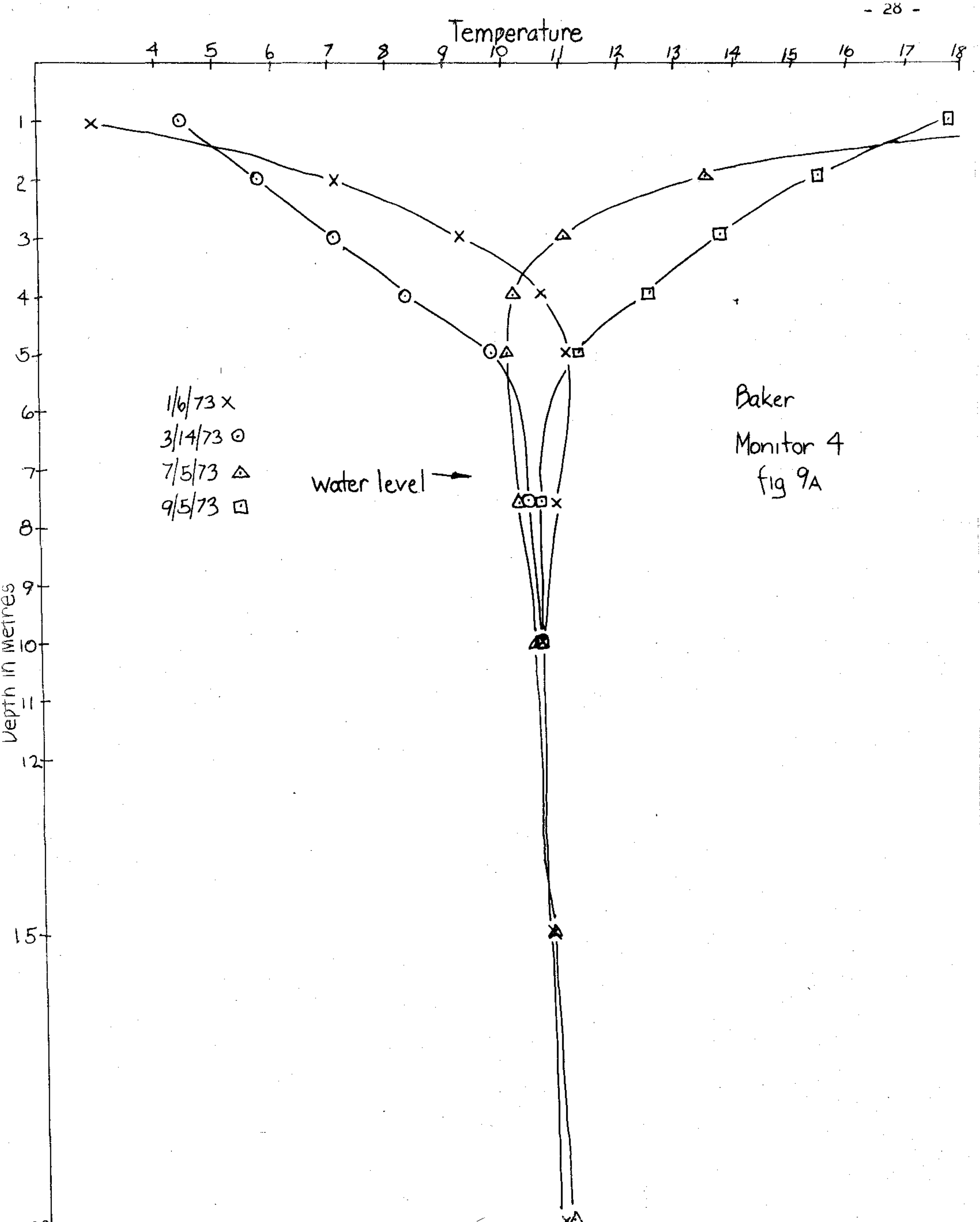

Time
March
April
May
June.
July.
Aug.
Sept.
Oct.
Nov.
Dec.
Jan.
Feb.
Pebble Springs
Monitor 3
Temperature vs Time
fig 8B
°C 20
19
18
17
16
15
14
13
12
11
10
9
Degrees Centigrade
20m.
10m
5m.
2m.
2 meters, X
5 meters, O
10 meters, Δ
20 meters, □

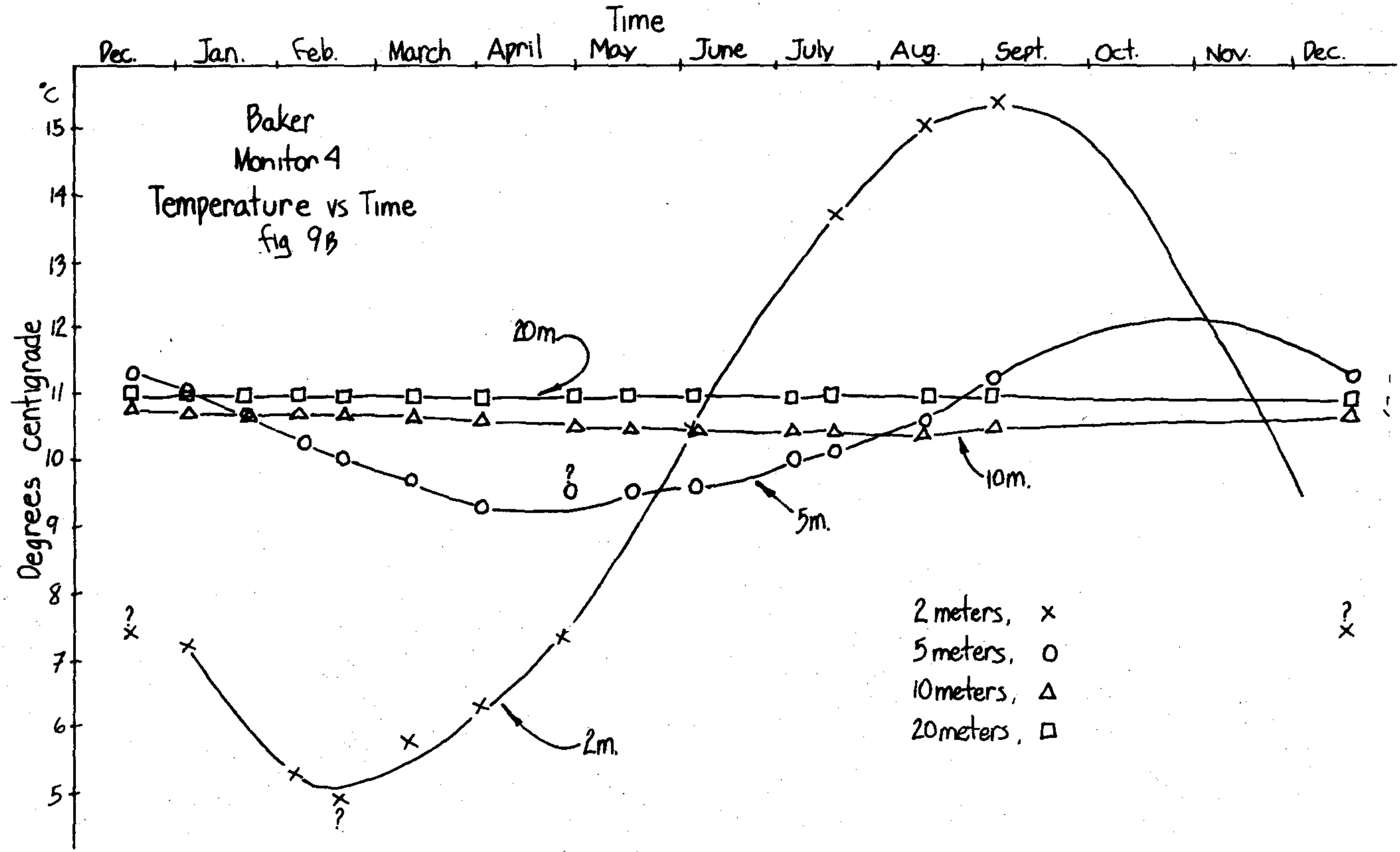
Table 3. Data from monitor well 3, Pebble Springs

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	

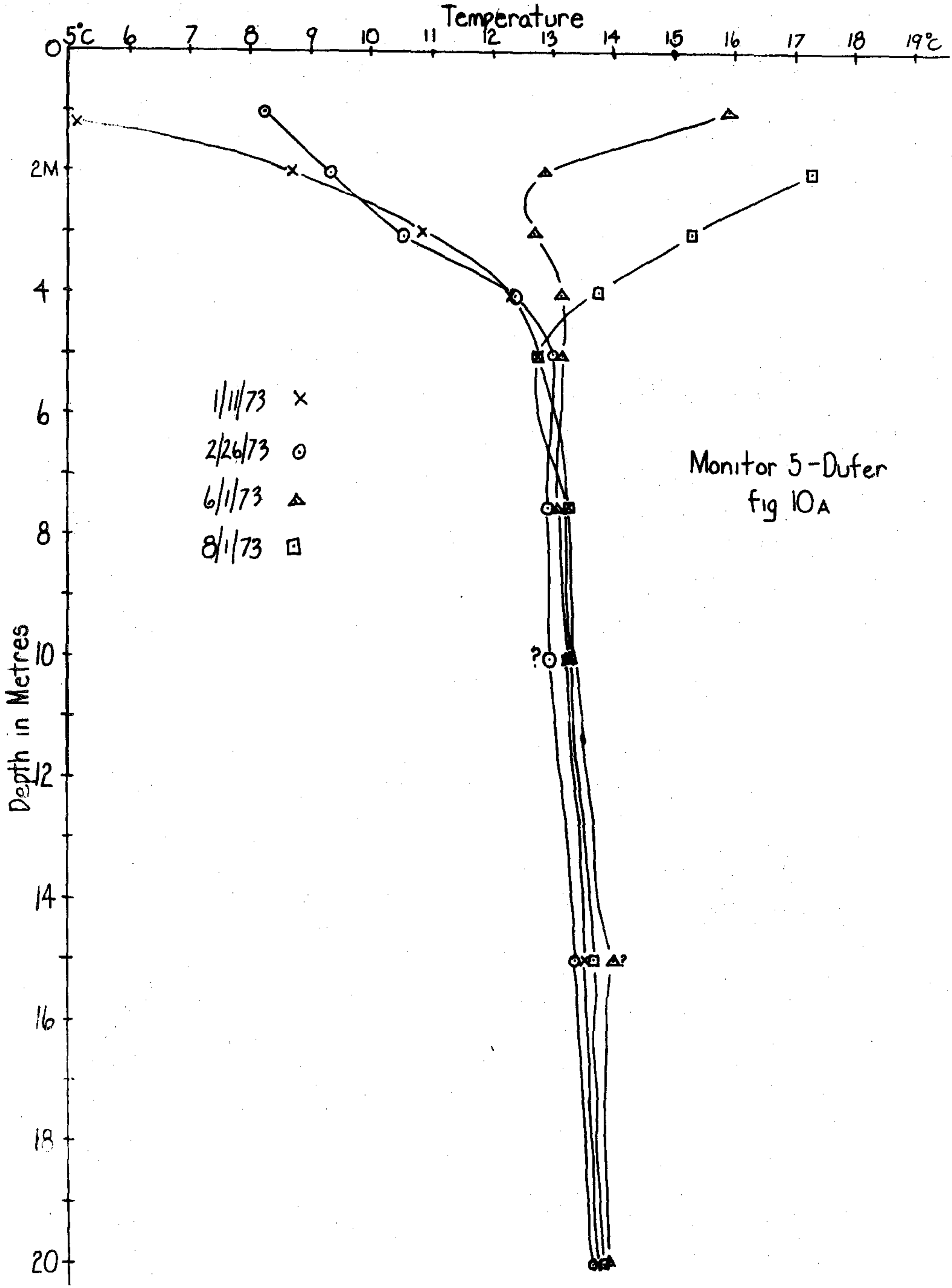
Table 4. Data from monitor well 4, Baker

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
Depth in Metres
1
2
3
4
5
6
7
8
9
10
11
12
15
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, ×
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
2M
4
6
8
10
12
14
16
18
20
Depth in Metres
1/11/73 ×
2/26/73 ⊙
6/1/73 △
8/1/73 ⊡
?
?
Monitor 5-Dufer
fig 10A

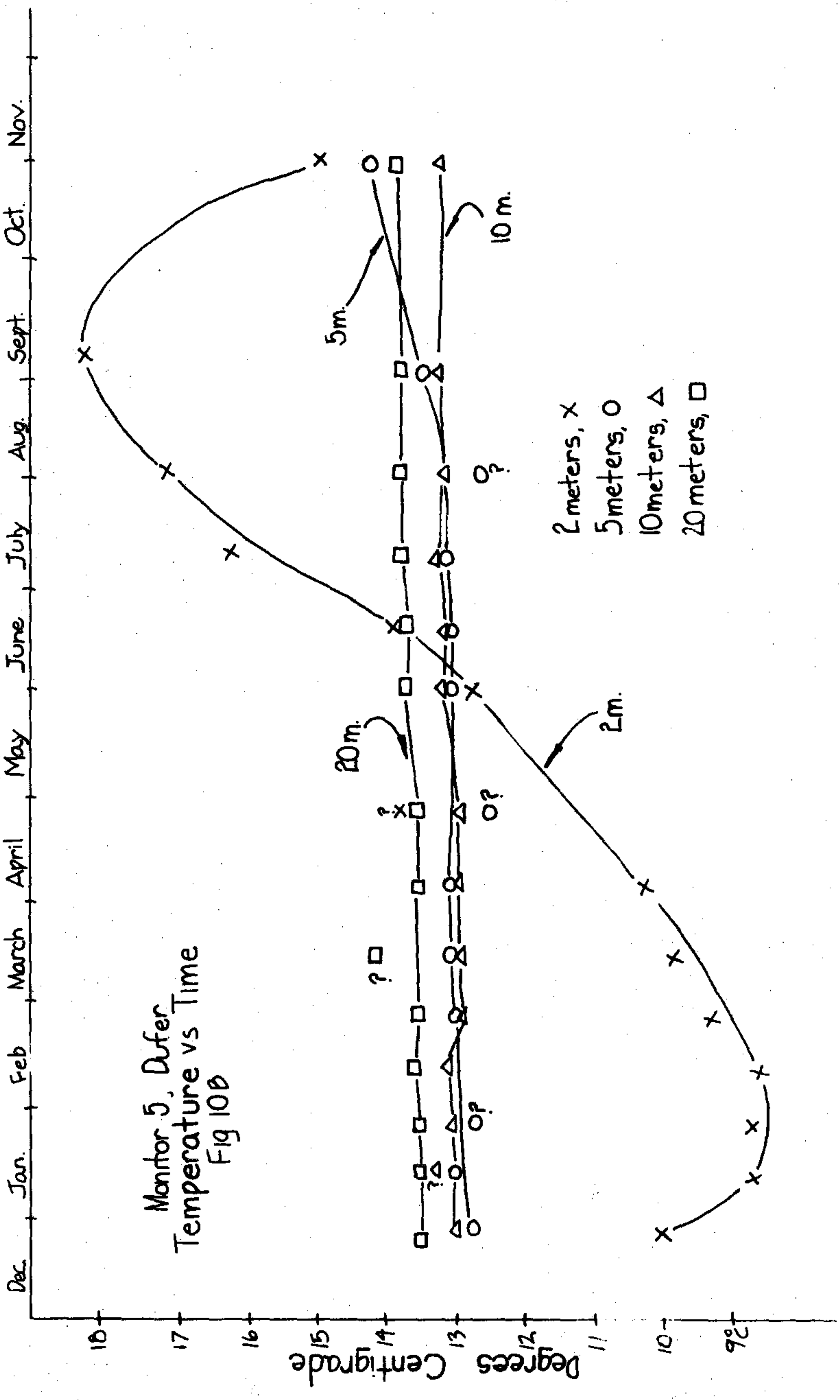
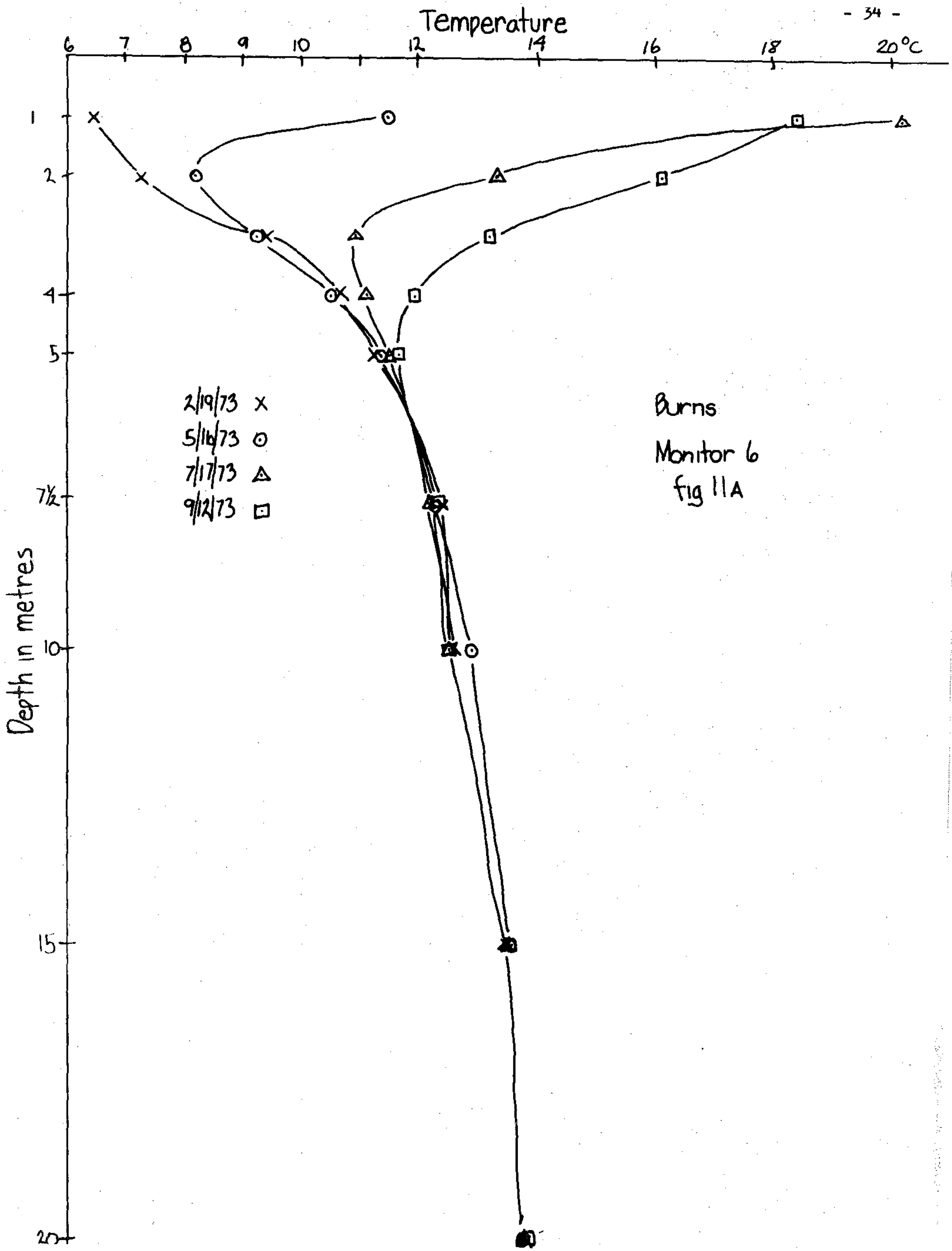

Monitor 5, Dufer
Temperature vs Time
Fig 10B
Time
Dec. Jan. Feb March April May June July Aug. Sept. Oct. Nov.
Degrees Centigrade
18 17 16 15 14 13 12 11 10 9°
2 meters, X
5 meters, O
10 meters, Δ
20 meters, □
2m.
5m.
10 m.
20m.

Table 5. Data from monitor well 5, Dufur

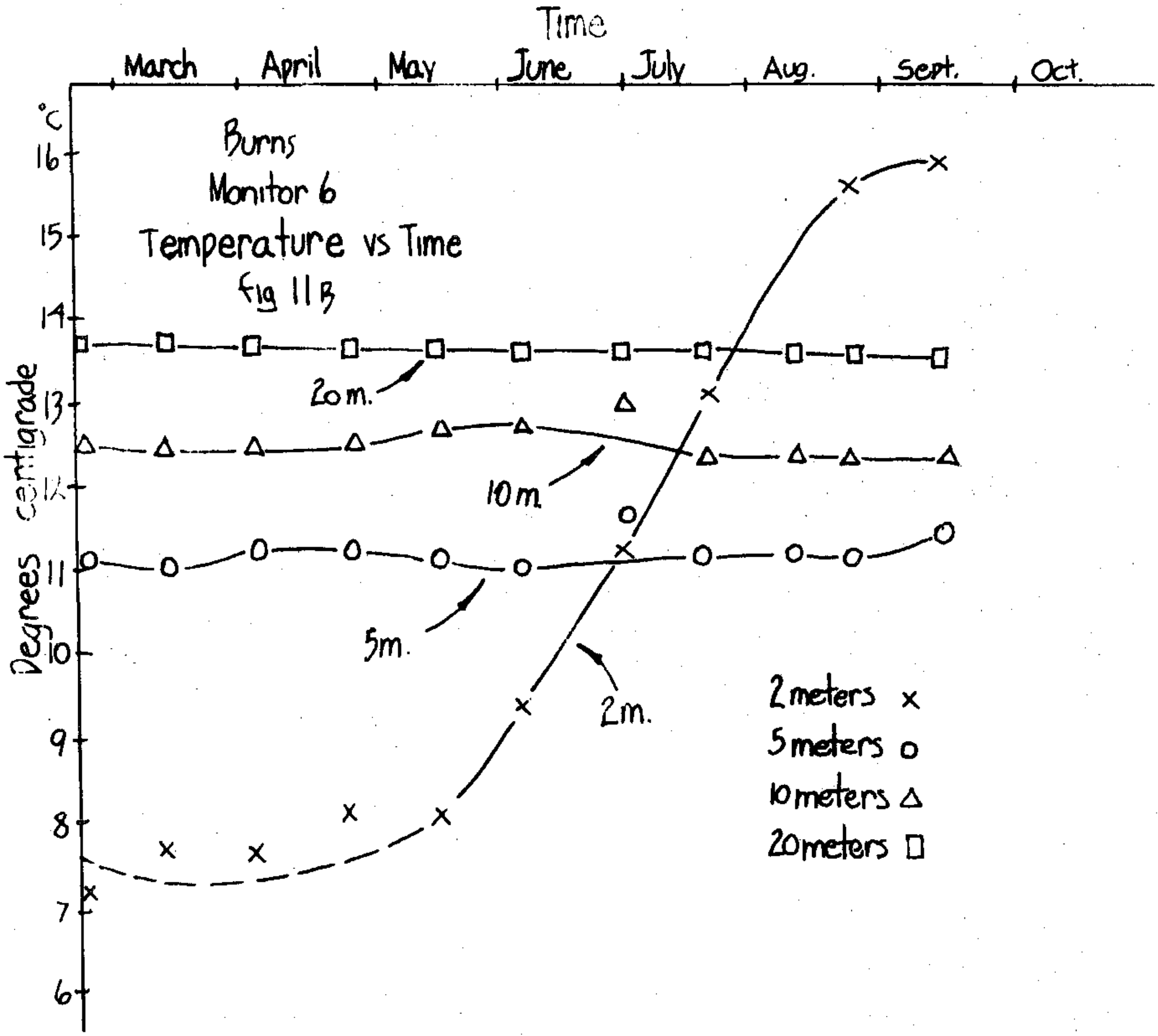
Date Logged	Mean Monthly Air Temp.	1m	2m	3m	4m	5m	7½m	10m	15m	20m	25m
12/22/72	-2.94	8.36	10.09	11.32	12.35	12.75	12.89	12.97	13.26	13.55	13.88
1/11/73	0.22	5.14	8.72	10.81	12.33	13.02	13.20	13.31	13.56	13.76	14.02
1/25/73	0.22	6.80	8.76	11.70	12.35	12.73	12.95	13.07	13.44	13.70	13.99
2/9/73	2.5	5.30	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
Depth in metres
1
2
4
5
7½
10
15
20
2/19/73 ×
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 ×
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°.

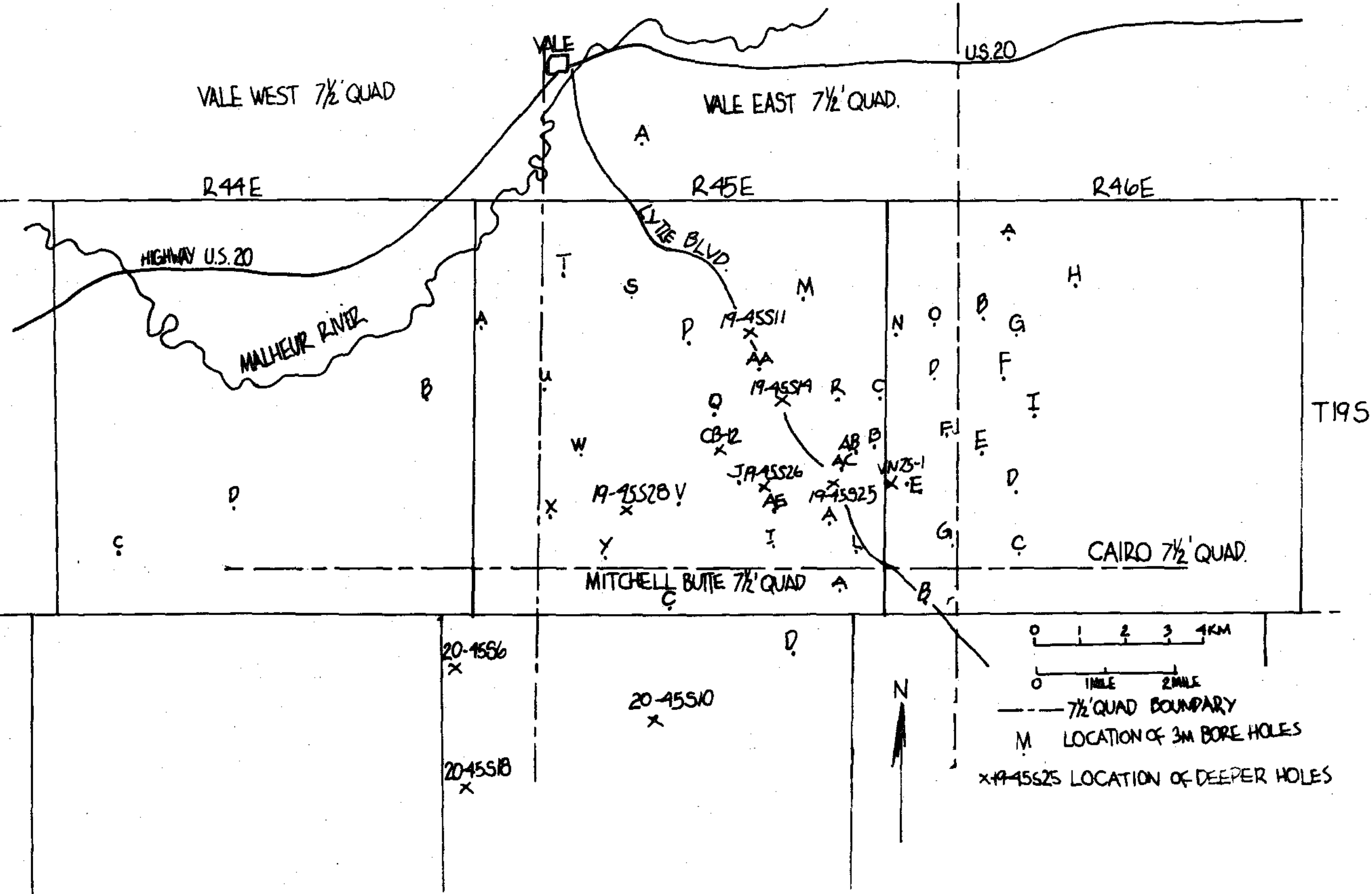
SHALLOW WELL PROGRAM

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 $-3^{o}C/km$. 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.

Table 7. Data from shallow holes, Cow Hollow

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 - 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		5/8/73		6/25/73		9/7/73	
			1m	3m	1m	3m	1m	3m	1m	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	depths logged 1m	2m	3m	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		
E¼SE¼	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	AdB$_5$	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

Paisley

Location	Hole			Date	1m	2m	3m	4m
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

Location	Hole			Date	1m	2m	3m	4m
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

Location	Hole			Date	1m	2m	3m	4m
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	VF-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/cm^{2}sec	
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

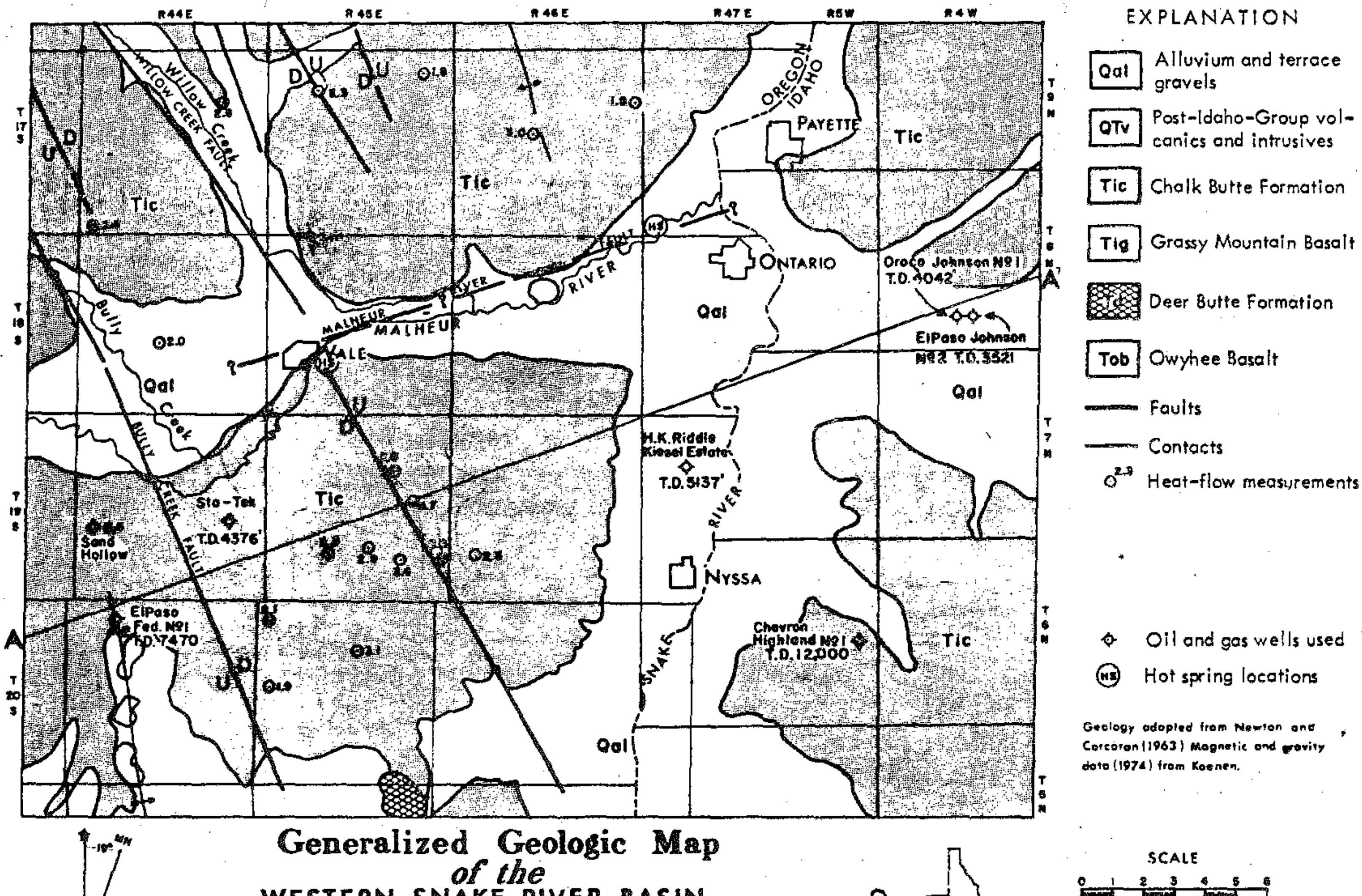
The final phase of the current geothermal study consisted of drilling five holes to depths ranging from 62-152 meters (203 to 500 feet). The purposes of the deeper drilling were (1) to study heat flow in areas where previous temperature-gradient measurements in pre-drilled wells had indicated abnormally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

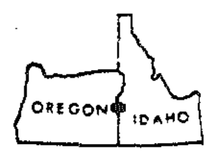
FIGURE 13



Generalized Geologic Map *of the* WESTERN SNAKE RIVER BASIN

Showing

Hot Spring and Heat Flow Measurement Locations

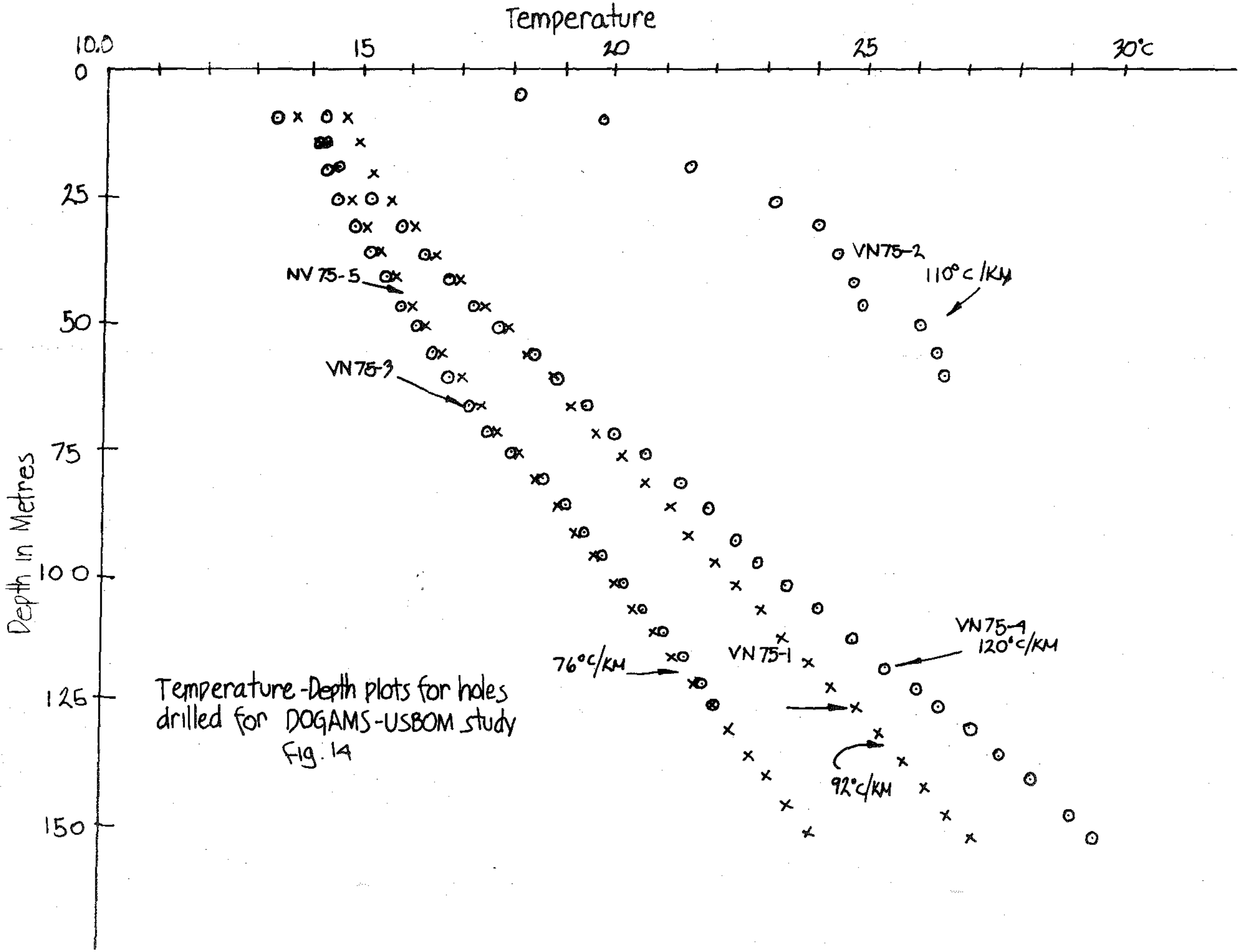


Holes were completed by inserting a water-filled and bottom-capped 1-inch diameter polyvinyl chloride (PVC) pipe to total depth and then backfilling the annulus around the PVC pipe with cement, a bentonite slurry, or drill cuttings. Cement was used in hole 75-2 which encountered artesian water. Either 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.

ADDITONAL REFERENCES

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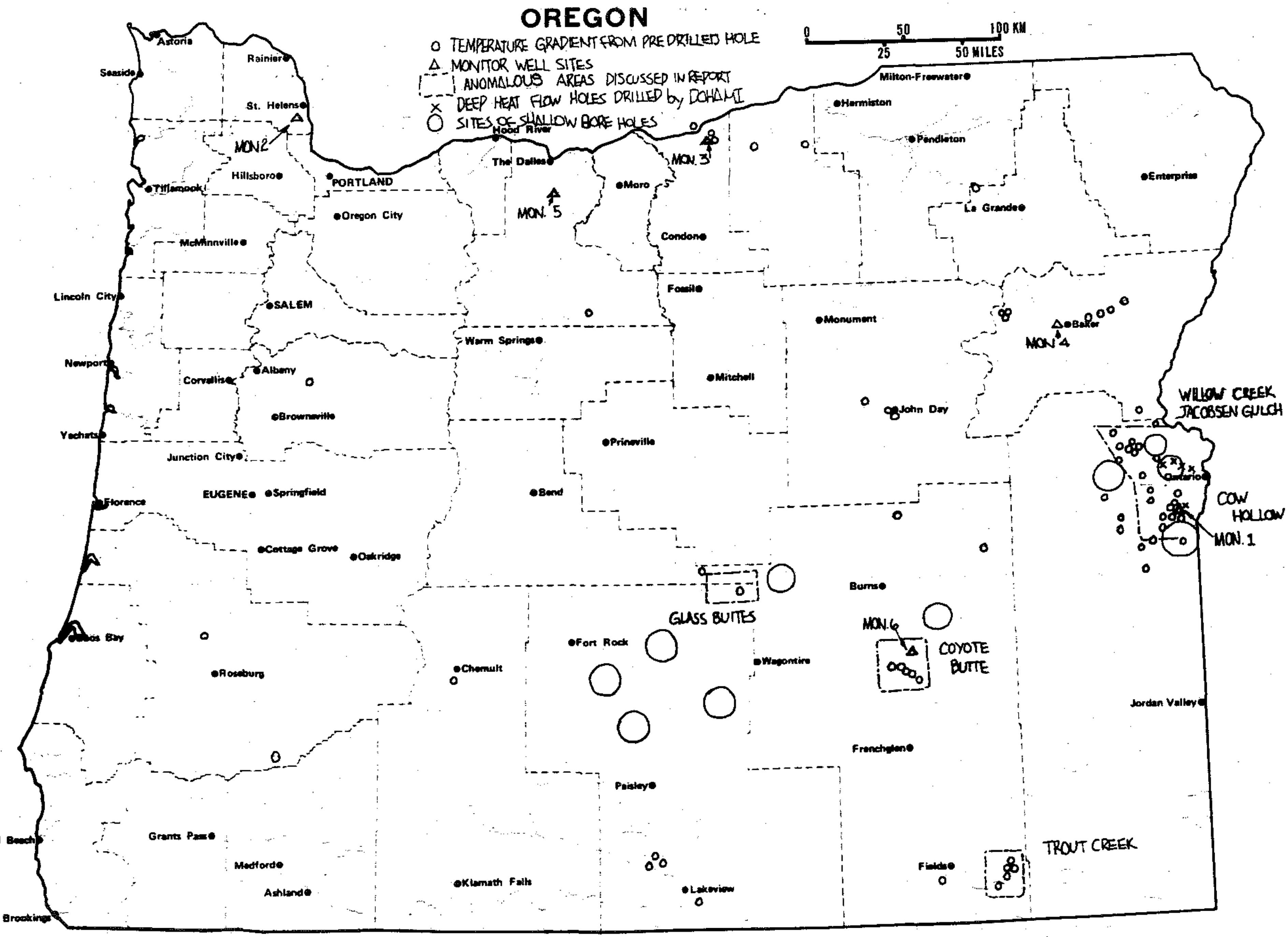
OREGON
TEMPERATURE GRADIENT FROM PRE DRILLED HOLE
MONITOR WELL SITES
ANOMALOUS AREAS DISCUSSED IN REPORT
DEEP HEAT FLOW HOLES DRILLED by DOHAMI
SITES OF SHALLOW BORE HOLES
0 50 100 KM
25 50 MILES
Astoria
Rainier
Seaside
St. Helens
MON 2
Hood River
The Dalles
MON. 3
Milton-Freewater
Hermiston
Pendleton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