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THE LOW TEMPERATURE GEOTHERMAL RESOURCE OF THE YAKIMA REGION - A PRELIMINARY REPORT

by

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Introduction

The low temperature geothermal resource of the Yakima region is currently at the initial stage of its development. Several domestic heat pump systems utilize the warm groundwater for space heating, and larger installations have been considered. This report provides a preliminary summary of the geothermal resource for portions of the Yakima region.

Location and Topography

The Yakima region lies in the western portion of the Columbia Plateau in south-central Washington. The region's major topographic and structural features are a series of southeast-trending anticlinal ridges and synclinal valleys. The Yakima River serves as the region's major drainage.

Stratigraphy of the Yakima Region

The lava flows of the Columbia River Basalt Group (CRBG) and the interbedded sediments of the Ellensburg Formation comprise the bulk of the region's near-surface stratigraphic section. The nature of the rocks underlying the basaltic lavas is uncertain, but they are probably related to older volcanic rocks (Ohanapecosh Formation) that are exposed to the west (Bentley and others, 1980). Oil and gas exploration boreholes are presently being drilled in Yakima County and should provide information on the deeper geologic units in the future. Alluvial sediments overlie the Ellensburg Formation throughout much of the lowlands of the Yakima region (Campbell, 1976, 1977a, 1977b; Swanson and others, 1979a).

The total thickness of the Columbia River Basalts is unknown but probably exceeds 1,000m in the Yakima region (Bentley, 1977; Bentley and others, 1980). All three formations of the Yakima Basalt Subgroup (CRBG)--the Grande

Ronde, Wanapum, and Saddle Mountains Formations--are found in surface exposures (Swanson and others, 1979a).

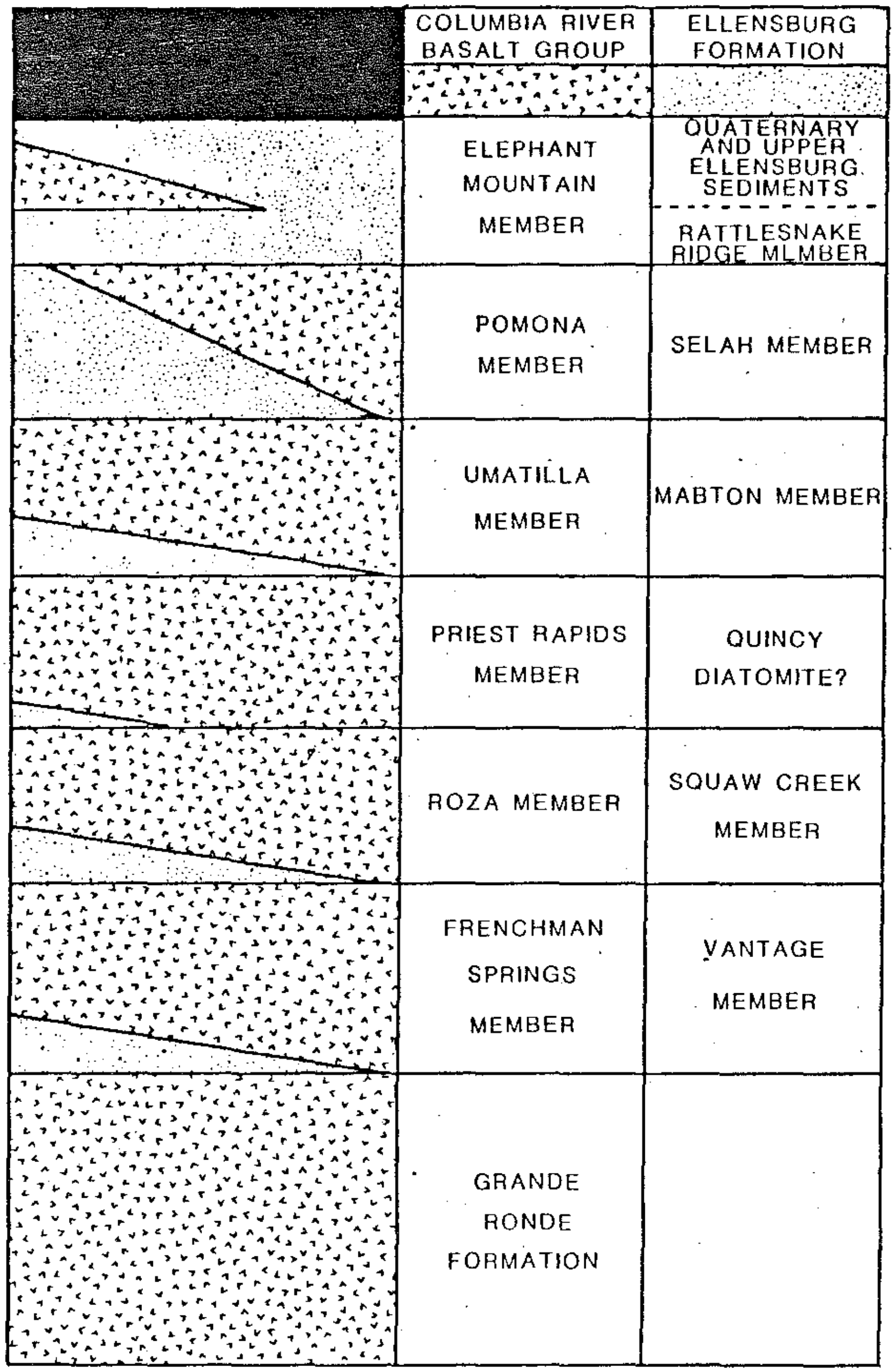
Individual basalt flows usually contain two major zones, the colonnade and the underlying entablature, which are set apart by differing joint characteristics (Swanson, 1967; Diery and McKee, 1969). Straight, vertical columns are typical of the colonnade, while thinner, inclined, or curved columnar joints are found in the entablature. Horizontal joints are found in both zones. A basal breccia is often observed beneath the colonnade, and a vesicular zone often occurs at the flow top.

An generalized stratigraphic section is shown in Figure 1. Subsurface stratigraphic correlation lines for the lower Yakima, Black Rock, and Moxee Valleys are shown in Figures 2 through 8. (Symbols used in Figures 2 through 8 are explained in Appendix A.) These correlation lines were constructed by interpreting both drillers' and borehole geophysical logs. Neutron-neutron logs are shown in Figures 2 through 8, but it should be noted that natural gamma, gamma-gamma, and neutron-gamma logs were also utilized for these correlations. Formation thicknesses reported in later sections of this report are apparent thicknesses, since dip corrections have not been made.

An overview of the region's geologic units is given below. Interested readers are referred to Swanson (1967), Schmincke (1967a and 1967b), Diery and McKee (1969), Bentley (1977), Campbell (1976, 1977a, and 1977b), Swanson and others (1979a), and Bentley and others (1980) for more detailed information.

Grande Ronde Formation

The Grande Ronde Formation has been informally divided into four magnetostratigraphic units of which three (N_1, R_2, and N_2) have been mapped in the region (Swanson and others, 1979a). The total thickness of this formation



COLUMBIA RIVER BASALT GROUP	ELLENSBURG FORMATION
ELEPHANT MOUNTAIN MEMBER	QUATERNARY AND UPPER ELLENSBURG SEDIMENTS RATTLESNAKE RIDGE MEMBER
POMONA MEMBER	SELAH MEMBER
UMATILLA MEMBER	MABTON MEMBER
PRIEST RAPIDS MEMBER	QUINCY DIATOMITE?
ROZA MEMBER	SQUAW CREEK MEMBER
FRENCHMAN SPRINGS MEMBER	VANTAGE MEMBER
GRANDE RONDE FORMATION	

FIGURE 1 GENERALIZED STRATIGRAPHIC SECTION

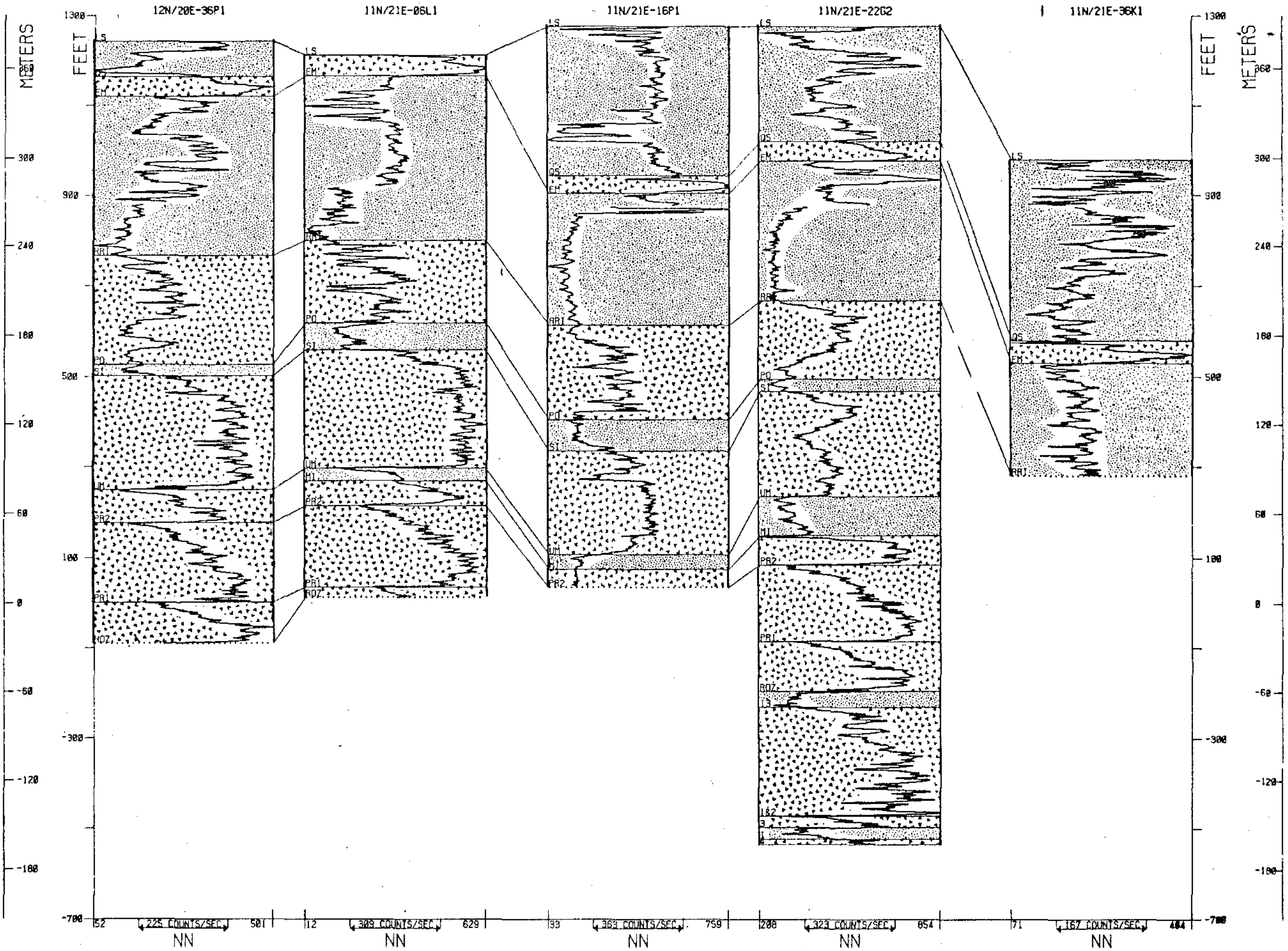


FIGURE 2 STRATIGRAPHIC CORRELATION LINE #1

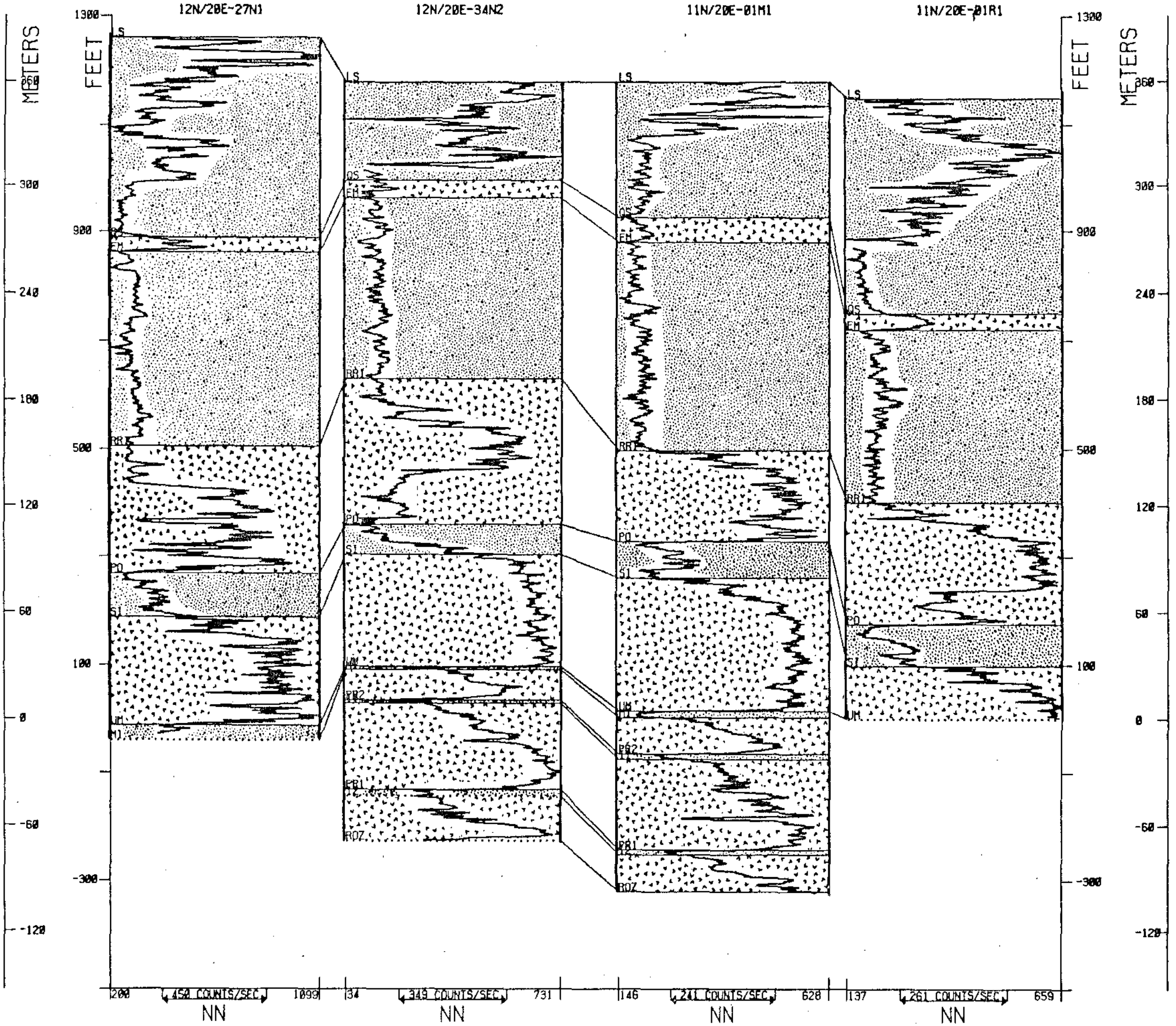


FIGURE 3 STRATIGRAPHIC CORRELATION LINE #2

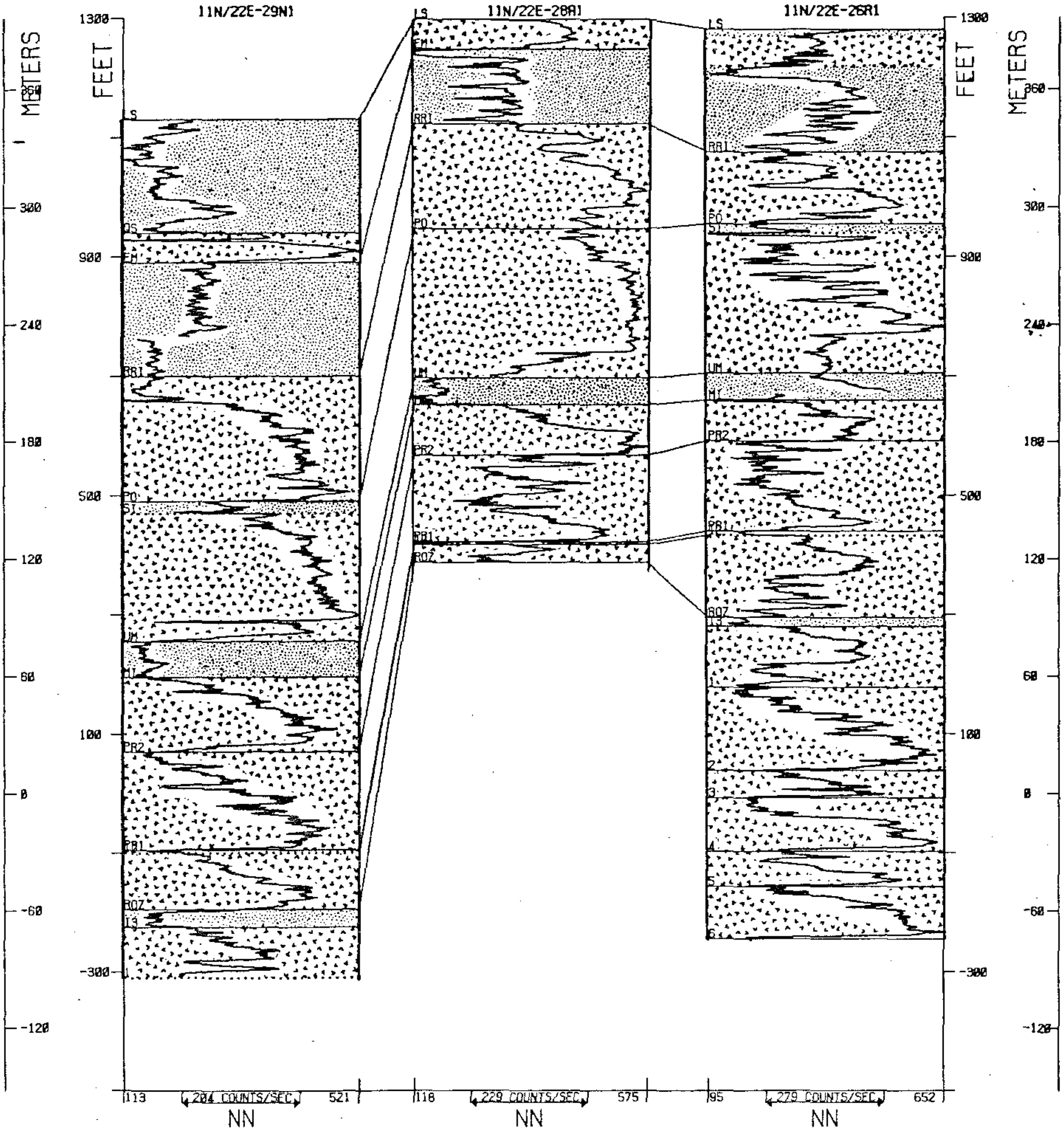


FIGURE 4 STRATIGRAPHIC CORRELATION LINE #3

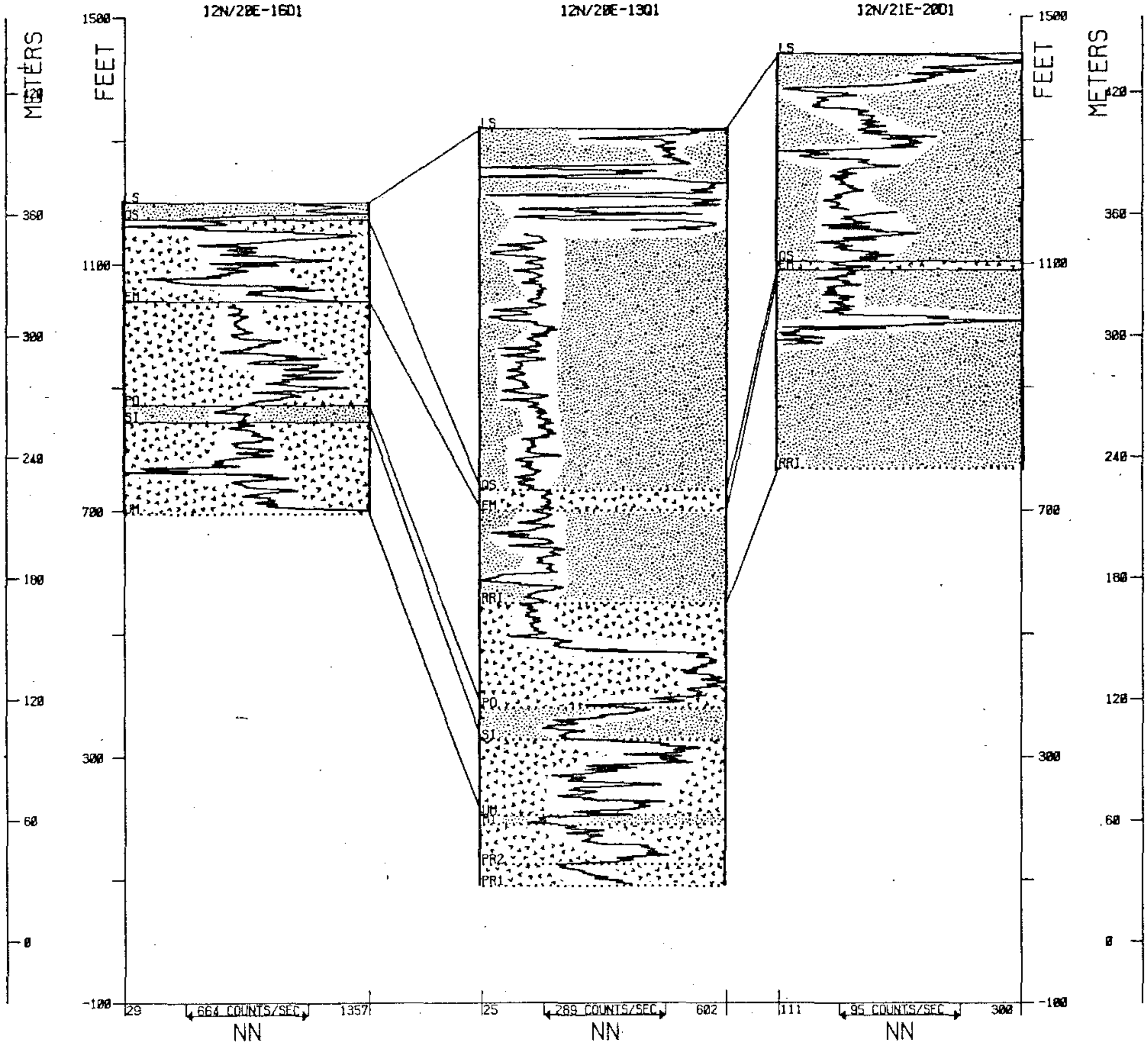


FIGURE 5 STRATIGRAPHIC CORRELATION LINE #4

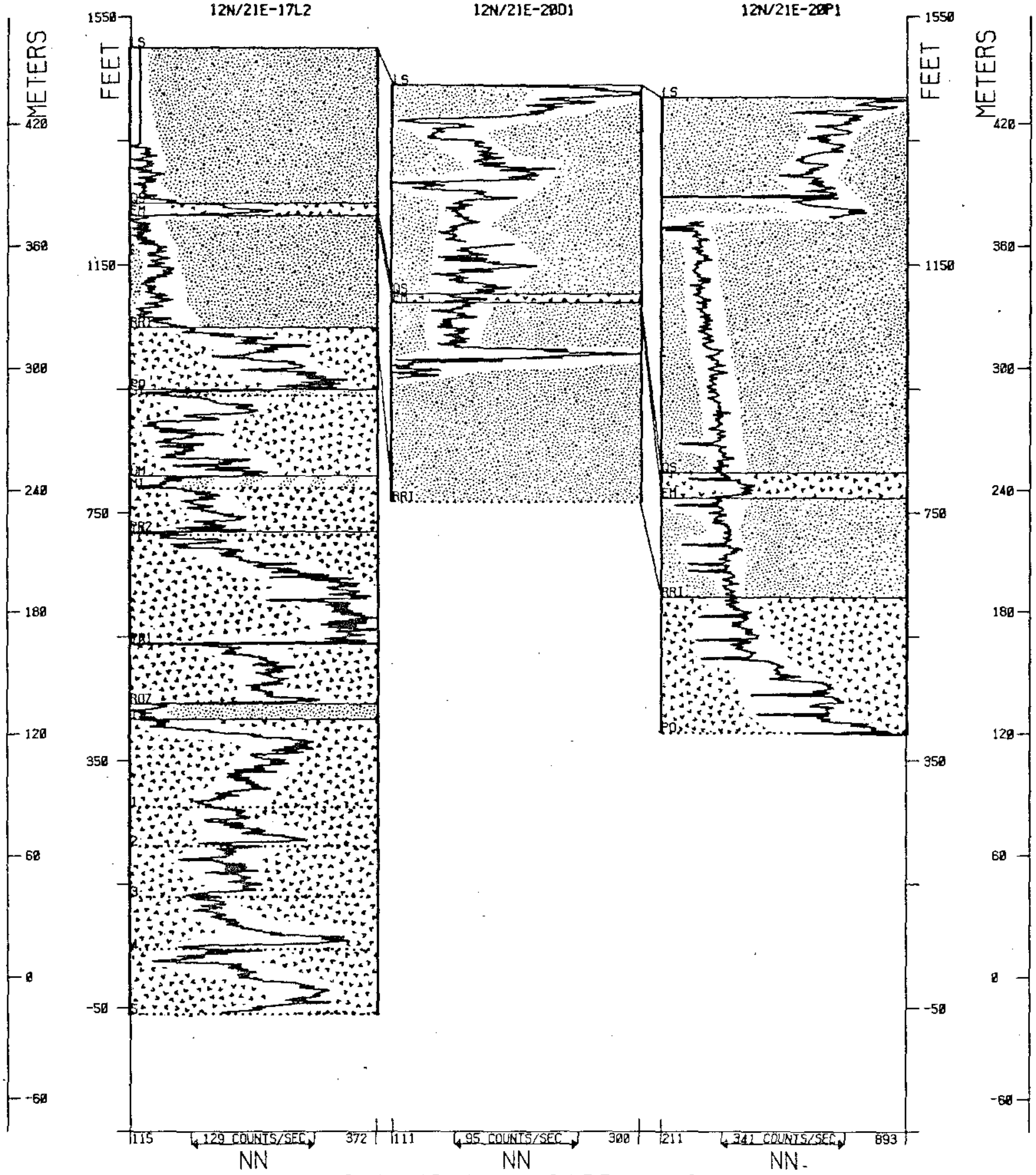


FIGURE 6 STRATIGRAPHIC CORRELATION LINE #5

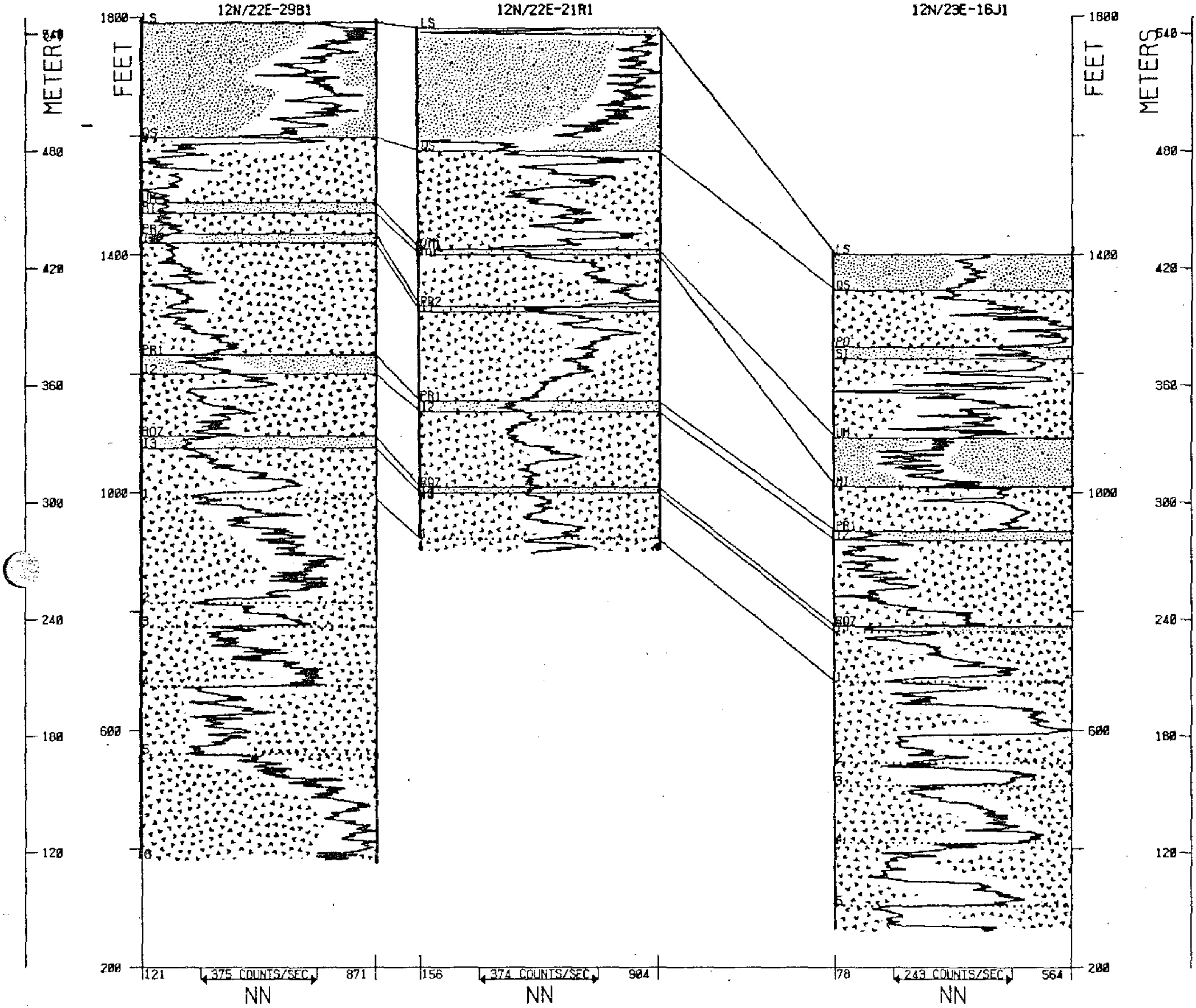


FIGURE 7 STRATIGRAPHIC CORRELATION LINE #6

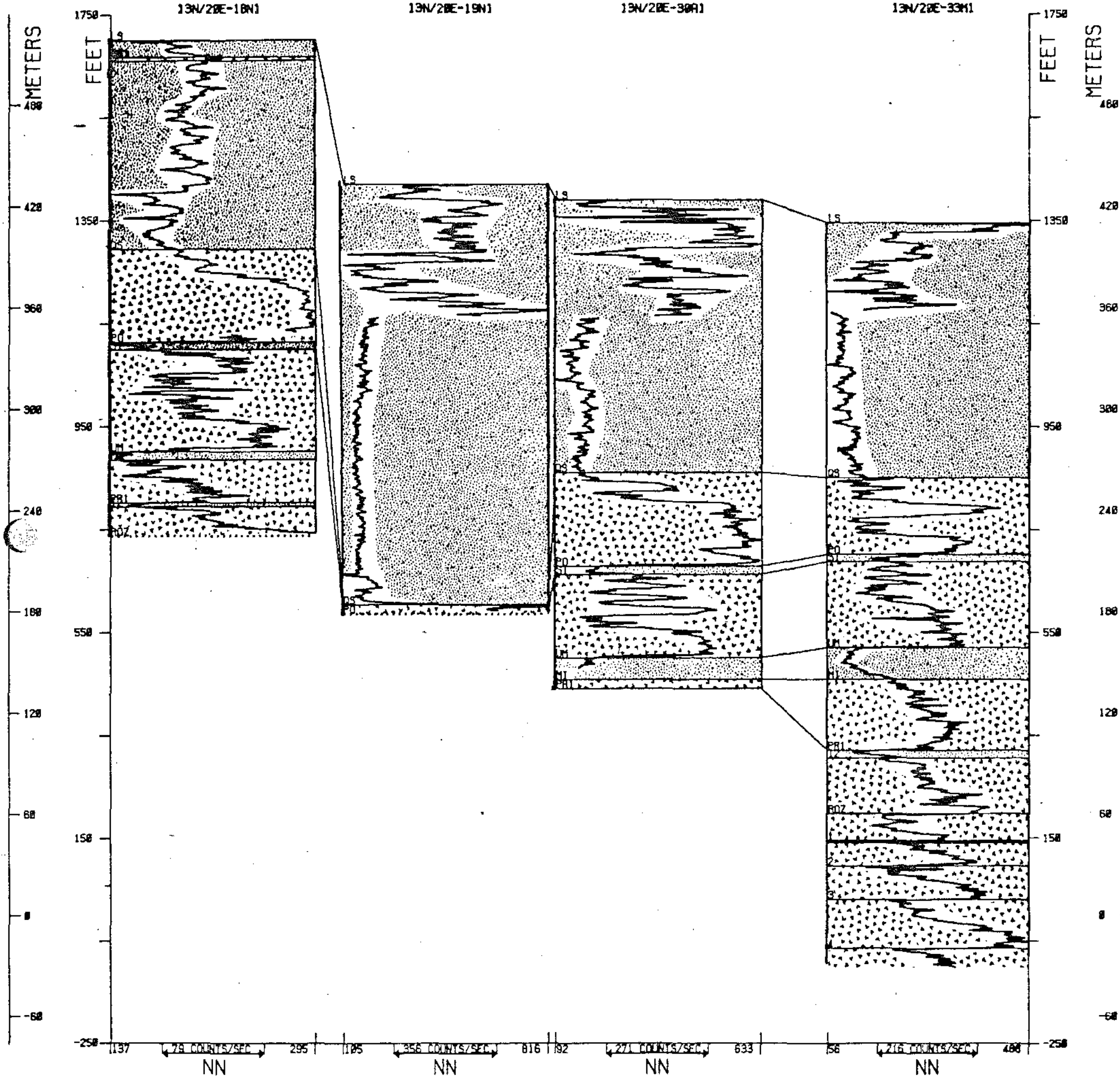


FIGURE 8 STRATIGRAPHIC CORRELATION LINE #7

in the Yakima region probably does not exceed 1,000m and may vary by as much as 400m because of an irregular pre-basalt topography (Bentley and others, 1980). Individual flows average 20 to 30m in thickness (Bentley and others, 1980).

Vantage Member of the Ellensburg Formation

The Vantage Member of the Ellensburg Formation lies between the Grande Ronde and Wanapum Basalt Formations throughout most of the region. The reported thickness of this member ranges from 0 to 30m (Diery and McKee, 1969; Bentley, 1977; Bentley and others, 1980). This member is composed of volcaniclastic sandstones, siltstones, claystones, and minor quantities of conglomerate and diatomite (Diery and McKee, 1969; Bentley and others, 1980). None of the wells for which stratigrahic sections are given in this report have penetrated the Vantage Member.

Wanapum Formation

In the Yakima Region, the Wanapum Basalt Formation is composed of three members: the Frenchman Springs, the Roza, and the Priest Rapids Members.

Frenchman Springs Member

The Frenchman Springs Member, the thickest (over 150m) and most widespread Wanapum Member, is composed of up to six flows at Union Gap (Bentley and others, 1980). None of the wells for which stratigrahic sections are given in this report have completely penetrated this member. Six flows have been tentatively recognized in several wells where their combined thickness ranges from 80 to over 150m. Several thin (up to 8m thick in well

11N/21E-22G2) discontinuous sedimentary interbeds lie between the flows of the Frenchman Springs Basalt Member.

Squaw Creek Member of the Ellensburg Formation

The Squaw Creek Member of the Ellensburg Formation lies between the Frenchman Springs and the Roza Members throughout much of the study area. The thickness of this member ranges from 0 to nearly 11m. This member can be used as a stratigraphic marker due to its high natural gamma response. A typical reponse is shown in Figure 9. The composition of the Squaw Creek Member varies from a diatomite or jasperoid to sandstone or conglomerate (Diery and McKee, 1969; Bentley and others, 1980).

Roza Member

The Roza Member occurs as a single flow in the Yakima region. The thickness of this member ranges from under 30m to almost 45m along the subsurface correlation lines. A thin (0 to 10m) interbed (Quincy Diatomite?) separates the Roza Member from the overlying basalt flow.

Priest Rapids Member

Two basalt flows of the Priest Rapids Member normally occur in the subsurface of the region, with the upper flow thickness ranging from 10m to almost 60m and the lower flow thickness ranging from 45m to almost 60m. A thin (up to 5m) interbed occurs rarely between these two flows. Only one flow was found to occur in several wells in the Black Rock and Moxee Valleys. The thickness of this flow ranges from more than 20m to 42m at these locations. The upper surface of the Priest Rapids Basalt Member is often deeply weathered (Bentley and others, 1980).

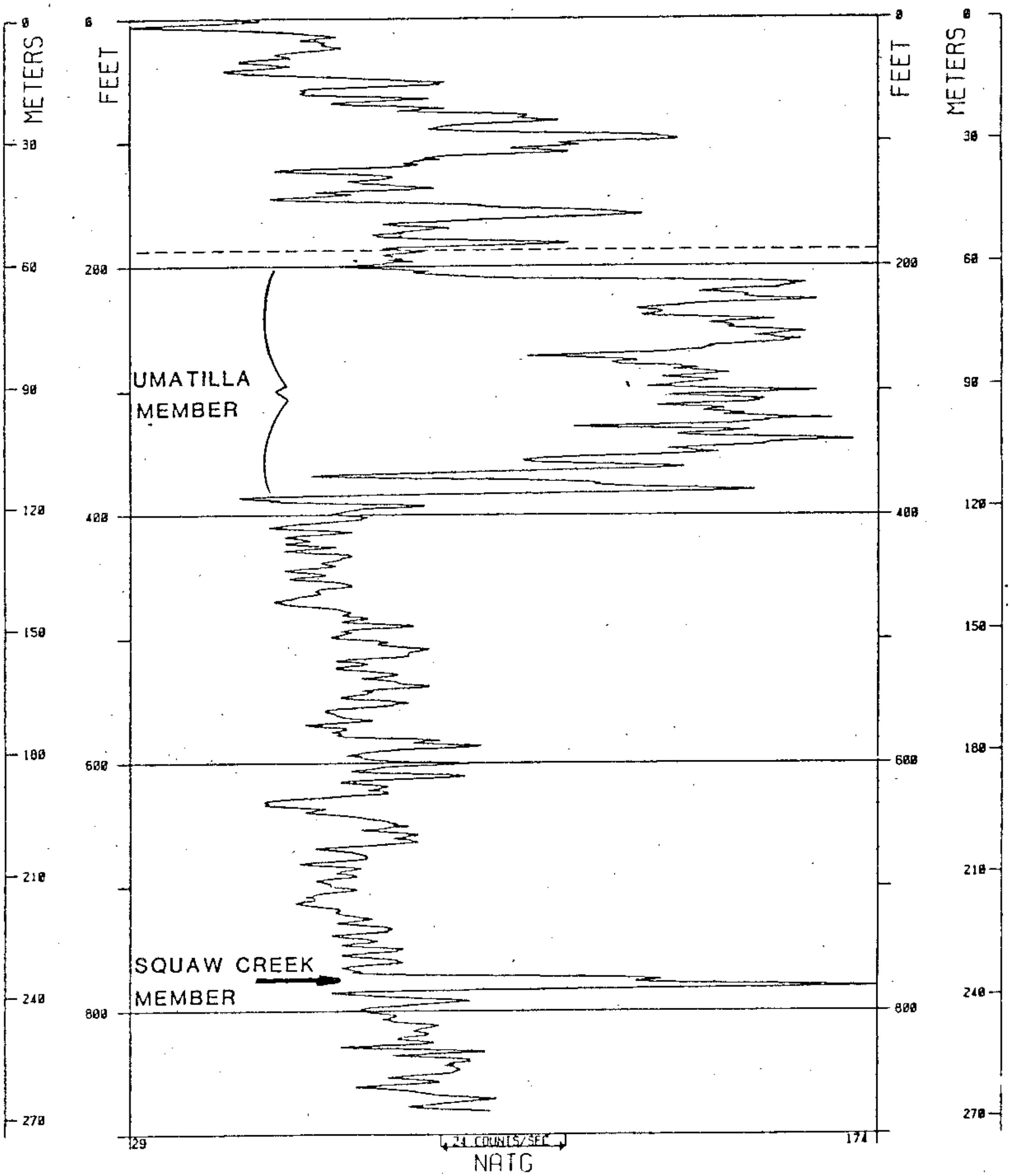


FIGURE 9 TYPICAL NATURAL GAMMA RESPONSE OF THE UMATILLA AND SQUAW CREEK MEMBERS

Mabton Member of the Ellensburg Formation

The Mabton Member of the Ellensburg Formation overlies the Priest Rapids Member throughout much of the Yakima region. The thickness of the member varies from 0m to over 25m. The Mabton Member is composed of volcaniclastic deposits and airfall tuff (Bentley and others, 1980).

Saddle Mountains Formation

Four members of the Saddle Mountains Formation are found in the Yakima region. These flows include the Umatilla, Huntzinger, Pomona, and Elephant Mountain Members. Interbedded between these flows are sediments of the Ellensburg Formation that may reach thicknesses greater than 100m.

Umatilla Member

The Umatilla Member consists of a single basalt flow with a thickness that ranges from 30m to 60m in the subsurface of the Black Rock and Moxee Valleys and from 60m to over 80m in the lower Yakima Valley. The colonnade contains poorly developed columns 1m to 2m in diameter and is overlain by a glassy entablature and flow top breccia (Schmincke, 1967b). The Umatilla Member serves as a stratigraphic marker because of its high natural gamma response (Crosby and others, 1972). A typical response is shown in Figure 9.

"Huntzinger" Valley Flow (Asotin Member?)

The Huntzinger Valley flow (Asotin Member?) occurs as a "valley filling" basalt flow southeast of Selah in the Moxee and Black Rock Valleys (Bentley, 1977; Campbell, 1977a). This flow has not been identified in any of the stratigraphic sections that were prepared for this report.

Selah Member of the Ellensburg Formation

The Selah Member, an interbed lying between the Umatilla and Pomona Members, is composed of volcaniclastic deposits and vitric tuffs (Schmincke, 1967a). The thickness of this member ranges from less than 10m to over 15m in the subsurface of the Black Rock and Moxee Valleys and from 0m to almost 25m in the lower Yakima Valley.

Pomona Member

The Pomona Member, a single basalt flow, ranges in thickness from less than 40m to over 80m in the subsurface of the lower Yakima Valley. In the subsurface of the Black Rock Valley, the Pomona Member was found to be only 30m thick and in several locations was absent altogether. The Pomona Member in the subsurface of the Moxee Valley was found to be 45m to 55m thick. The upper surface of the Pomona Member is often broken into blocks of highly oxidized scoria (Schmincke, 1967b).

Rattlesnake Ridge Member of the Ellensburg Formation

The Rattlesnake Ridge Member, an interbed lying between the Pomona and Elephant Mountain Members, is composed primarily of siltstone and claystone with interbedded conglomerate (Bentley and others, 1980). The thickness of this member ranges from 40m to over 100m in the subsurface of the region. Bentley and others (1980) report thicknesses of up to 200m for this member in the Toppenish basin.

Elephant Mountain Member

The Elephant Mountain Member usually occurs as one flow in the Yakima region with a second flow, the Ward Gap, being found at Snipes Mountain

(Campbell, 1977b) and at Ward Gap (Schmincke, 1967a). The thickness of this flow ranges from 8m to over 15m in the subsurface of the lower Yakima Valley and is absent in most of the wells studied in the Black Rock Valley. In the subsurface of the Moxee Valley, the thickness ranges from 0m to just over 10m. A thick (48m) section occurs in well 12N/20E-16D1, but it is uncertain whether the entire section is Elephant Mountain Basalt.

Upper Ellensburg Formation and Quaternary Sediments

Overlying the Elephant Mountain Basalt Member are Ellensburg and younger Quaternary sediments. The thickness of these sediments range from 0 to over 170m along the correlation lines that were prepared for this report, and it is expected that greater thicknesses would be found towards the center of the lower Yakima Valley. The Ellensburg sediments consist of volcaniclastic deposits with interbedded conglomerates and sandstones, whereas the Quaternary sediments consist of silt, sand, gravel, and loess deposits (Campbell, 1976, 1977a, and 1977b; Bentley and others, 1980).

In regions where the Elephant Mountain and/or Pomona Basalt Members are absent, the Selah and Rattlesnake Ridge Members are difficult to separate from the upper Ellensburg sediments. Where this situation occurs, the Selah and Rattlesnake Ridge Members have not been differentiated from the upper Ellensburg sediments on the correlation lines that are shown in this report.

Previous Geophysical Investigations in the Yakima Region

Gravity and aeromagnetic studies have been conducted in the Yakima region by Robbins and others (1975), Konicek (1975), and Swanson and others (1979c). The known seismic history of the region is summarized by Myers and Price (1979).

Analysis of gravity data suggests that the basalts (CRBG) extend to a depth of 2m to 4km in the Yakima and Toppenish Valleys and to a depth of about 1km in the Ahtanum Valley (Robbins and others, 1975; Konicek, 1975). Circular gravity lows were observed just west of the cities of Yakima and Zillah and were interpreted as possibly resulting from buried volcanic cones or deposits of rock having a lower density than the basalts (Robbins and others, 1975). A large gravity high, centered just south of Union Gap, was attributed to a thin layer of sediments (Robbins and others, 1975).

The aeromagnetic study showed low intensity, small amplitude anomalies over the valleys and anomalies of greater intensity and amplitude over the ridges (Swanson and others, 1979c). Magnetic studies may prove useful for mapping the younger valley-filling Yakima Basalts (Swanson and others, 1979c). Magnetotelluric studies hold promise for exploration work below the level of the basalts, but unfortunately none have been published for this region.

Historical earthquake epicenters with hypocenters equal to or greater than 10km deep tend to be concentrated along a north-south line between the cities of Yakima and Ellensburg (Myers and Price, 1979). Historical earthquake epicenters with hypocenters less than 10km deep tend to be concentrated along the same north-south line and along a northwest-southeast line trending through the lower Yakima Valley (Myers and Price, 1979). Magnitudes of 4 or less have been reported for these shallow and deep-seated earthquakes (Myers and Price, 1979).

Previous Geothermal Research in the Yakima Region

Geothermal research in the Yakima region began with a report by Smith (1901). In this report, Smith noted the warm temperatures (approximately 22°C) of the ground water flowing from artesian wells in the Moxee Valley and calculated geothermal gradients of 50 to 73°C/km for the region.

Foxworthy (1962) reported an average geothermal gradient of 40.5°C/km in water wells greater than 15m deep in the Ahtanum Valley and suggested that the rock type had little effect on the gradient.

Blackwell (1980) reported geothermal gradients of 26 to 37°C/km and heat flow values of 57 to $64 mWm^{-2}$ from water wells in the region.

Schuster (1980) noted that goeothermal gradients of 50 to 70°C/km were commonly measured in water wells of the region and that several very shallow wells produced warm waters. Depth to 20°C in water wells of the Yakima region were reported to range from 9m to 471m (Schuster, 1980).

Temperature Data

Subsurface temperature data in the Yakima region has been collected by the Geological Engineering Section of Washington State University (WSU), by the Department of Geological Sciences of Southern Methodist University (SMU), by the Washington State Department of Natural Resources (DNR), by the U. S. Geological Survey (USGS), and by the Oregon Institute of Technology (OIT). Some 200 bottomhole temperatures and depths for wells in the Yakima region are given in Appendix B. Well locations are shown in Figure 10.

The accuracy of the temperature data varies with the collecting agency. The temperature data collected by SMU and the DNR have an accuracy of approximately ±0.2°C (Blackwell, 1980). The accuracy of the temperature data collected by the USGS and OIT is unknown.

The temperature probes utilized by WSU since 1974 were recalibrated in a water bath as part of this project. Prior calibrations were only approximate because of the use of a nonstandard thermometer. Previously published WSU temperature data have been corrected to reflect the calibration changes. The change in calibration averaged less than -1.0°C. The precision of the WSU temperature probes is approximately ±0.2°C, and the field accuracy is approximately ±0.4°C. The temperature probes used by WSU prior to 1974 are no longer available, and their accuracy is therefore uncertain.

The DNR Black Rock well #1 was logged on successive days with the WSU temperature probe "A" and with the SMU probe VPR 1. The temperature logs are plotted in Figure 11 and are in close agreement, even though the WSU probe was the fourth tool to be run in the hole that day.

Calculation of Geothermal Gradients in the Yakima Region

Determination of geothermal gradients in water wells of the Yakima region is complicated by intra-aquifer borehole flow. The net result of the borehole flow is a distorted thermal gradient, often assuming a step-like form, with the recorded temperature distribution being unrepresentative of the actual geothermal gradient (see Figure 12).

Three options were available to past investigators in their attempts to determine accurate geothermal gradients in these water wells. The first, and most common method, is based on recorded bottom hole temperatures (BHT) and assumed land surface temperatures (LST), as shown in equation (1).

$$\text{Geothermal Gradient} = \frac{\text{BHT - LST}}{\text{depth(km)}} \qquad (1)$$

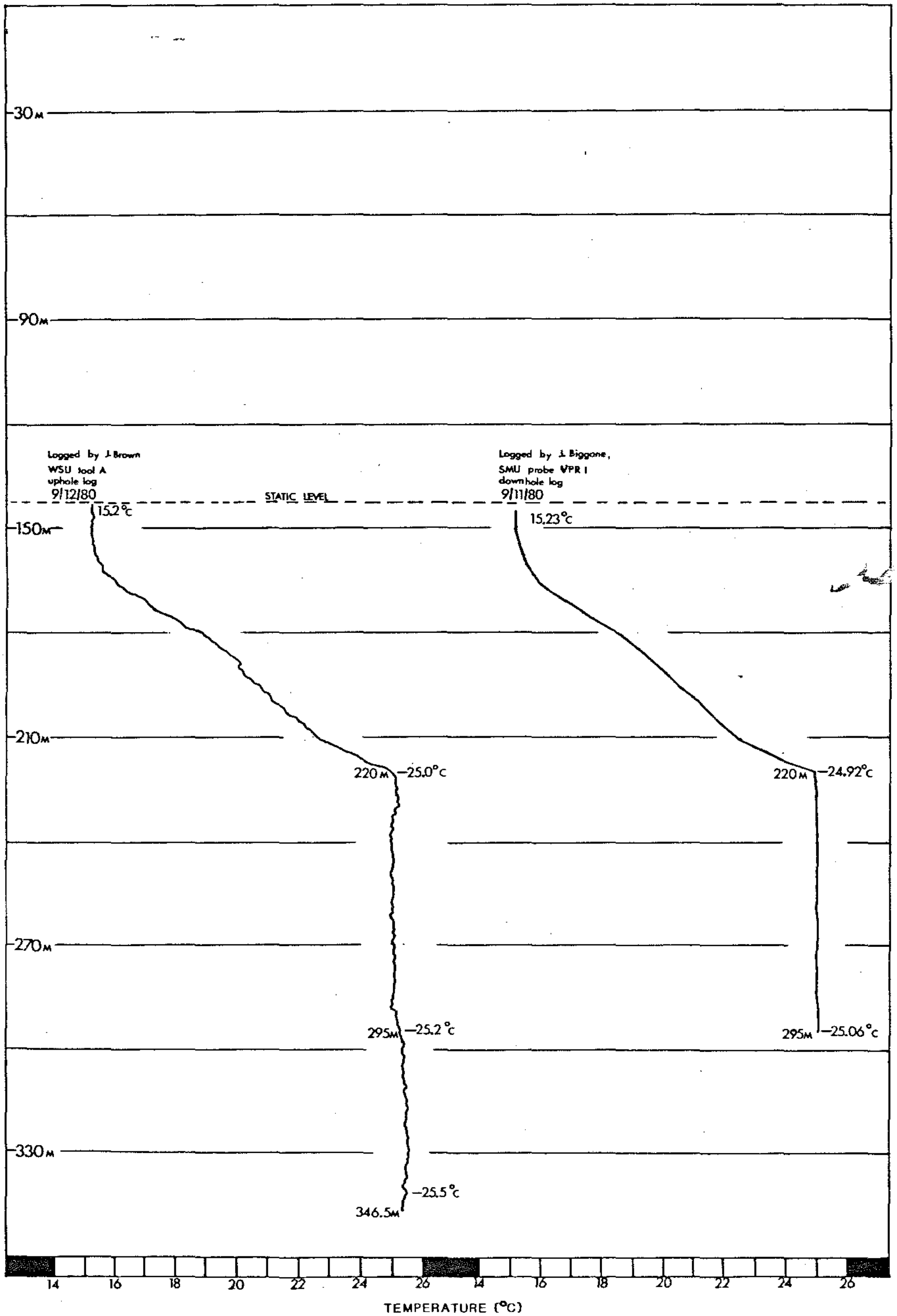


FIGURE 11 TEMPERATURE LOGS OF THE DNR BLACK ROCK WELL #1

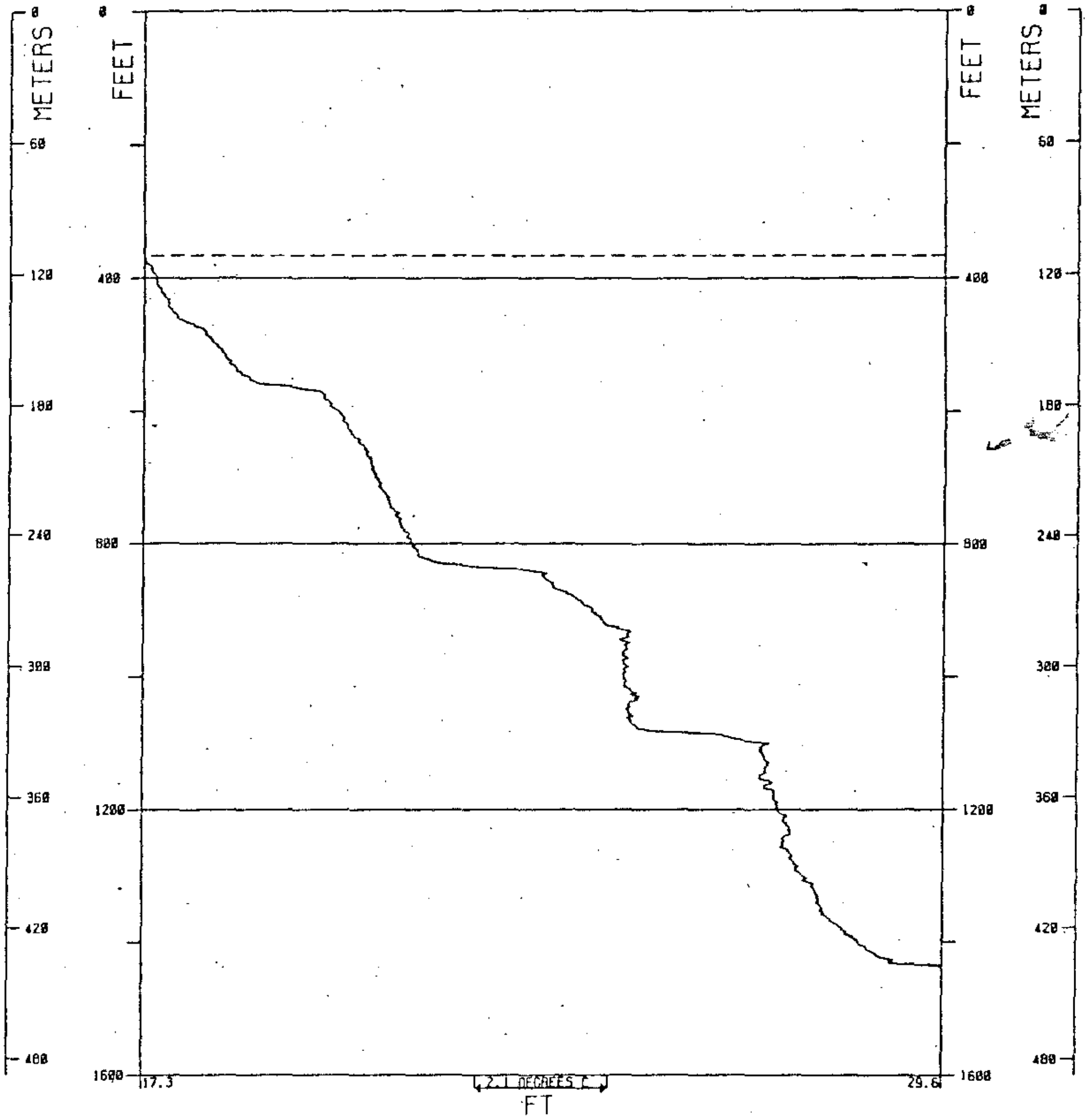


FIGURE 12 'STEP - LIKE' DISTORTION OF A TEMPERATURE LOG

For shallow wells, it is very important that an accurate LST be used in this method. The error involved varies according to equation (2) and is large for even small errors in the LST.

$$\text{error} = \frac{\text{LST}_{(\text{assumed})} - \text{LST}_{(\text{actual})}}{\text{depth(km)}} \qquad (2)$$

This method was applied in the Yakima region with very limited success because accurate LST are not available. The geothermal gradients of neighboring wells calculated in such a manner often differed by more than 100 percent.

A second method is based on selecting portions of the recorded thermal gradient that appear undistorted and then calculating the geothermal gradient over that interval. This method is time-consuming and does not allow a check on whether the selected interval is actually unaffected by borehole flow.

The third option available to the investigator is to disregard the data altogether.

A new approach to the problem was developed for this report. This method involves a simple least squares linear regression analysis of the BHT's of a group of wells. Well data groups were based on proximity and similar slope aspect and angle. An additional well data group was selected for well depths greater than 650m.

The BHT linear regression analysis has several advantages over the other gradient determination methods. Uphole flow does not affect the BHT, and poor quality data can be discriminated by its "lack of fit" to the rest of the data. Downhole flow can affect the BHT, but in many cases the deepest portion of the well appears to be isolated from the flow. A very rapid increase of temperature is recorded in the bottom of the wells that are isolated from the downhole flow (see Figure 12). Wells in which downhole flow does affect the BHT are discussed in a later section of this report.

Geothermal Gradients in the Yakima Region

Plots of BHT vs. depth for the well data groups are shown in Figures 13 through 26. (Symbols used in Figures 13 through 26 are explained in Appendix A.) The results of the least squares linear regression analysis are summarized in Table 1. Geothermal gradients for the shallow (less than 650m deep) well data groups range from 25.1°C/km to 52.2°C/km. Projected land surface temperatures range from 10°C to 14°C. Depths to the 20°C isotherm range from 142m to 344m. The areal distribution of the geothermal gradients, projected land surface temperatures, and depths to the 20°C isotherm are shown in Figure 27.

The majority of wells that were included in the deep (greater than 650m deep) well data group are located outside of Yakima County. Despite the fact that these deep wells are separated by large distances, an excellent relationship between BHT and depth exists (Figure 26). The least squares regression analysis of the deep well data group yielded a geothermal gradient of 29.9°C/km, a projected land surface temperature of 24.3°C, and a depth to the 100°C isotherm of 2,532m. A listing of the wells that were included in the individual well data groups is given in Appendix C.

Accuracy of the Geothermal Gradients Obtained by the Regression Analysis

Temperature logs (Figures 28 through 32) of wells in well data groups 4,

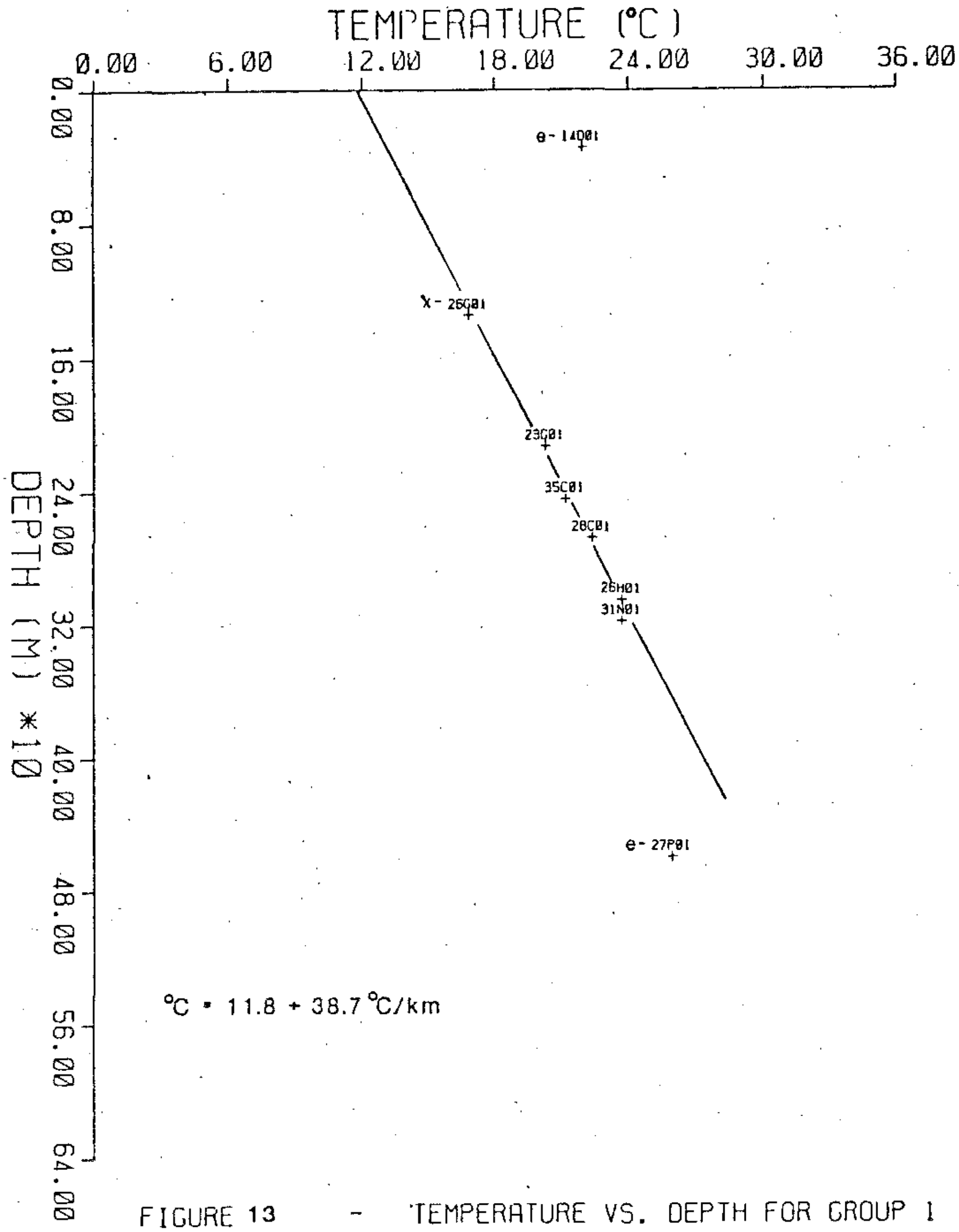
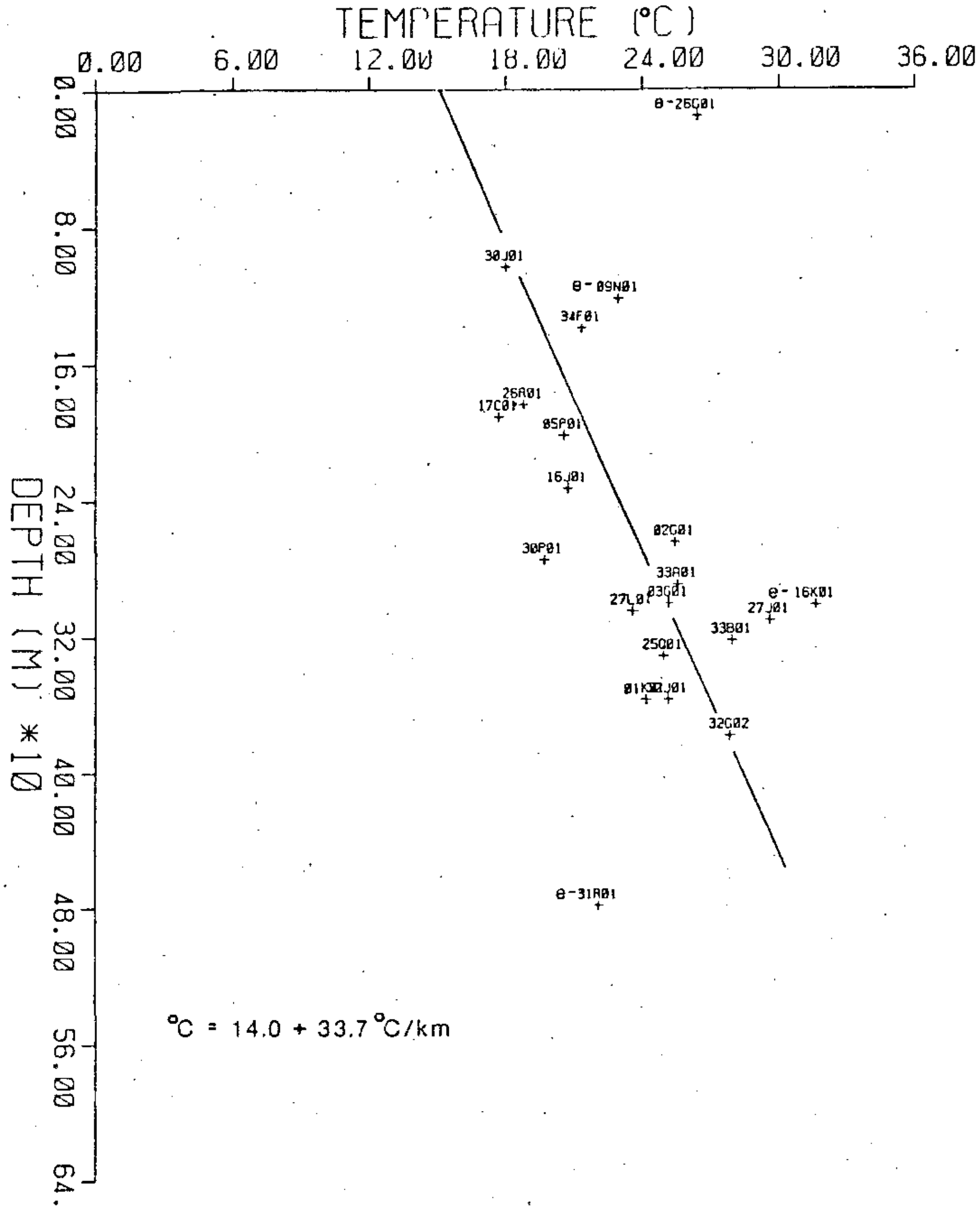


FIGURE 13 - TEMPERATURE VS. DEPTH FOR GROUP I



°C = 14.0 + 33.7°C/km

FIGURE 14 - TEMPERATURE VS. DEPTH FOR GROUP 2

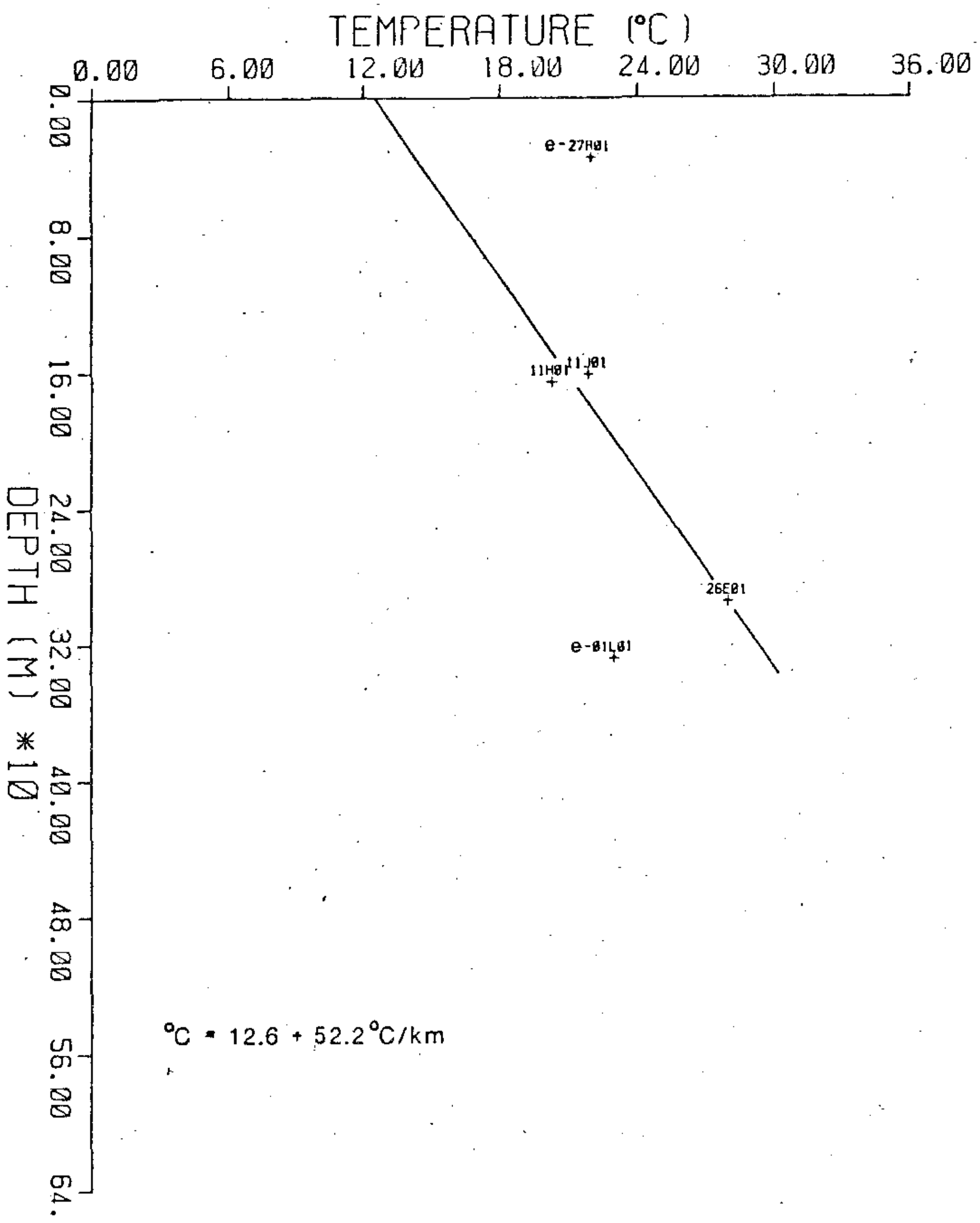


FIGURE 15 – TEMPERATURE VS. DEPTH FOR GROUP 3

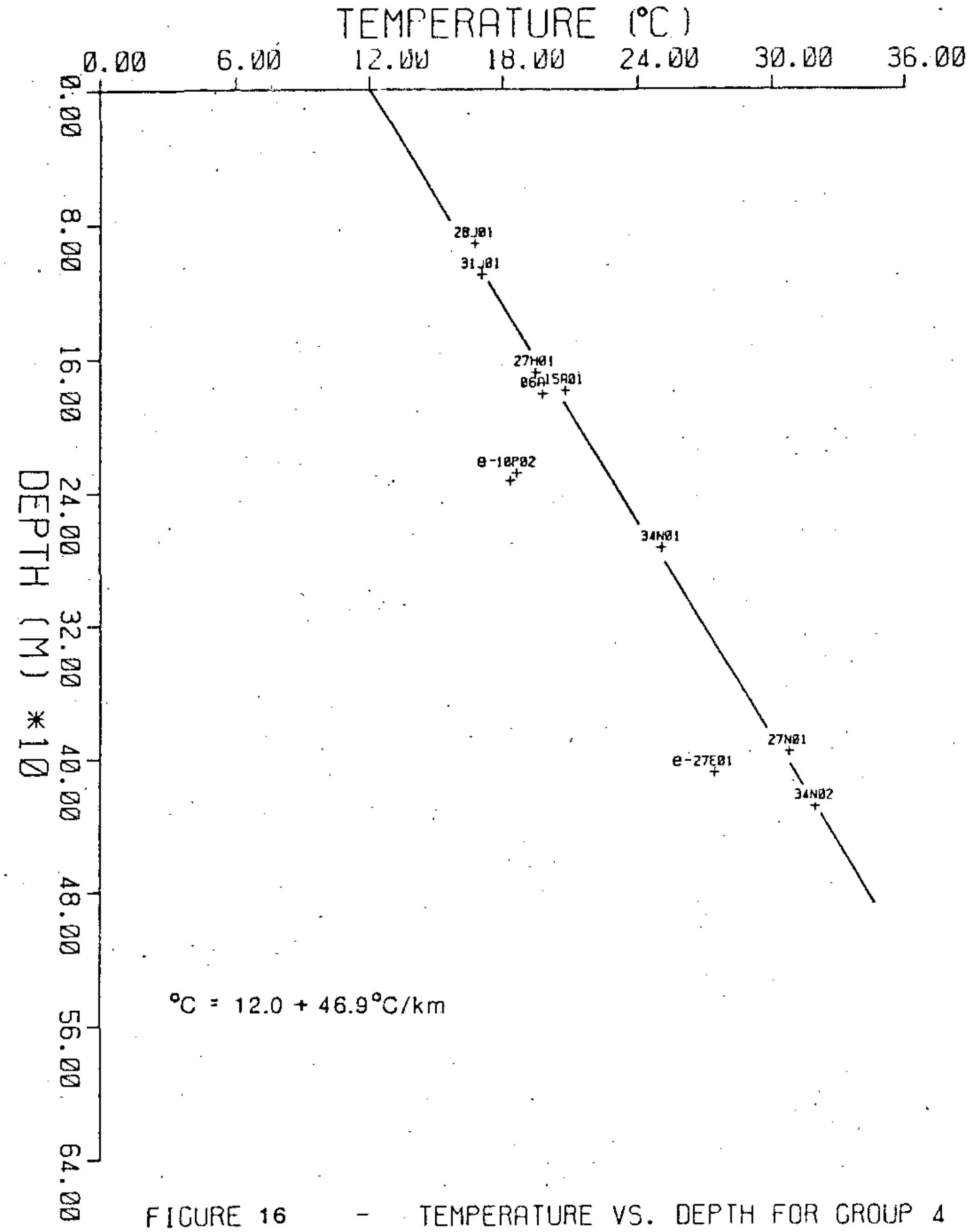


FIGURE 16 - TEMPERATURE VS. DEPTH FOR GROUP 4

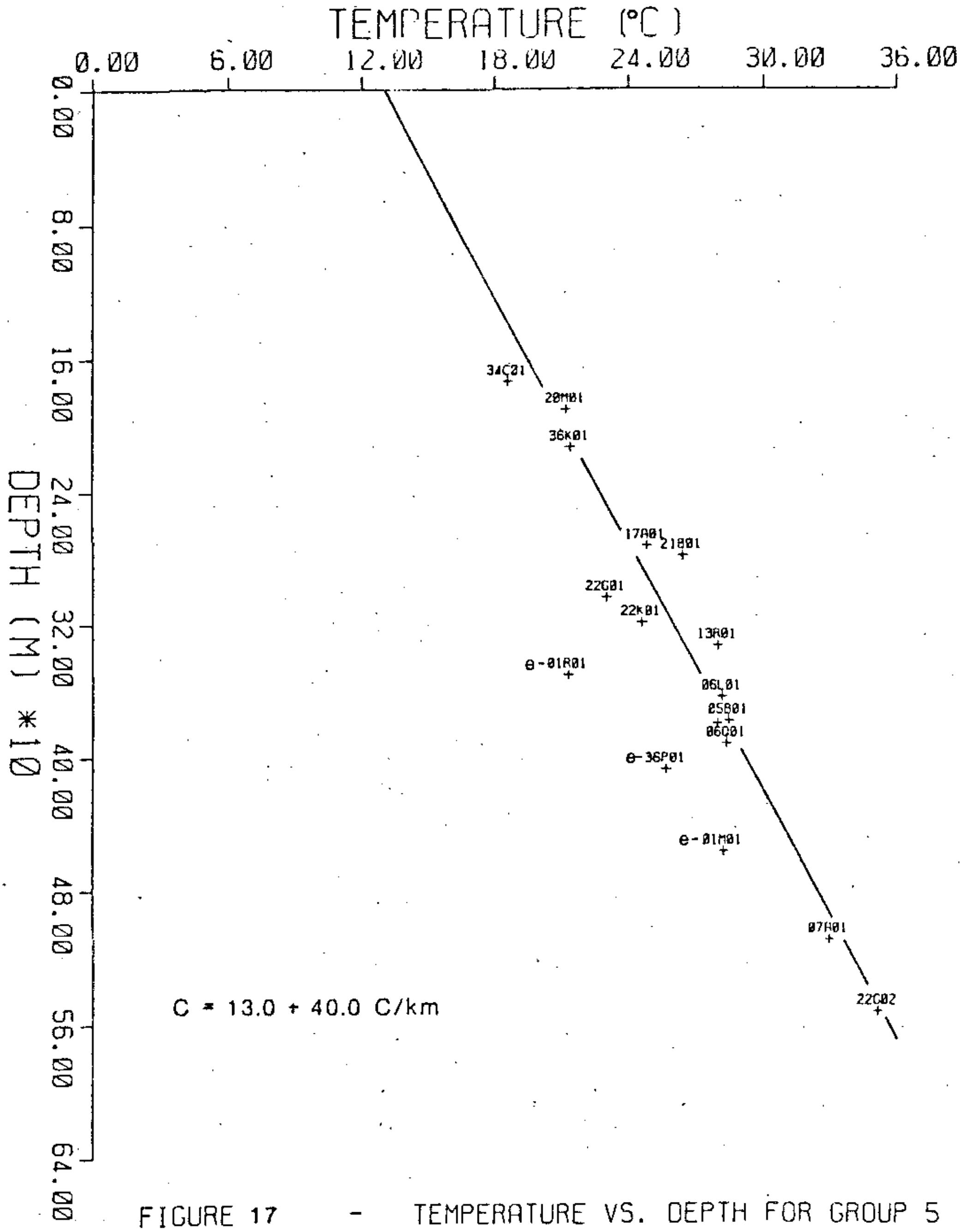


FIGURE 17 - TEMPERATURE VS. DEPTH FOR GROUP 5

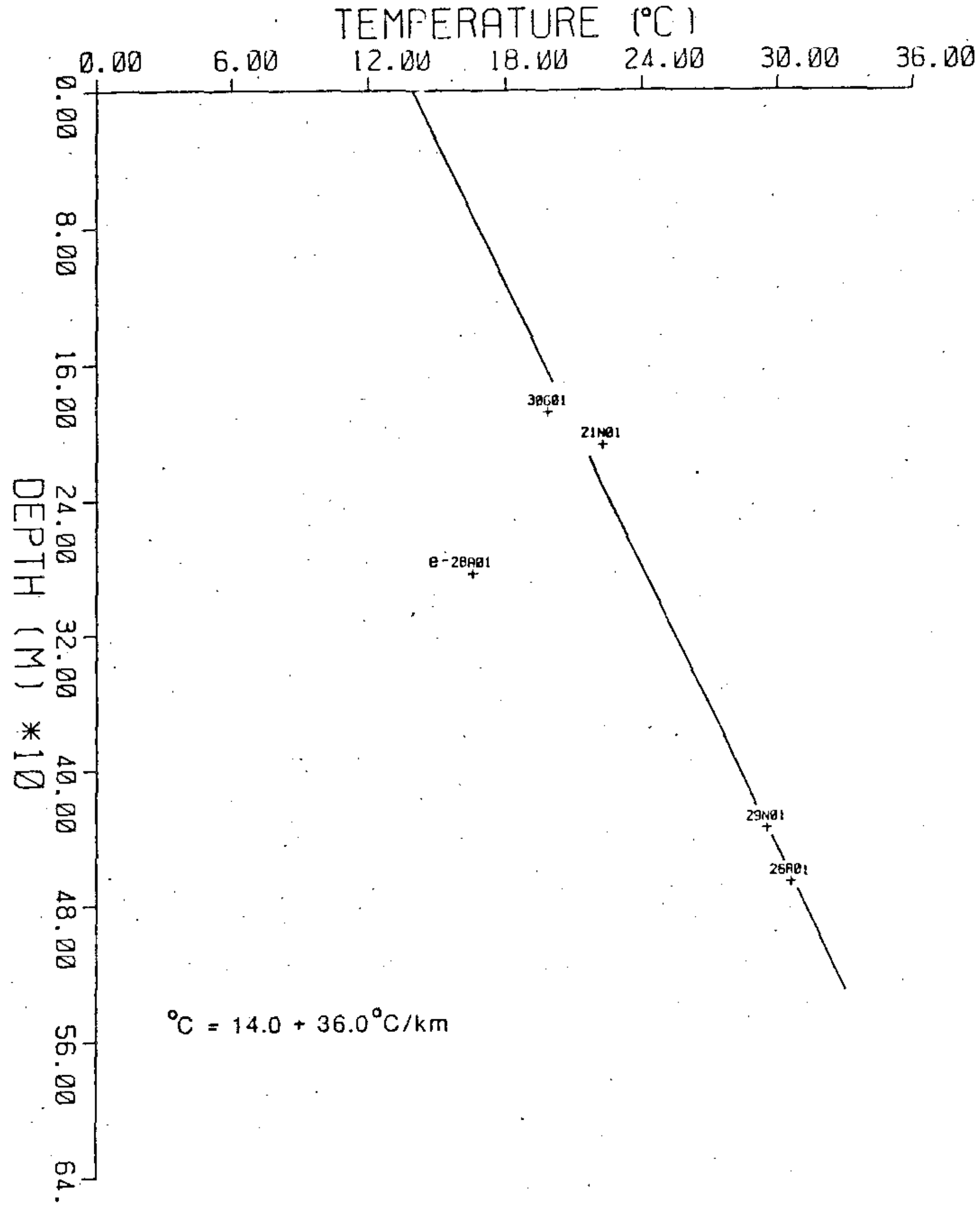


FIGURE 18 - TEMPERATURE VS. DEPTH FOR GROUP 6

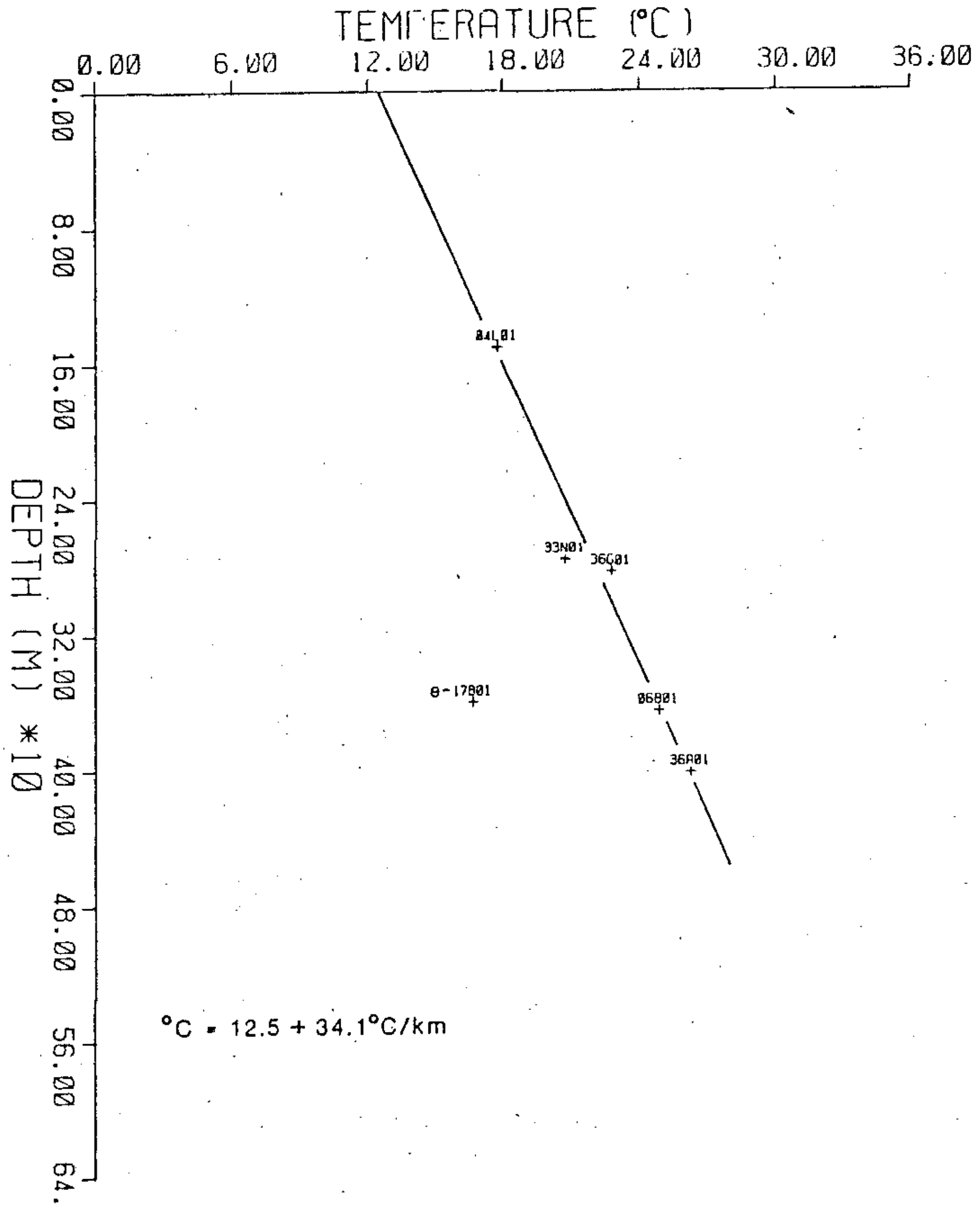


FIGURE 19 - TEMPERATURE VS. DEPTH FOR GROUP 7

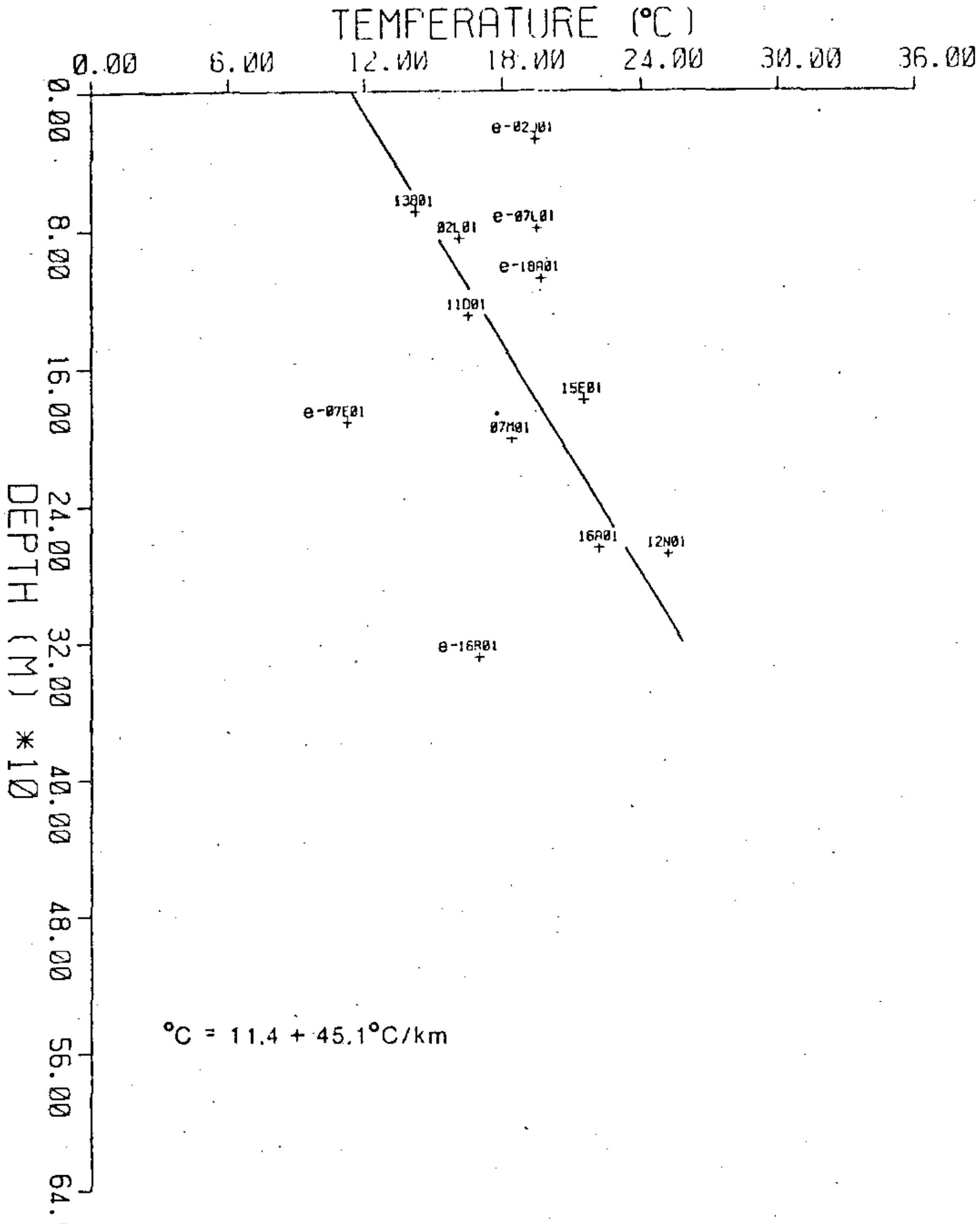


FIGURE 20 - TEMPERATURE VS. DEPTH FOR GROUP 8

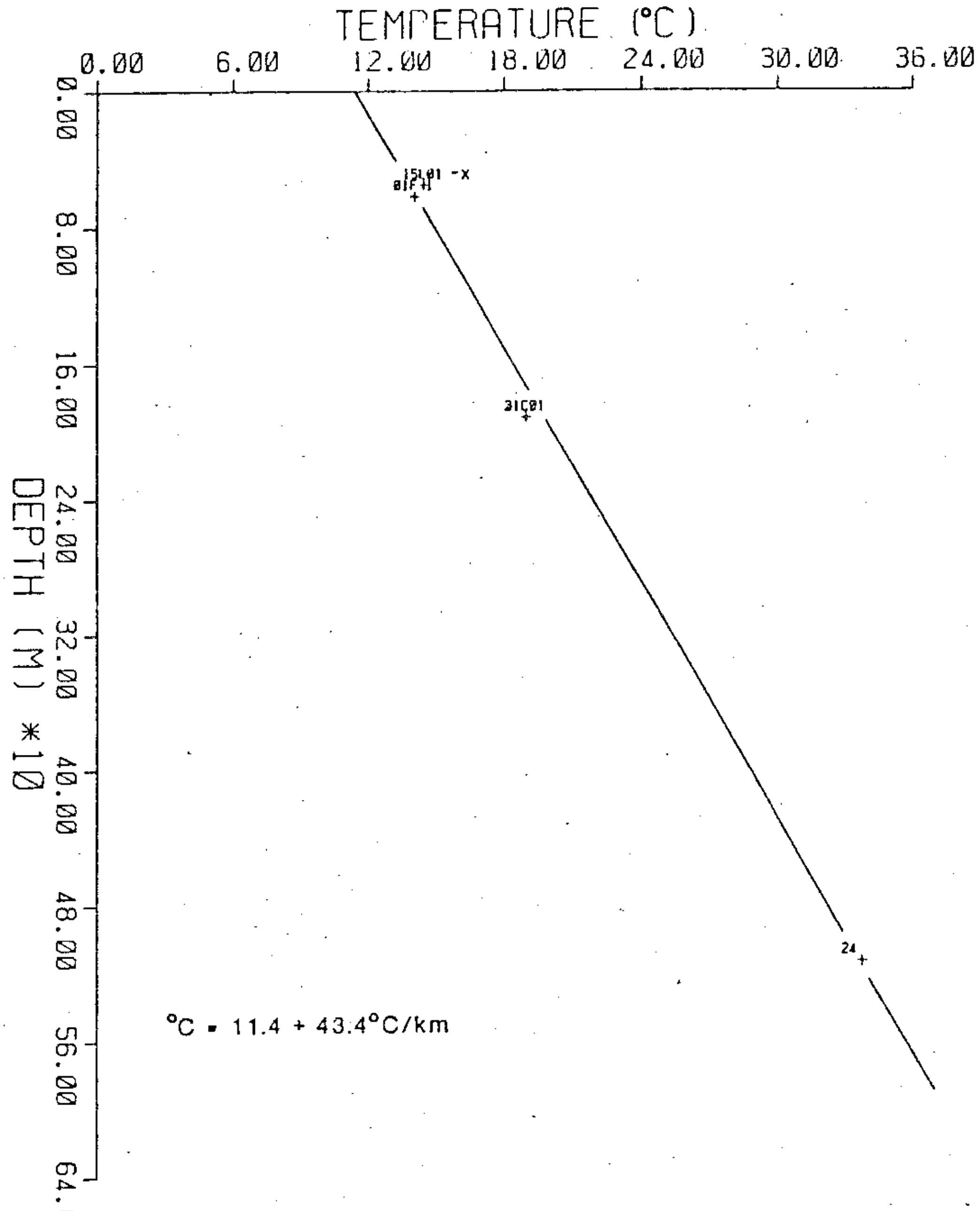
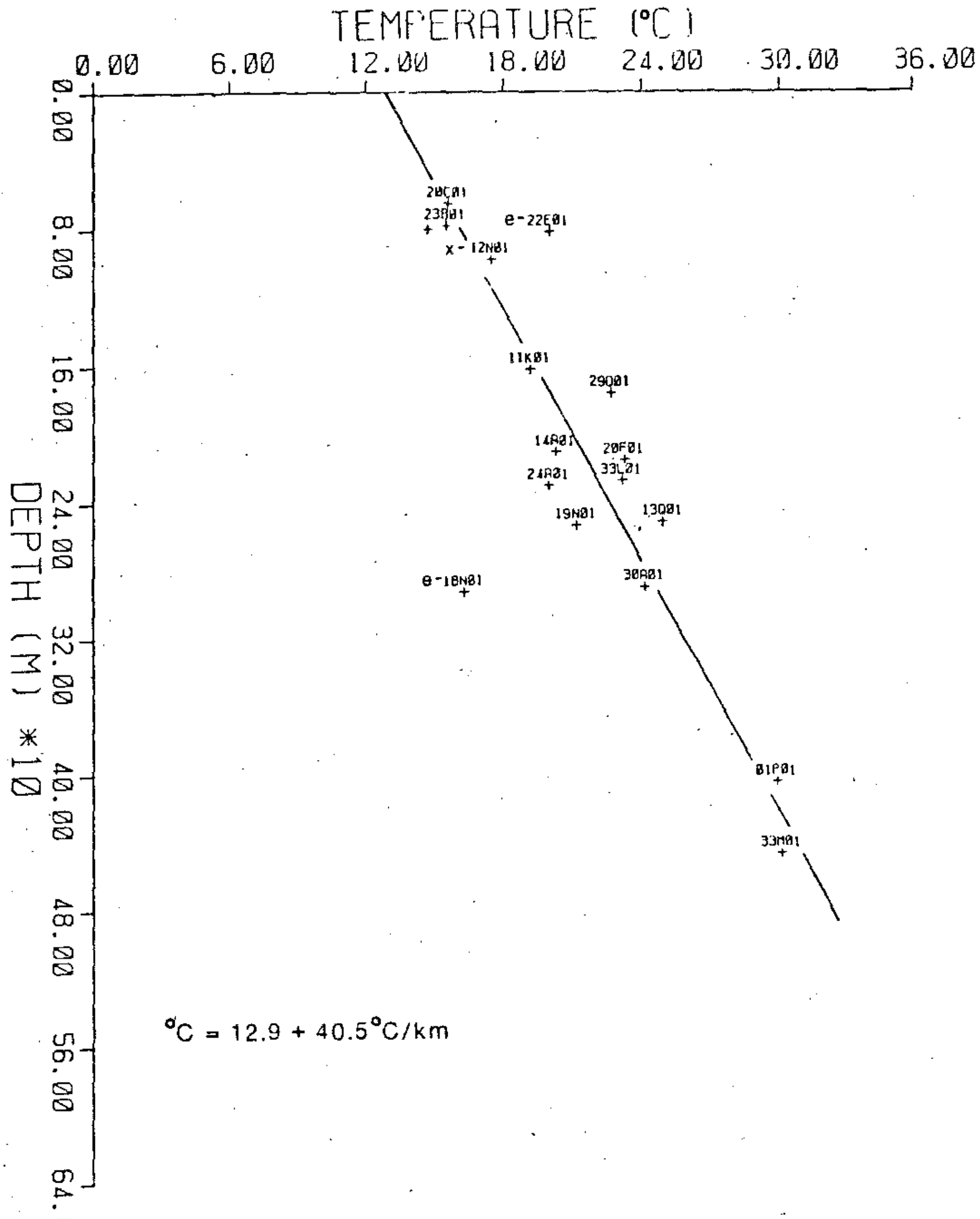


FIGURE 21 - TEMPERATURE VS. DEPTH FOR GROUP 9



$^{\circ}C = 12.9 + 40.5^{\circ}C/km$

FIGURE 22 - TEMPERATURE VS. DEPTH FOR GROUP 10

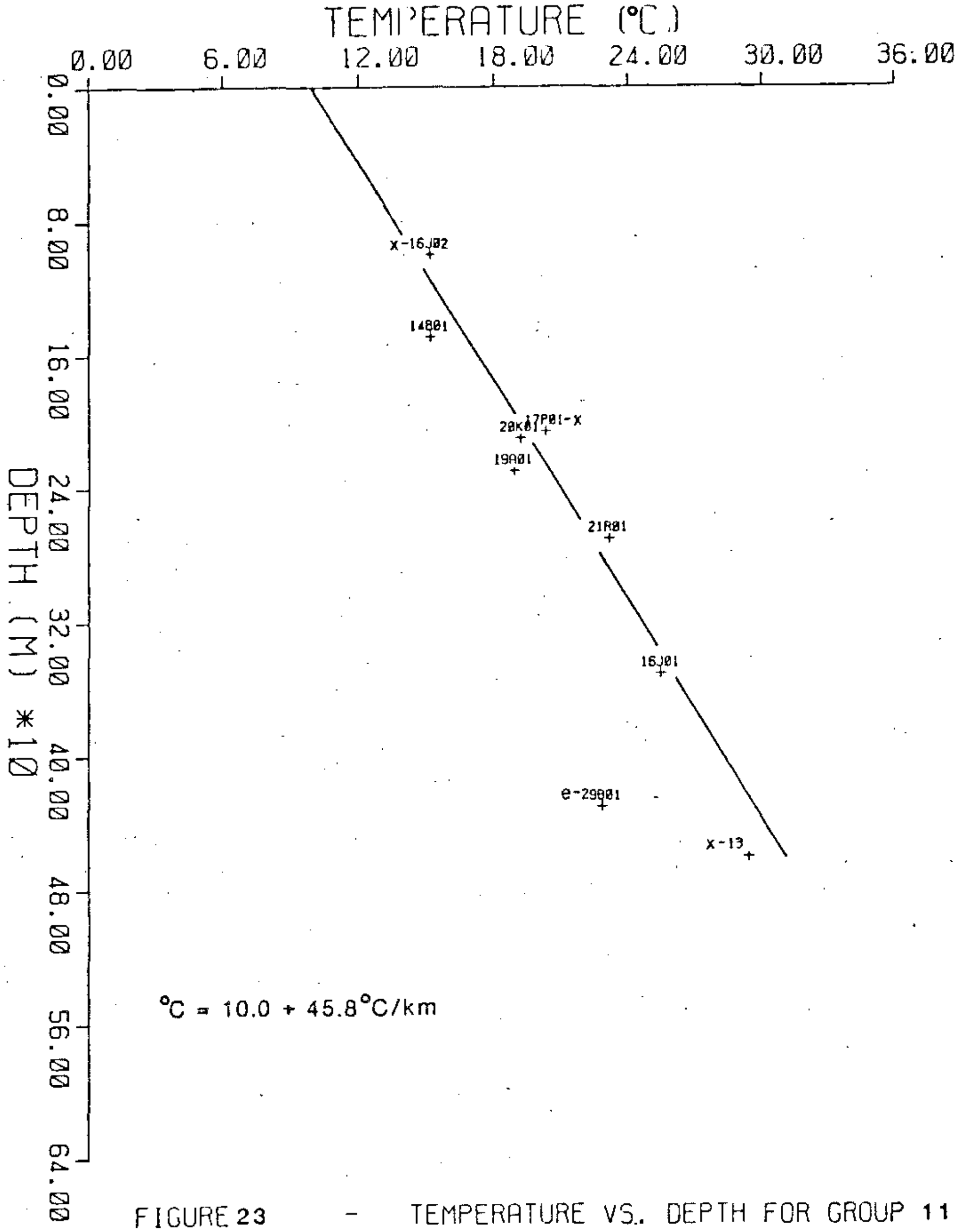


FIGURE 23 - TEMPERATURE VS. DEPTH FOR GROUP 11

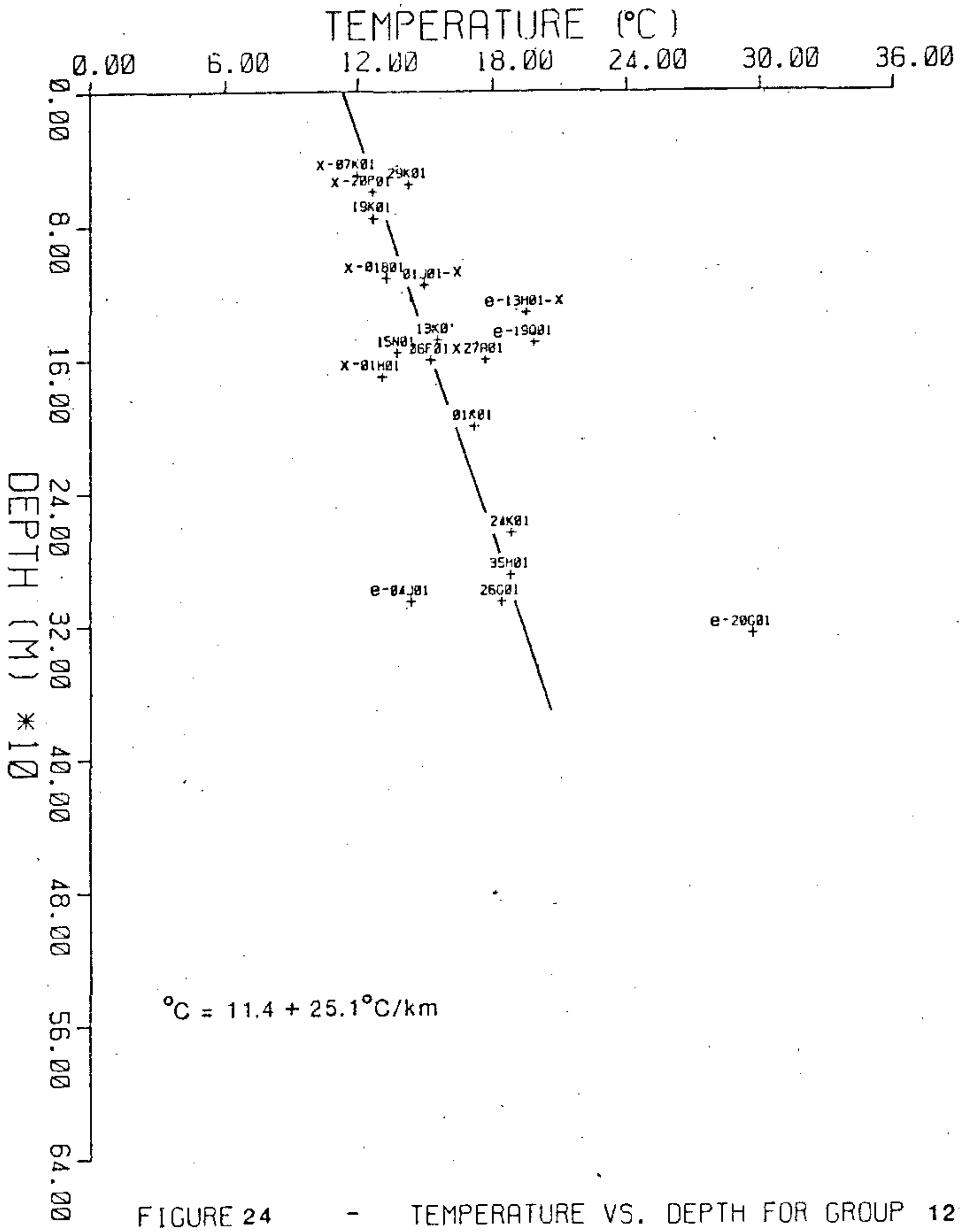
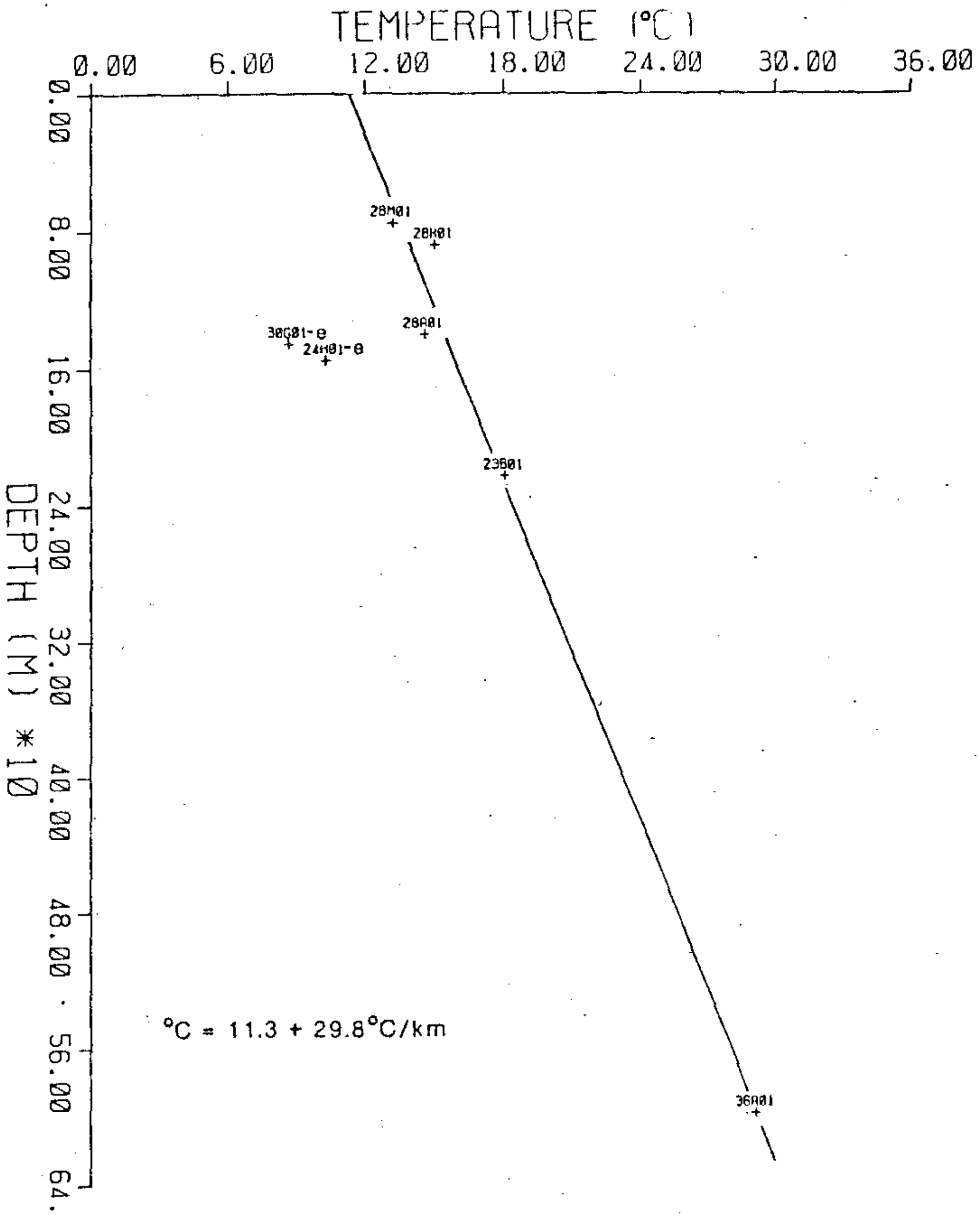


FIGURE 24 - TEMPERATURE VS. DEPTH FOR GROUP 12



°C = 11.3 + 29.8°C/km

FIGURE 25 - TEMPERATURE VS. DEPTH FOR GROUP 13

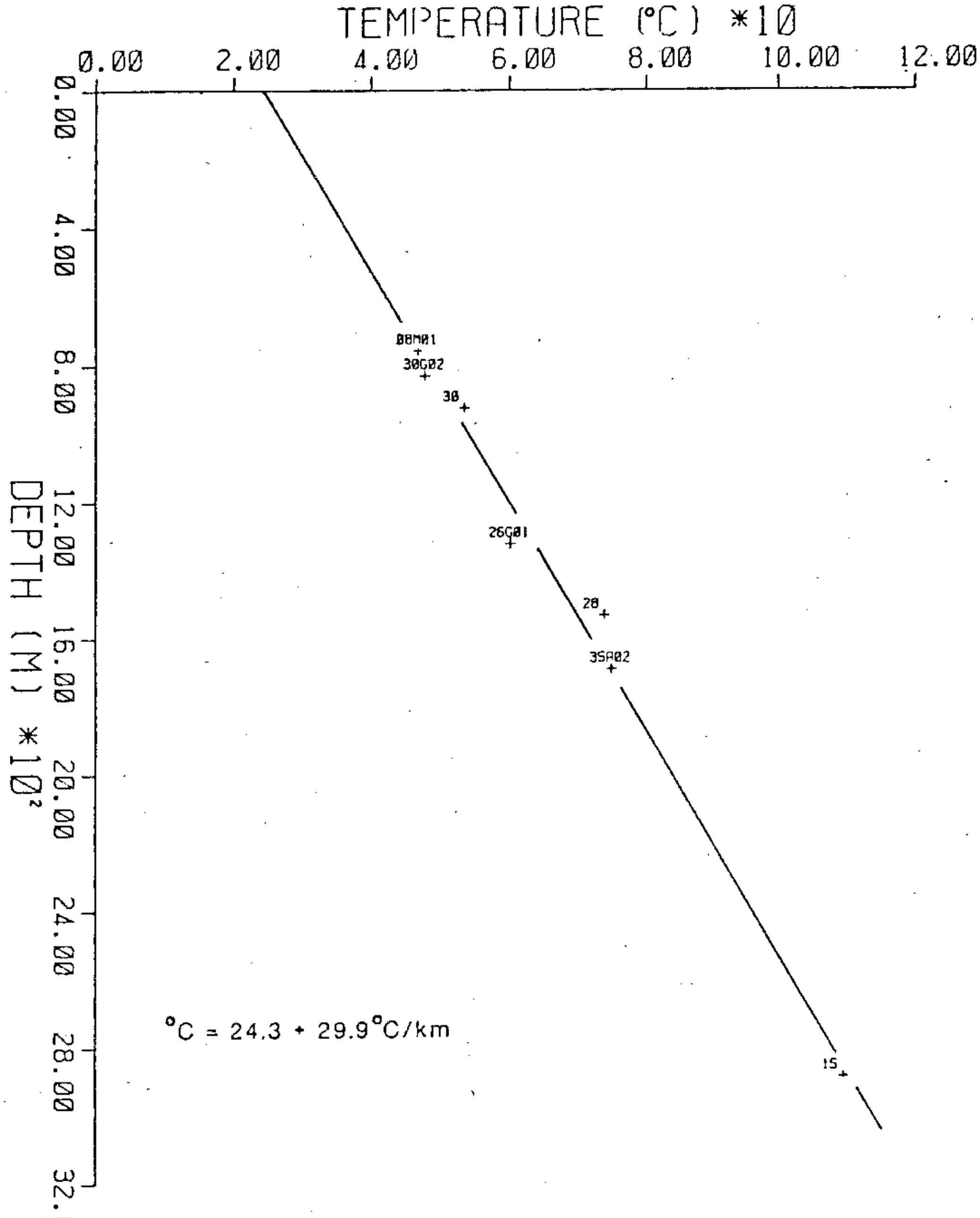


FIGURE 26 - TEMPERATURE VS. DEPTH FOR GROUP 14

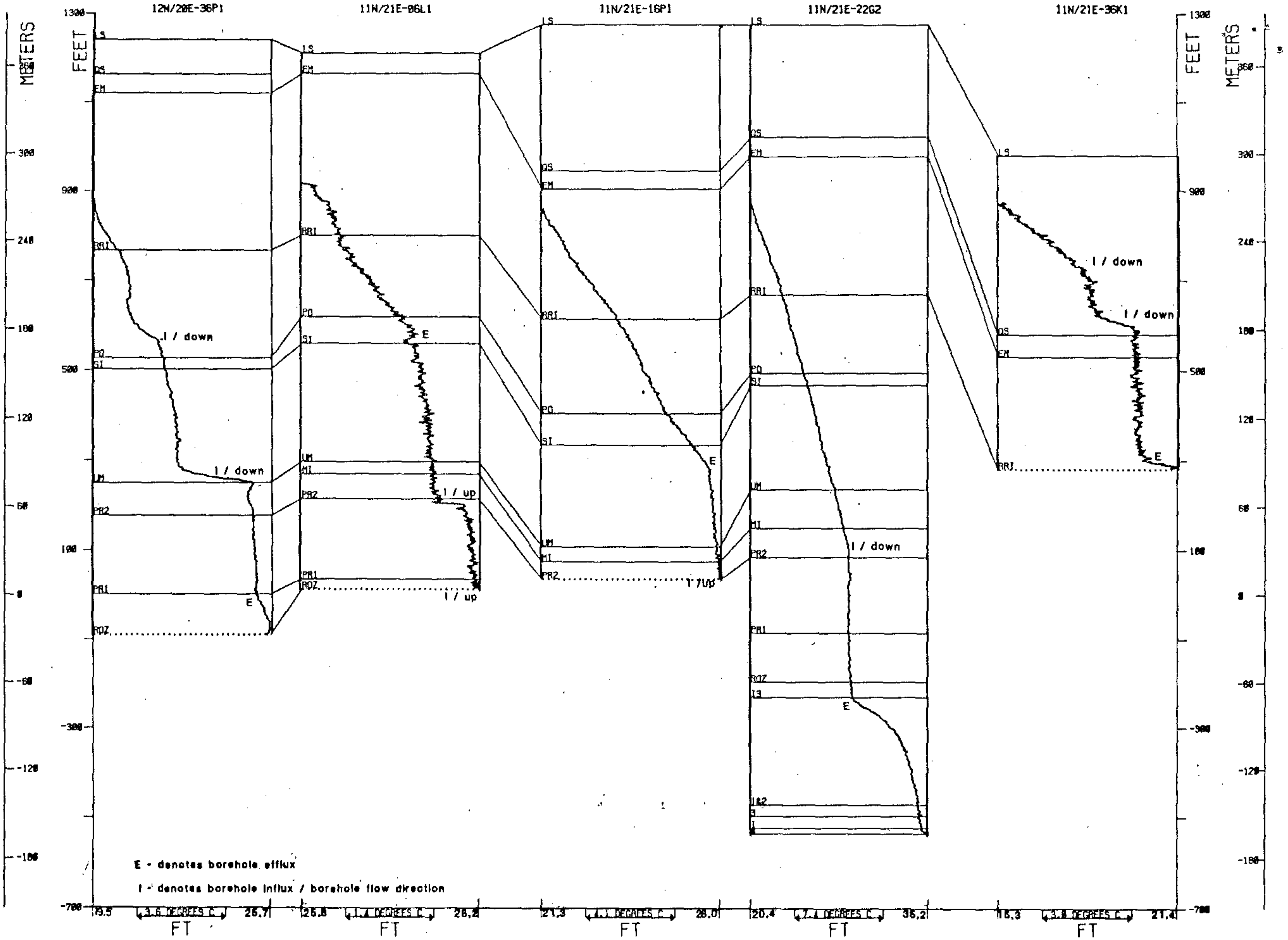


FIGURE 28 TEMPERATURE LOGS - LINE #1

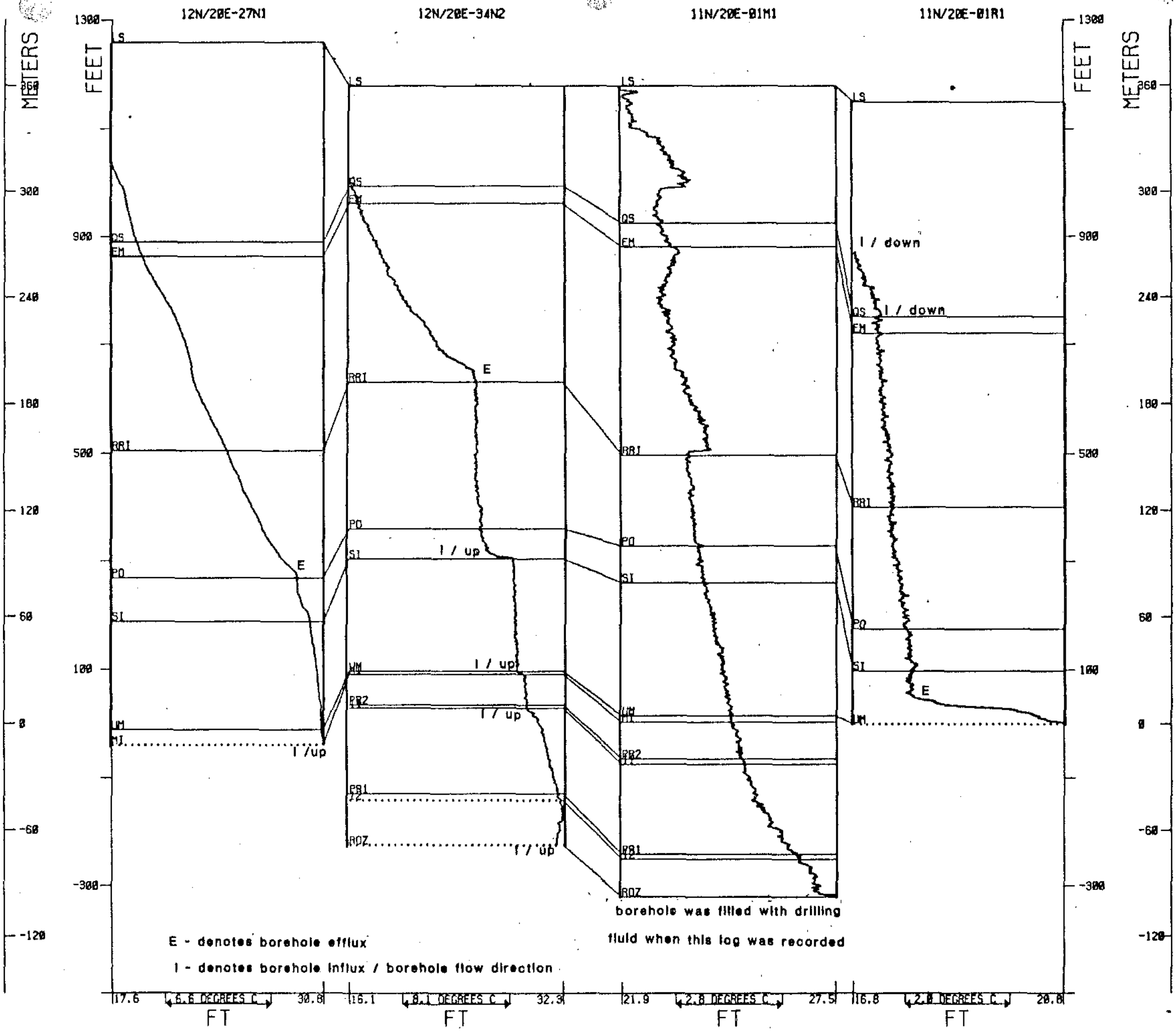


FIGURE 29 TEMPERATURE LOGS - LINE #2

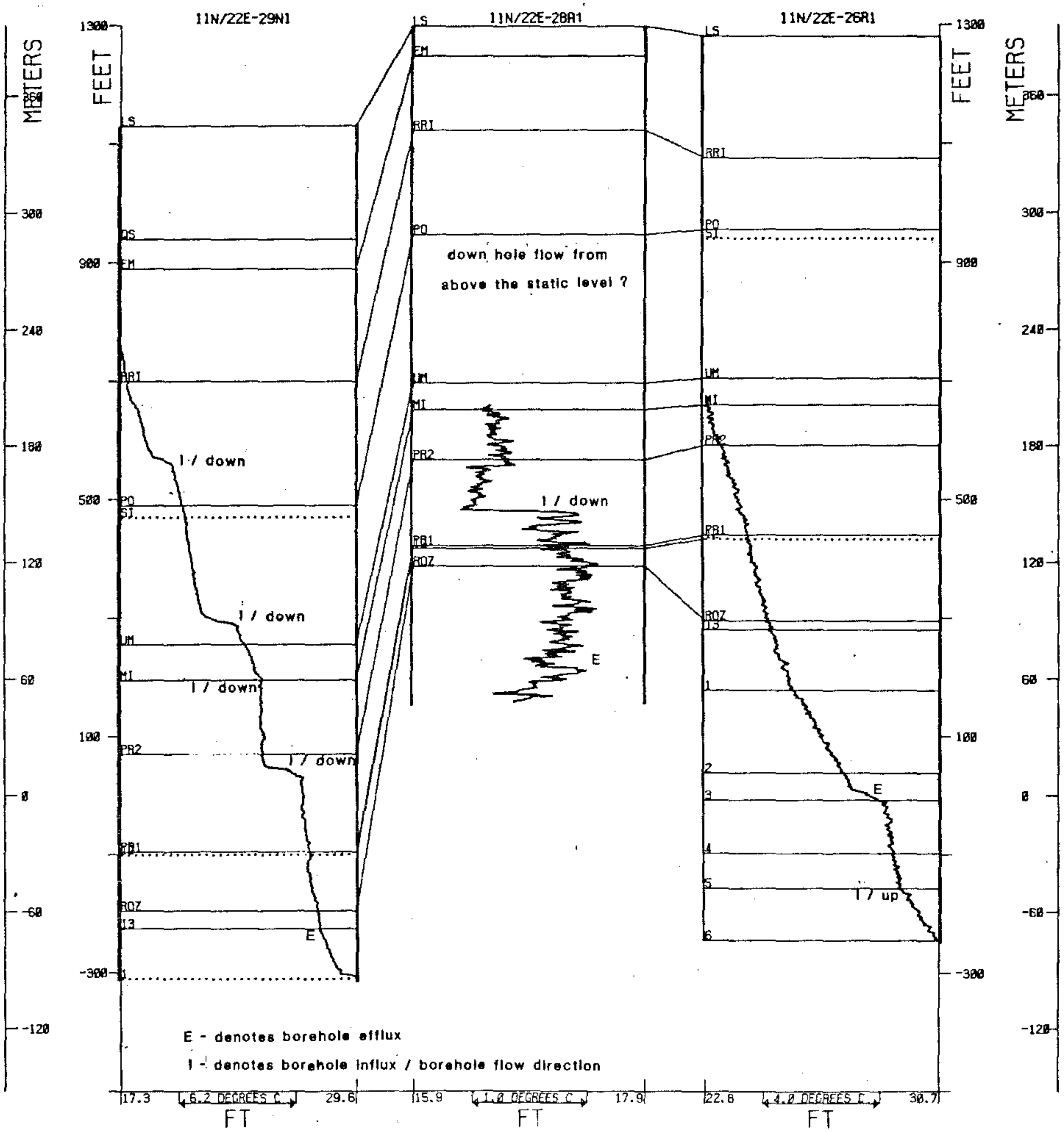


FIGURE 30 TEMPERATURE LOGS - LINE #3

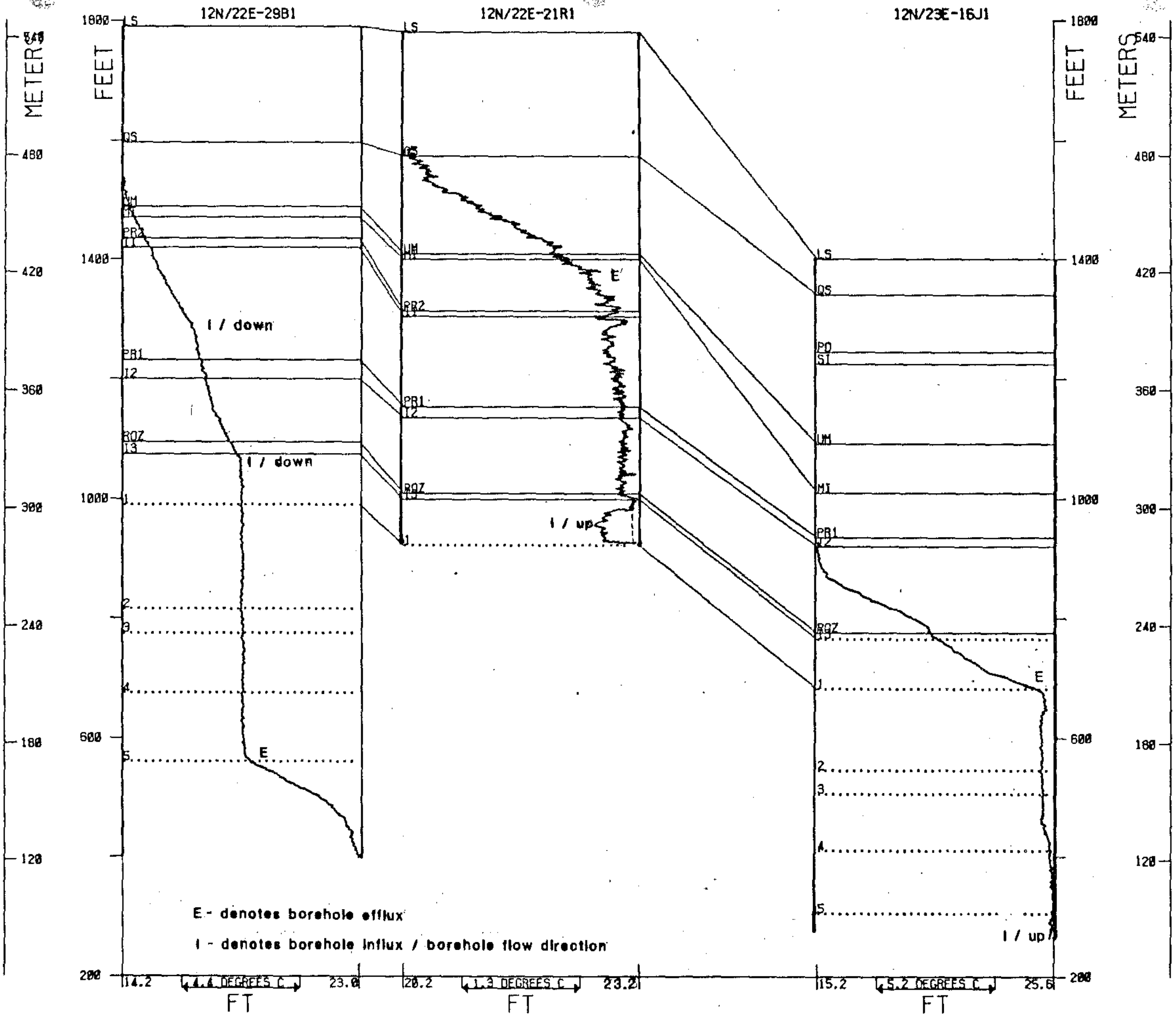


FIGURE 31 TEMPERATURE LOGS - LINE #6

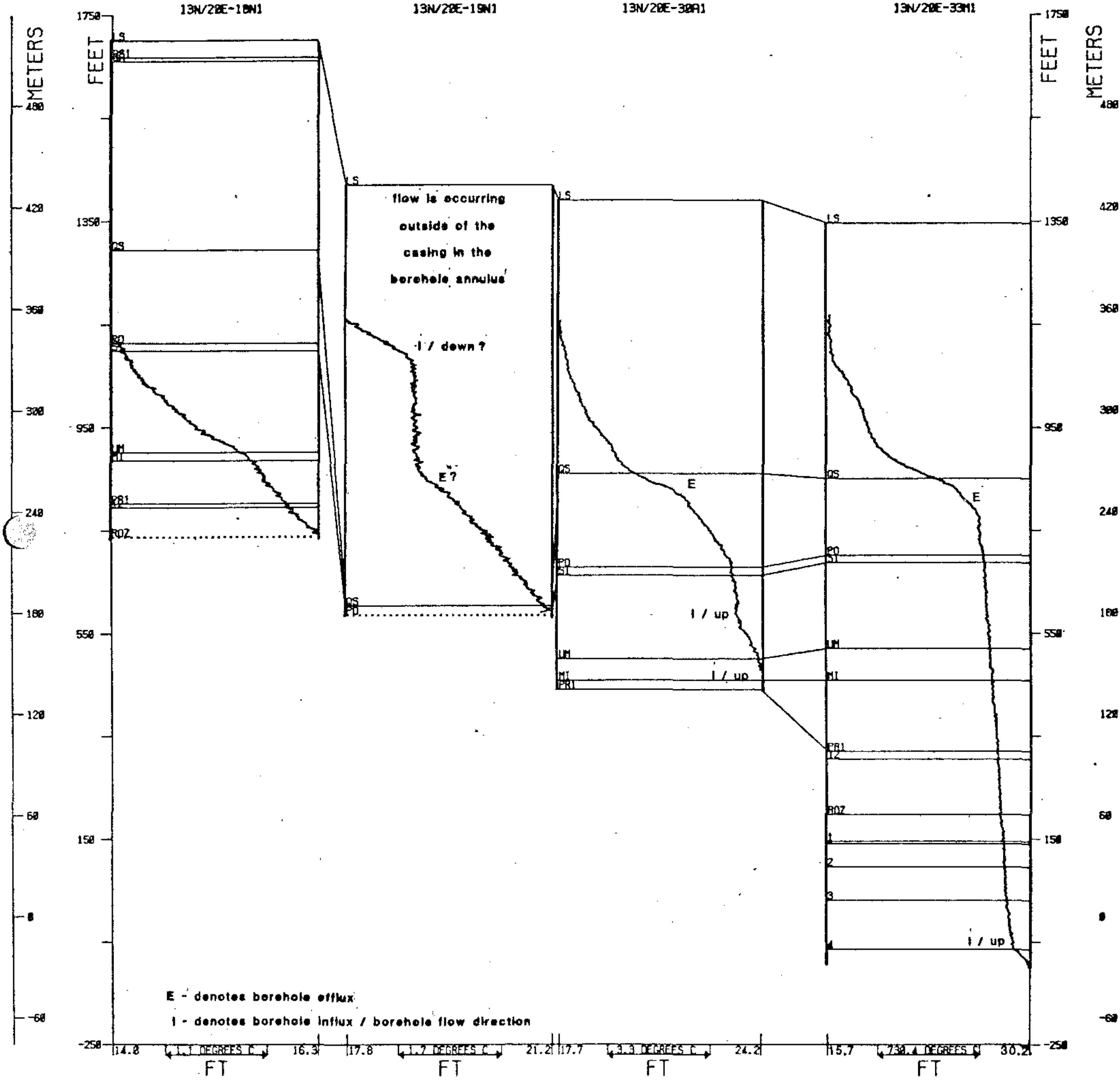


FIGURE 32 TEMPERATURE LOGS - LINE #7

Table 1. Geothermal Gradients, Land Surface Temperatures, and Depths to the 20°C Isotherm

Well Data Group	Geothermal Gradient (°C/km)	Land Surface Temperature (°C)	Depth to the 20°C Isotherm (m)
1	38.7	11.8	212
2	33.7	14.0	179
3	52.2	12.6	142
4	46.9	12.0	171
5	40.0	13.0	175
6	36.0	14.0	167
7	34.1	12.5	220
8	45.1	11.4	191
9	43.4	11.4	199
10	40.5	12.9	176
11	45.8	10.0	219
12	25.1	11.4	343
13	29.8	11.3	292
14 (deep wells)	29.9	24.3	2532*

---

*depth to the 100°C isotherm

5, 6, 10, and 11 were analyzed to determine whether the geothermal gradients obtained by the BHT regressions could be used to predict aquifer temperatures. The results of this analysis are summarized in Table 2 and indicate that the BHT regression equations do provide a reasonable estimate of aquifer temperature. Exact correspondence between the measured and predicted temperatures should not be expected, because the accuracy and quality of the temperature data vary and because of the large areas considered in the well data groups.

The BHT's of several of the wells that were analyzed plot below the line that represents the geothermal gradient of the well data group (for example, wells 11N/20E-1R1, 11N/22E-22G2, and 12N/20E-36P1 for well data group 5). In all but one case, the borehole flow direction in these wells was downhole, and the downhole flow from a higher level to the well bottom would result in the colder than normal temperatures. It should be noted that the recorded temperature at the zone of influx of the downhole flow corresponds to the predicted temperature as given by the regression equation for the depth of the influx zone. The one exception, well 13N/20E-18N1 of well data group 10, was interpreted as having uphole flow, but the discrepancy may be caused by a poor quality temperature log.

Projected Land Surface Temperatures and Slope Aspect

The relationship between the projected land surface temperature and the land surface slope aspect of the well data groups was also investigated. Land surface temperatures were normalized to a 305m (1000ft) elevation according to a lapse rate of 7°C/km and plotted vs. the land surface slope aspect of the well data groups (Figure 33). Inspection of Figure 33 indicates that the land surface temperature is related to slope aspect for the majority of the well

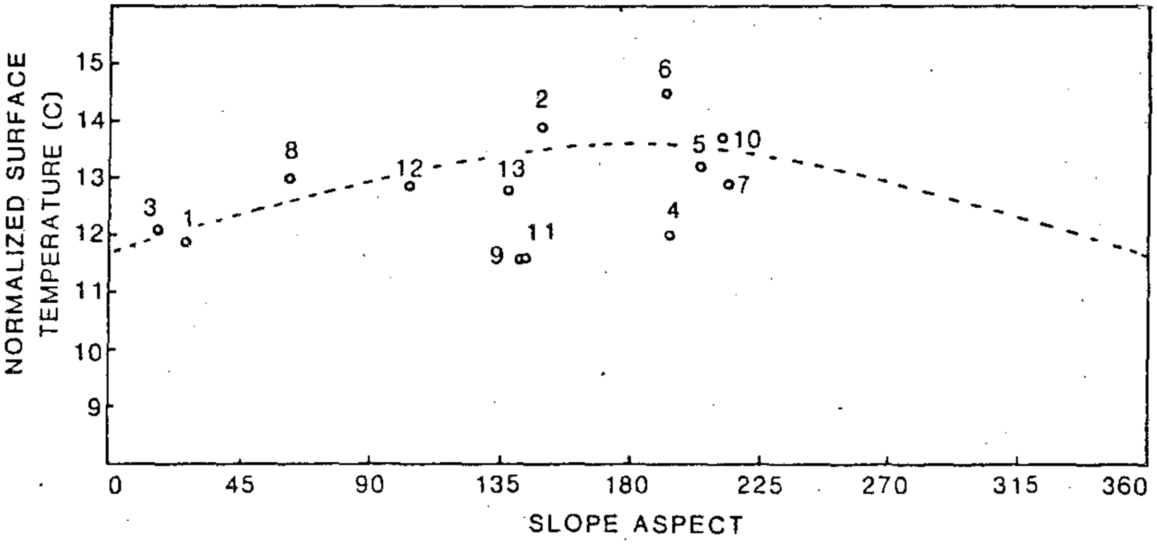


FIGURE 33 SLOPE ASPECT VS. NORMALIZED SURFACE TEMPERATURE

Table 2. Measured and Predicted "Aquifer" Temperatures

Location	"Aquifer" Depth (m)	Measured Temperature (C°)	Predicted Temperatures (C°)	Borehole Flow Direction	"Aquifer" Identity	Pump Test Temperature (C°)
11N/20E-1R1	85.3	17.0	16.4	down	QS	--
	120.4	17.5	17.8	down	QS	
11N/21E-6L1	304.8	27.6	25.2	up	PR	--
	364.8	28.2	27.6	up	Roza	
11N/21E-16P1	377.9	28.0	28.1	up	PR	--
11N/21E-22G2	352.0	28.5	27.1	down	PR	--
11N/21E-36K1	76.2	18.0	16.0	down	QS	--
	115.8	20.2	17.6	down	QS	
11N/22E-26R1	438.0	28.5	29.8	up	FS	--
11N/22E-28A1	195.1	16.4	21.0	down	MI	--
11N/22E-29N1	173.7	19.6	20.3	down	PO	--
	257.8	22.8	23.3	down	UM	
	285.0	23.7	24.3	down	MI	
	335.3	25.9	26.1	down	PR	
12N/20E-27N1	393.2	30.7	30.4	up	MI	--
12N/20E-34N2	266.7	25.6	24.5	up	SI/UM	27.2
	332.2	28.1	27.6	up	UM/MI	
	349.0	28.9	28.4	up	PR	
	402.3	32.3	30.9	up	PR	
	428.2	32.0	32.1	up	Roza	
12N/20E-36P1	204.2	21.7	21.2	down	PO	27.8
	301.7	25.0	25.1	down	PR	
12N/22E-21R1	268.1	22.8	22.3	up	FS	--

Table 2. Measured and Predicted "Aquifer" Temperatures (cont.)

Location	"Aquifer" Depth (m)	Measured Temperature (C°)	Predicted Temperatures (C°)	Borehole Flow Direction	"Aquifer" Identity	Pump Test Temperature (C°)
12N/22E-29B1	153.3	16.7	17.0	down	PR	17.8
	196.0	17.5	19.0	down	Roza	
	220.7	19.4	20.1	down	FS	
12N/23E-16J1	349.0	25.6	26.0	up	FS	--
13N/20E-18N1	275.8?	16.0	24.1	up	PR/Roza	--
13N/20E-19N1	108.2	18.9	17.3	down	QS	--
13N/20E-30A1	253.0	23.5	23.1	up	UM	--
	280.4	24.1	24.3	up	MI/PR	
13N/20E-33M1	429.7	29.0	30.3	up	FS	--

data groups. Well data groups 4, 6, 9, and 11 do not show a good fit to the curve, and the reason for these exceptions is uncertain. Possible explanations include differences in vegatation, land use, irrigation, and whether the area lies in a recharge or discharge portion of the groundwater flow system.

Mean elevation, slope aspect, and normalized land surface temperature are given in Table 3. Mean slope angle was similar for all of the well data groups and averaged about 2°.

Chemical Geothermometers

The geochemistry of ground water can provide an indication of the maximum temperature that the water was subjected to while underground. Chemical data were compiled for 16 springs and 32 wells that are located in the Yakima region. The locations of these springs and wells are shown in Figure 10.

Predicted source temperatures were calculated according to the Na-K-Ca method of Fournier (1977). The predicted source temperature is given by equation (3):

$$\log\left(\frac{Na}{K}\right) + \beta \log\left(\frac{\sqrt{Ca}}{Na}\right) = \frac{1647}{{}^{o}C + 273} - 2.24 \qquad (3)$$

Calculated source temperatures for the spring waters range from 6°C to 137°C. Calculated source temperatures for the well waters range from 14°C to 222°C. Chemical concentrations and calculated source temperatures for the springs and wells are summarized in Tables 4 and 5, respectively.

Table 3. Mean Elevation, Slope Aspect, and Normalized Land Surface Temperatures for Well Data Groups 1-13

Well Data Group	Projected Land Surface Temperature (°C)	Mean Elevation of Well Data Group (ft.)	Slope Aspect of Well Data Group (°)	Normalized Land Surface Temperature (°C)
1	11.8	1047	28	11.9
2	14.0	983	149	14.0
3	12.6	722	18	12.1
4	12.0	1012	194	12.0
5	13.0	1209	207	13.4
6	14.0	1220	192	14.5
7	12.5	1202	214	12.9
8	11.4	1757	62	13.0
9	11.4	1110	143	11.6
10	12.9	1356	211	13.7
11	10.0	1764	142	11.6
12	11.4	1707	104	12.9
13	11.3	1683	138	12.8

Table 4. Chemical Data for Springs in Yakima County, Washington

Location	Name	Sample Collection Date	Chemical Data (Molality × 10^{-4})			Recorded Temperature (°C)	Predicted Source Temperature (°C)[1]	Data Source[2]
			Na	K	Ca			
7/11-18	Gotchen Creek Spr.	9/15/72	1.48	0.38	0.10	3.0	85	C
7/12-1	Bacon Creek Spr.	9/16/72	25.66	0.31	0.17	6.0	98	C
7/12-4M		6/10/74	1.26	0.15	1.67	6.1 to 8.0	9	A
7/12-28A	McCumber Spr.	4/3/74	1.26	0.38	1.07	5.6	37	A
7/13-33Q		4/24/74	1.74	0.15	2.50	8.6	6	A
8/12-15G	Bup Spr.	6/13/74	1.30	0.18	1.32	4.8 to 5.0	16	A
8/12-27L		7/15/74	1.22	0.61	1.42	6.3	44	A
9/12-35B		6/13/74	1.57	0.23	1.37	5.6 to 6.3	23	A
9/13-18P		9/12/74	65.25	4.09	24.20	12.2	84	A
10/11-19L		7/15/74	0.35	0.15	0.52	2.9	17	A
11/12-24L	Soda Spr.	8/15/74	56.55	0.56	29.94	9.5	23	A
11/13-3E		9/05/74	1.35	0.66	1.32	4.5	49	A
11/13-4K		9/05/74	43.50	0.90	0.67	13.8	137*	A
12/25-29A		9/12/60	3.13	0.43	5.49	---	21	D
14/18-3	Mulford Spr.	11/19/48	5.65	1.48	7.98	15.0	51	D
16/17-32	Mallotite Spr.	11/19/48	7.39	1.10	2.99	17.0	64	D

[1] *indicates that $\beta = 1/3$; otherwise, $\beta = 4/3$

[2] Data source:

A) Cline, R. D., 1976

C) Schuster, J. F. et al., 1978

D) Van Denburgh, A. S., and Santos, J. F., 1965

Table 5. Chemical Data for Wells in Yakima County, Washington

Location	Name	Sample Collection Date	Chemical Data (Molality × 10^{-4})			Recorded Temperature (°C)	Predicted Source Temperature (°C)[1]	Principal Aquifer	Data Source[2]
			Na	K	Ca				
7/23-36	Chesley (DNR)	10/17/77	34.36	3.66	1.97	--	209*	--	E
7/23-36	Chesley (DNR)	3/30/78	26.10	3.81	2.17	--	222*	--	E
8/24-2J	City of Prosser #2	10/30/59	18.70	3.07	3.49	18.9	105/217*	basalt	D
8/24-2H	City of Prosser #3	10/30/59	23.49	2.51	4.24	17.2	96/194*	basalt	D
8/24-2Q	City of Prosser #4	5/11/61	20.01	2.56	3.99	15.6	96/202*	basalt	D
9/22-12H	Pride	5/05/61	7.39	1.89	11.98	16.1	53	gravel?	D
10/20-3N	City of Toppenish #2	1/26/39	2.96	0.49	5.49	13.9	23	gravel	D
10/20-9A	City of Toppenish #6	10/19/59	8.26	1.05	3.24	20.6	62	sand, gravel	D
10/22-30	Snipes Mt.	6/13/75	11.87	1.74	5.99	--	68	--	E
12/16-13D	Herke	8/30/51	4.35	0.46	3.99	--	30	basalt	B
12/16-17J	Mondor	8/30/51	2.44	0.95	2.50	--	52	alluvium	B
12/17-16D	Brown	10/21/59	7.39	0.82	3.24	15.6	53	basalt	D
12/17-16R	Borton	4/18/52	3.13	0.79	2.99	17.2	46	basalt	B
12/18-5G	Anderson	8/29/51	8.26	1.36	5.74	--	58	alluvium	B
12/18-5J	Richwine	8/29/51	6.96	1.43	5.99	--	57	alluvium	B
12/18/11E	Schreiner	8/30/51	4.18	0.82	7.49	--	34	Ellensburg	B
12/20-16	Gangle (DNR)	6/14/74	3.87	1.28	6.74	--	46	--	E
12/20-36	Cheyne (DNR)	10/05/79	3.00	2.09	1.40	--	120/185*	--	E
12/23-13B	Wright	5/05/61	4.78	0.74	6.99	16.1	34	--	D
13/19-31J	Yakima Farmers Supply	8/29/51	5.22	1.23	8.48	--	44	cemented gravel	B
14/18-12D	Knopp	11/22/48	10.00	0.74	10.48	--	33	gravel	D
14/18-13R	Barnheart	11/19/48	26.97	1.23	14.97	--	48	--	D

Table 5. Chemical Data for Wells in Yakima County, Washington (cont.)

Location	Name	Sample Collection Date	Chemical Data (Molality × 10^{-4})			Recorded Temperature (°C)	Predicted Source Temperature (°C)[1]	Principal Aquifer	Data Source[1]
			Na	K	Ca				
14/19-19G	Larson	5/05/61	25.23	1.61	20.96	12.2	49	sand?	D
14/19-28B	U.S.A.	9/14/60	8.26	0.95	3.74	20.0	56	basalt	D
14/19-28F	U.S.A.	10/05/55	13.05	1.13	8.48	15.0	50	basalt?	D
14/19-28NE¼	U.S.A.	10/05/55	8.70	1.18	4.24	17.2	60	basalt	D
15/17-13C	Cameron	11/22/48	10.00	1.28	2.99	12.8	71	sand, basalt	D
15/17-36	Wenas (DNR)	9/14/79	14.79	1.54	2.50	--	86	--	E
15/18-33P	Kershaw	11/22/48	5.65	1.02	5.74	--	47	sand	D
16/14-1J	U.S.F.S.	5/04/59	19.57	0.18	20.96	--	-3/75	basalt	D[3]
16/14-1R	U.S.F.S.	11/04/59	3.44	0.33	6.49	--	14	sand, gravel	D
16/17-19E	Green	11/19/48	3.83	1.23	3.99	--	55	sand	D

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[1] *indicates that $\beta = 1/3$; otherwise, $\beta = 4/3$

[2] Data source:

B) Foxworthy, B. L., 1962

D) Van Denburgh, A. S., and Santos, J. F., 1965

E) W.S.U. Soil Testing Lab - Water Sample Analysis, various dates

[3] poor data?

Summary

The Yakima region of south-central Washington possesses a low temperature geothermal resource (i.e., greater than 20°C) within the depth range already penetrated by domestic and irrigation water wells. The geothermal gradients developed by the regression analysis appear capable of predicting the temperature-depth distribution and can be used as a guide for future development. Future research will be aimed at expanding these findings to other areas within the Yakima region and on explaining the variation in the geothermal gradients from one area to another.

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Appendix A

Symbols Used on Figures 2 through 8 and 13 through 26

Symbols Used on Figures 2 through 8

QS	Quaternary sediments and Ellensburg Formation
EM	Elephant Mountain Basalt Member
RRI	Rattlesnake Ridge Member
PO	Pomona Member
SI	Selah Member
UM	Umatilla Member
MI	Mabton Member
PR2	Upper Priest Rapids Member
I1	Unnamed interbed, Ellensburg Formation
PR1	Lower Priest Rapids Member
I2	Quincy Diatomite?
ROZ	Roza Member
I3	Squaw Creek Member
1-6	Frenchman Springs Member

Symbols Used on Figures 13 through 26

e	temperature data that was excluded from the least squares regression analysis
x	not a bottom hole temperature

Appendix B

Well Locations and Bottom Hole Temperatures from Wells in the Yakima Region

Source[1]	TT/RG-SEC	LATLON	Depth (ft.)	Name	Elevation (ft.)	Bottom Hole Temperature (°C)
3	07N/19E-10C01		390.4			14.4
3	07N/19E-14N01		420.0			14.2
1	07N/22E-23B01	460458 1200103	990.0	Sharpe, Jack	2105.0	23.4
1	07N/23E-36R01	460232 1195159	805.0	Chesley (DNR)	950.0	19.2
1	07N/24E-08D01	460644 1195101	1091.0	Horrigan Farms	1450.0	22.5
1	07N/25E-23F01	460440 1193908	1249.0	Palmer, Marvin, #2	840.0	18.9
1	07N/25E-35M01	460254 1193939	1008.0	Palmer, Marvin	793.0	18.1
1	07N/25E-36F01	460305 1193804	867.0	Barber #2 (DNR)	753.0	17.2
1	07N/25E-36N01	460237 1193829	840.0	Paterson Test Well (DOE)	730.0	21.9
1	07N/26E-05B01	460750 1193520	1075.0	Moon, John	1130.0	22.0
1	07N/27E-36A01	460323 1192229	1209.0	Horse Heaven Test Well (DOE)	1325.0	26.3
3	08N/22E-01L01		1079.0			23.0
1	08N/22E-11J01	461144 1200108	530.0	Flower, Bill	758.0	21.9
1	08N/24E-01J01	461235 1194506	1250.0	Prosser Municipal Well	730.0	25.2
1	08N/27E-29Q01	460836 1192731	725.0	Smith, Tom	1492.0	19.6
3	09N/21E-26E01		968.0			28.0
4	09N/21E-27R01		114.8			22.0
3	09N/22E-11H01		544.6			20.3
4	09N/23E-23L01		1148.4			16.0
1	09N/23E-22J01	461455 1195507	1409.0	Grandview City	837.0	21.2
1	09N/25E-06B01	461805 1194346	1197.0	Prosser Experiment Station	1270.0	24.9
1	09N/27E-25M01	461407 1192314	1057.0	79-07 (DNR)	850.0	21.6
1	09N/28E-34H01	461325 1191714	890.0	Bauder, Milo	740.0	21.1
1	10N/23E-04L01	462252 1195701	493.0	Yakima Valley College	1200.0	17.8
2*	10N/16E-26G01		442.9	Lawrence		16.9
4	10N/17E-14D01		114.8			22.0
1	10N/23E-17B01	462135 1195749	1180.0	Stout, Bud/Golob, Don	950.0	16.7
4	10N/17E-23G01		698.9			20.3
4	10N/17E-26H01		1000.7			23.8
4	10N/17E-27P01		1509.3			26.0
4	10N/17E-28C01		879.3			22.4
4	10N/17E-35C01		803.8			21.2
3	10N/18E-05P01		662.8			20.6
4	10N/18E-31N01		1043.4			23.8
4	10N/20E-03E01		800.6			14.8

Source	TT/RG-SEC	LATLON	Depth (ft.)	Name	Elevation (ft.)	Bottom Hole Temperature (°C)
4	10N/20E-04G01		1023.7			22.6
3	10N/20E-09A01		839.9			20.5
4	10N/22E-25K01		1574.9			20.0
1	10N/23E-36A01	462429 1200114	1316.0	Evans, Bill	1220.0	26.3
1	10N/23E-36G01	461843 1195243	928.0	White, John	1180.0	22.8
1	10N/25E-33N01	461812 1194155	904.0	J & R Orchards	1310.0	20.8
1	10N/26E-27Q01	461911 1193234	775.0	Shaw, O. B.	1050.0	16.7
1	11N/16E-25Q01	462430 1204550	1091.0	Pace, W. B.	1100.0	25.0
4	11N/16E-34F01		456.1			21.4
4	11N/17E-01K01		1174.6			24.2
4	11N/17E-02G01		869.5			25.5
4	11N/17E-03G01		987.6			25.2
4	11N/17E-16K01		990.9			31.6
4	11N/17E-16J01		764.5			20.8
4	11N/17E-30P01		902.3			19.7
4	11N/18E-09N01		400.3			23.0
4	11N/18E-17C01		626.7			17.7
4	11N/18E-26G01		52.5			26.4
3	11N/18E-30J01		340.2			18.0
4	11N/19E-10P01		764.5			18.4
4	11N/19E-10P02		751.3			18.7
3	11N/19E-15A01		588.0			20.8
1	11N/20E-01M01	462801 1201603	1500.0	Johnson, Forrest	1170.0	27.5
1	11N/20E-01R01	462751 1201518	1151.0	Lynch, Bob	1150.0	20.8
1	11N/20E-06A01	462830 1202121	595.0	Peters, Charles	1060.0	19.8
1	11N/20E-13R01	462558 1201503	1095.0	Soost Brothers	1005.0	28.0
1	11N/21E-05B01	462822 1201305	1243.0	Weatherly, Bob	1460.0	28.5
1	11N/21E-06L01	462757 1201425	1195.0	Dahl, Ted	1210.0	28.2
1	11N/21E-06Q01	462747 1201408	1288.0	Dahl, Ted	1230.0	28.4
2	11N/21E-07A01		1673.3	Clyde		33.0
1	11N/21E-16P01	462607 1201210	1248.0	Ramsier (DNR)	1275.0	28.0
2	11N/21E-17A01		895.7	Garretson		24.8
1	11N/21E-20M01	462533 1201308	625.0	Hanrahan, Pete	1090.0	21.2
1	11N/21E-21B01	462554 1201143	916.0	Ambrose, Al	1260.0	26.4
1	11N/21E-22G01	462544 1201035	997.0	Sandlin, Jerry	1220.0	23.0

Source	TT/RG-SEC	LATLON	Depth (ft.)	Name	Elevation (ft.)	Bottom Hole Temperature (°C)
1	11N/21E-22G02	462539 1201032	1815.0	Sandlin, Jerry, #2	1275.0	35.2
1	11N/21E-22K01	462533 1201025	1048.0	Best, Peter	1235.0	24.6
1	11N/21E-34C01	462413 1201040	570.0	Slagg, L.	1000.0	18.6
1	11N/21E-36K01	462341 1200751	700.0	Gay, Harry	975.0	21.4
2	11N/22E-21N01		679.2			22.3
1	11N/22E-26R01	462429 1200114	1530.0	Evans, Bill	1280.0	30.7
1	11N/22E-28A01	462449 1200345	930.0	Kershaw, R.	1297.0	16.6
1	11N/22E-29N01	462426 1200604	1425.0	Rowe Farms	1130.0	29.6
1	11N/22E-30G01	462443 1200632	617.0	de La Chapelle, Charles	1160.0	19.9
1	11N/22E-30G02		2720.0	de La Chapelle, Charles		47.8
1	11N/22E-15		9480.0	Rattlesnake Hills #1		110.0
1	12N/16E-12N01		881.9			25.2
2	12N/16E-13B01		229.7			14.2
1	12N/16E-15E01	463146 1204853	588.0	White, Hirum	1886.0	21.5
1	12N/16E-18A01		355.0	Meyer, C.		19.7
3	12N/17E-02L01		278.9			16.1
1	12N/17E-02J01		89.9			19.4
3	12N/17E-07L01		260.2			19.5
1	12N/17E-07E01	463250 1204519	628.0	Gilbert, Craig	1704.0	11.2
1	12N/17E-07M01	463230 1204505	661.0	Bates, K. P.	1680.0	18.4
2	12N/17E-11D01		426.5			16.5
4	12N/17E-16A01		869.5			22.2
4	12N/17E-16R01		1079.4			17.0
2	12N/18E-01F01		203.4			14.0
2	12N/18E-26R01		603.7	Douglas		18.8
4	12N/18E-27L01		1000.7			23.6
4	12N/18E-27J01		1020.4			29.6
4	12N/18E-31R01		1571.6			22.2
4	12N/18E-32J01		1174.6			25.2
3	12N/18E-32G02		1243.5			27.9
4	12N/18E-33A01		951.5			25.6
1	12N/18E-33B01	462930 1203358	1060.0	Mt. Adams Feed #3	1143.0	28.0
4	12N/19E-01P01		1325.5			30.0
1*	12N/19E-27H01	463004 1202513	553.0	Stepniewski, Stan	1120.0	19.5
1	12N/19E-28J01	462949 1202619	300.0	Sunnyside Dam	920.0	16.8

Source	TT/RG-SEC	LATLON	Depth (ft.)	Name	Elevation (ft.)	Bottom Hole Temperature (°C)
1	12N/20E-13Q01	463121 1201534	1235.0	Charron, Sebastian	1320.0	27.6
1	12N/20E-16D01	463205 1201959	505.0	Gangl (DNR)	1200.0	22.0
1	12N/20E-27N01	462933 1201833	1300.0	Logan, Wilbur	1260.0	30.8
3	12N/20E-27E01		1341.9			27.5
2*	12N/20E-31J01		360.9	Brooks		17.1
1	12N/20E-34N01	462843 1201834	899.0	Estes, Marvin	1160.0	25.1
1	12N/20E-34N02	462843 1201836	1410.0	Estes, Marvin	1180.0	32.3
1	12N/20E-36P01	462843 1201545	1338.0	Cheyne Road Well (DNR)	1240.0	25.7
2	12N/21E-16R01		771.0	DNR		25.1
1	12N/21E-17L01		1551.0	Martinez, D.		28.5
1	12N/21E-20D01	463101 1201326	472.0	Martinez, Daniel T., #1	1440.0	21.4
1	12N/21E-20P01	463026 1201313	1032.0	Griswald, Port	1460.0	24.3
2*	12N/22E-13		1509.3	Changala		29.5
3	12N/22E-14B01		488.9			15.2
2	12N/22E-20K01		689.0	Martinez		19.2
1	12N/22E-21R01	463026 1200339	886.0	Marley Orchards	1780.0	23.2
1	12N/22E-29B01	463017 1200530	1411.0	Changala, Steven	1790.0	22.9
1	12N/23E-16J01	463131 1195619	1151.0	Blackrock #1 (DNR)	1400.0	25.5
2*	12N/23E-16J02		328.1			15.2
2*	12N/23E-17P01		675.9			20.3
1	12N/23E-19A01	463107 1195855	753.0	Taggares Ranches	1560.0	18.9
1	12N/24E-05A01	463343 1195000	834.0	Tramel, J. D.	1380.0	23.0
1	13N/17E-28B01	463540 1204228	560.0	C-6 (DOE)	1570.0	13.9
2	13N/18E-01F01		91.9	Silvercove		8.4
3	13N/18E-12A01		659.5			24.8
2*	13N/18E-15L01		180.5	Nazerene		14.4
4	13N/18E-24		1683.0	Creamery Well		33.9
2	13N/19E-11K01		531.5			19.2
2*	13N/19E-12N01		319.9	Hill		17.5
1	13N/19E-13Q01		823.9	Terrace Heights		25.0
2	13N/19E-14A01		690.7	Watkins		20.3
3	13N/19E-22E01		269.0			20.0
2	13N/19E-23B01		255.9	Watkins		15.5
2	13N/19E-23C01		262.5	Watkins		14.7
3	13N/19E-24C01		754.6			44.5

Source	TT/RG-SEC	LATLON	Depth (ft.)	Name	Elevation (ft.)	Bottom Hole Temperature (°C)
2	13N/19E-24A01		754.6			20.0
4	13N/19E-31C01		626.7			19.0
1	13N/20E-18N01	463632 1202239	958.0	Riebe, John	1700.0	16.3
1	13N/20E-19N01	463533 1202241	831.0	Sundquist Fruit	1060.0	21.2
2	13N/20E-20C01		213.3	Coppornall		15.6
2	13N/20E-20F01		705.4	Champoux		23.3
3	13N/20E-29D01		577.5			22.7
1	13N/20E-30A01	463521 1202150	949.0	Yergen, Reginald	1390.0	24.2
1	13N/20E-33L01	463410 1201950	745.0	Coombs, Bruce	1375.0	23.2
1	13N/20E-33M01	463406 1202002	1464.0	Coombs, Bruce, #2	1345.0	30.2
2*	13N/21E-12D01		147.6			11.7
1	13N/21E-34H01	463415 1201021	1020.0	Martinez, Daniel T., #2	2320.0	21.2
1	13N/22E-13P01	463117 1200032	1696.0	Changala, Steven, #2	1710.0	30.7
4	13N/26E-35A02		5550.0	ARH DC-1		75.0
1	13N/27E-26G01		4343.0	DC-6		60.2
2	14N/15E-29M01		219.8	Troutlodge		13.6
2*	14N/16E-01B01		364.2	Englund		13.3
2*	14N/16E-01H01		557.8	Huck		13.1
2*	14N/16E-01J01		377.3	Marmion		15.0
2	14N/16E-01K01		656.2	Shearer		17.2
1	14N/16E-13K01	464206 1204604	485.0	Keller Fruit & Cold Stor. #2	2010.0	15.6
1	14N/16E-24K01	464114 1204607	868.0	Keller Fruit & Cold Stor. #1	2100.0	18.8
4	14N/17E-04J01		1000.7			14.4
2*	14N/17E-06F01		525.0	Perham		15.3
2*	14N/17E-13H01		433.1	Murray		19.5
1	14N/17E-15N01	464154 1204150	511.0	Majnarich, Frank	1955.0	13.8
2	14N/17E-19K01		246.1	Knutson		12.7
2	14N/17E-19Q01		492.2	Mansperger		19.9
2*	14N/17E-20P01		196.9	Dardon		12.7
1	14N/17E-26G01	464026 1203956	1002.0	Allen, Bruce	1740.0	18.4
1	14N/17E-27A01	464041 1204042	525.0	Zuetenhorst, W.	1900.0	17.7
1	14N/17E-35H01	463943 1203936	950.0	Hargrave, Hugh	1750.0	18.8
2*	14N/18E-07K01		164.1	Murray		12.0
1	14N/18E-20G01	464122 1203609	1065.0	Zirkle, William H.	1620.0	29.7
2	14N/18E-29K01		180.5	McFarlane		14.3

Source	TT/RG-SEC	LATLON	Depth (ft.)	Name	Elevation (ft.)	Bottom Hole Temperature (°C)
1	14N/19E-16N01	464144 1202753	880.0	Roche Fruit Company	1290.0	22.3
4	14N/19E-28C01		600.4			21.0
2*	14N/20E-16B01		95.1	Yakima Firing Center #2		12.1
3	14N/20E-20N01		602.1			17.0
1	14N/31E-08M01		2487.0	Rathbun		46.8
2	15N/17E-02K01		295.3	Picatti		15.8
2	15N/17E-23B01		728.4	Day		18.1
2	15N/17E-24H01		508.6	Day		10.3
2	15N/17E-36A01		1962.0	Wenas (DNR)		29.2
2	15N/18E-28A01		459.3	McNeilly		14.6
2	15N/18E-28R01		288.7	McNeilly		15.0
1	15N/18E-30G01	464551 1203708	478.0	Boyd, John	1540.0	8.7
2	15N/18E-28M01		246.1	Young		13.2
1	15N/19E-22L01	464615 1202610	400.0	Burbank Creek (USGS)	1400.0	24.3
1	15N/19E-22P01	464608 1202543	1289.0	Larson Fruit	1440.0	31.5
1	15N/24E-28		5034.0	DH-5		74.0
1	15N/28E-30		3032.0	DH-4		53.5
2	16N/16E-24N01		574.2	Dept. of Game and Fish #2		17.8
2	16N/17E-29H01		393.7	Dept. of Game and Fish #1		13.1
2*	16N/18E-03F01		557.8	Kummer #1		14.7
2	16N/18E-04J01		131.2	Kummer #2		10.3
1	16N/19E-28C01	465109 1202729	1018.0	Umtanum Creek (USGS)	1400.0	29.0
2	16N/21E-33P01		337.9	Yakima Firing Center		13.1
2	17N/18E-34E01		229.7	Kummer		11.3

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[1] Data Sources:

1 = W.S.U. Geological Engineering Section
2 = S.M.U. Dept. of Geological Sciences
3 = U.S.G.S.
4 = others
* = Not a bottom hole temperature

Appendix C

Well Data Groups Used in the Bottom Hole Temperature Regression Analysis

Group 1

10N/16E-26G01
10N/17E-14D01
10N/17E-23G01
10N/17E-26H01
10N/17E-27P01
10N/17E-28C01
10N/17E-35C01
10N/18E-31N01

Group 2

10N/18E-05P01
11N/16E-25Q01
11N/16E-34F01
11N/17E-01K01
11N/17E-02G01
11N/17E-03G01
11N/17E-16K01
11N/17E-16J01
11N/17E-30P01
11N/18E-09N01
11N/18E-17C01
11N/18E-26G01
11N/18E-30J01
12N/18E-26R01
12N/18E-27L01
12N/18E-27J01
12N/18E-31R01
12N/18E-32J01
12N/18E-32G02
12N/18E-33A01
12N/18E-33B01

Group 3

08N/22E-01L01
08N/22E-11J01
09N/21E-26E01
09N/21E-27R01
09N/22E-11H01

Group 4

11N/19E-10P01
11N/19E-10P02
11N/19E-15A01
11N/20E-06A01
12N/19E-27H01
12N/19E-28J01
12N/20E-27N01
12N/20E-27E01
12N/20E-31J01
12N/20E-34N01
12N/20E-34N02

Group 5

12N/20E-36P01
11N/20E-01M01
11N/20E-01R01
11N/20E-13R01
11N/21E-06L01
11N/21E-06Q01
11N/21E-07A01
11N/21E-16P01
11N/21E-17A01
11N/21E-20M01
11N/21E-21B01
11N/21E-22G01
11N/21E-22G02
11N/21E-22K01
11N/21E-34C01
11N/21E-36K01
11N/21E-05B01

Group 6

11N/22E-29N01
11N/22E-21N01
11N/22E-26R01
11N/22E-28A01
11N/22E-30G01

Group 7

10N/25E-33N01
09N/25E-06B01
10N/23E-04L01
10N/23E-17B01
10N/23E-36A01
10N/23E-36G01

Group 8

12N/16E-12N01
12N/16E-13B01
12N/16E-15E01
12N/16E-18A01
12N/17E-02L01
12N/17E-02J01
12N/17E-07L01
12N/17E-07E01
12N/17E-07M01
12N/17E-11D01
12N/17E-16R01
12N/17E-16A01

Group 9

12N/18E-01F01
13N/18E-15L01
13N/18E-24
13N/19E-31C01

Group 10

13N/19E-13Q01
12N/19E-01P01
13N/19E-11K01
13N/19E-12N01
13N/19E-14A01
13N/19E-22E01
13N/19E-23B01
13N/19E-23C01
13N/19E-24A01
13N/20E-18N01
13N/20E-19N01
13N/20E-20C01
13N/20E-20F01
13N/20E-29D01
13N/20E-30A01
13N/20E-33L01
13N/20E-33M01

Group 11

12N/22E-14B01
12N/22E-20K01
12N/22E-21R01
12N/22E-29B01
12N/23E-16J01
12N/23E-16J02
12N/23E-17P01
12N/23E-19A01
12N/22E-13

Group 12

14N/16E-01B01
14N/16E-01H01
14N/16E-01J01
14N/16E-01K01
14N/16E-13K01
14N/16E-24K01
14N/17E-04J01
14N/17E-06F01
14N/17E-13H01
14N/17E-15N01
14N/17E-19K01
14N/17E-19Q01
14N/17E-20P01
14N/17E-26G01
14N/17E-27A01
14N/17E-35H01
14N/18E-07K01
14N/18E-20G01
14N/18E-29K01

Group 13

15N/17E-23B01
15N/17E-24H01
15N/17E-36A01
15N/18E-28A01
15N/18E-28R01
15N/18E-30G01
15N/18E-28M01

Group 14

11N/22E-30G02
13N/26E-35A02
13N/27E-26G01
14N/31E-08M01
15N/24E-28
15N/28E-30
11N/22E-15

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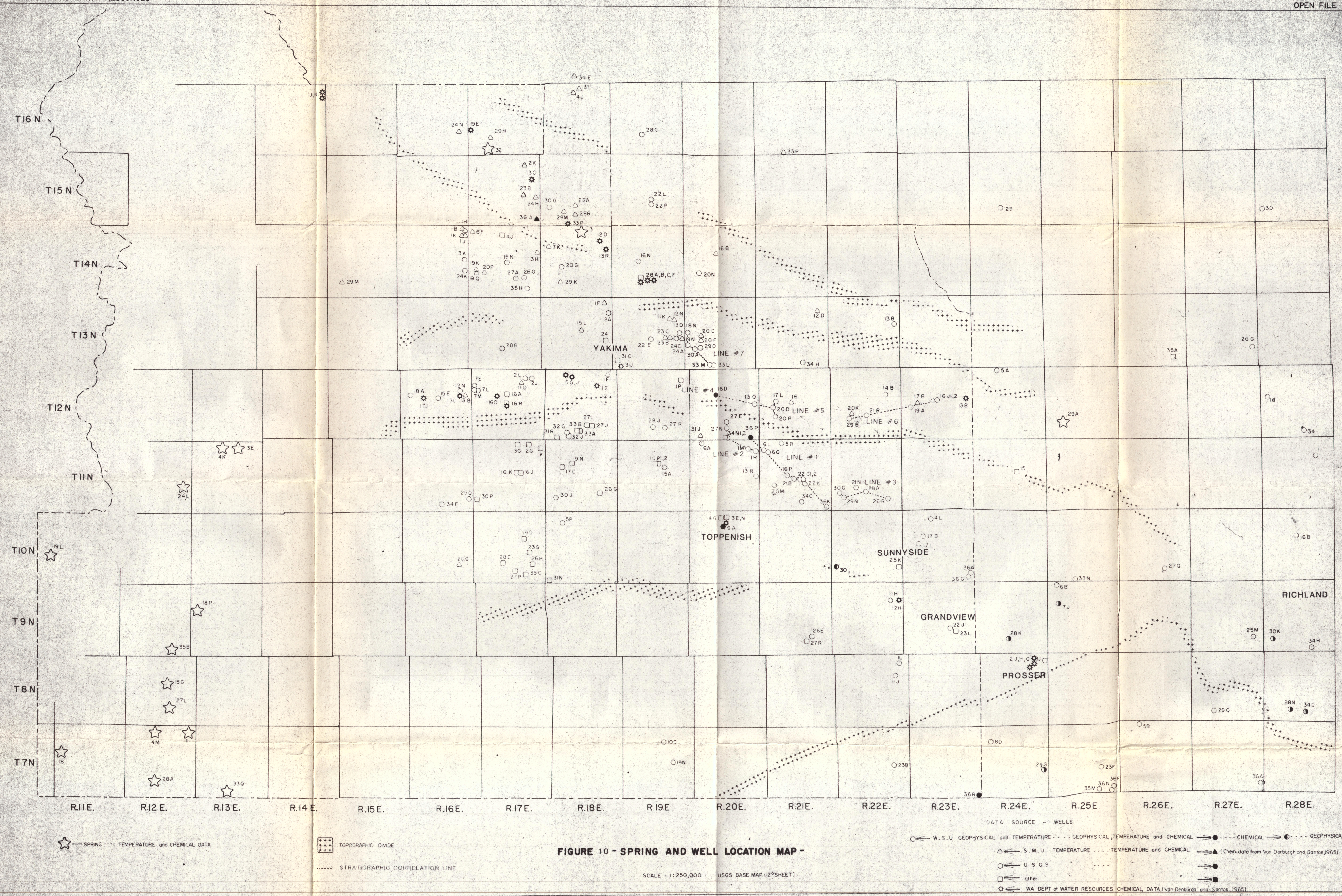

FIGURE 10 - SPRING AND WELL LOCATION MAP -

SCALE - 1:250,000 USGS BASE MAP (2° SHEET)

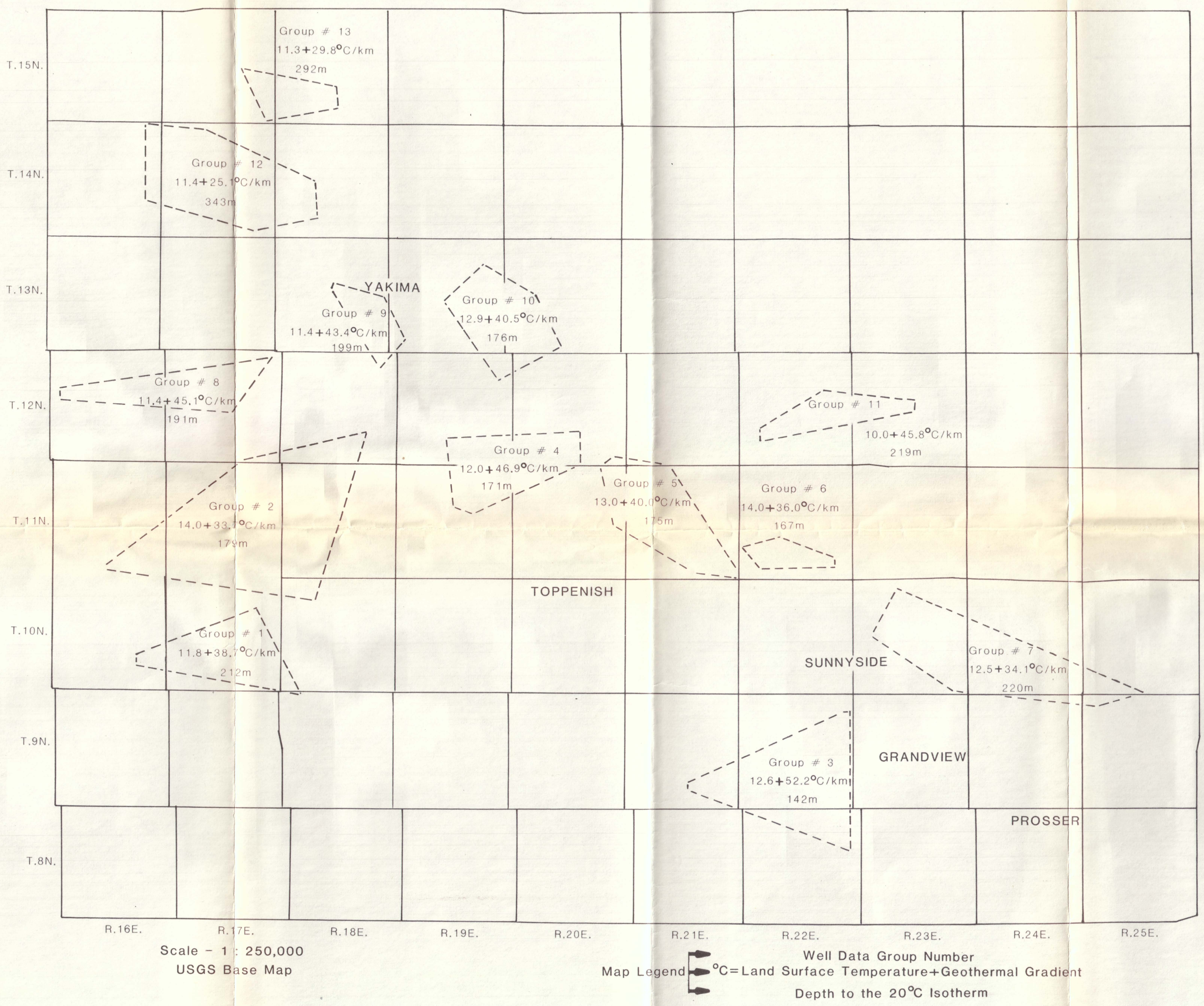

FIGURE 27 WELL DATA GROUP LOCATION MAP

WASHINGTON DEPARTMENT OF NATURAL RESOURCES
DIVISION OF GEOLOGY AND EARTH RESOURCES

FIGURE 27A
MAP SHOWING LOCATIONS OF WELL DATA GROUPS
WITH RESPECT TO THE LOCATIONS OF SPRINGS AND WELLS