GL02931

A PRELIMINARY INVESTIGATION OF THE POSSIBLE EXISTENCE OF A HOT WATER AQUIFER UNDER THE PILGRIM RIVER

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Introduction

A previous investigation of the Pilgrim Springs geothermal system by Geophysical Institute personnel (Osterkamp, et al., 1980) suggests the presence of a hot water aquifer under the Pilgrim River adjacent to the Pilgrim Springs and extending some distance downstream. The evidence for the presence of this aquifer is indirect and circumstantial. Pilgrim Springs is situated in an area of continuous permafrost approximately 100 m in thickness (Wescott, et al., 1980) with a thawed ground area of about 1-3 km^2. There is a small surface discharge of $\approx 4.2 \times 10^{-3}\ m^3\ s^{-1}$ (Harrison and Hawkins, 1980). Landsat imagery of the general area shows an unusually large number of icings and open water areas along the Pilgrim River during the winter season. This evidence suggests the presence of an underground discharge of hot water from Pilgrim Springs. Since the permafrost in the area is thought to be continuous the most likely location for this hot water aquifer is in the thaw bulbs associated with the Pilgrim River and/or the small surface discharge stream from Pilgrim Springs. Data gathered during the summer of 1979 show that there is an increase in water temperature of the Pilgrim River near Pilgrim Springs of $\approx 1.5°C$ and an increase in the electrical conductivity of the river water of $\approx 4.2\ \mu S\text{-}cm^{-1}$. Assuming a river discharge of 50 $m^3\ s^{-1}$, the water temperature increase requires a heat input of ≈ 300 MW to the river (Osterkamp et al., 1980). This temperature increase would also require an influx of $\approx 1\ m^3\ s^{-1}$ of 78°C water. However, the conductivity increase requires an influx of a few hundredths $m^3 s^{-1}$ of 5-10 $mS\text{-}cm^{-1}$ water which would increase the water temperature only $\approx 0.05°C$. Consequently, we concluded that there must be a substantial heat transfer from a hot water aquifer to the river bed with very little leakage of hot water into the river. Evidence for the presence of this hot water aquifer also exists in the geophysical (electrical resistivity) measurements of Wescott, et al., 1980. The importance of this potential hot water aquifer is that, if it exists, then the Pilgrim Springs system must be relatively large with the accessible power approaching 500 MW. If the aquifer does not exist, then the accessible power would probably be less than 1/10 this value.

Our previous research suggests that, if the hot water aquifer exists, then the temperature in the river bed must increase with depth by several °C per meter. This report describes temperature profiles measured in the river bed as well as other measurements made during March, 1980 to confirm the presence or absence of a hot water aquifer under the Pilgrim River. These measurements were made by drilling holes in the river ice through which water samples were obtained. Pipe for measuring temperature profiles was driven into the river bed by the methods discussed in Osterkamp et al., (1980). Three sites labeled W, X, and Y and a shallow lake shown in Figure 1 were investigated. Three holes were drilled at W and Y, two at X and two at the lake.

Electrical Conductivity Measurements

The electrical conductivity measurements are summarized in Table 1. These conductivity values have been used to estimate the mass flux of saline water from the hot water aquifer into the river through its bed. The river width was estimated to be ≈18 m with a mean flow depth, from measurements at site W, of 52.4 cm. Flow velocity was measured with a Pygmy current meter at 0.25 $m\text{-}s^{-1}$. These values imply a river discharge of ≈2.4 $m^3\text{-}s^{-1}$; about 5% of the estimated summer discharge. The mass flux required to produce the observed increase in electrical conductivity

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Table 1. Electrical conductivity values for water samples obtained from the Pilgrim River and lake at the locations shown in Figure 1. The values are an average of measurements on three samples obtained in each hole. Units are $\mu S\text{-}cm^{-1}$.

	Sites			
	W	Y	X	Lake
Hole 1	264.6	306.7	316.9	581.1
Hole 2	269.8	311.5	335.7	550.2
Hole 3	271.4	351.5	-	
Average	268.6	323.2	326.3	

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values between sites W and X (upstream → downstream) is ≈ 0.01 - 0.03 m^3-s^{-1}. A mass flux of 0.02 - 0.05 m^3-s^{-1} was estimated from the measurements made during the summer of 1979.

These measurements and calculations confirm that there is little saline water intrusion into the river and that both winter and summer flow regimes are characterized by a mass flux of saline water on the order of 0.05 m^3-s^{-1} or less over the length of river studied (site W to X).

Table 1 shows what appear to be transverse gradients in conductivity between the near and far shores of the river (with respect to the Pilgrim Springs). A tentative explanation for these gradients is that the mass flux of saline water into the river comes primarily from the near shore (southern) side of the river (i.e. the same side as Pilgrim Springs). However, all of the study sites shown in Figure 1 are on the near side of river loops opening to the north. As a result, the similarities in hydrologic conditions may be responsible for the gradients rather than the directional characteristics of the inflowing saline water.

Electrical conductivity measurements were also made on water samples obtained from 2 holes in the small lake shown in Figure 1. These conductivity values, 550.2 and 581.1 µS-cm^{-1}, are very high when compared to values for the river water, ≈ 125-130 µS-cm^{-1}. However, our calculations show that these high conductivity values may be entirely attributable to rejection of impurities from the lake ice during the winter ice cover formation and growth.

Temperature Measurements

Temperature profiles in the river bed are shown in Figures 2, 3 and 4 and in the lake in Figure 5 (note changes in scale). The warmest temperature, measured at site Y, was +14°C at the 5 m depth in hole 3. In general, temperatures were warmest on the near (south) side of the river again suggesting that the hot water aquifer may be located on that side. The coolest temperatures were measured at site X, the farthest point downstream, where they did not exceed +2°C. These relatively warm temperatures and high temperature gradients suggest heating of the river bed from below, probably, by the proposed hot water aquifer. At some of the locations, particularly site Y hole 3, the observed temperature values and curvature suggest a vertical flow of ground water, as discussed in our earlier report. For example, the site Y hole 3 profile shown in an expanded scale in Figure 6 suggests a vertical water velocity of ≈ 4 m a^{-1} with the flow directed toward the river bed. The temperature profile in the lake bed also suggests strong vertical transport there. Temperatures measured at site X are probably near "normal" and do not reflect the presence of a hot water aquifer at depth.

Ice Thickness Measurements

Measurements of ice thickness were made at all holes and are graphed in Figure 7 as a function of temperature at the 2 1/2 or 3 1/2 m depths in the river bed. Apparently, there is an inverse relationship that holds between river ice thickness and temperature at depth but not for lake ice thickness. It is suggested that the decrease in ice thickness with increasing river bed temperature at depth may be caused by vertical heat flux to the ice cover. An approximate fit to the data is given by

$$h - 45 = \frac{61.6}{T_b - 0.837} \qquad (1)$$

where h is the ice thickness and T_b is the temperature at depth. A simple model of conductive heat transfer through the ice and convective heat transfer through the river bed shows that

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$$-k \frac{T_s}{h} = H T_B \qquad (2)$$

or

$$h = \frac{-k T_s}{H T_b} \qquad (3)$$

where k is the thermal conductivity of ice, T_s is surface temperature of the ice, and H is a heat transfer coefficient. Equation 3 is similar in form to the empirical equation 1 and, furthermore, it appears that H may be a weak function of h.

The variation in the ice cover thickness from one location to another suggests that the heat flux from the river bed is being utilized in maintaining a relatively thin ice cover. We expect that the greater portion of the 300 MW of energy input to the river from the hot water aquifer serves to warm the river water during summer and to decrease the ice thickness and warm the thaw bulb during winter.

Aerial Observations

Several aerial photographs using hand-held 35 mm cameras were made of the Pilgrim Springs area. The areas of thawed ground where the snow cover has melted off are clearly identifiable in these photographs. It is suggested that a photographic study conducted during late winter could be used to identify the local "hot spots" within the thawed area. These "hot spots" would probably be the best locations for obtaining hot water from shallow depths during developmental drilling.

Summary

Temperature profiles measured in the bed of the Pilgrim River show a strong heat influx from depth at 2 of 3 sites. Curvature in these profiles suggests that the heat transport through the river bed is by convective motion of the pore water. The temperatures on the near side

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(south) of the river (relative to Pilgrim Springs) are somewhat warmer. Electrical conductivity measurements of the river water show that the increase in conductivity can be accounted for by a flow of saline water on the order of 0.05 m^3-s^{-1} or less from a hot, saline water aquifer at depth. This flow is not sufficient to heat the river water more than a few tenths °C.

These results are consistent with the presence of a hot, saline water aquifer at some depth, perhaps 10-15 m under the river. Our present thinking is that this aquifer consists of a hot, saline groundwater discharge from the Pilgrim Springs hydrothermal system. It appears to be overlain by an impervious cap and to be about 55 m in thickness. Heat from this aquifer appears to be transferred to the river water primarily by convection of pore water in the river bed above the impervious cap. The presence of this aquifer implies that the accessible resource base of the Pilgrim Springs system may be on the order of 500 MW, as previously suggested by Osterkamp et al., (1980).

Questions and Need for Additional Research

We believe we have established the presence of a hot water aquifer under the Pilgrim River. Some additional questions and needs to be addressed by future research are:

1. Are the Pilgrim Springs and Pilgrim River aquifers connected? If so, what is the direction and volume of flow? We note that it is possible that the Pilgrim River is heated by deep hot water sources rather than by flow from the Pilgrim Springs. Additional temperature, conductivity and geophysical measurements extending both upstream and downstream would be required

to answer these questions. A related question is why are the X1 and X2 temperature profiles substantially colder than the W or Y profiles?

2. Aerial photography clearly delineates the hot ground areas. A systematic study using aerial photography to define areas where hot water may be found at shallow depths should be carried out. If this is not possible, then a shallow magnetic induction survey should be carried out over a small grid spacing for the purpose of defining these shallow hot water areas.

3. A study of the groundwater hydrology in the Pilgrim Springs thawed area and in the Pilgrim River and nearby lakes should be carried out with a view toward defining the routing and flow of water to and from the thawed area.

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Acknowledgements

We want to thank D. R. Markle, C. J. Phillips and the Louis Green family for their cooperation and support of this investigation. Funds were provided by the Division of Energy and Power Development of the Department of Commerce and Economic Development, State of Alaska.

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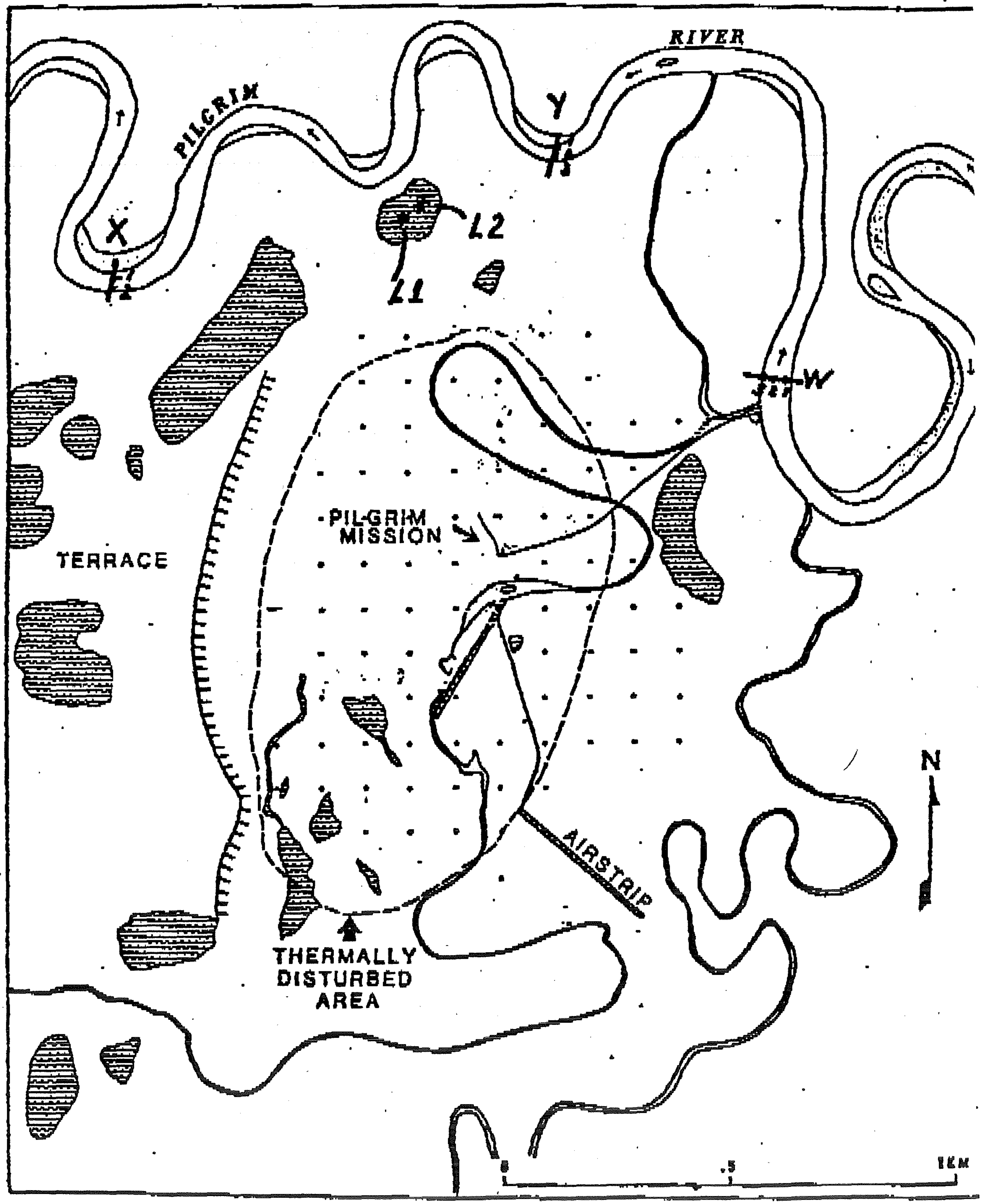
References to previous work are contained in,

Turner, D. L. and Forbes, R. B., (editors). A geological and geophysical study of the geothermal energy potential of Pilgrim Springs, Alaska. Report UAG R-271, Geophysical Institute, University of Alaska, Fairbanks, Alaska, January 1980.

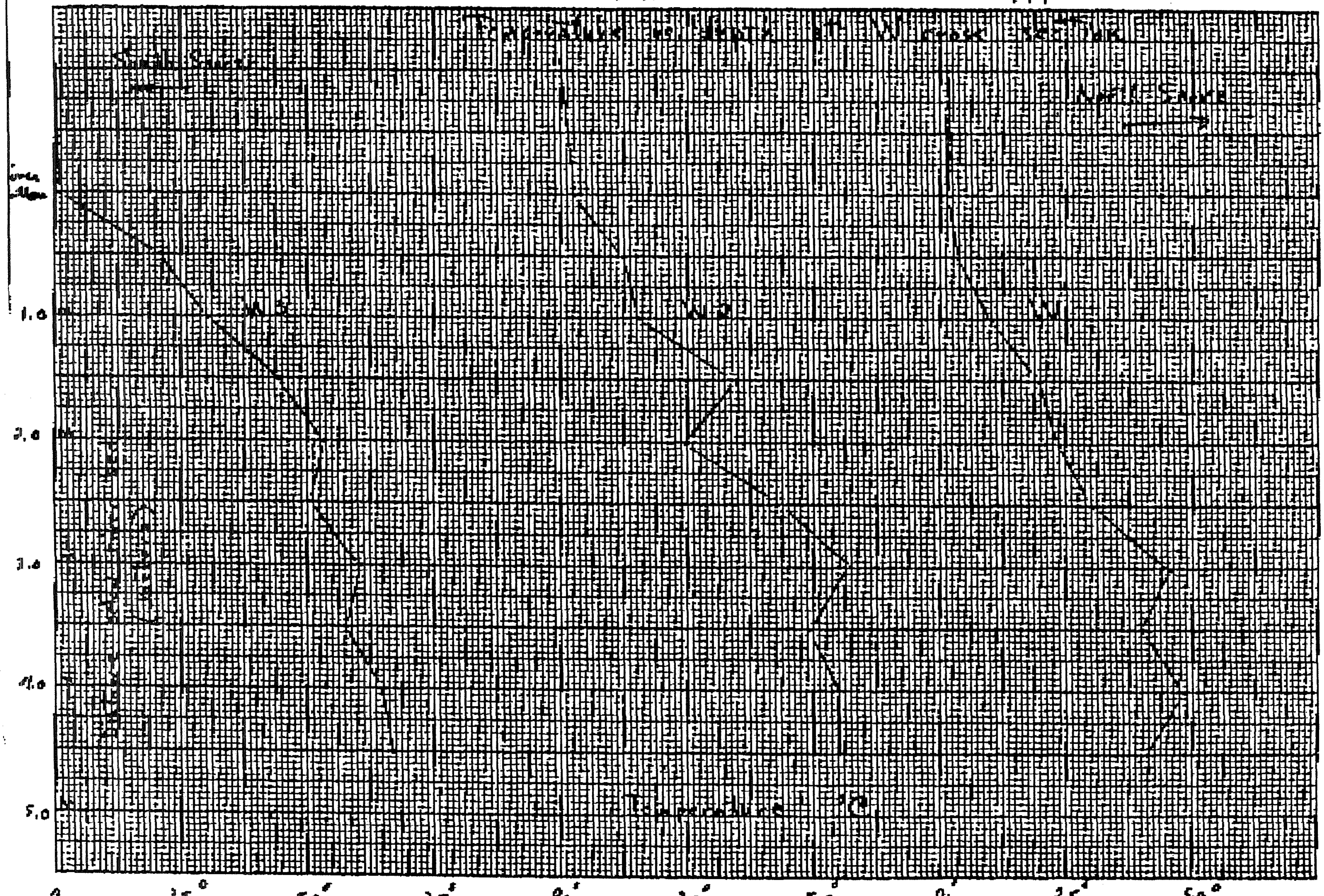
List of Figures

List of Tables

Figure 1



RIVER
PILGRIM
Y
X
L2
L1
W
PIL-GRIM MISSION
TERRACE
AIRSTRIP
THERMALLY DISTURBED AREA
N
0
.5
1KM


South Shore
North Shore
W3
W2
W1
Temperature °C
1.0
2.0
3.0
4.0
5.0
0.
2.5
5.0
7.5
0.
2.5
5.0
0.
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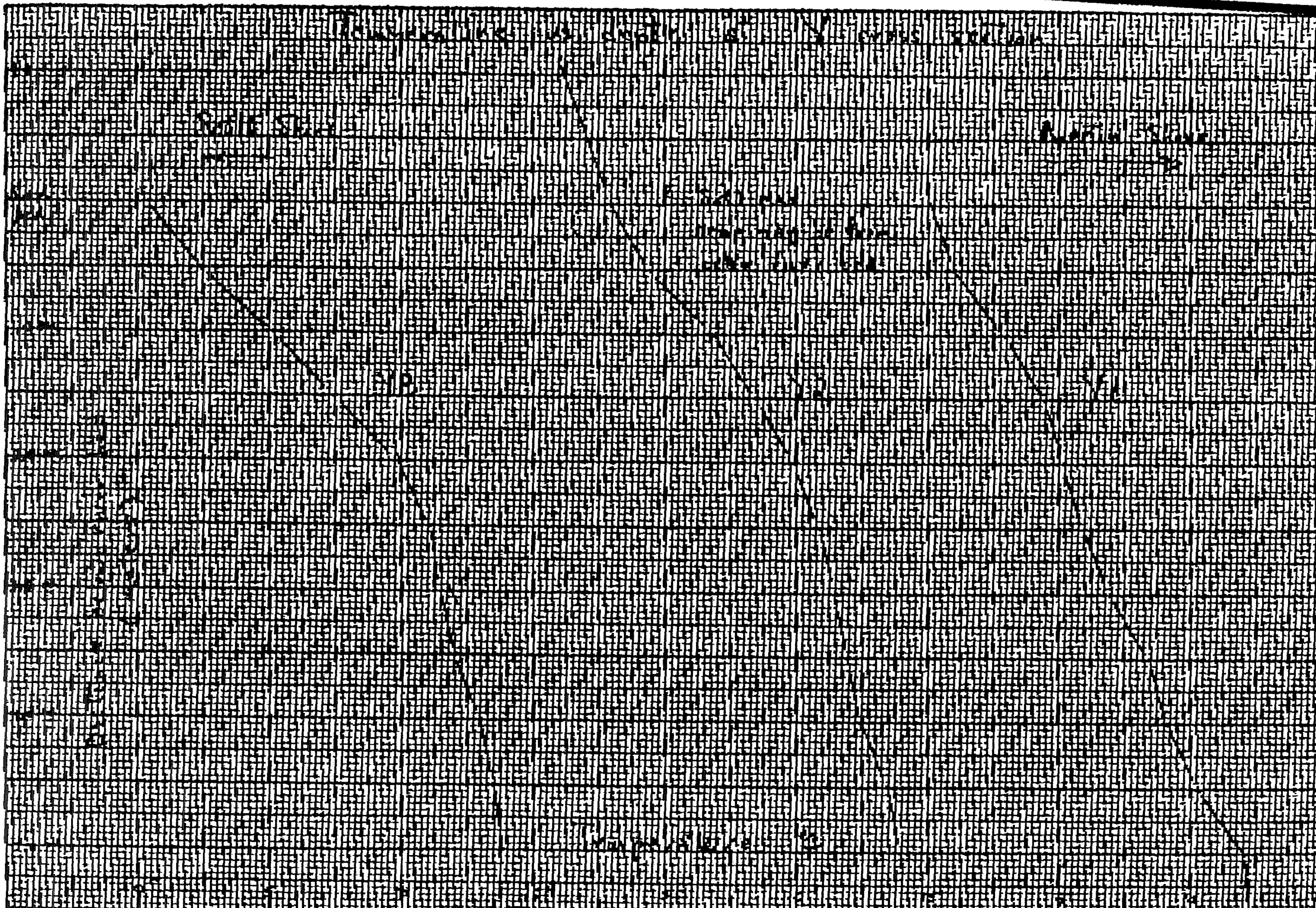

Figure 3

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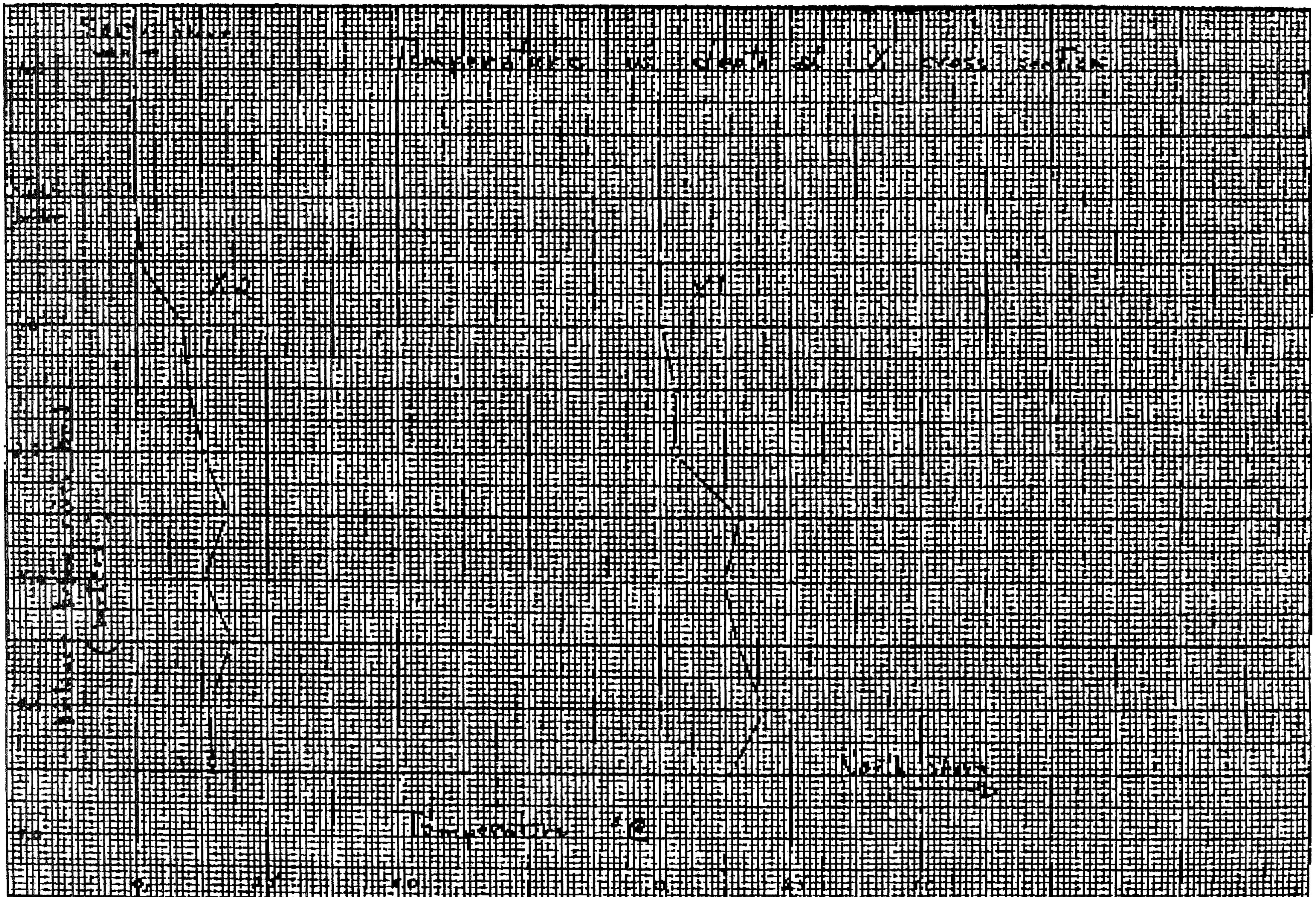
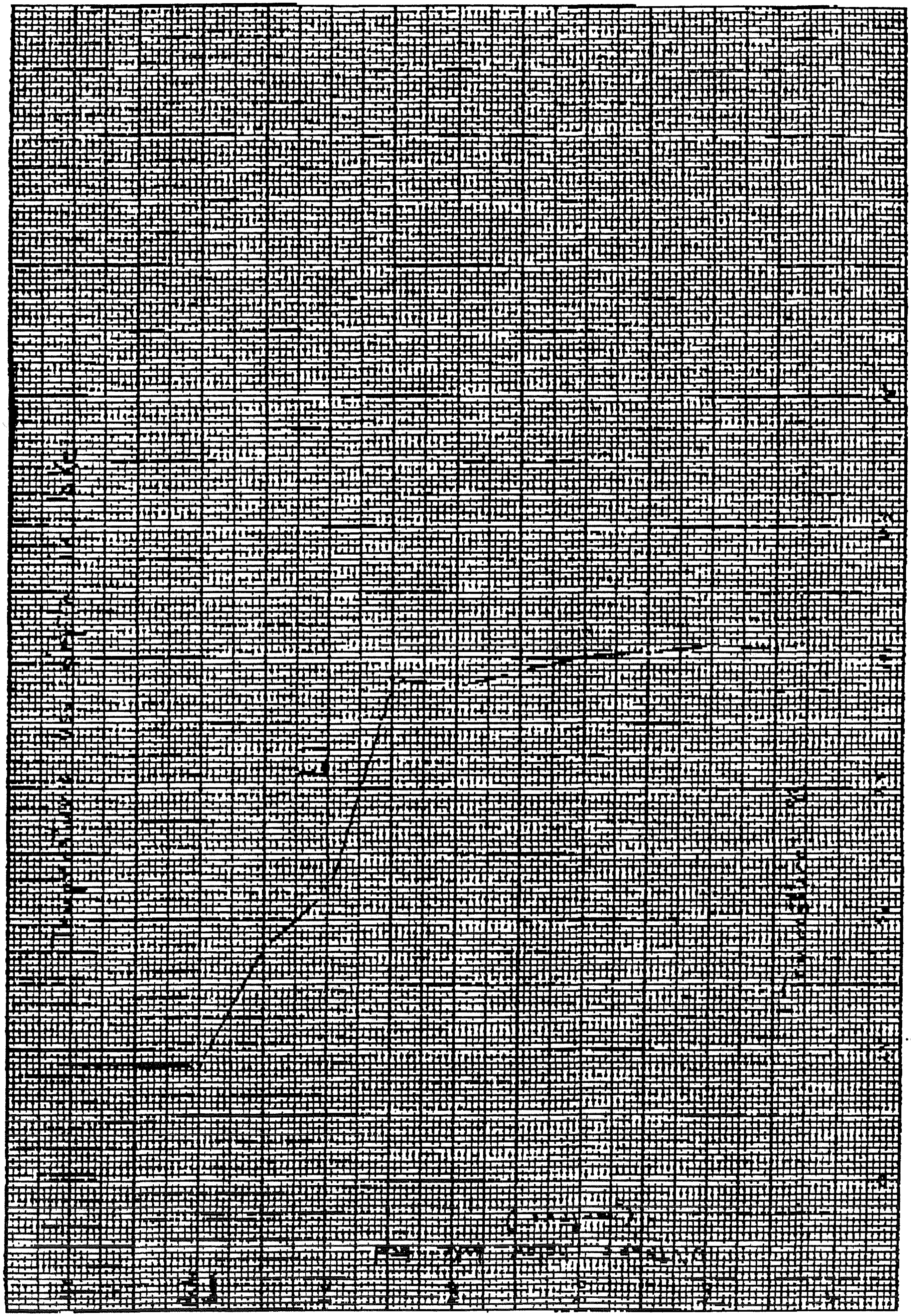


Figure 4



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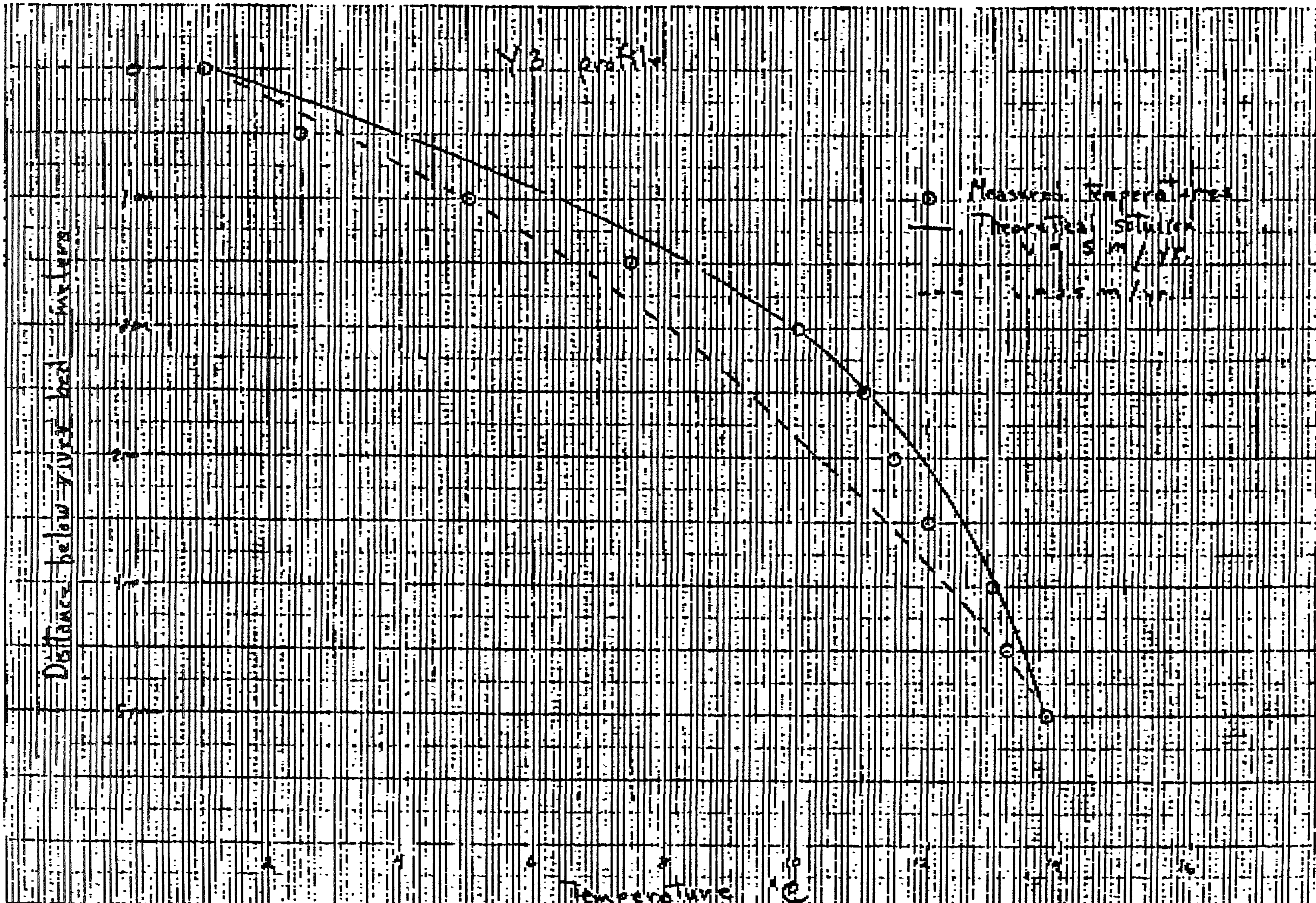
Y3 profile
Measured Temperatures
Theoretical solution
Distance below river bed meters
Temperature °C

Figure 6

46 1333

K+E

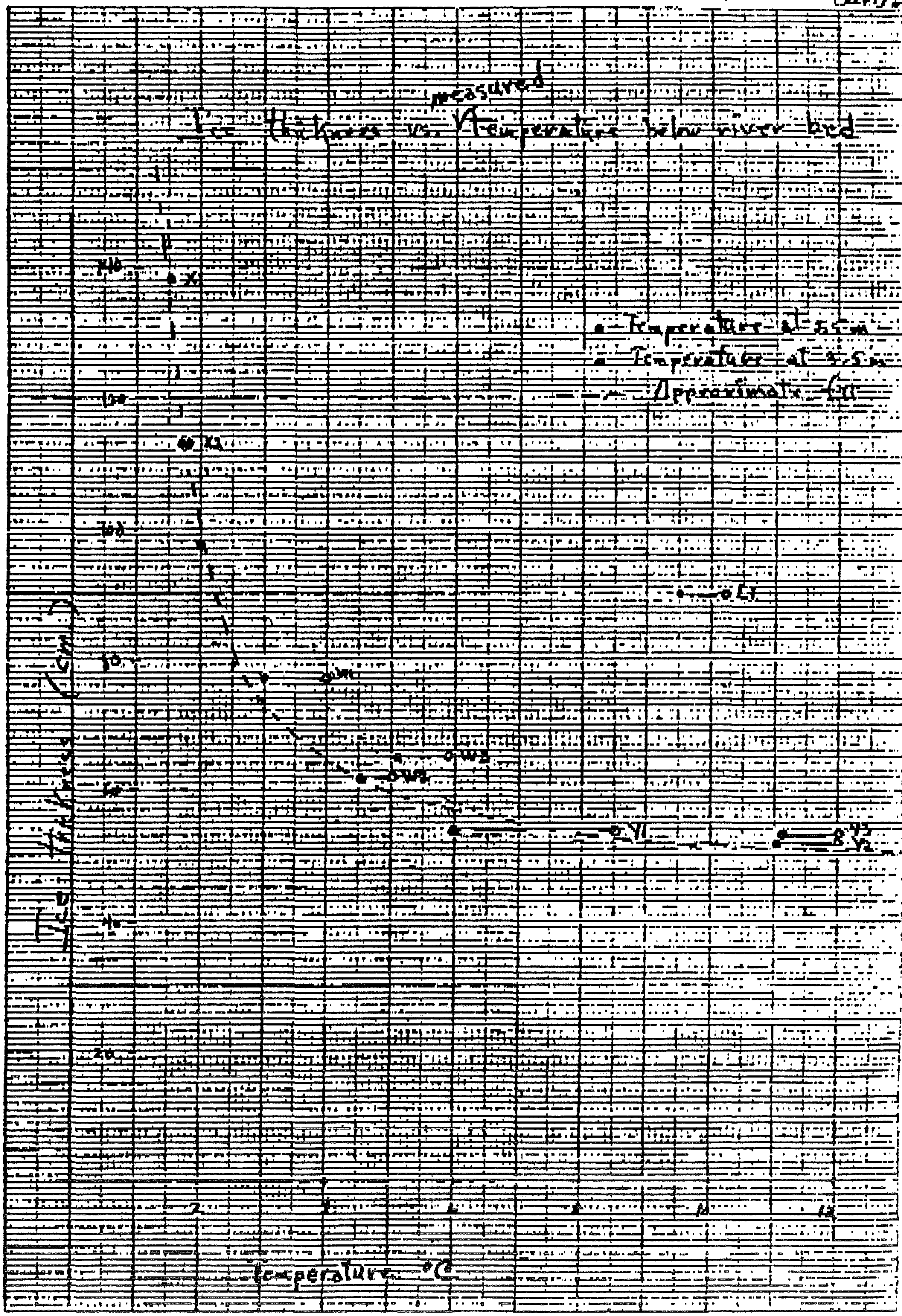

Figure 7

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Pg 1 of 21

ALASKA DIV. OF
ENERGY AND POWER

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TO: DAVE DALLEM
GEOTECH DIV., SFO

Dear Don:

We are enclosing 2 copies of our report, "A preliminary investigation of the possible existence of a hot water aquifer under the Pilgrim River". Our business office told me that a bill on the RSA for funds expended through June 30, 1980 will follow soon. I do not anticipate any excess funds. The water samples were shipped to the Chemical and Geological Analyses Laboratories in Anchorage following Bob Burkett's direction. Burkett should know where the samples are currently located.

We do not have any information which can tell us if the discharge under the Pilgrim River is continuous. A hot and saline water aquifer appears to be present during winter and summer, but we have not even established that this aquifer comes from Pilgrim Springs. For example, it could come from a separate deep water source. Also, the cool temperatures at site X may suggest some variability in the depth or location of the aquifer or, again, that the heating of the river is a result of separate sources. Before we can answer questions on the continuity of the system we will have to provide answers to the above questions and determine the routing and flow of water in the system as suggested by our proposed water balance model (p. 149 of the report). I also note that our estimate of the thawed ground could be off by a factor of 2 to 3 which would have an effect on the power estimates.

Obviously much more work needs to be done on the Pilgrim Springs system. We hope that it will be possible to obtain funding to do it, but note that our participation must be quite limited until such funding becomes available.

Sincerely,

Tom Osterkamp
Professor of Physics and Geophysics

Joan Gosink
Post Doctoral Fellow

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Enclosure: 2 copies of report

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