GLACIER LAKES HYDROLOGIC BALANCE

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TABLE OF CONTENTS

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Introduction

The Rocky Mountain Forest and Range Experiment Station (RMS) is responsible for baseline monitoring of the inputs and outputs from the Glacier Lakes watershed located in the Snowy Range Mountains of southeastern Wyoming as a part of their Glacier Lakes Ecosystem Experiment Site (GLEES). The University of Wyoming and the Wyoming Water Research Center (WWRC), at the University of Wyoming, operate the Snowy Range Observatory in the Medicine Bow National Forest. The Snowy Range Observatory operates meteorological and streamgaging sites at several points within the Observatory, including the area in and around the Glacier Lakes watershed. The monitoring of hydrologic information which allows for a water budget analysis of the Glacier lakes watershed could best be accomplished with a cooperative arrangement between hydrologic expertise at the WWRC and personnel at the RMS.

The work performed under this contract for the RMS by the WWRC to help describe the water balance in the Glacier Lakes watershed has the following defined tasks:

1. Installation of Parshall flumes and associated monitoring equipment for the East Glacier Lake outlet and on Meadow and Cascade Creeks near their inlets to West Glacier Lake.
2. Estimation of an approximate hydrologic balance of inputs and outputs from the watershed areas of East Glacier and West Glacier Lake watersheds.

3. Estimation of the approximate errors associated with the hydrologic balance determined for East Glacier and West Glacier Lake watersheds.
4. Definition of a plan by which the hydrologic balance of each gaged watershed can be determined with some precision which minimizes the errors associated with the estimation.
5. Measurement of the depth of unconsolidated material at several locations throughout the GLEES study site within the East Glacier and West Glacier Lake watersheds.

A discussion of each of the tasks follows with associated data and any analysis that was needed to complete the task.

Task 1. Installation of Parshall Flumes

Three Parshall flumes were installed within the Glacier Lakes watershed at mutually agreed upon locations in consultation with the RMS during the summer of 1987. Each Parshall flume was prefabricated fiberglass construction fitted with a hypolon liner to bring as much groundwater flow as possible to the surface so that it could be measured by passing the water through the flume. The liner was buried as deep as was practical in front of the flume and to the sides of the flume for as reasonable a distance as was possible to intercept groundwater moving through the area. Some difficulty was encountered in burying the liner because of large boulders which could not be removed without substantial disturbance at all three locations.

East Glacier Lake outlet was fitted with a 12-inch Parshall flume and associated stilling well, monitoring equipment and shelter. The recording equipment used was an F-1 Type recorder with a weekly chart.

Meadow Creek and Cascade Creek inlets to West Glacier Lake were both fitted with 9-inch Parshall flumes and associated stilling wells, F-1 recorders and shelters.

Plexiglass 90° V-notch weirs were fabricated to fit into the Parshall flumes for low flow measurements during the fall season. It was felt by the WWRC investigators that the accuracy gained in measuring flow using the V-notches was an unnecessary burden on field technicians because it was questionable if additional accuracy was gained because of substantial fluctuations in flow during the day and ice conditions occurring at night during the fall period.

Task 2. Preliminary Water Balance

Based on meteorological, precipitation and flow measurement data collected on the GLEES site, an approximate water balance for East Glacier and West Glacier Lake watersheds was developed. The water balance, and an estimation of the measurement errors associated with the development of the water balance for each watershed, is discussed below.

These two watersheds posed a unique problem in the development of a water balance because of the fact that more water flows out of each watershed than is indicated from the precipitation gage measurements. This is believed to be a result of the large semi-permanent (semi-glacial) snowfield that exists near the upper end (highest elevation areas near the watershed divide) of the two watersheds. These high elevation and steep relief areas collect blowing and drifting snow from adjacent watersheds because they are on the leeward side of the adjacent watersheds. This will be discussed in more detail later in this and following sections of this report.

A topographic map of the surface hydrologic boundaries of East Glacier and West Glacier Lake watersheds were prepared from a 1:12,000 scale map provided by the RMS and was field verified for each watershed and the sub-watersheds of West Glacier Lake watershed for Cascade and Meadow Creeks during the Spring and Summer of 1988. The original and all copies were turned over to the RMS during 1988. As a result, estimates of surface area hydrologic boundaries for East Glacier and West Glacier Lake watersheds used in the water balance studies were performed as indicated below.

Two topographic maps of the Glacier Lakes study area are available at 1:24,000 (USGS map) and at 1:12,000 (Snowy Range Observatory-Nash Fork Creek map). The Nash Fork Creek map was preferred due to the greater detail it offers. However, this map is only a photo enlargement of the USGS map and its accuracy was suspect due to the distortions that can occur during the enlargement process. The East Glacier Lake watershed area was selected, for purposes of comparison, to determine the extent of any distortions that may have occurred. A K & E Vernier planimeter was used to measure the areas. From each map, five measurements were taken and the high and low values discarded. The mean of the remaining three values was calculated and used as the true value. The results of this comparison indicate that the Nash Fork Creek map is suitable for use and that the enlargement process resulted in an overestimation of only approximately one percent. The calculations are shown in Appendix A, Sections 1 to 3.

The isohyetal method was used to determine the average precipitation over the East and West Glacier Lake watersheds for the 1988 and 1989 water years. Four precipitation stations were used as control points. These four stations are Brooklyn Lake (0115A-35), Brooklyn Lake (0115-2), Lost Lake (0126) and Glacier Lake (0125) shown on maps in Appendix A, Section 7. The monthly precipitation data for these stations were compiled from the WWRC Water Resources Data System database. This database extended through June of 1988 and supplemental data were compiled from the weekly strip charts of each station. Although lapses occur in the strip chart data, these omissions are unlikely to have a significant impact on the precipitation totals. The results of the isohyetal analysis are as indicated in Appendix A, Section 7. Preliminary calculations are shown in Appendix A, Sections 4-6.

Three major streams exist in the Glacier Lakes area; Cascade, Meadow, and West Glacier Lake outlet. All three streams occur within the boundaries of the West Glacier Lake watershed area and all three are gaged with Parshall flumes. Cascade and Meadow Creeks discharge into West Glacier Lake and, as suggested by its name, West Glacier Lake outlet flows out of the lake. The East Glacier Lake watershed does not contain any intermittent or perennial streams. Small ephemeral streams exist in the area within the watershed surrounding the lake.

The total annual flows for the Cascade, Meadow, and West Glacier Lake outlet were calculated for the 1988 water year. The record for this year extends from May 24 to September 30, with several daily records missing, as noted in Appendix A, Section 8. In addition, it is assumed that although flow probably occurs from October through April, these volumes are insignificant. Furthermore, records are not available for this time period. The records for the 1989 water year were so incomplete that compilation of total flow volumes for the year are virtually impossible.

A regression analysis was performed (Appendix A, Section 9) on Meadow and Cascade Creeks for the 1988 water year in an effort to derive missing streamflow data for Cascade Creek during that year. The Minitab statistical software package was used to perform the analysis.

A review of the database and regression analysis suggest the following:

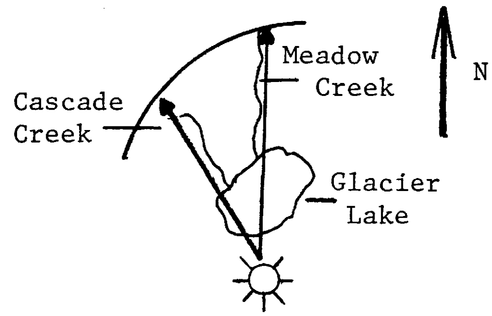
A. The high flows in Cascade Creek, as reflected by the mean monthly flows, are lagged relative to the high flows in Meadow Creek.

B. The direct correlation between the two streams for the period of record available is generally poor, with the exception of the month of July.

The following factors may be responsible for these observations:

A. Lag of high flows

The geographic and topographic features of the two catchments are essentially the same. In addition, the 1988 isohyetal map suggests that precipitation over the two catchments is essentially the same. Furthermore, types, distribution, and density of vegetation are assumed to be approximately the same. These factors, therefore, cannot influence the lag observed. It is suggested that variations in net solar radiation input between the two areas may be responsible. The topographic map indicates that this area scribes a 1/4 circle as indicated in the figure below. The differences in slope aspect may be sufficient to cause the observed lag in flows because the Meadow Creek watershed would receive more direct solar radiation input for a longer duration of time during the late spring and summer months. The result would be that the snowpack in the Meadow Creek watershed would begin to melt earlier and at a faster rate than the snowpack in the Cascade Creek watershed and be expressed as larger early season flows as observed.



The above hypothesis is based on limited information. To determine the validity of this hypothesis, the necessary equipment to determine the solar radiation influx would have to be installed. The data provided by this instrumentation would allow for the calculation of potential rates of melting.

In addition, the potentially significant effects of a large ice field in this area have been ignored. It has been assumed, for purposes of the above argument, that this ice field covers both watersheds uniformly (which it does not) and can therefore be considered a constant (i.e., affecting the watersheds in a manner similar to uniform PPT). Cascade Creek also has much steeper relief than Meadow Creek which may also be a cause for the differences.

B. Correlation of Streamflows

As indicated, the data show poor correlation, with the exception of the month of July. Although this poor correlation may be due to random events, it is proposed that what may actually be occurring is a transition between two states of equilibrium. These two states of equilibrium are categorized, for purposes here, as a "winter equilibrium" and "summer equilibrium" state with the transition between the two states occurring at different rates in the two catchments. The winter equilibrium state for both catchments would be characterized by the following conditions:

1. Soil, and zone of interflow, frozen to the frost line.
2. Deactivation of the groundwater system as a direct result of 1.
3. Losses in the catchment are only a result of:
    - (a) surface flow
    - (b) evaporation (sublimation)
    - (c) transpiration - affecting only waters directly adjacent to roots of coniferous vegetation.

The period of equilibrium under the above conditions would exist from late October or early November to late April or early May.

The summer equilibrium state would be characterized by different conditions. These would include:

1. An entirely thawed zone of interflow.
2. An entirely reactivated groundwater system as a direct result of 1.
3. Losses in the catchment as a result of:
    - (a) surface flow, evaporation and/or sublimation, and transpiration at maximum rates,

(b) groundwater flow.

The period of equilibrium under the above conditions would exist in mid-summer; July and August.

Between these two equilibrium extremes the following conditions would exist:

1. A gradually thawing or freezing zone of interflow.
2. A gradually reactivation or deactivation of groundwater systems and response to 1.
3. A gradual increase or decrease in evaporation and/or sublimation, and transpiration at gradually increasing or decreasing rates.

These intermediate conditions would occur from late April or early May to mid-summer; July or August with one of the two proposed equilibrium conditions occurring before or after this transitory state.

The lack of correlation between streamflows in Cascade and Meadow Creeks during these transition periods may again be the result of variations of net solar radiation input due to variations of the slope aspect. In as much as these two catchments have similar aerial extent, topographic features, vegetation cover, and precipitation input, a subtle feature such as variations in slope aspect may not be beyond the realm of possibilities to explain the observed differences.

The estimated total annual flows at the inlet to West Glacier Lake are given in Appendix A, Section 10 and for West Glacier Lake outlet in Appendix A, Section 11.

The mass transfer method (Appendix A, Section 12) was used to calculate the reservoir evaporation for East and West Glacier Lakes. This method was selected over other methods as the more extensive data required by these other methods were not available. The data used here were obtained from a totalizing anemometer and hygrothermograph located at the Telephone Lakes station and better reflect conditions at Glacier Lakes when compared to other stations in the area. Factors considered when selecting this station included topography, elevation, and exposure.

It was assumed that a free surface exists from June 1 to September 30 and that evaporation occurs only during this time interval. It is further assumed that the surface area of the lakes remained constant. The computed total annual loss by evaporation is 9.9 acre-feet for both East and West Glacier Lakes.

The Blaney-Criddle method (Appendix A, Section 13) was used to determine the evapotranspiration losses for both catchments. As with the mass transfer method, this method was selected as the more extensive data required by other methods were not available. It was assumed that the total evapotranspiration for the season could be reasonably approximated by considering only the losses occurring between June 1 and September 30 which is the period of maximum plant growth. A significant fraction of the watershed areas consists of bare rock with negligible moisture-holding capacity. Evaporation from such a surface would be limited to the drying of a wet surface immediately after a precipitation event. Therefore, the majority of moisture returned to the atmosphere occurs over areas where soil development is sufficient to retain water and support plant life. The evapotranspiration estimate must therefore be adjusted to reflect the percentage of groundcover in the catchment. For computational purposes it has been assumed that 35 percent groundcover exists in both catchments and that a linear relationship exists between percent groundcover and total evapotranspiration losses. The results of the computations indicate that 288.1 acre-feet of moisture is lost via evapotranspiration over the West Glacier Lake watershed and 119.9 acre-feet is lost over the East Glacier Lake watershed during the indicated time period.

Using the values computed for surface discharge, evapotranspiration, and precipitation input, a water budget was calculated for East and West Glacier Lakes (Appendix A, Sections 14 and 15). The water budget computations for West Glacier Lake indicate that 517.5 acre-feet more of water was discharged from the catchment than was being supplied by precipitation input. It is proposed that this excess moisture is being supplied by a large semi-permanent snowfield that has been receding over the past several years. This ice field straddles the northwestern most portions of the East and West Glacier Lakes watersheds and was formed by blowing snow being deposited on the leeward side of the mountain peaks. This snow (or ice) represents a net moisture input to the catchments that is not recorded by precipitation gages located lower in the catchment. An estimate of the size of the snowfield needed to produce the required volume of water can be made by selecting a density value for the snow and calculating the equivalent water content on a volume basis. Then, by selecting various values for the depth of snow, the areal size can be computed. Such computations (Appendix A, Sections 14 and 15) indicate that for a density of 2.8 pounds/cu. foot and a 10-foot uniform depth, the snowfield would have to cover 119 acres. For a 20-foot depth, 59.5 acres would be required. Direct observations of the size of the snowfield indicates that these values are not completely unreasonable as upper and lower size limits and that the largest amount of unaccounted outflow comes from this snowfield. It is observed during the summer season that a large amount of flow into West Glacier Lake and to the outlet of the lake results from water melting from the permanent snowfield. Water can be heard running through the large boulders in a small drainage to the east of Meadow Creek and also one to the west of Cascade Creek which are unavailable for surface measurement.

However, several other quantities can contribute to the outflow in West Glacier Lake, including subsurface flow from East Glacier Lake into West Glacier Lake. The 26.1 acre-feet of unaccounted water from the East Glacier Lake Water Balance could be seeping into West Glacier Lake. The largest problem in this whole water balance effort is the unknown of groundwater movement in the area.

Task 3. Errors Associated With Water Balance

An excellent summary of the problems associated with water balance studies on lakes is given in a paper by Winter (1981) entitled "Uncertainties in Estimating the

Water Balance of Lakes." These same problems exist with trying to do water balance studies on East and West Glacier Lakes and their watershed areas. A reproduction of the abstract of that paper is given below.

> *ABSTRACT: Evaluation of hydrologic methodology used in a number of water balance studies of lakes in the United States shows that most of these studies calculate one or more terms of the budget as the residual. A literature review was made of studies in which the primary purpose was error analysis of hydrologic measurement and interpretation. Estimates of precipitation can have a wide range of error, depending on the gage placement, gage spacing, and areal averaging technique. Errors in measurement of individual storms can be as high as 75 percent. Errors in short-term averages are commonly in the 15-30 percent range, but decrease to about 5 percent or less for annual estimates. Errors in estimates of evaporation can also vary widely depending on instrumentation and methodology. The energy budget is the most accurate method of calculating evaporation; errors are in the 10-15 percent range. If pans are used that are located a distance from the lake of interest, errors can be considerable. Annual pan-to-lake coefficients should not be used for monthly estimates of evaporation because they differ from the commonly used coefficient of 0.7 by more than 100 percent. Errors in estimates of stream discharge are often considered to be within 5 percent. If the measuring section, type of flow profile, and other considerations, such as stage discharge relationship, are less than ideal, errors in estimates of stream discharge can be considerably greater than 5 percent. Errors in estimating overland (nonchannelized) flow have not been evaluated, and in most lake studies this component is not mentioned. Comparison of several lake water balances in which the residual consists solely of errors in measurement, shows that such a residual, if interpreted as ground water, can differ from an independent estimate of ground water by more than 100 percent.*

Precipitation measurements overall seemed very good except for the Lost Lake precipitation gage. This gage seems to record actual precipitation, on the average, about 25 percent lower than many of the surrounding gages. A check of this precipitation gage will be made in the near future.

It is difficult to estimate evaporation and evapotranspiration accurately by the methods used. The values obtained could be as high as 75 to 100 percent error.

Streamflow measurements of surface water discharge should generally be within 5 percent of actual because of the Parshall flumes being used, except during Fall freeze periods. On a yearly basis, however, the values obtained should definitely be within 5 percent, except perhaps for West Glacier Lake outlet. During most of the year, a small amount of seepage occurs at the outlet of West Glacier Lake under the hypalon cutoff liner which could amount to as much as 0.5 cfs during larger flows and approximately 0.25 cfs during the fall period.

Groundwater flow was considered to be in balance over a yearly period. This assumption should be approximately true with errors in the range of 5 to 10 percent. However, as noted under Task 2, it is believed that seepage does occur from East Glacier into West Glacier which could account for some of the difference. Any water balance studies done on less than a yearly period would have to account for groundwater movement into and out of the area. The amount of groundwater movement out of the two watershed areas could be sizeable during certain months such as June, July and August.

It is believed that the largest source of error in the West Glacier Lake Watershed is the permanent snowfield that exists along the north and west ends of the watershed divide. It is believed that the accumulation of blowing snow from adjacent watersheds along with the difference between yearly hold-over storage of the snowfield can result in over 100 percent errors in estimation of the water balance of West Glacier Lake. It is indicated from the water balance study done that this phenomena is not as pronounced on East Glacier Lake.

Task 4. Suggestions for Error Minimization

The following ideas and/or suggestions are made to reduce the errors associated with a water balance study on either East or West Glacier Lake watersheds.

Precipitation gages should be checked to make sure that they are operating correctly and the weighing mechanisms are accurate to within the limits of the instrumentation as indicated by the manufacturer. All precipitation gages should be shielded from the wind since much of the area is subject to high winds during the winter period.

At least one land evaporation pan should be installed within the entire watershed area so that the estimates of evaporation and evapotranspiration can be made more accurately than was done under this study of water balance. Reference on this point is also made to Winter (1981).

A detailed snow survey of the two watershed areas needs to be made in late April or when the snowpack is close to being ripe to determine the actual amount of water stored during the winter period as a result of precipitation and blowing snow accumulation from adjacent watersheds. This task could be very difficult on the West Glacier Lake Watershed because of the cornices that are formed as a result of the blowing snow.

The semi-permanent snowfield needs to be measured in the fall of each year near the end of the melt period for the snowfield. The change in volume each year can then be determined. It will be necessary to get a reasonably accurate estimate of the density of the snowfield at this time also.

Any water balance studies made over a shorter period than one year will require runoff occurring either as overland flow directly into the lake or unmeasured surface inflow that cannot be obtained due to boulder fields. Both of these estimations (groundwater movement and unmeasured surface flows) on these two watershed areas can amount to as much as 100 percent or greater errors in the water balance. No easy solution to these problems exist. Physical measurement techniques to quantify the amount of water input to or output from the given lake water balance in these two watersheds is almost impossible without an undue amount of land disturbance.

Groundwater movement can be estimated by placing piezometers at selected locations throughout the watershed area to determine groundwater gradients. Using an estimate for hydraulic conductivity that can be done either by estimation from soil type and structure or infield tests (several available including pumping), Darcy's Law can be applied to a cross section of the area to determine flow. Cross sections can be obtained in these areas using surface geophysical techniques as performed in Task 5.

Finally, the hypalon liner at the West Glacier Lake outlet should be improved to prevent as much seepage as possible from moving under the liner.

Task 5. Depth Measurement of Unconsolidated Material

In order to get a better feel for possible groundwater movement in the East and West Glacier Lake watersheds, a number of cross sections were selected to obtain the depth of unconsolidated material available for groundwater flow throughout the watersheds. A surface geophysical technique known as seismic refraction was performed using a hammer to create the sound wave and several geophones to detect the sound wave movement to determine the depth to bedrock material.

Eight different cross sections were obtained using the seismic refraction technique. The cross-sectional sites were selected in cooperation with the RMS. Appendix D has a map which indicates the location of the 8 cross sections. Each of the 8 cross sections is schematically shown in Appendix D as determined from the seismic refraction data. The analysis of the data obtained is also contained as a part of Appendix D.

Most of the depths to the base of the weathering layer (velocity 200-500 fps) are quite reliable. The layer with velocities in the range from 200-4,000 fps is probably glacial material. Velocities above 4,000 fps and up to 7,000 fps are at a higher velocity than would be expected for glacial debris, but it is possible. The cross sections drawn are, therefore, the author's interpretations in some instances. The granite bedrock material was expected to have a velocity around 16,000-18,000 fps. Since these velocities were not measured that often, it could be possible for the glacial material to be as much as 20 feet thick as is shown on most of the cross sections which rests on a highly disturbed bedrock surface which would account for the slower velocities measured in several instances.

A crude estimate of hydraulic conductivity was determined using information from the water balance study and the seismic refraction cross sections. Appendix E shows the calculations and gives the limitations used in the estimates. Values for the hydraulic conductivity were found to be between 25 and 146 gpd/ft^2.

Reference

Winter, T.C., "Uncertainties In Estimating the Water Balance of Lakes", Water Resources Bulletin, American Water Resources Association, Vol. 17, No. 1, pp. 82-115, February, 1981.

APPENDIX A

SECTION 1.

CALCULATION OF WATERSHED AREA FOR EAST GLACIER LAKE (EGL) USING 1:24000 USGS MAP.

PURPOSE: TO DETERMINE TRUE AREA OF EGL WATERSHED

METHODOLOGY: K + E VERNIER PLANIMETER.

WATERSHED FOR
EAST GLACIER LAKE FROM 1:24000 MAP (USGS)

A = 0062

A = 62 × .01 = .62 IN^2

@ 1:24,000 6.969 IN^2 = 640 ACRES

$.62 IN^2 \left(\frac{640 ACRES}{6.969 IN^2}\right)$ = 56.9 ACRES ∴ LOW

A = 0066 = .66 IN^2

$.66 IN^2 \left(\frac{640 ACRES}{6.969 IN^2}\right)$ = 60.6 ACRES

0132
− .0066
66

A = 60.6 ACRES

0200
− 0132
68

A = $.68 IN^2 \left(\frac{640 ACRES}{6.969 IN^2}\right)$ = 62.45 ACRES
∴ HIGH

0265
− 0200
65

A = $.65 IN^2 \left(\frac{640 ACRES}{6.969 IN^2}\right)$ = 59.7 ACRES

THROW OUT HIGH AND LOW ; AVE. REMAINING
3

$\frac{60.6 + 60.6 + 59.7}{3}$ = 60.3 ACRES

SECTION 2

CALCULATION OF WATERSHED AREA FOR EGL USING 1:12000 NASH FORK CK. MAP

PURPOSE: TO DETERMINE POTENTIAL DISTORTIONS OF ENLARGEMENT. (THE NASH FORK CK. MAP IS AN ENLARGED VERSION OF 1:24000 USGS MAP).

METHODOLOGY: K + E VERNIER PLANIMETER

WATERSHED FOR EAST GLACIER LAKE FROM 1:12000 MAP

SNOWY RANGE OBS.
NASH FORK CREEK

A = 0266 .01 sq IN = 1 V.U.

A = 266 × .01 = 2.66 IN²

1 IN = 1000' 1 SECTION = 1 mi² = 640 ACRES

$$1\,mi = 5280\,ft\left(\frac{1\,IN}{1000\,ft}\right) = 5.28\,IN$$

$$1\,SECTION = (5.28\,IN)^2 = 27.878\,IN^2 = 640\,ACRE$$

$$2.66\,IN^2 \times \left(\frac{640\,ACRE}{27.878\,IN^2}\right) = \underline{\underline{61.0\ ACRES}}$$

0263 = 2.63 IN²

$$2.63\left(\frac{640}{27.878}\right) = \underline{\underline{60.38\ ACRES}} \quad \therefore LOW$$

$$\begin{array}{r} 0529 \\ -0263 \\ \hline 0266 \end{array} \qquad A = \underline{\underline{61.0\ ACRES}}$$

$$\begin{array}{r} 0794 \\ -0529 \\ \hline 265 \end{array} \qquad A = 2.65\left(\frac{640}{27.878}\right) = \underline{\underline{60.84}}\ ACRES$$

$$\begin{array}{r} 1062 \\ -0794 \\ \hline 268 \end{array} \qquad A = 2.68\left(\frac{640}{27.878}\right) = \underline{61.53\ ACRES}$$

∴ HIGH

THROW OUT HIGH AND LOW; AVE. REMAINING 3

$$\frac{61 + 61 + 60.84}{3} = \underline{60.95\ ACRES} \longleftarrow$$

SECTION 3

CALCULATION OF WATERSHED AREA FOR WEST GLACIER LAKE (WGL) USING 1:12000 NASH FORK CK. MAP

PURPOSE: TO DETERMINE THE AREA OF THE WGL WATERSHED

METHODOLOGY: K + E VERNIER PLANIMETER

WATERSHED FOR
WEST GLACIER LAKE FROM 1:12000 MAP
SNOWY RANGE OBSERVATORY
NASH FORK CREEK

$A = 0639 = 6.39\ in^2$

$6.39\ in^2 \left(\frac{640\ ACRES}{27.878\ in^2} \right) = \underline{146.7\ ACRES}$

$$\begin{array}{r} 1279 \\ -0639 \\ \hline 640 \end{array}$$

$A = 6.40\ in^2 \left(\frac{640\ ACRES}{27.878\ in^2} \right) = \underline{146.9\ ACRES}$

$\therefore$ HIGH

$0633 = 6.33\ in^2$

$A = 6.33\ in^2 \left(\frac{640\ ACRES}{27.878\ in^2} \right) = \underline{145.3\ ACRES}$

$\therefore$ LOW

$$\begin{array}{r} 1271 \\ -0633 \\ \hline 638 \end{array} = 6.38\ in^2$$

$6.38\ in^2 \left(\frac{640\ ACRES}{27.878\ in^2} \right) = \underline{146.5\ ACRES}$

$$\begin{array}{r} 1908 \\ -1271 \\ \hline 637 \end{array} = 6.37\ in^2$$

$6.37\ in^2 \left(\frac{640\ ACRES}{27.878\ in^2} \right) = \underline{146.2\ ACRES}$

THROW OUT HIGH AND LOW; AVE REMAINING 3

$\frac{146.7 + 146.5 + 146.2}{3} = \underline{146.5\ ACRES}$

SECTION 4

PRELIMINARY COMPILATION OF YEARLY PPT TOTALS, BY WATER YEAR, AT SITES AROUND EGL AND WGL

PURPOSE: TO DEVELOP DATABASE REQUIRED FOR GENERATION OF ISOHYETAL MAPS.

DATA BASE: WWRC - WRDS DATA FILE; APPENDIX B

YEARLY PPT TOTALS BY WATER YEAR (FROM WRDS)

BROOKLYN LAKE: (0115A - 35)

OCT. 87 TO SEPT, 88

33.14 IN - INCOMPLETE (THROUGH JUNE '88)

BROOKLYN LAKE: (0115 - 2)

OCT, 86 TO SEPT. 87 : 32.69"

OCT. 87 TO SEPT. 88 : 42.14" INCOMPLETE (THROUGH JUNE '88)

LOST LAKE (0126)

OCT. 86 TO SEPT. 87 : 26.84"

OCT. 87 TO SEPT. 88 : 23.42" INCOMPLETE (THROUGH JUNE '88)

GLACIER LAKE (0125)

OCT. 86 TO SEPT. 87 : 26.24"

OCT. 87 TO SEPT. 88 : 31.24" INCOMPLETE (THROUGH JUNE 88)

SECTION 5

CALCULATION OF MONTHLY PPT. TOTALS AT SITES
AROUND EGL AND WGL

PURPOSE: TO PROVIDE MISSING DATA FOR
CALCULATION OF YEARLY PPT.

METHODOLOGY: COMPILED FROM STATION STRIP
CHARTS - WWRC

MONTHLY PPT TOTALS

LOCATION: BROOKLYN LAKE (0115A - 35)

MONTH - YR	PPT (INCHES)	
JUNE 88	1.26	NOTE: 3rd WEEK MISSING
JULY 88	1.0	
AUG. 88	.81	
SEPT. 88	1.74	
OCT. 88	.75	
NOV. 88	4.74	PROBLEM WITH CHART. LAST 2 DAYS OF NOV. INCLUDED WITH DEC.
DEC. 88	5.39	
JAN 89	3.85	
FEB 89	4.80	
MARCH 89	4.64	
APRIL 89	3.50	
MAY 89	2.17	
JUNE 89	1.5	
JULY 89	1.23	
AUG. 89	1.43	
SEPT. 89	1.23	

MONTHLY PRECIPITATION TOTALS

LOCATION : BROOKLYN LAKE (0115 -2)

MONTH - YR	PPT (INCHES)
JULY 88	1.13
AUG. 88	.98
SEPT. 88	2.17
OCT. 88	.67
NOV. 88	6.72
DEC. 88	3.04
JAN. 89	3.42
FEB. 89	6.18
MARCH 89	6.2
APRIL 89	4.08
MAY 89	2.23
JUNE 89	1.72
JULY 89	1.23
AUG 89	1.69
SEPT. 89	1.8

MONTHLY PRECIPITATION TOTALS

LOCATION: LOST LAKE (0126)

MONTH - YR	PPT. (INCHES)
JUNE 88	1.65
JULY 88	.91
AUG. 88	.94
SEPT. 88	1.70
OCT. 88	.57
NOV. 88	3.46
DEC. 88	1.94
JAN. 89	1.81
FEB. 89	3.06
MARCH 89	2.55
APRIL 89	1.63
MAY 89	1.54
JUNE 89	1.81
JULY 89	2.32
AUG. 89	1.74
SEPT 89	1.79

NOTE: CLOCK STOPPED FROM 9/27 → 10/4. TOTAL COLLECTED = .52" THIS IS ADDED INTO SEPT. VALUE.

NOTE: DEC 21 → 27 MISSING

MONTHLY PPT TOTALS

LOCATION: GLACIER LAKE (0125)

MONTH - YR	PPT (INCHES)	
JUNE 88	.96	
JULY 88	.82	
AUG. 88	.84	
SEPT 88	2.00	
OCT. 88	.69	
NOV. 88	5.24	
DEC. 88	3.0	
JAN. 89	2.84	
FEB 89	3.99	
MARCH 89	3.84	
APRIL 89	2.74	
MAY 89	1.84	
JUNE 89	1.5	NOTE: 1st WEEK OF JUNE MISSING
JULY 89	1.58	
AUG. 89	1.44	
SEPT. 89	1.78	

SECTION 6

REVISED CALCULATIONS OF YEARLY PPT. TOTALS, BY WATER YEAR, AT SITES AROUND EGL AND WGL.

YEARLY PPT TOTALS BY WATER YEAR

- REVISED WITH DATA FROM STRIP CHARTS

BROOKLYN LAKE (0115A - 35)

OCT. 87 TO SEPT. 88 : 37.95"

OCT. 88 TO SEPT. 89 : 35.73"

BROOKLYN LAKE (0115 - Z)

OCT. 87 TO SEPT. 88 : 46.42"

OCT 88 TO SEPT 89 : 38.98"

LOST LAKE (0126)

OCT 87 TO SEPT 88 : 26.97"

OCT 88 TO SEPT 89 : 24.22"

Question these data values?

GLACIER LAKE (0125)

OCT 87 TO SEPT 88 : 34.9"

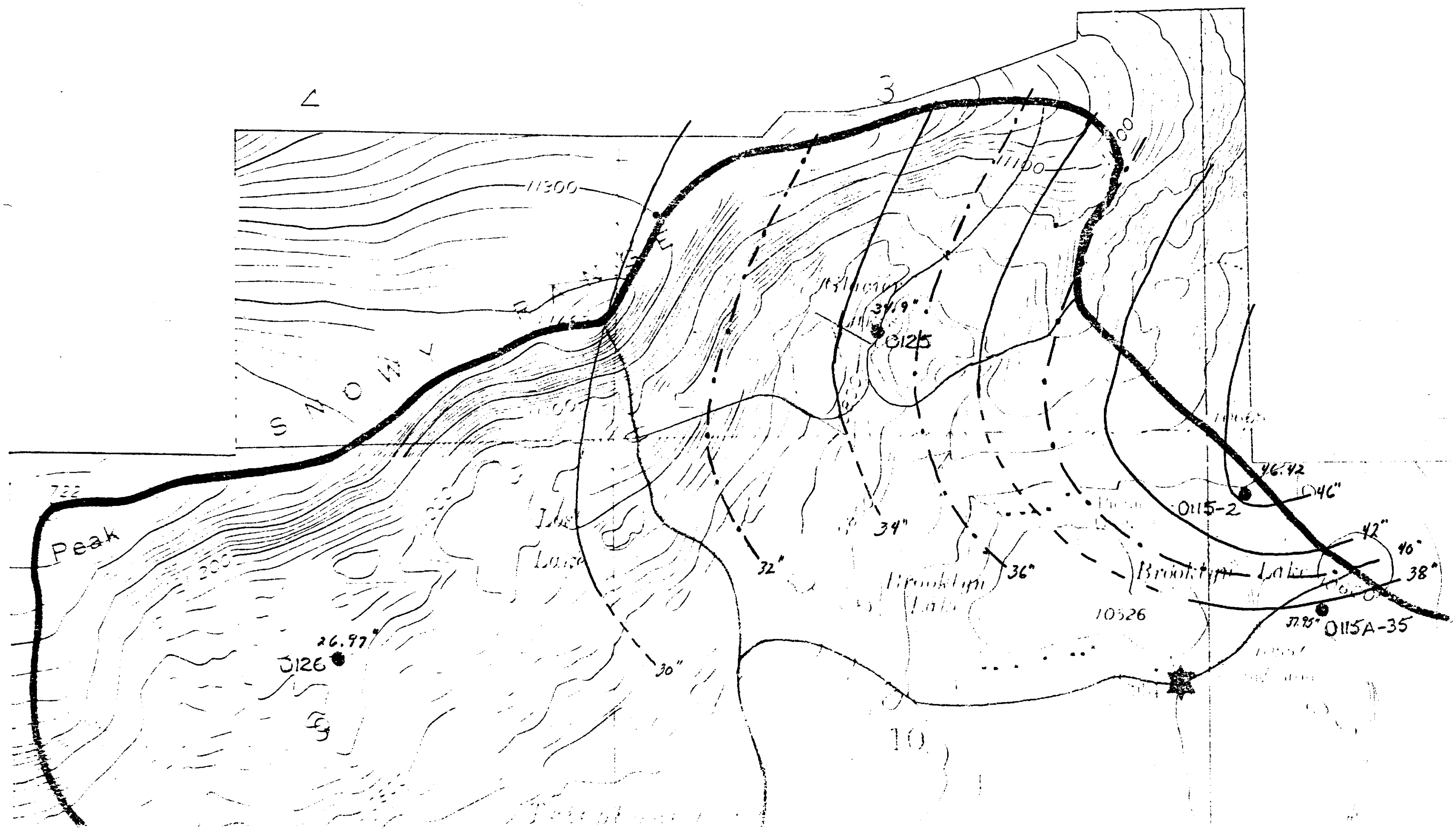
OCT 88 TO SEPT 89 : 30.48"

SECTION 7

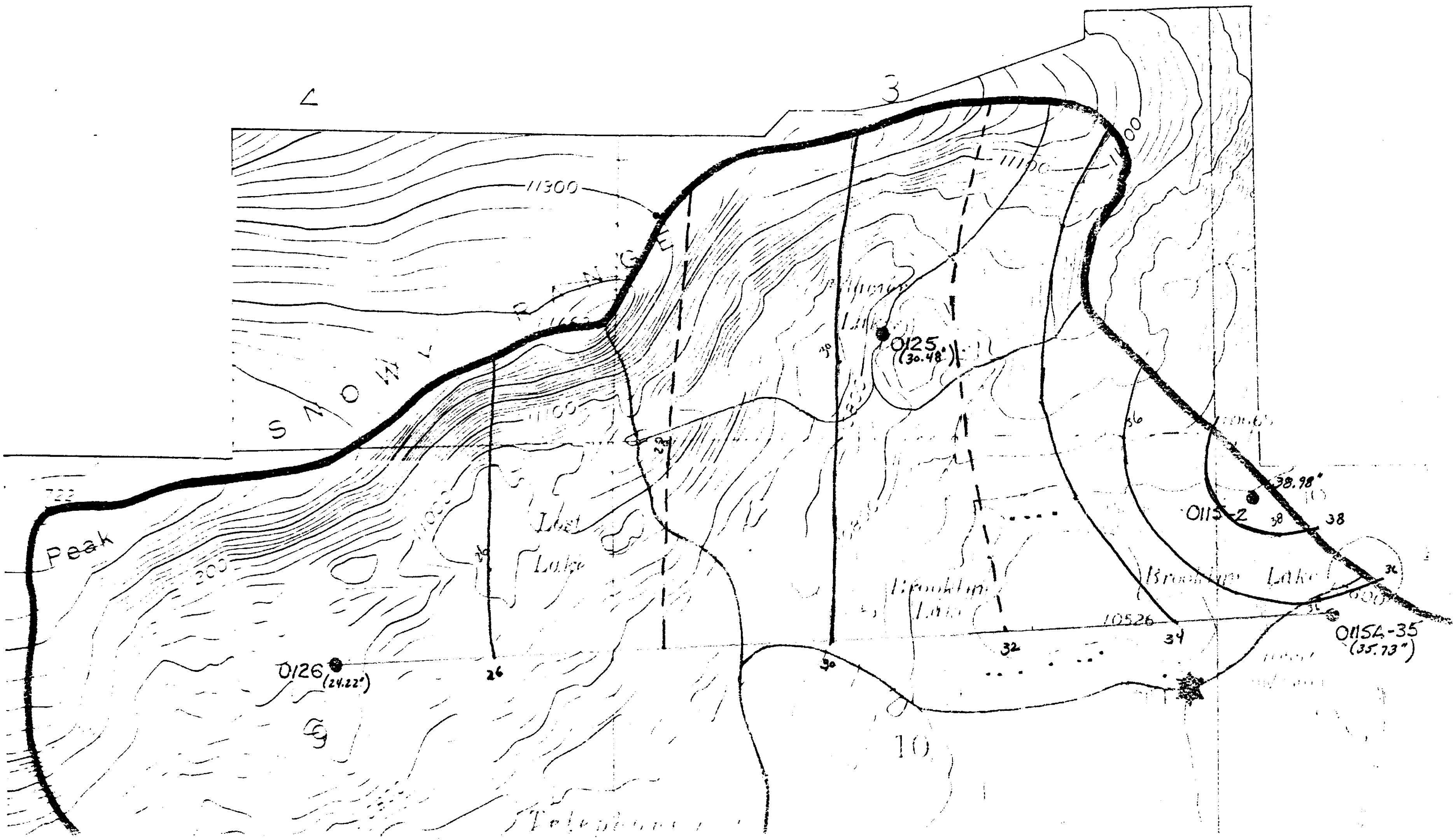
DETERMINATION OF AVERAGE PPT. OVER EGL AND WGL FOR 1988 AND 1989 WATER YEARS.

METHODOLOGY : ISOHYETAL METHOD

Isohyetal Map for 1988
Water Year



ISOHYETAL MAP FOR
1989 WATER YEAR



CALCULATION OF PPT. OVER WATERSHEDS FOR 1988 WATER YEAR USING ISOHYETAL METHOD

WEST GLACIER LAKE:

31" ISOHYET: $A = 0217 = 2.17\ in^2$

$$2.17\ in^2 \left(\frac{640\ ACRES}{27.878\ in^2} \right) = 49.82\ ACRES$$

$$\begin{array}{r} 0433 \\ -\,0217 \\ \hline 0216 \end{array}$$

$A = 0216 = 2.16\ in^2$

$$2.16\ in^2 \left(\frac{640\ ACRES}{27.878\ in^2} \right) = 49.59\ ACRES$$

$$A_{AVE} = \left(\frac{49.59 + 49.82}{2} \right) ACRES = \underline{49.71\ ACRES}$$

34" ISOHYET:

$A = 0387 = 3.87\ in^2$

$$3.87\ in^2 \left(\frac{640\ ACRES}{27.878\ in^2} \right) = 88.84\ ACRES$$

$$\begin{array}{r} 0776 \\ -\,0387 \\ \hline 389 \end{array}$$

$$3.89\ in^2 \left(\frac{640\ ACRES}{27.878\ in^2} \right) = 89.3\ ACRES$$

$$A_{AVE} = \left(\frac{89.3 + 88.84}{2} \right) ACRES = \underline{89.07\ ACRES}$$

37" ISOHYET:

$A = 0029 = .29\ ACRES$

$$.29\ ACRES \left(\frac{640\ ACRES}{27.878\ in^2} \right) = 6.66\ ACRES$$

CALC. OF PPT. OVER WATERSHED FOR 1998 WATER YEAR CONT.

WEST GLACIER LAKE (CONT)

$$A = \frac{\begin{array}{r}0057\\ \cdot 0029\end{array}}{28} = .28\,IN^2$$

$$.28\,IN^2 \left(\frac{640\ ACRES}{27.878\,IN^2} \right) = 6.43\ ACRES$$

$$A_{AVE} = \frac{(6.66 + 6.43)}{2}\ ACRES = \underline{6.55\ ACRES}$$

$$PPT_{AVE} = \Sigma(PA)/\Sigma A$$

$$= \frac{31''(49.71\,AC) + 34''(89.07\,AC) + 37''(6.55\,AC)}{145.33\,AC}$$

$$\underline{= 33.11''}$$

EAST GLACIER LAKE:

<u>35" ISOHYET:</u>

$$A = 0042 = .42\,IN^2 = 9.64\ ACRES$$

$$\frac{\begin{array}{r}0081\\ 0042\end{array}}{39} = .39\,IN^2 = 8.95\ ACRES$$

$$A_{AVE} = 9.30\ ACRES$$

<u>38" ISOHYET</u>

$$A = 0224 = 2.24\,IN^2 = 51.42\ ACRES$$

$$A = 0223 = 2.23\,IN^2 = 51.19\ ACRES$$

$$A_{AVE} = 51.31\ ACRES$$

CALC. OF PPT. OVER WATERSHED FOR 1988 WATER YEAR CON'T.

EAST GLACIER LAKE (CON'T.)

$$PPT_{AVE} = \frac{35''(9.3\text{ AC}) + 38''(51.31\text{ AC})}{60.61\text{ ACRES}}$$

$$= 37.54''$$

CALC. OF PPT. OVER WATERSHED FOR 1989 WATER YEAR. USING ISOHYETAL METHOD

WEST GLACIER LAKE:

27.5" ISOHYET:

$A = 0085 = .85\ in^2 = 19.51$ ACRES

0171
-0085
0086 $\quad A = .86\ in^2 = 19.74$ ACRES

$A_{AVE} = 19.63$ ACRES

30" ISOHYET:

$A = 0544 = 5.44\ in^2 = 124.89$ ACRES

$A = 0540 = 5.40\ in^2 = 123.97$ ACRES

$A_{AVE} = 124.43$ ACRES

33" ISOHYET

$A = 0051 = .51\ in^2 = 11.71$ ACRES

0102
-0051
51 ; SAME AREA

$$PPT_{AVE} = \frac{27.5''(19.63\text{ AC}) + 30''(124.43\text{ AC}) + 33''(11.71\text{ AC})}{155.88\text{ AC.}}$$

$= 29.89''$

CALC. OF PPT. OVER WATERSHED FOR 1989 WATER YEAR
USING ISOHYETAL METHOD

EAST GLACIER LAKE:

31.5" ISOHYET:

$A = 0065 = .65\,in^2 = 14.92$ ACRES

$$\begin{array}{r} 0129 \\ -0065 \\ \hline 0064 \end{array} \qquad A = .64\,in^2 = 14.69 \text{ ACRES}$$

$A_{AVE} = 14.81$ ACRES

34" ISOHYET:

$A = 0198 = 1.98\,in^2 = 45.46$ ACRES

$$\begin{array}{r} 0395 \\ -0198 \\ \hline 197 \end{array} \qquad A = 1.97\,in^2 = 45.23 \text{ ACRES}$$

$$PPT_{AVE} = \frac{31.5\,(14.81\,AC) + 34''\,(45.23\,AC)}{60.04}$$

$$= \underline{\underline{33.38''}}$$

SECTION 8

PRELIMINARY COMPILATION OF TOTAL ANNUAL STREAMFLOWS FOR CASCADE AND MEADOW CREEKS IN THE WGL WATERSHED.

DATA BASE: WWRC - WRDS DATA FILE
APPENDIX C

STREAMFLOWS: (TOTAL ANNUAL FLOWS)*

THE 1988 WATER YEAR IS THE ONLY YEAR FOR WHICH ADEQUATE DATA EXISTS FOR ALL STREAMFLOWS:

CASCADE CREEK: 117.35 ACRE·FT

THE RECORD RUNS FROM MAY 24th TO SEPT. 30th WITH 9 DAILY RECORDS MISSING IN JUNE, 1 IN JULY, 1 IN AUG., AND 7 IN SEPT.

MEADOW CREEK: 107.55 ACRE·FT

THE RECORD RUNS FROM MAY 27th TO SEPT. 30th

A SIMPLE REGRESSION ANALYSIS HAS BEEN RUN TO PROVIDE THE MISSING RECORDS. THIS WILL PROVIDE CONTINUOUS RECORD RUNNING FROM MAY 24th TO SEPT. 30th ON CASCADE AND MEADOW CREEKS.

* ASSUMES THAT ALTHOUGH FLOW PROBABLY OCCURS FROM OCT. THROUGH APRIL THESE VOLUMES ARE INSIGNIFICANT. IN ADDITION, RECORDS ARE NOT AVAILABLE FOR THIS TIME PERIOD.

SECTION 9

REGRESSION ANALYSIS OF MEADOW (MDW) AND CASCADE (CASC) CREEKS.

PURPOSE: TO FILL IN MISSING RECORDS

METHODOLOGY: MINITAB STATISTICAL SOFTWARE PACKAGE

```
MTB > PRINT C1 C2

 ROW  CASC5/88  MDW5/88

   1      0.39      0.47
   2      0.41      0.48
   3      0.47      0.54
   4      0.44      0.55
   5      0.24      0.44

MTB >
MTB > REGR C2 ON 1 PREDICTOR IN C1

The regression equation is
MDW5/88 = 0.321 + 0.450 CASC5/88

Predictor        Coef        Stdev     t-ratio        p
Constant      0.32062      0.06430        4.99    0.016
CASC5/88       0.4497       0.1615        2.78    0.069

s = 0.02881      R-sq = 72.1%      R-sq(adj) = 62.8%

Analysis of Variance

SOURCE        DF          SS           MS          F        p
Regression     1   0.0064305    0.0064305       7.75    0.069
Error          3   0.0024895    0.0008298
Total          4   0.0089200
```

```
MTB > PRINT C1 C2

 ROW  MDW6/88  CASC6/88

   1     0.38      0.16
   2     0.36      0.22
   3     0.44      0.39
   4     0.63      0.63
   5     0.84      0.79
   6     0.97      0.79
   7     0.93      0.77
   8     0.81      0.73
   9     0.78      0.75
  10     0.78      0.87
  11     0.74      0.77
  12     0.68      0.72
  13     0.57      0.65
  14     0.59      0.64
  15     0.55      0.72
  16     0.82      1.16
  17     0.90      1.22
  18     0.90      1.15
  19     0.78      1.03
  20     0.76      1.00
  21     0.69      0.80

MTB > REGR C2 ON 1 PREDICTOR IN C1

The regression equation is
CASC6/88 = - 0.147 + 1.28 MDW6/88

Predictor       Coef       Stdev    t-ratio        p
Constant     -0.1469      0.1505      -0.98    0.341
MDW6/88       1.2782      0.2062       6.20    0.000

s = 0.1619      R-sq = 66.9%     R-sq(adj) = 65.2%

Analysis of Variance

SOURCE       DF          SS          MS         F        p
Regression    1      1.0078      1.0078     38.44    0.000
Error        19      0.4982      0.0262
Total        20      1.5060

Unusual Observations
Obs. MDW6/88  CASC6/88       Fit Stdev.Fit  Residual   St.Resid
  6    0.970    0.7900    1.0929    0.0643   -0.3029     -2.04R

R denotes an obs. with a large st. resid.
```

MTB > PRINT C1 C2

ROW	MDW7/88	CASC7/88
1	0.62	0.75
2	0.62	0.78
3	0.65	0.81
4	0.76	0.95
5	0.77	1.00
6	0.74	0.97
7	0.66	0.85
8	0.61	0.81
9	0.53	0.68
10	0.45	0.61
11	0.43	0.60
12	0.48	0.69
13	0.54	0.75
14	0.55	0.75
15	0.51	0.70
16	0.51	0.70
17	0.52	0.72
18	0.51	0.70
19	0.50	0.65
20	0.44	0.56
21	0.44	0.58
22	0.46	0.59
23	0.45	0.57
24	0.49	0.64
25	0.46	0.59
26	0.39	0.55
27	0.44	0.57
28	0.51	0.70
29	0.53	0.71
30	0.55	0.78

```
MTB > REGR C2 ON 1 PREDICTOR IN C1

The regression equation is
CASC7/88 = 0.0760 + 1.18 MDW7/88

Predictor        Coef        Stdev     t-ratio        p
Constant      0.07598      0.02924        2.60    0.015
MDW7/88       1.18056      0.05353       22.06    0.000

s = 0.02887     R-sq = 94.6%     R-sq(adj) = 94.4%

Analysis of Variance

SOURCE         DF          SS          MS         F        p
Regression      1     0.40555     0.40555    486.45    0.000
Error          28     0.02334     0.00083
Total          29     0.42890

Unusual Observations
Obs. MDW7/88  CASC7/88        Fit Stdev.Fit  Residual   St.Resid
  1     0.620   0.75000   0.80793   0.00688  -0.05793     -2.07R
  4     0.760   0.95000   0.97320   0.01303  -0.02320     -0.90 X
  5     0.770   1.00000   0.98501   0.01352   0.01499      0.59 X
```

```
MTB > PRINT C1 C2

 ROW   MDW8/88   CASC8/88

   1      0.48       0.59
   2      0.40       0.56
   3      0.40       0.56
   4      0.35       0.46
   5      0.32       0.45
   6      0.32       0.49
   7      0.28       0.41
   8      0.28       0.38
   9      0.30       0.44
  10      0.31       0.47
  11      0.31       0.43
  12      0.32       0.49
  13      0.35       0.54
  14      0.34       0.49
  15      0.36       0.64
  16      0.26       0.49
  17      0.22       0.47
  18      0.21       0.39
  19      0.19       0.42
  20      0.28       0.65
  21      0.27       0.60
  22      0.22       0.41
  23      0.24       0.43
  24      0.20       0.33
  25      0.21       0.40
  26      0.22       0.41
  27      0.20       0.35
  28      0.19       0.32
  29      0.20       0.39
  30      0.23       0.40

MTB > REGR C2 ON 1 PREDICTOR IN C1

The regression equation is
CASC8/88 = 0.226 + 0.835 MDW8/88

Predictor        Coef       Stdev     t-ratio        p
Constant      0.22643     0.04609        4.91    0.000
MDW8/88        0.8353      0.1583        5.28    0.000

s = 0.06256     R-sq = 49.8%     R-sq(adj) = 48.1%

Analysis of Variance

SOURCE       DF          SS          MS          F         p
Regression    1     0.10891     0.10891      27.83     0.000
Error        28     0.10957     0.00391
Total        29     0.21848

Unusual Observations
Obs. MDW8/88  CASC8/88      Fit Stdev.Fit  Residual    St.Resid
  1    0.480    0.5900   0.6274    0.0334   -0.0374    -0.71 X
 20    0.280    0.6500   0.4603    0.0114    0.1897     3.08R
 21    0.270    0.6000   0.4520    0.0116    0.1480     2.41R
```

```
MTB > PRINT C1 C2

 ROW   MDW9/88   CASC9/88

   1      0.24       0.43
   2      0.24       0.41
   3      0.22       0.37
   4      0.20       0.30
   5      0.19       0.40
   6      0.19       0.37
   7      0.21       0.33
   8      0.20       0.34
   9      0.20       0.37
  10      0.22       0.21
  11      0.20       0.10
  12      0.10       0.05
  13      0.06       0.16
  14      0.07       0.17
  15      0.06       0.17
  16      0.07       0.18
  17      0.09       0.21
  18      0.09       0.21
  19      0.08       0.18
  20      0.09       0.17
  21      0.04       0.07
  22      0.03       0.05
  23      0.03       0.06

MTB > REGR C2 ON 1 PREDICTOR IN C1

The regression equation is
CASC9/88 = 0.0487 + 1.34 MDW9/88

Predictor         Coef        Stdev     t-ratio        p
Constant       0.04875      0.03258        1.50    0.150
MDW9/88         1.3426       0.2108        6.37    0.000

s = 0.07489     R-sq = 65.9%     R-sq(adj) = 64.3%

Analysis of Variance

SOURCE         DF          SS           MS          F         p
Regression      1     0.22742      0.22742      40.55     0.000
Error          21     0.11777      0.00561
Total          22     0.34518

Unusual Observations
Obs. MDW9/88  CASC9/88        Fit Stdev.Fit  Residual    St.Resid
 11     0.200    0.1000     0.3173    0.0207   -0.2173      -3.02R

R denotes an obs. with a large st. resid.
```

SECTION 10

REVISED TOTAL ANNUAL FLOWS FOR MEADOW AND CASCADE CREEKS

REVISED TOTAL ANNUAL FLOWS FOR CASCADE AND MEADOW CREEKS BASED ON ADDITION OF MISSING MEAN DAILY FLOW DATA BY USE OF REGRESSION ANALYSIS. (1988 WATER YEAR)

CASCADE CREEK:

	MAY	JUNE	JULY	AUG.	SEPT.
TOTAL (CFS)	2.72	24.4	21.96	14.5	6.36
MEAN (CFS)	.34	.81	.71	.47	.21
AC·FT	5.40	48.38	43.66	28.9	12.5

TOTAL ANNUAL FLOW: 138.84 AC·FT

MEADOW CREEK:

	MAY	JUNE	JULY	AUG.	SEPT.
TOTAL (CFS)	3.79	22.50	16.61	8.96	3.67
MEAN (CFS)	.47	.75	.54	.29	.12
AC·FT	7.46	44.63	32.95	17.77	7.28

TOTAL ANNUAL FLOW: 110.1 AC·FT

FROM THE REVISED DATA THE TOTAL SURFACE FLOW INTO W. GLACIER LAKE FROM CASCADE AND MEADOW CREEKS IS:

$$\begin{array}{r} 138.84 \text{ AC·FT} \\ +\ 110.10 \text{ AC·FT} \\ \hline 248.94 \text{ AC·FT} \end{array}$$

SECTION 11

COMPILATION OF ANNUAL STREAMFLOW FOR THE WEST GLACIER LAKE OUTLET.

DATA BASE: WWRC-WRDS DATA FILE
APPENDIX C

CALC. OF ANNUAL FLOW, WGL OUTLET

MONTH	FLOW (AC·FT)
MAY	46.73
JUNE	262.81
JULY	199.54
AUG.	81.12
SEPT.	33.52
	623.72

623.72 AC·FT

A CONTINUOUS RECORD EXISTS FOR THIS STATION OVER THE PERIOD MAY 24 TO SEPT 30.

SECTION 12

CALCULATION OF RESERVIOR EVAPORATION FOR WEST AND EAST GLACIER LAKES.

DATABASE: FROM TOTALIZING ANEMOMETER AND HYGROTHERMOGRAPH DATA ENTRY FORMS; WWRC

METHODOLOGY: MASS TRANSFER METHOD

COMMENTS:

1. THE MASS TRANSFER METHOD WAS SELECTED OVER OTHER METHODS AS THE MORE EXTENSIVE DATA REQUIRED BY THE OTHER METHODS WAS UNAVAILABLE.

2. DATA USED HERE WAS OBTAINED FROM THE TELEPHONE LAKES STATION. THIS STATION WAS SELECTED OVER OTHER STATIONS AS IT MAY BETTER REFLECT CONDITIONS AT GLACIER LAKES. THESE CONDITIONS INCLUDE:

   A. TOPOGRAPHY
   B. ELEVATION
   C. EXPOSURE

CALCULATION OF RESERVOIR EVAPORATION FOR WEST AND EAST GLACIER LAKES

MASS TRANSFER METHOD:

$$E = C(e_o - e_a)\left[1 + \frac{\bar{W}}{10}\right]$$

E = IN./MONTH
C = 14
e_o : SAT. VAPOR PRESS. @ MEAN MONTHLY TEMP IN INCHES OF MERCURY
e_a : VAPOR PRESS. @ MEAN MONTHLY TEMP IN INCHES OF Hg
$\bar{W}$: MEAN MONTHLY WINDSPEED @ 25' (mi/hr)

ASSUME: A FREE SURFACE EXISTS FROM JUNE 1 TO SEPT 30

DATA IS FROM TOTALIZING ANEMOMETER @ TELEPHONE LAKES STATION

1. CALC OF MEAN MONTHLY WINDSPEEDS ($\bar{W}$):

A) JUNE 1988

$$\bar{W} = \frac{\Sigma \bar{X}}{\#\text{ OF OBSERVATIONS}}$$

$$= \frac{6.49 + 4.67 + 5.70}{3}$$

$= 5.62$ mi/hr

DATE	$\bar{X}$ (mi/hr)
6/7	6.49
6/14	4.67
6/21	5.70
6/27	—

B) JULY 1988

$\bar{W} = 6.67$ mi/hr

DATE	$\bar{X}$ (mi/hr)
7/5	9.51
7/12	4.94
7/19	6.25
7/26	5.99

C) AUG 1988

$\bar{W} = 5.78$ mi/hr

DATE	$\bar{X}$ (mi/hr)
8/2	5.99
8/9	6.12
8/16	6.93
8/23	5.51
8/29	4.35

CALC. OF RESERVOIR EVAP CONT.

d) SEPT 1988

$\bar{W}$ = 8.22 mi/hr

DATE	$\bar{X}$ (mi/hr)
9/6	5.62
9/12	9.43
9/19	8.24
9/26	9.59

2. MEAN MONTHLY TEMPS. AND CORRESPONDING SAT. VAPOR PRESS. (e_o)

$$T_{MEAN} = \frac{\Sigma \left(\text{DAILY HIGH} + \text{DAILY LOW} / 2\right)}{\text{NUMBER OF DAYS}}$$

JUNE : 51.3 °F .383 IN Hg

JULY : 63.3 °F .594 IN Hg

AUG: 54.7 °F .437 IN Hg

SEPT: 41.9 °F .270 IN Hg

3. RELATIVE HUMIDITY (RH) - MEAN FOR MONTH %

JUNE : 41.3 % = 41%

JULY : 55.3 % = 55%

AUG : 55.2 % = 55%

SEPT : 61.9 % = 62%

4. PARTIAL PRESSURES (e_a)

$$e_a = e_o \, RH(\%) / 100$$

JUNE : e_a = (.383 in Hg)(41%)/100 = .157

JULY : .327

AUG : .240

SEPT : .167

CALC. OF RES. EVAP. CONT.

5. MONTHLY EVAPORATION VALUES

$$E = c\,(e_o - e_a)\left[1 + \frac{W}{10}\right]$$

JUNE: $E = 14\,(.383 - .157)\left[1 + \frac{5.62}{10}\right]$

$= 4.94$ IN/MONTH

JULY: E = 6.23 IN/MONTH

AUG: E = 4.35 IN/MONTH

SEPT: E = 2.63 IN/MONTH

SURFACE AREA OF WEST GLACIER LAKE

$0029 = .29\,IN^2$

$.29\,IN^2 \left(\frac{640 \text{ ACRE}}{27.878\,IN^2}\right) = 6.66$ ACRES

$0028 = .28\,IN^2 = 6.43$ ACRES

$A_{AVE} = 6.55$ ACRES

SURFACE AREA OF E. GLACIER LAKE

$0029 = .29\,IN^2 = 6.66$ ACRES

$$\begin{array}{r} 0057 \\ -0029 \\ \hline 28 \end{array} = .28\,IN^2 = 6.43 \text{ ACRES}$$

$A_{AVE} = 6.55$ ACRES

CALC. OF RES. EVAP. CONT.

W. GLACIER LAKE:

JUNE: $E_{AC\,FT} = 6.55\,\text{ACRES}\left(4.94\,\text{IN}\right)\left(\frac{1\,\text{ft}}{12\,\text{IN}}\right) = 2.7\,\text{AC}\cdot\text{FT}$

JULY: E = 3.40 AC·FT

AUG: E = 2.4 AC·FT

SEPT: E = 1.4 AC·FT

TOTAL LOSS FOR YEAR = 9.9 AC. FT

E. GLACIER LAKE

SINCE THE EVAP. VALUES TO BE USED FOR E. GLACIER ARE THE SAME AS W. GLACIER AND THE SURFACE AREAS ARE THE SAME THE ANNUAL LOSSES ARE ALSO THE SAME;

TOTAL LOSS = 9.9 AC. FT

SECTION 13

CALCULATION OF EVAPOTRANSPIRATION RATES FOR WEST AND EAST GLACIER LAKES.

METHODOLOGY: BLANEY - CRIDDLE

COMMENTS:

1. THE BLANEY-CRIDDLE METHOD WAS SELECTED OVER OTHER METHODS AS THE MORE EXTENSIVE DATA REQUIRED BY OTHER METHODS WAS NOT AVAILABLE.

2. A REFERENCE CROP E.T. WAS NOT CALCULATED AS THIS IS A NON-HOMOGENEOUS COVER; CROP COEFFICIENTS MAY NOT EXIST FOR SOME OF THE COVER TYPES FOUND IN THIS AREA.

CALCULATION OF EVAPOTRANSPIRATION (E.T.) FOR W. GLACIER LAKE WATERSHED, 1988 WATER YEAR

BLANEY - CRIDDLE METHOD

$$F = pT_m$$

F = EVAPORATION (IN/MONTH)
p = DAY - LENGTH VARIABLE (LATITUDE DEPENDENT)
T_m = MEAN MONTHLY TEMPERATURE

ASSUME: THAT THE SIGNIFICANT E.T. LOSSES FROM THE AREA OCCUR BETWEEN JUNE 1 AND SEPT 30.

USING DAY - LENGTH VARAIBLE VALUES FOR 41° N. LATITUDE

JUNE: $p = .344$ $T_m = 51.3°F$

$F = .344 (51.3) = 17.6$ IN/MONTH

JULY: $p = .322$ $T_m = 63.3°F$

$F = 21.0$ IN/MONTH

AUG: $p = .311$ $T_m = 54.7°F$

$F = 17.0$ IN/MONTH

SEPT: $p = .28$ $T_m = 41.9°F$

$F = 11.73$ IN/MONTH

TOTAL E.T. = 67.33 IN

ASSUME: 35% GROUNDCOVER AND THAT A LINEAR RELATIONSHIP EXISTS BETWEEN GROUNDCOVER AND E.T., THEN,

E.T. = .35 (67.33 IN) = 23.6 IN

CALC. OF E.T. FOR WGL (CON'T)

TOTAL E.T. LOSS PER SEASON ($E.T._S$) IN AC·FT

$$E.T._S = 146.5\ AC \left(23.6\ IN\right)\left(\frac{1\ FT}{12\ IN}\right) = \underline{\underline{288.1\ AC \cdot FT}}$$

FOR OTHER PERCENTAGES OF GROUNDCOVER THE RESULTING $E.T._S$ VALUES ARE AS SHOWN:

% GROUND-COVER	$E.T._S$ (AC·FT)
10	82.2
20	164.4
30	246.6
40	328.8
50	411.0
60	493.2

CALCULATION OF E.T. FOR THE EAST GLACIER LAKE WATERSHED.

SINCE THE VALUES OF P (DAY-LENGTH VARIABLE) AND T_m ARE THE SAME FOR EGL AS WGL THE TOTAL E.T. IS ALSO THE SAME.

TOTAL E.T. = 67.33 IN

ASSUMING, AGAIN, 35% GROUNDCOVER THE TOTAL E.T. LOSS PER SEASON ($E.T._s$) IN AC·FT IS:

$$E.T._s = 60.95\,AC\,(23.6\,IN)\left(\frac{1\,FT}{12\,IN}\right) = \underline{\underline{119.9\,AC\cdot FT}}$$

FOR OTHER PERCENTAGES OF GROUND COVER THE RESULTING $E.T._s$ VALUES ARE AS SHOWN:

% GROUND COVER	$E.T._s$ (AC·FT)
10	34.2
20	68.4
30	102.6
40	136.8
50	171.0
60	205.2

SECTION 14

DEVELOPMENT OF A WATER BUDGET FOR THE WEST GLACIER LAKE WATERSHED.

WATER BUDGET FOR W. GLACIER LAKE WATERSHED

TOTAL PPT: 33.11"

$$33.11"\left(146.5 \text{ ACRES}\right)\left(\frac{1 \text{ FT}}{12"}\right) = 404.2 \text{ AC}\cdot\text{FT}$$

TOTAL DISCHARGE: 623.72 AC·FT
TOTAL E.T.: 288.1 AC·FT (@ 35% COVER)

USING A WATER BUDGET EQUATION THAT INCLUDES BOTH SURFACE AND GROUNDWATER:

$$\Delta S = P - (E + E.T. + Q + G)$$

WHERE:

ΔS = CHANGE IN STORAGE
P = PPT OVER WATERSHED
$E.T.$ = EVAPOTRANSPIRATION
Q = SURFACE FLOW
G = GROUNDWATER FLOW
E = LAKE EVAPORATION

ASSUMING:

1. NO CHANGES IN STORAGE
2. NO GROUNDWATER INFLOW FROM OUTSIDE WATERSHED (WESTERN BORDER IS DEFINED BY THE CONTINENTAL DIVIDE)
3. THAT GROUNDWATER IS 100% INTERCEPTED BY STRUCTURE AT W. GLACIER LAKE OUTLET.

(Believe groundwater flow from East Glacier Lake but not able to quantify)

THEN:

$$P = E.T. + Q_m + E$$

$$\text{WHERE } Q_m \text{ (MEASURED)} = Q + G$$

$$404.2 \text{ AC}\cdot\text{FT} + X = (9.9 + 288.1 + 623.7) \text{ AC}\cdot\text{FT}$$

WHERE X IS THE VOLUME OF WATER THAT MUST BE PROVIDED BY SNOWFIELD

$$X = 517.5 \text{ AC}\cdot\text{FT}$$

TO DETERMINE THE SIZE OF THE SNOWFIELD REQUIRED TO PRODUCE THIS VOLUME OF WATER:

CALCULATION OF EQUIVALENT WATER CONTENT OF SNOWPACKS OF VARIOUS DENSITIES.

FROM SOMMERFELD ET AL.

ASSUME:

1. THE AVERAGE DENSITY OF SNOWPACK IS 435.0 Kg/m^3 $= (27.15\ lbs/ft^3)$
2. THE AVERAGE DENSITY OF WATER IS 1000 Kg/m^3

THEREFORE:

THE SNOWPACK IS 43.5 % AS DENSE AS LIQUID WATER.

AND: $\frac{1}{.435} = 2.299$

IN CONCLUSION: IT TAKES 2.299 VOLUMES OF SNOW TO PRODUCE 1 VOLUME OF LIQUID WATER

FOR VARIOUS DENSITIES OF A SNOWPACK THE VOLUME OF WATER EQUIVALENTS ARE AS SHOWN

DENSITY OF SNOWPACK (Kg/m^3)	VOLUMES OF SNOW / VOLUME OF WATER
300	3.33
350	2.86
400	2.5
450	2.22
500	2.0
550	1.82
600	1.67
650	1.54

WATER BUDGET FOR WGL WATERSHED (CONT)

$$A = \frac{VC}{U.D.}$$

WHERE:

A = SURFACE AREA OF SNOW COVER
V = VOLUME OF WATER PRODUCED
C = CONVERSION FACTOR (EQUIVALENT WATER CONTENT OF SNOW) *
U.D. = UNIFORM DEPTH OF SNOW

ASSUME: A 10 FT UNIFORM DEPTH

$$A = \frac{517.5\ AC\cdot FT\ (2.299)}{10\ FT} = \underline{\underline{119.0\ AC}}$$

ASSUME: A 20 FT UNIFORM DEPTH

$$A = \frac{517.5\ AC\cdot FT\ (2.299)}{20\ FT} = \underline{\underline{59.5\ AC}}$$

IF THE SNOWFIELD IS CONSIDERED TO BE PPT. OVER THE ENTIRE WGL WATERSHED THE TOTAL EFFECTIVE PPT. ($PPT_{EFF.}$) BECOMES:

$$33.11'' + 517.5\ AC\cdot FT \left(\frac{1}{146.5\ AC}\right)\left(\frac{12''}{1\ FT}\right) = PPT_{EFF.}$$

$$33.11'' + 42.39'' = 75.50'' = 921.7\ AC\cdot FT$$

BY THIS ACCOUNT THE SNOWFIELD IS CONTRIBUTING 128.0% MORE WATER THAN IS CONTRIBUTED BY ACTUAL PPT. OVER THE WATERSHED.

BY SUBTRACTING THE E.T. LOSSES FROM THIS TOTAL IT IS FOUND, AGAIN, THAT ≈ 673.72 AC.FT OF WATER IS AVAILABLE FOR DISCHARGE AS SURFACE AND GROUNDWATER FLOW.

* REFER TO APPENDIX C

BECAUSE THE TWO STREAMS THAT FEED WGL TRANSPORT 248.94 AC.FT OF WATER TO THE LAKE AND THE DISCHARGE FROM THE LAKE IS 623.72 AC.FT THEN:

$$(623.72 - 248.94)\,AC\cdot FT = 374.78\ AC\cdot FT$$

OF WATER MOVES TO THE WGL OUTLET AS SUBCONCENTRATED SURFACE FLOW, INTERFLOW AND GROUNDWATER FLOW. AS THERE IS ONLY ONE UNCONFINED ALLUVIAL AQUIFER IN THIS AREA NEAR SURFACE INTERFLOW SHOULD NOT OCCUR UNTIL THE ENTIRE DEPTH OF THE AQUIFER IS SATURATED. ASSUMING, THEN, THAT THE G.W. AND INTERFLOW SYSTEMS CAN BE CONSIDERED AS ONE SYSTEM CALCULATIONS CAN BE MADE TO DETERMINE THE VOLUMETRIC FLOW RATES OF GROUNDWATER AND SUBCONCENTRATED SURFACE WATER.

TOTAL VOLUME: 374.78 AC.FT

$$x\,gal = 374.78\ AC\cdot FT\left(\frac{325851\ gal}{AC\cdot FT}\right) = 1.221\times10^{8}\ gal$$

ASSUME: THE G.W. SYSTEM IS ACTIVE FROM MAY 24th TO SEPT. 30th, 130 DAYS (SAME RECORD LENGTH AS STREAMFLOW DATA)

$$\text{THEN:}\quad 1.221\times10^{8}\,gal\left(\frac{1}{130\ DAYS}\right) = 9.394\times10^{5}\ \frac{gal}{DAY}$$

FLOWS AS SUBCONC. SURFACE FLOW, INTERFLOW, AND G.W. FLOW IN THE WGL WATERSHED.

VOLUMETRIC FLOWRATES IN THE SUBCONC SURFACE AND G.W. SYSTEMS AS A % OF TOTAL FLOW FOLLOW;

% OF TOTAL FLOW AS SUBCONC. SURFACE FLOW	VOL. (gal/day)	% OF TOTAL FLOW AS G.W FLOW	VOL. (gal/day)
0	0	100	939400
10	93940	90	845460
20	187881	80	751520
30	281821	70	657580
40	375761	60	563642
50	469702	50	469702
60	563642	40	375761
70	657580	30	281821
80	751520	20	187881
90	845460	10	93940
100	939400	0	0

SECTION 15

DEVELOPMENT OF A WATER BUDGET FOR THE EAST GLACIER LAKE WATERSHED

WATER BUDGET FOR E. GLACIER LAKE WATERSHED

TOTAL PPT: 37.54"

$$37.54" (60.95 \text{ ACRES}) \left(\frac{1 \text{ FT}}{12"} \right) = 190.7 \text{ AC} \cdot \text{FT}$$

TOTAL DISCHARGE: 86.99 AC·FT
TOTAL E.T.: 119.9 AC·FT ((@ 35% COVER)

USING THE METHODS DESCRIBED IN SECTION 14

$$P = E.T. + Q_m + E$$

$$190.7 \text{ AC} \cdot \text{FT} + x = (9.9 + 119.9 + 86.99) \text{ AC} \cdot \text{FT}$$

$$x = 26.09 = 26.1 \text{ AC} \cdot \text{FT}$$

IF THE SNOWFIELD IS CONSIDERED TO BE PPT. OVER THE ENTIRE WATERSHED THEN THE TOTAL EFFECTIVE PPT. (PPT_{EFF}) BECOMES:

$$37.54" + 26.1 \text{ AC} \cdot \text{FT} \left(\frac{1}{60.95 \text{ AC}} \right) \left(\frac{12"}{1 \text{ FT}} \right) = PPT_{EFF.}$$

$$37.54" + 5.14" = 42.68" = 216.8 \text{ AC} \cdot \text{FT}$$

BY THIS ACCOUNT THE SNOW FIELD PROVIDES 13.7% OF THE TOTAL WATER OBSERVED OVER THE WATERSHED.

THE SIZE OF THE SNOWFIELD REQUIRED TO PRODUCE THIS VOLUME OF WATER IS:

ASSUME: A 10 FT. UNIFORM DEPTH

$$\frac{26.1 \text{ AC} \cdot \text{FT} (2.299)}{10 \text{ FT}} = 6.0 \text{ AC}$$

WATER BUDGET FOR E. GLACIER LAKE CON'T.

ASSUME: A 20 FT UNIFORM DEPTH

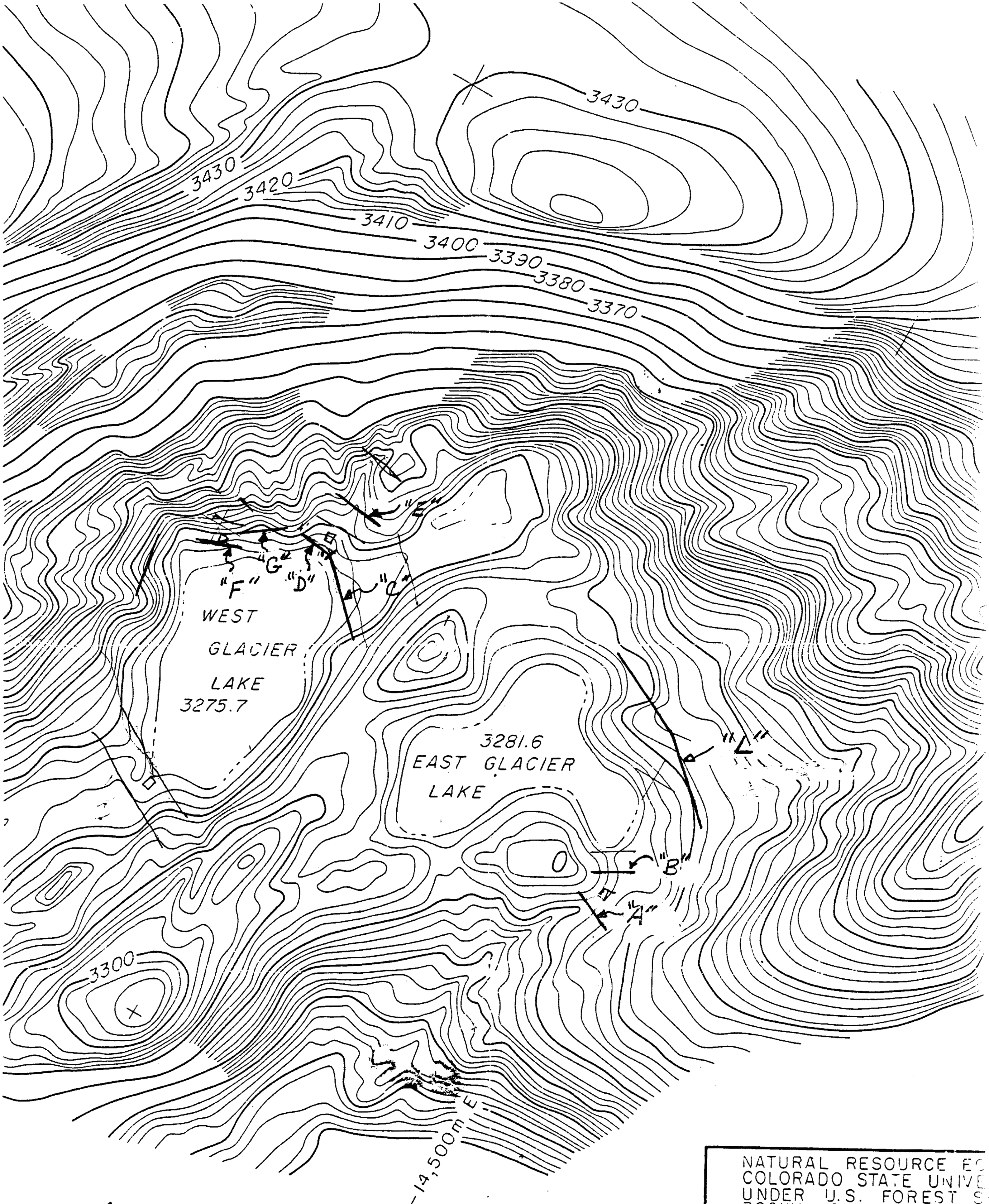
$$\frac{26.1 \text{ AC}\cdot\text{FT} \ (2.299)}{20 \text{ FT}} = 3.0 \text{ AC}$$

AS THERE ARE NO GAGED STREAMS FLOWING INTO E. GLACIER LAKE IT IS POSSIBLE THAT THE ENTIRE OBSERVED DISCHARGE AT THE OUTLET ARRIVED AT THE LAKE AS SUBCONCENTRATED SURFACE AND GROUNDWATER FLOW. IT IS MORE LIKELY, HOWEVER, THAT CHANNELIZED FLOW OCCURS IN THE NUMEROUS DRAWS, RAVINES, AND OTHER TOPOGRAPHICALLY FAVORABLE SITES AROUND THE LAKE DURING SPRING RUNOFF

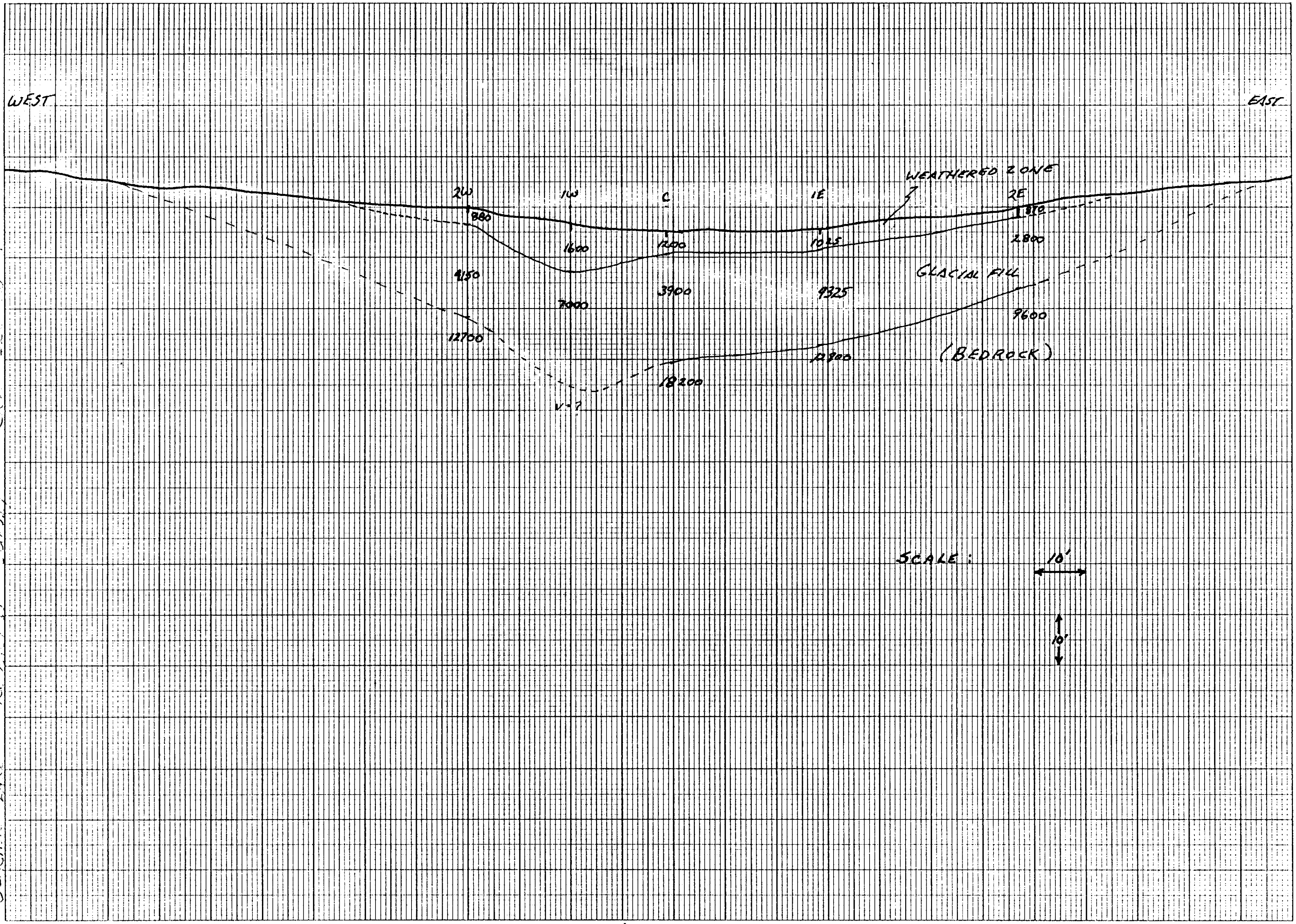
APPENDIX B

PRECIPITATION RECORDS

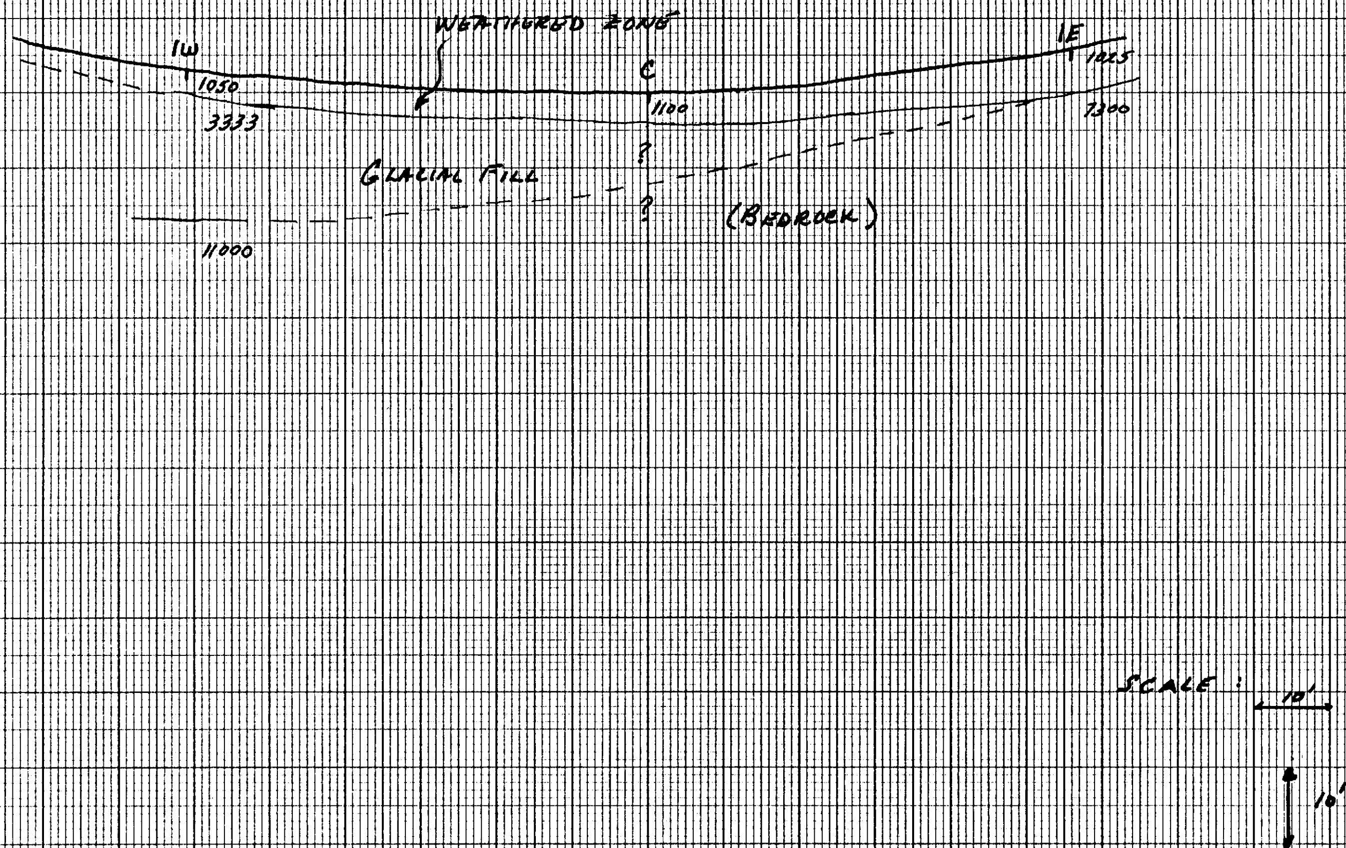
APPENDIX D



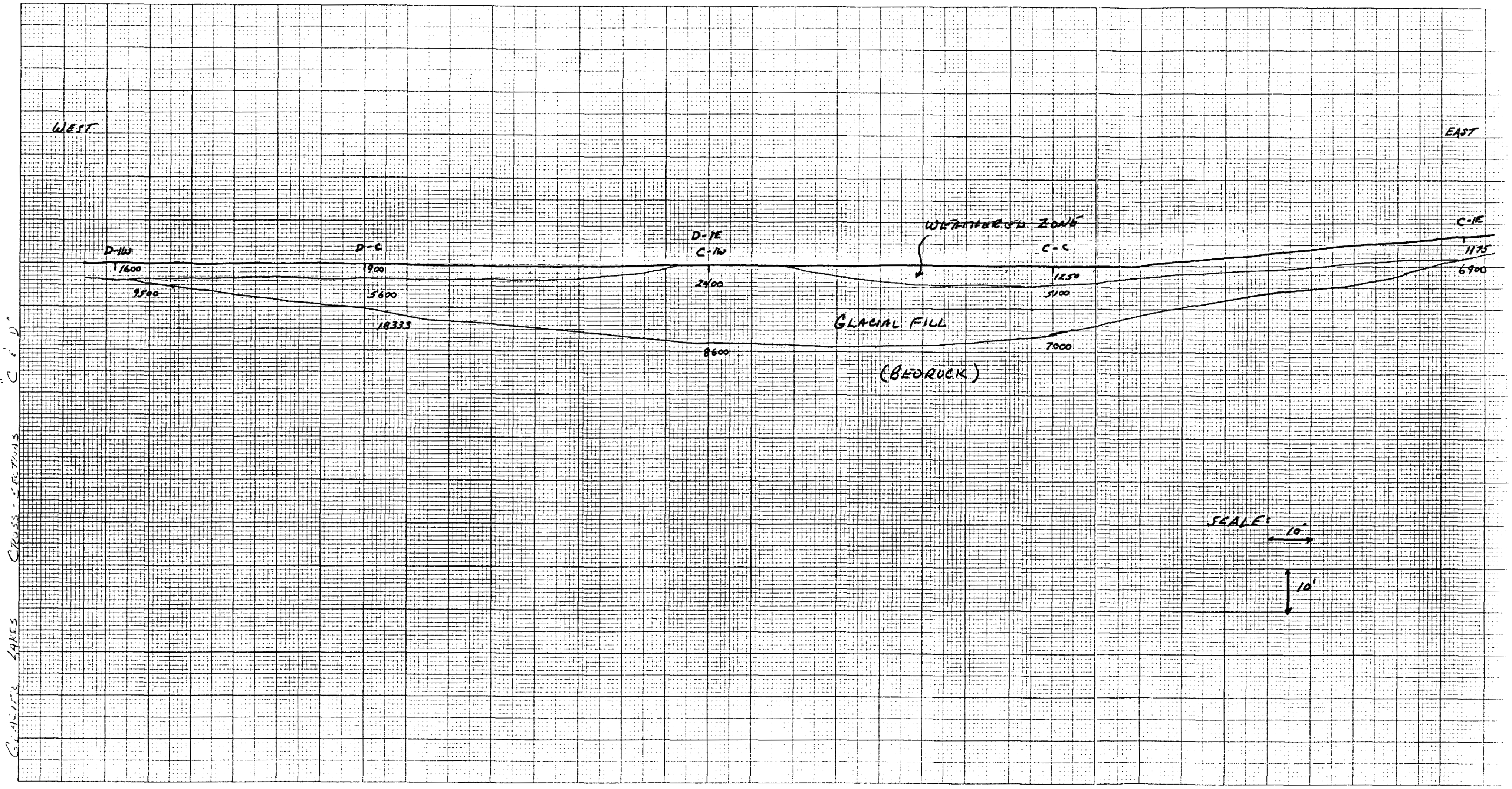
MAP INDICATING
CROSS-SECTION LOCATIONS
OF SEISMIC REFRACTIONS


WEST
EAST
WEATHERED ZONE
2W
1W
C
1E
2E
880
820
1600
1200
1025
2800
4150
GLACIAL FILL
3900
9325
7000
9600
12700
(BEDROCK)
12900
18200
V=?
SCALE : 10'
10'

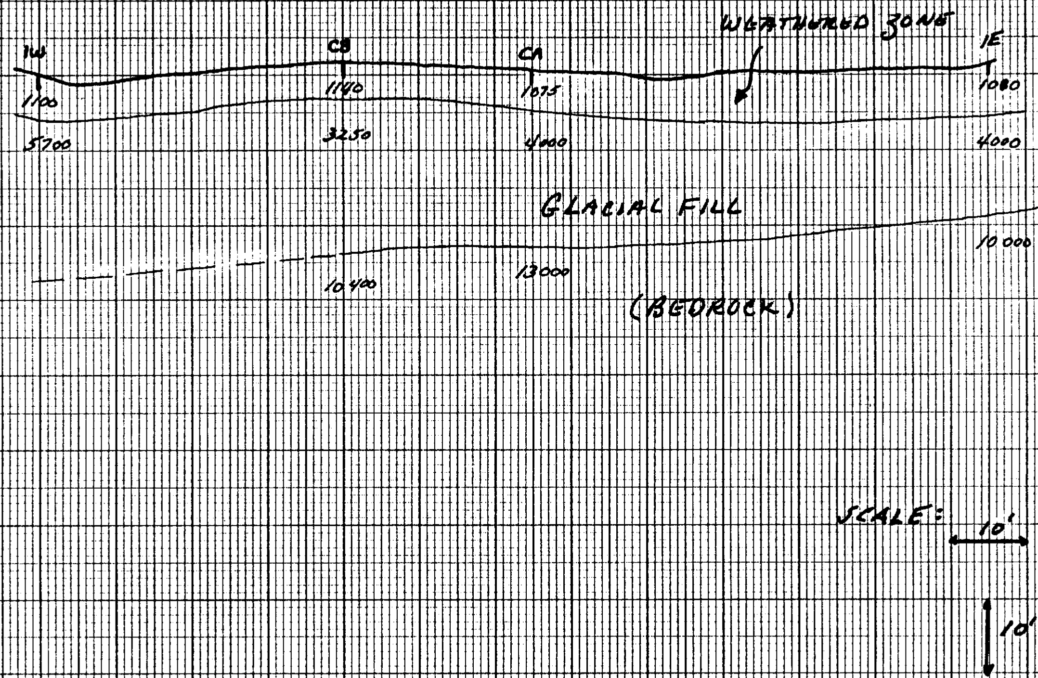
GLACIER LAKE CROSS-SECTION "B"



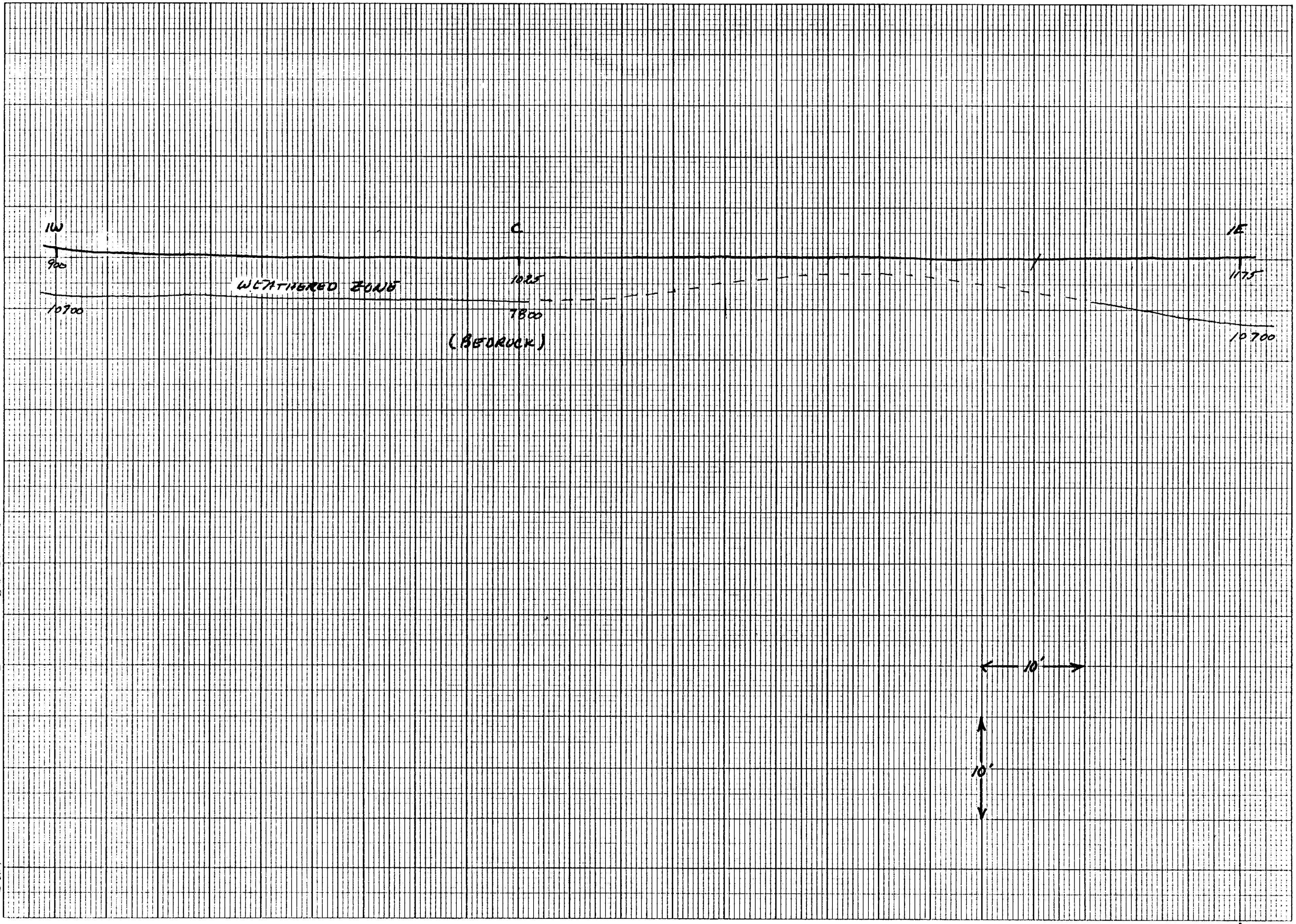
LAKES CROSS-SECTIONS "C & D"

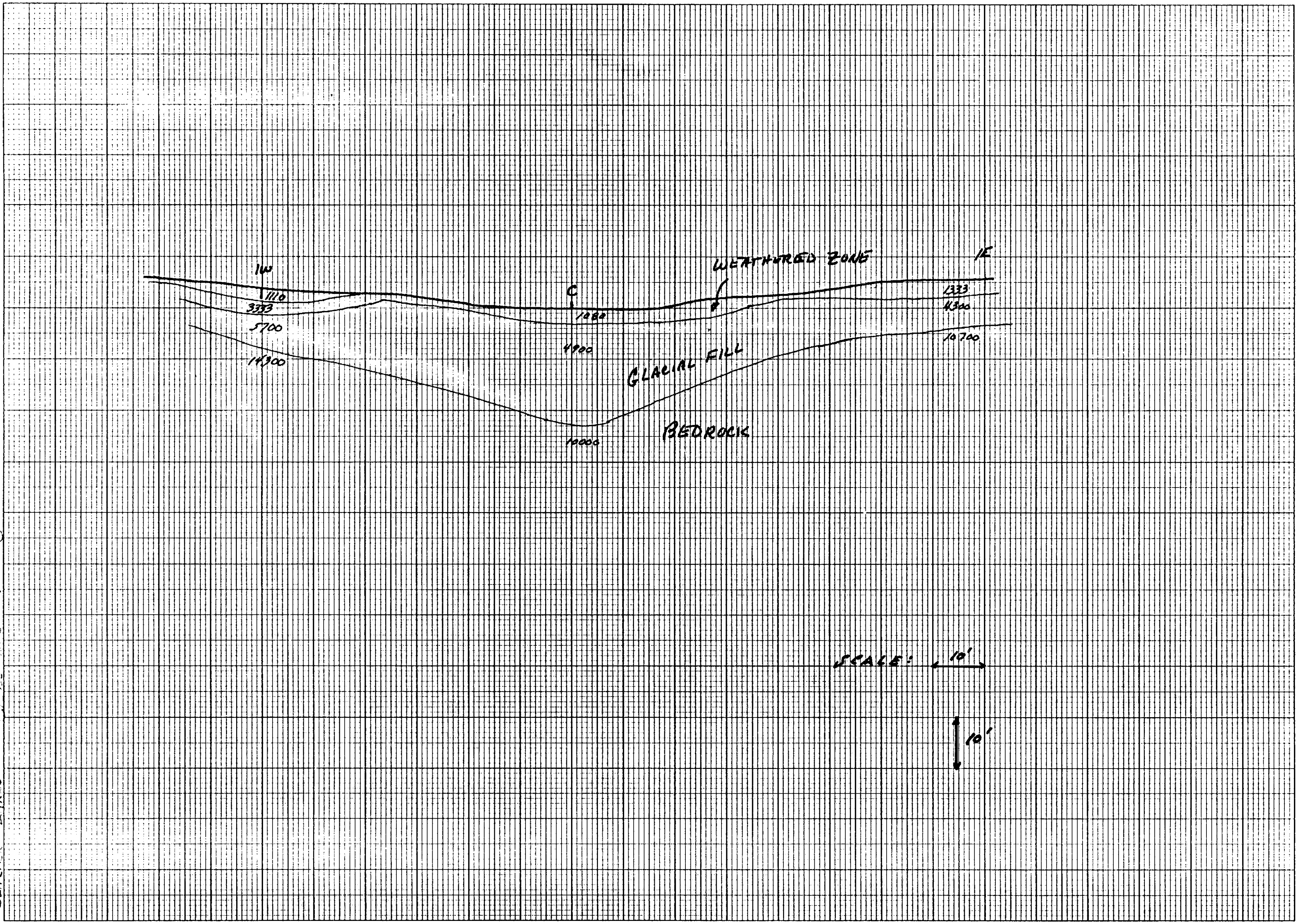


Cross - Section "F"

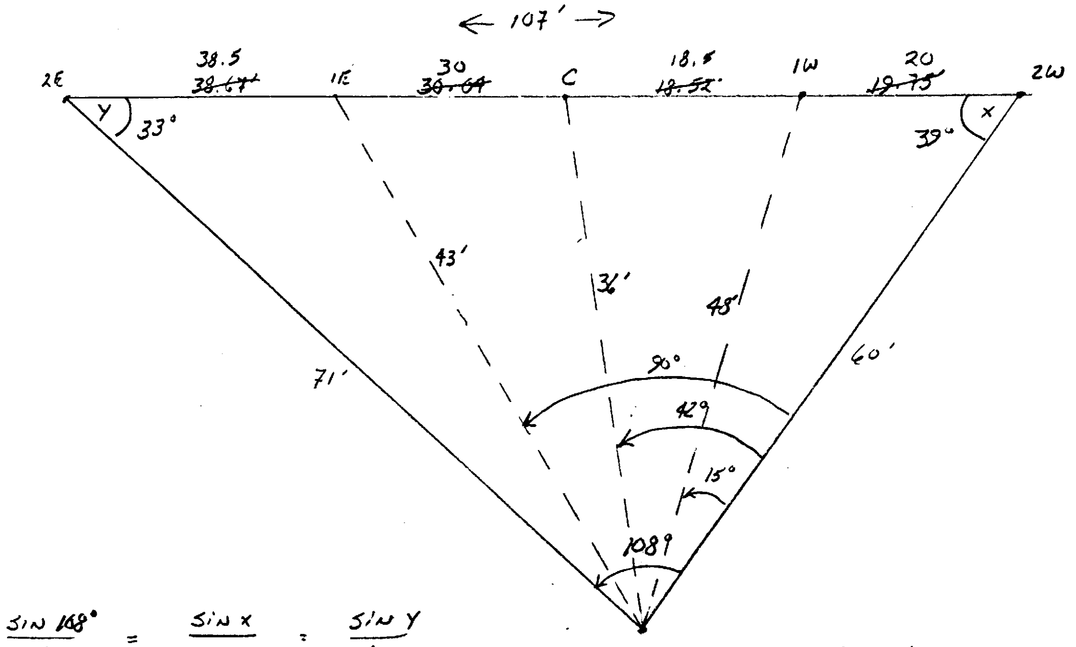


GLACIER LAKES CROSS SECTION "F"




1W
WEATHERED ZONE
1E
C
1110
3333
5700
14300
1080
4900
1333
4300
10700
GLACIAL FILL
BEDROCK
10000
SCALE: 10'
10'

GLACIER LAKE | REFRACTION SURVEY | CROSS-SECTION "A"



$$\frac{\sin 108°}{107} = \frac{\sin x}{71} = \frac{\sin Y}{60}$$

$X = 39°$

$Y = 33°$

$$\frac{\sin 39°}{49} = \frac{\sin 15}{1W - 2W}$$

$D\,(1W - 2W) = 19.75'$

$$\frac{\sin 39°}{36} = \frac{\sin 42°}{D(C - 2W)}$$

$D\,(C - 2W) = 38.28'$

$$\frac{\sin 39°}{43'} = \frac{\sin 90}{D(1E - 2W)}$$

$D\,(1E - 2W) = 68.33'$

GLACIER LAKE REFRACTION SURVEY CROSS-SECTION "A"

GEOPHONE LOCATION 2W (W/O DATUM CORRECTIONS)

WEST DIRECTION

$V_0 = 10'/12.25ms = 800 \text{ ft/sec}$

$V_1 = 20'/4.25ms = 4700 \text{ ft/sec}$

$V_2 = 50'/4.5ms = 11100 \text{ ft/sec}$

$X_{cross} = 8.3'$

$T_{i_2} = 15.1 \text{ ms}$

EAST DIRECTION

$V_0 = 10'/10.38ms = 960 \text{ ft/sec}$

$V_1 = 20'/5.5ms = 3600 \text{ ft/sec}$

$V_2 = 50'/3.5ms = 14300 \text{ ft/sec}$

$X_{cross} = 9'$

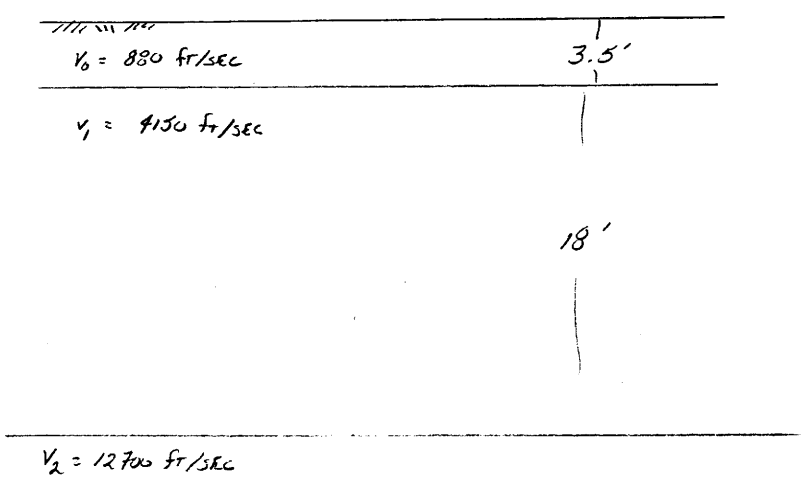
$T_{i2} = 17.125 \text{ ms}$

AVG. THE DATA

$V_0 = 880 \text{ ft/sec}$
$V_1 = 4150 \text{ ft/sec}$
$V_2 = 12700 \text{ ft/sec}$
$X_{cross} = 8.6'$
$T_{i_2} = 16.1 \text{ ms}$

$$Z_0 = \frac{1}{2}\sqrt{\frac{4150-880}{4150+880}}\,(8.6) = 3.5 \text{ ft}$$

$$Z_1 = \frac{1}{2}\left(16.1\text{ ms} - 2(3.5)\frac{\sqrt{12700^2-880^2}}{12700\,(880)}\right)\frac{12700\,(4150)}{\sqrt{12700^2-4150^2}} = 18 \text{ ft}$$



GEOPHONE LOCATION 2W

ELEVATION & WEATHERING CORRECTIONS

$$\text{TOTAL CORRECTION} = \left[(e-d)+(E-t-d)\right]\frac{\sqrt{V_2^2-V_1^2}}{V_2V_1} + \frac{t\sqrt{V_2^2-V_0^2}}{V_2V_0}$$

e = HAMMER LOCATION ELEV. = X
E = GEOPHONE LOCATION ELEV = 100
d = DATUM ELEV. = 100
t = WEATHERING LAYER THICKNESS = 3.5'

V_2 = 12700 ft/sec
V_1 = 4150 ft/sec
V_0 = 880 ft/sec

CORRECT THE 60, 80 & 100 ft DISTANCE TIMES

HAMMER LOCATION	MEASURED TIME	CORRECTION	NEW TIME
60 W	21.2	-4.05	17.15
80 W	24.3	-4.61	19.69
100 W	25.2	-4.81	20.39
60 E	21.0	+ 2.16	23.16
80 E	22.7	+ 2.63	25.33
100 E	24.0	+ 2.90	26.90

(EAST) $V_2 = 54'/4.75\,ms = 11\,400$ ft/sec
$T_{i2} = 18.125$ ms

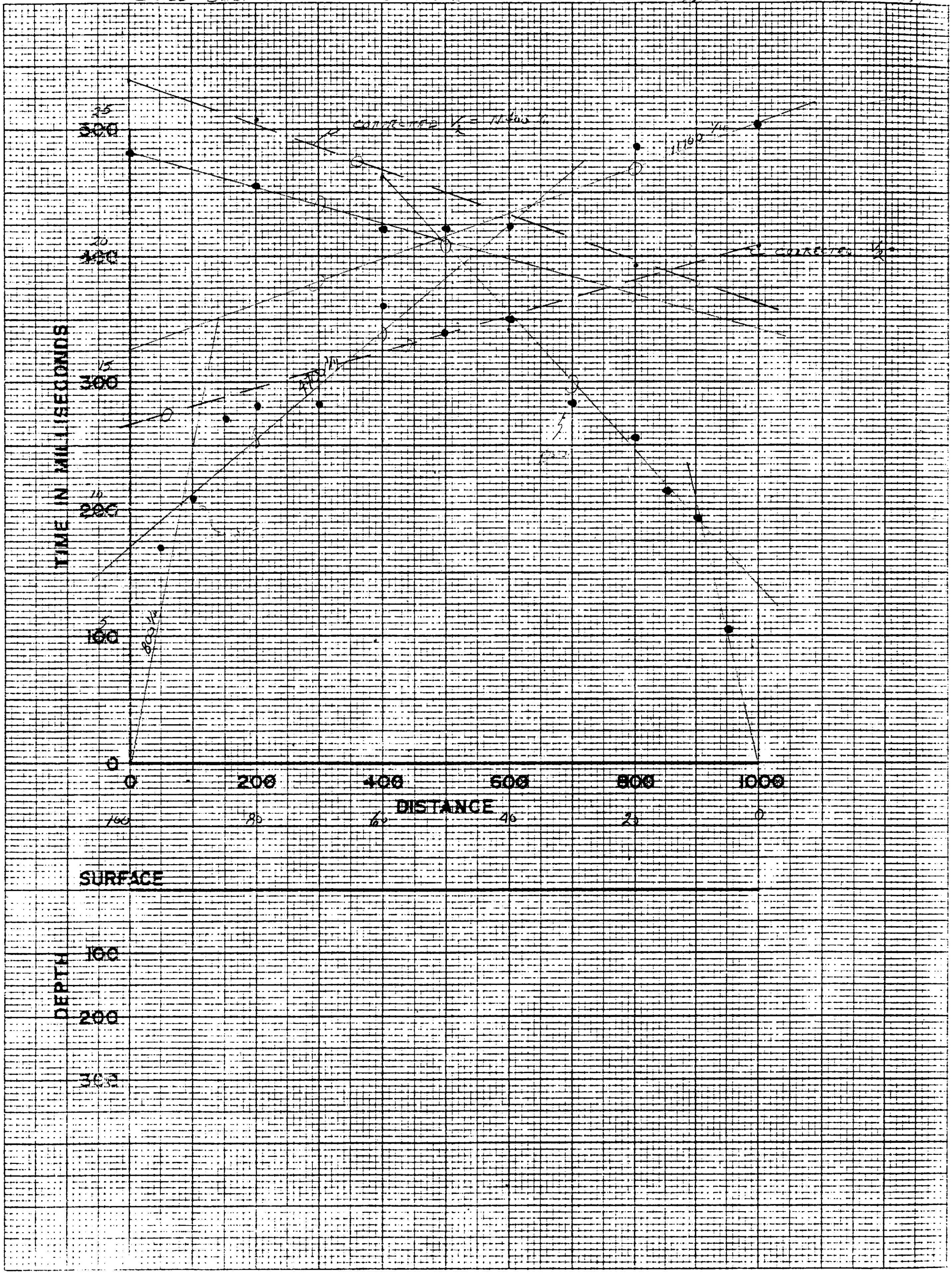
AVERAGE: $V_2 = 12600$
$T_{i2} = 16.61$

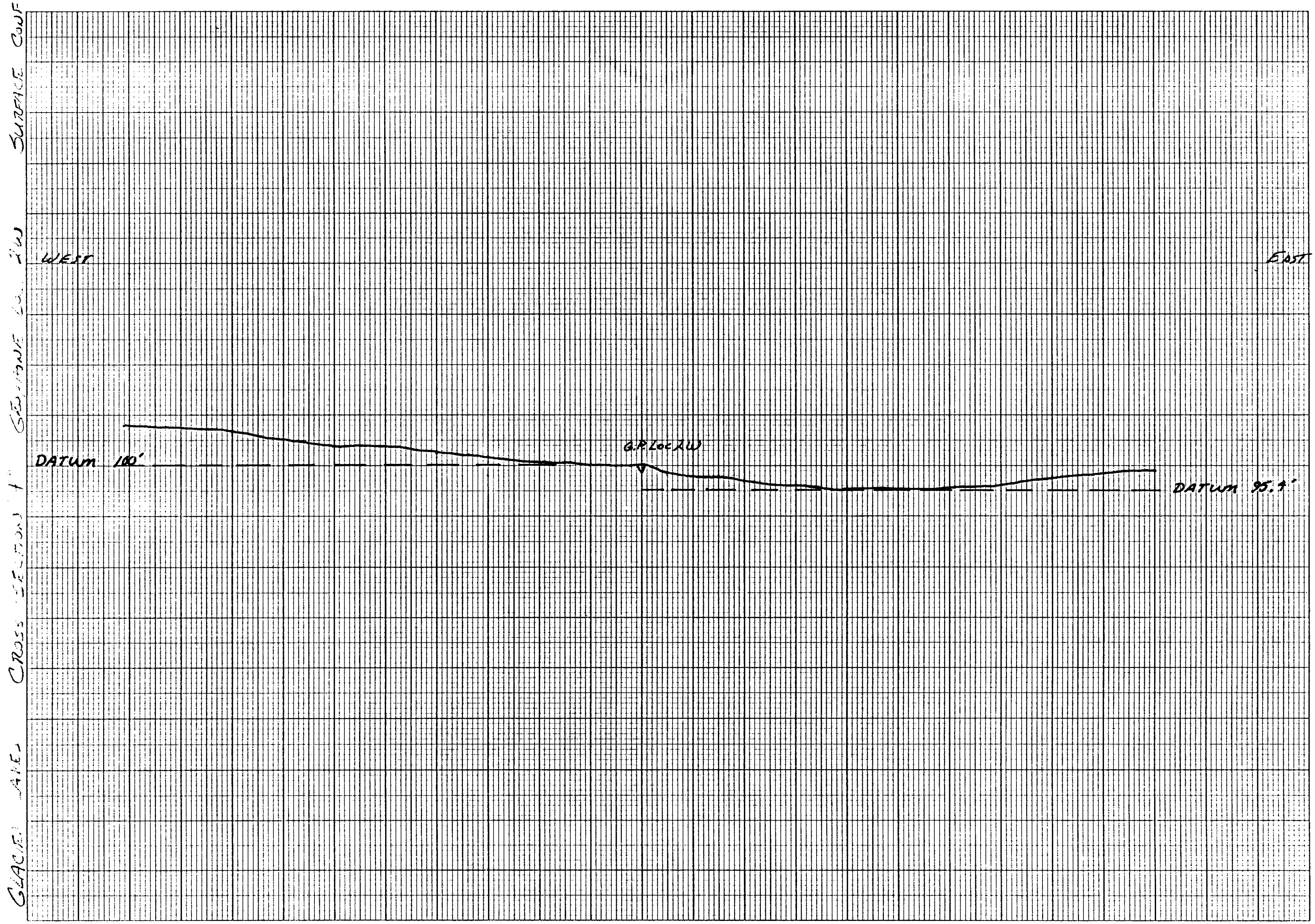
WEST $V_2 = 38'/2.7\,ms = 13800$ ft/sec
$T_{i2} = 15.1$ ms

$$z_1 = \frac{1}{2}\left(16.6\,ms - 2(3.5)\frac{\sqrt{12600^2-880^2}}{12600\,(880)}\right)\frac{12600\,(4150)}{\sqrt{12600^2-4150^2}} = 19\text{ ft}$$

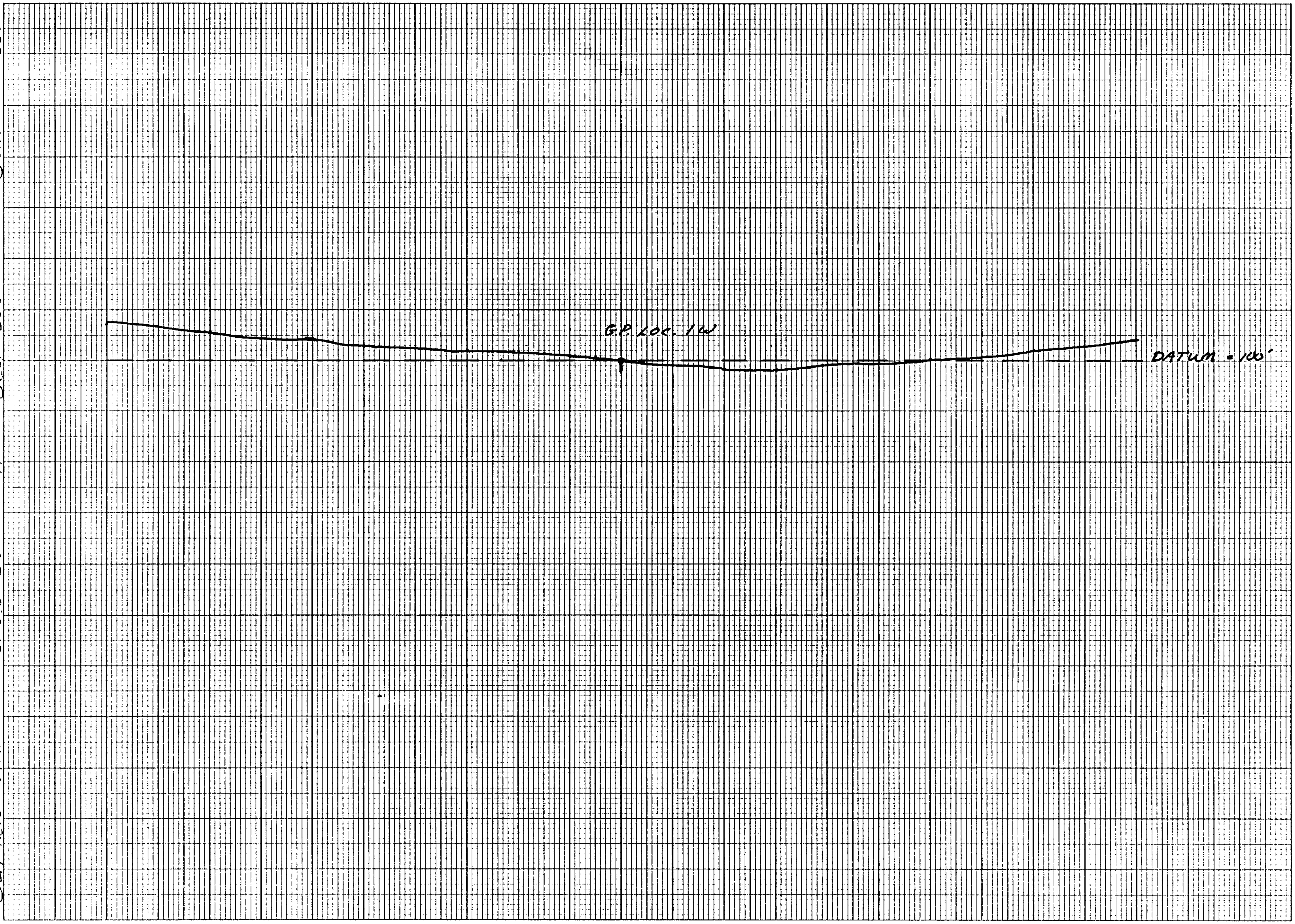
* THIS IS CLOSE TO THE UNCORRECTED DEPTH ESTIMATE & IS WITHIN THE ACCURACY OF WHICH THE DEPTH CAN BE ESTIMATED, ∴ FROM HERE ON OUT I WILL NEGLECT DATUM CORRECTIONS WHERE I FEEL IT IS ALLOWABLE.

CROSS-SECTION ... LOCATION 2W




WEST
EAST
DATUM 100'
G.P. Loc 2W
DATUM 95.4'
CROSS
SURFACE

GLACIER LAKES CROSS SECTION "A" GEOP. LOC. 1W SURFACE



GLACIER LAKES   CROSS-SECTION "A"   REFRACTION SURVEY

GEOPHONE LOCATION 1W

EAST HAMMER LOCATIONS

$V_0 = 10'/5.5ms = 1800$ ft/sec

$V_1 = 20'/2.5ms = 8000$ ft/sec

$X_{CROSS} = 29'$

WEST HAMMER LOCATIONS

$V_0 = 5'/3.5ms = 1400$ ft/sec

$V_1 = 30'/5ms = 6000$ ft/sec

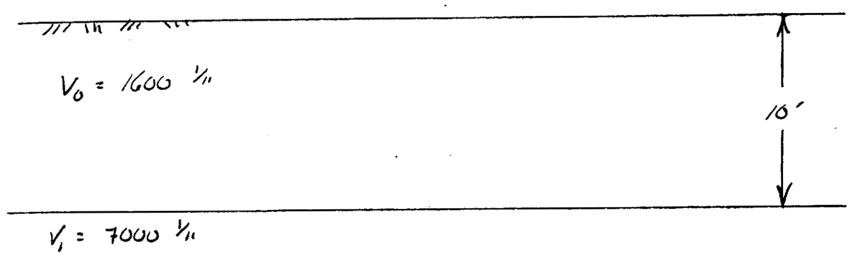
$X_{CROSS} = 19.5$ ft

AVG. : $V_0 = 1600$ ft/sec

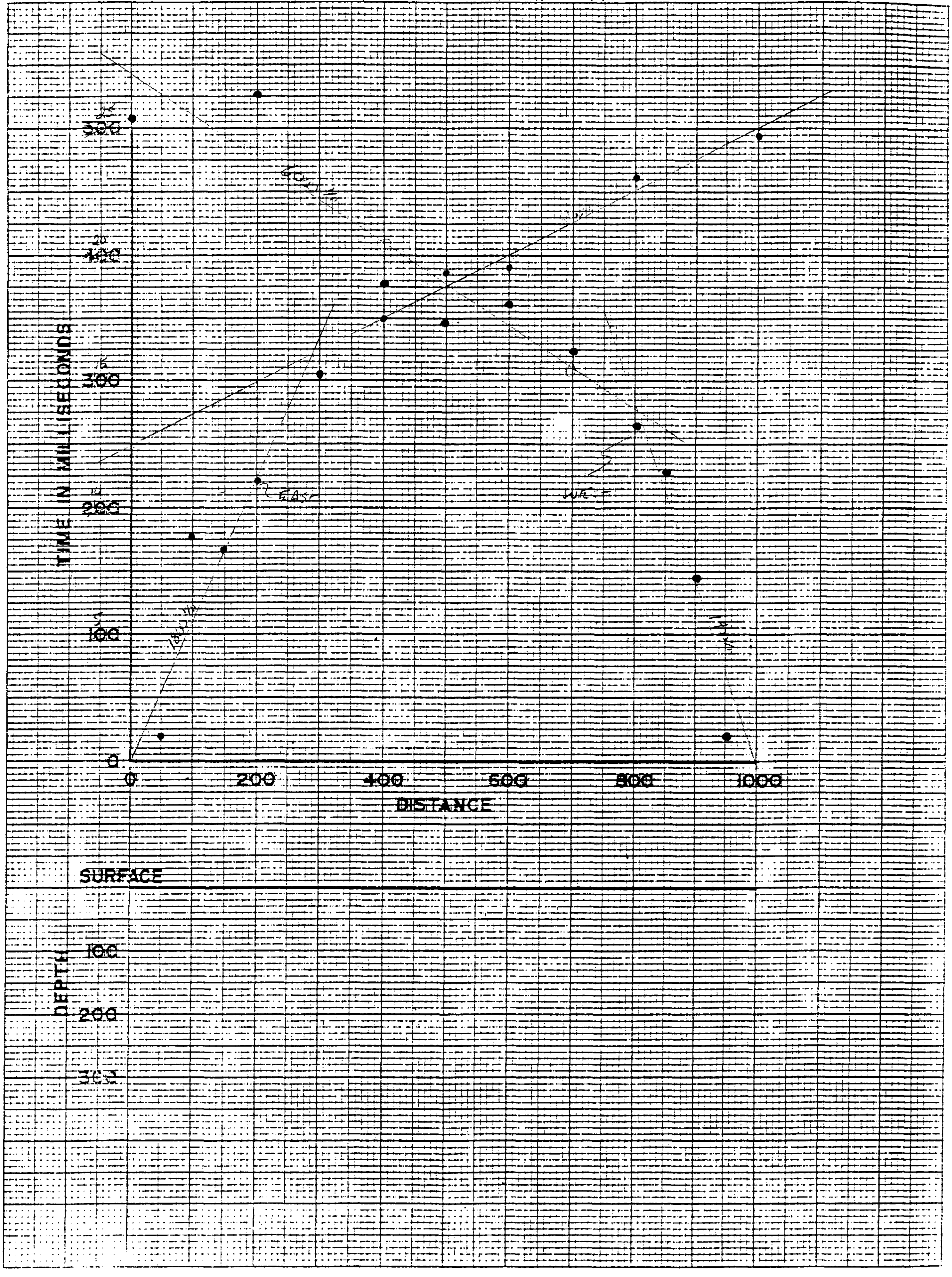
$V_1 = 7000$ ft/sec

$X_c = 24.25$ ft

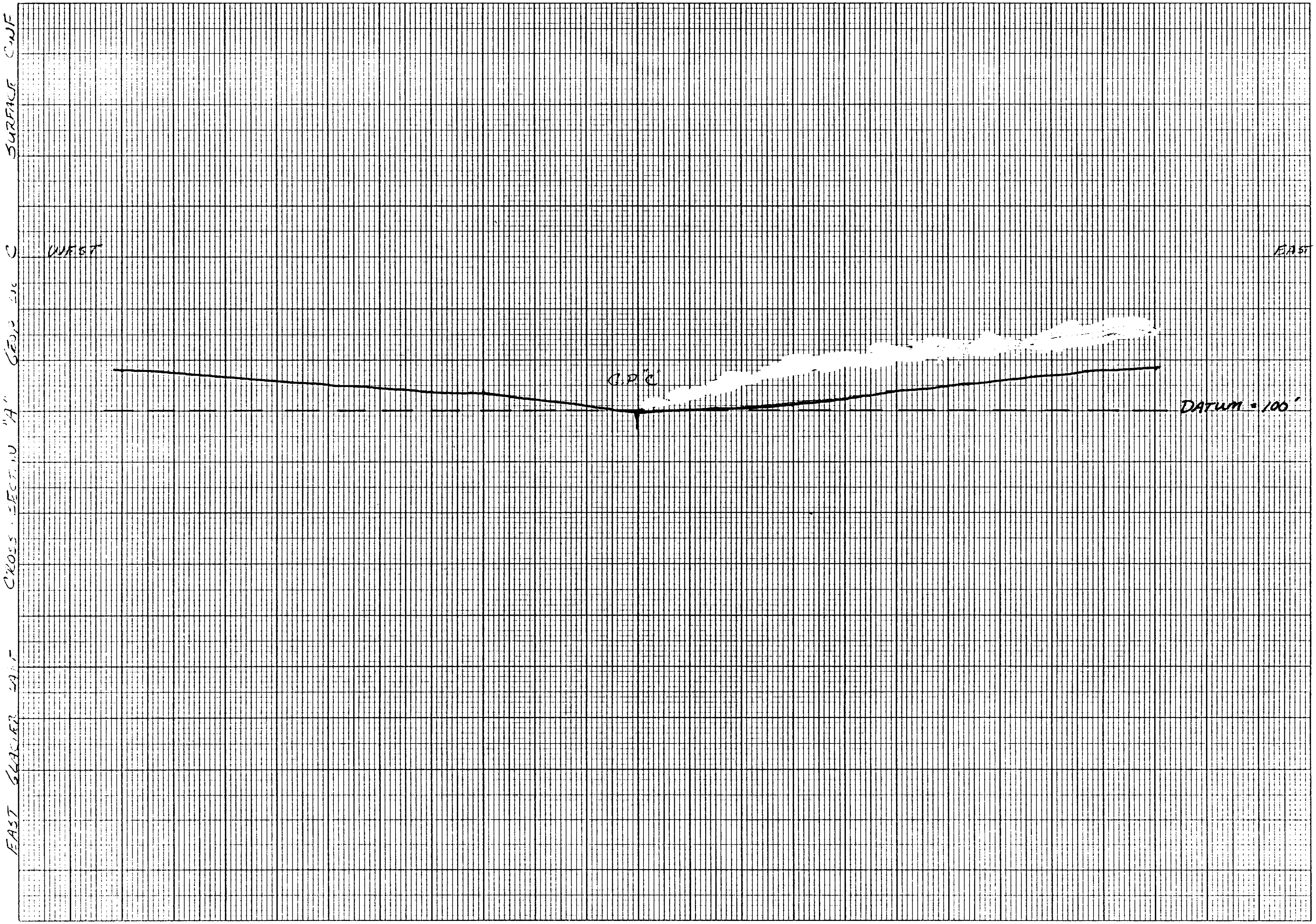
$$Z_0 = \frac{1}{2}\sqrt{\frac{7000-1600}{8600}}\ 24.25 = 9.6' = 10'$$



CROSS-SECTION "A" GEOPHONE LOCATION 1W



EAST GLACIER [illegible] CROSS SECTION "A" [illegible] SURFACE [illegible]



GLACIER LAKE   REFRACTION SURVEY   CROSS-SECTION "A"

GEOPHONE LOC. C

EAST DIRECTION	WEST DIRECTION
$V_0 = 18'/13.75\,ms = 1300$ ft/sec	$V_0 = 13'/12.5\,ms = 1040$ ft/sec
$V_1 = 25'/6\,ms = 4200$ ft/sec	$V_1 = 10'/2.75\,ms = 3600$ ft/sec
$V_2 = 30'/1.50\,ms = 20{,}000$ ft/sec	$V_2 = 37'/2.25\,ms = 16\,400$ ft/sec
$X_c = 16.6'$	$X_c = 9'$
$T_{i2} = 17.9\,ms$	$T_{i2} = 18.37$

AVG. :

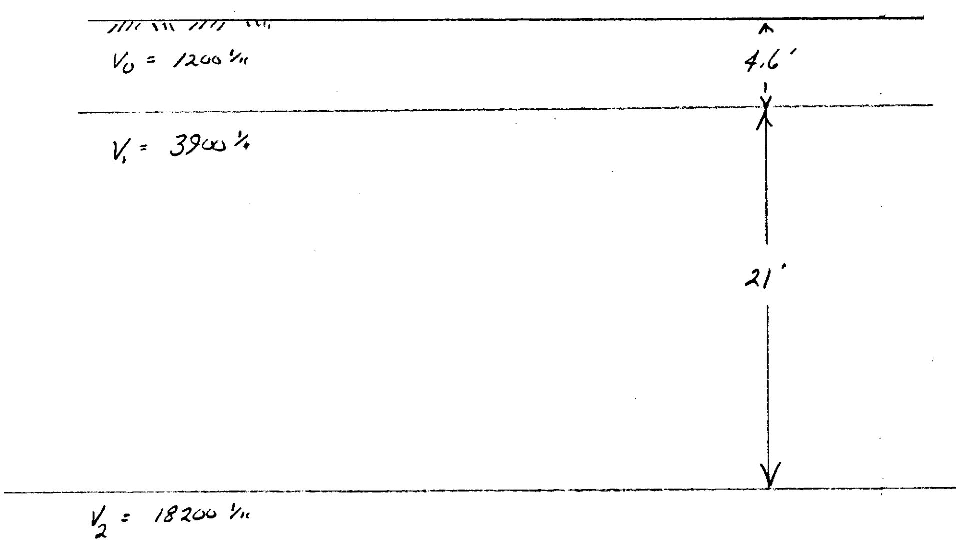
$V_0 = 1200$ ft/sec
$V_1 = 3900$ ft/sec
$V_2 = 18200$ ft/sec

$X_c = 12.8'$

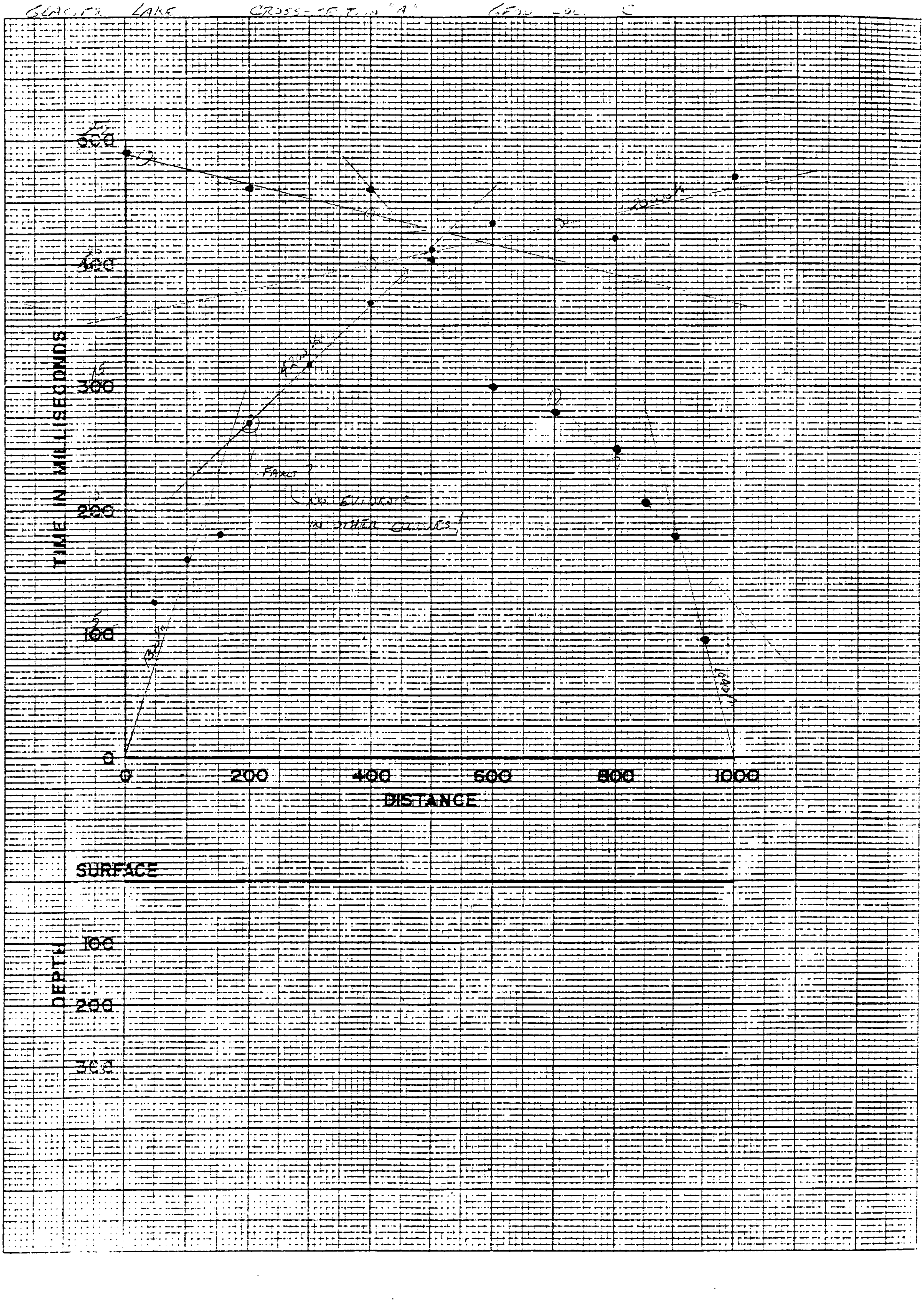
$T_{i2} = 18.1\,ms$

$$Z_0 = \frac{1}{2}\sqrt{\frac{3900-1200}{3900+1200}}\;12.8 = 4.6 \text{ ft}$$

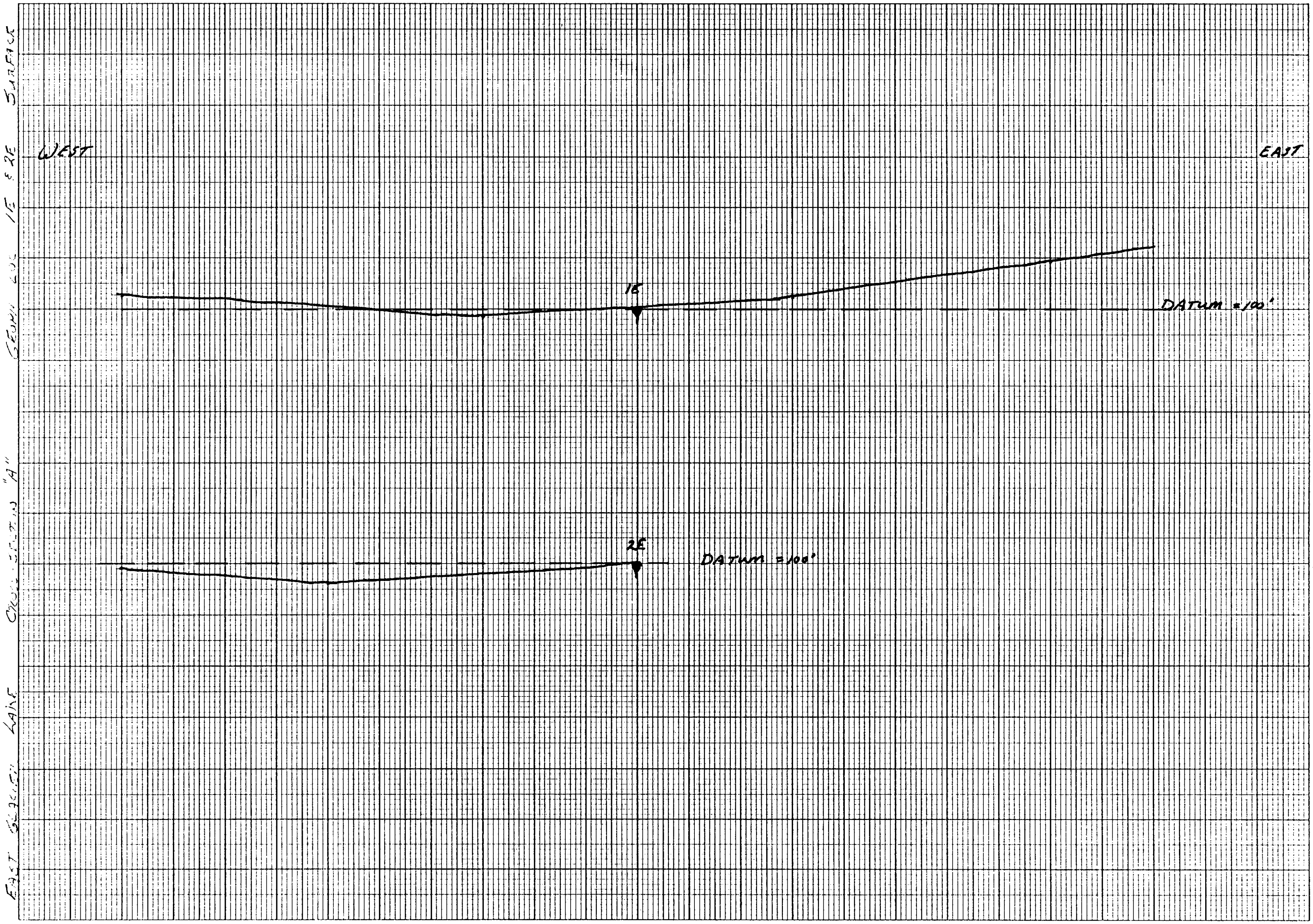
$$Z_1 = \frac{1}{2}\left(0.0181 - 2(4.6)\frac{\sqrt{18200^2 - 1200^2}}{18200(1200)}\right)\frac{18200(3900)}{\sqrt{18200^2 - 3900^2}} = 21'$$



GLACIER LAKE CROSS-SECTION "A" GEO...



EAST GLACIER LAKE CROSS SECTION "A" 1E & 2E SURFACE



GEOPHONE LOCATION 1E

EAST DIRECTION

$V_0 = 10/6\,ms = 1666$ ft/sec
$V_1 = 20/5.75\,ms = 3475$ ft/sec
$V_2 = 37/6.25\,ms = 5900$ ft/sec

$X_c = 13'$

$T_{i2} = 7.5\,ms$

WEST DIRECTION

$V_0 = 10/9.75\,ms = 1025$ ft/sec
$V_1 = 40/9.25\,ms = 4325$ ft/sec
$V_2 = 45/3.5\,ms = 12800$ ft/sec

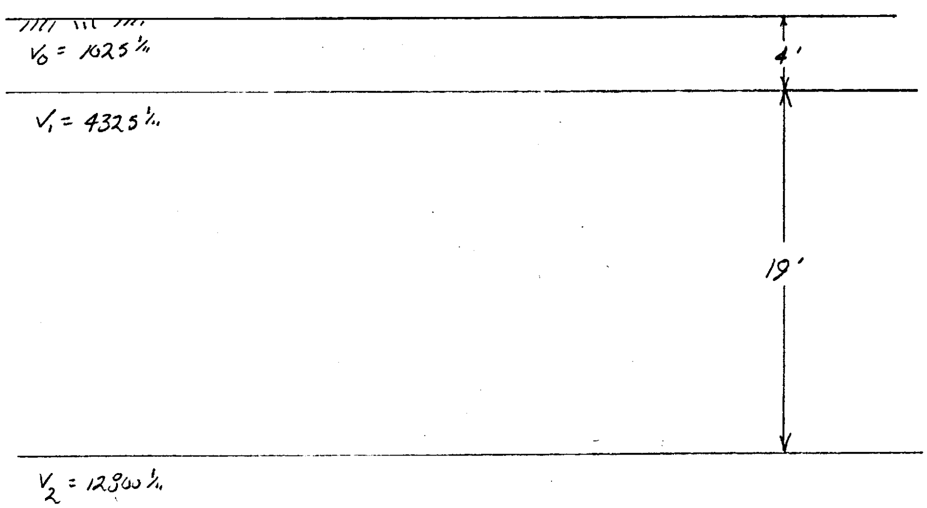
$X_c = 10.2'$

$T_{i2} = 16.125\,ms$

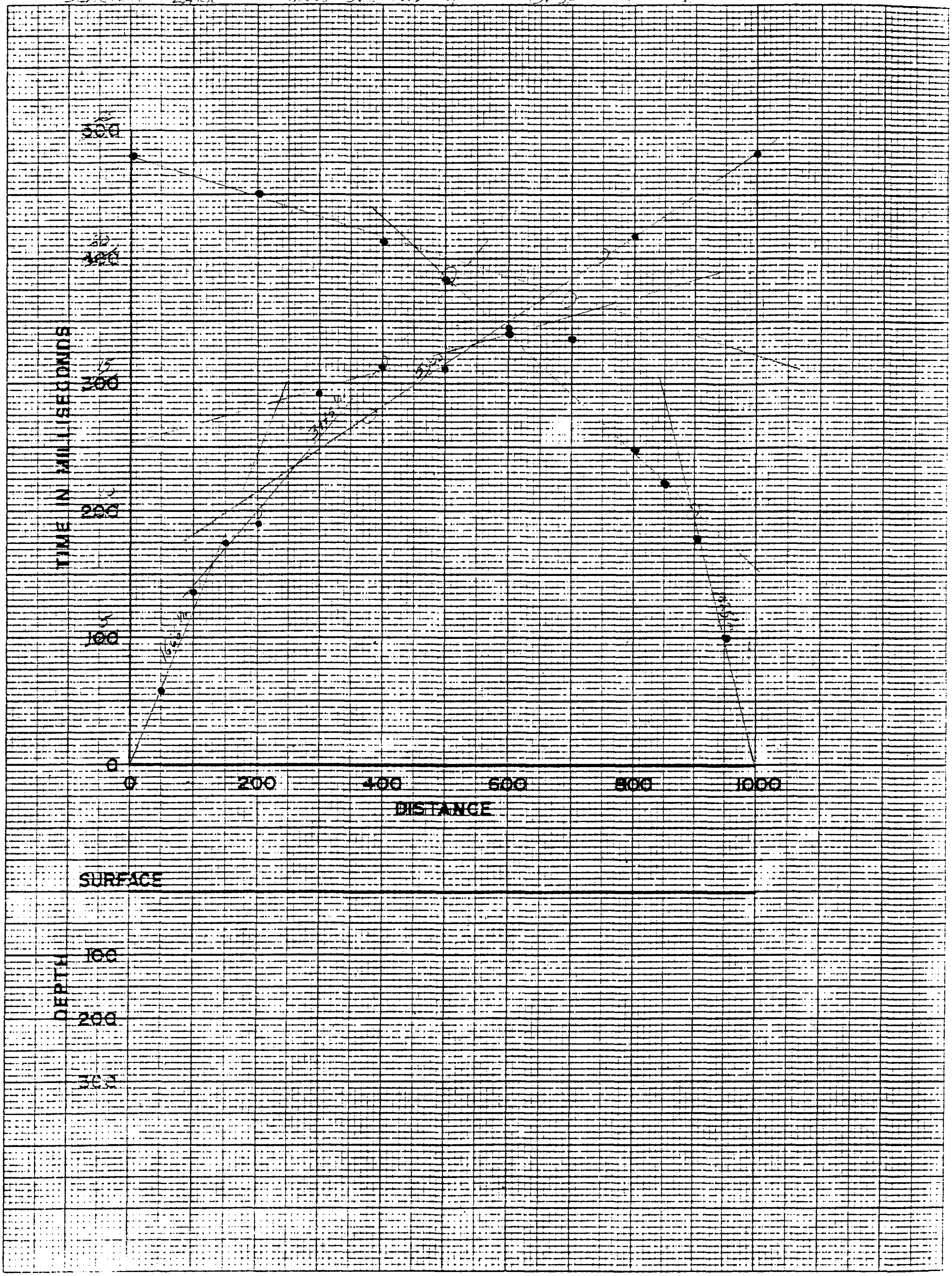
DISREGARD EAST DIRECTION (INCONSISTENT W/ THE REST OF GEOPHONE LOC.)
WHY?

$$Z_0 = \frac{1}{2}\sqrt{\frac{4325-1025}{5350}}\,(10.2) = 4.0'$$

$$Z_1 = \frac{1}{2}\left(.016125 - 2(4)\frac{\sqrt{12800^2-1025^2}}{12800\,(1025)}\right)\frac{12800\,(4325)}{\sqrt{12800^2-4325^2}} = 19'$$



GLACIER LAKE CROSS SECTION "J"



GLACIER LAKE | REFRACTION SURVEY | CROSS-SECTION "A"

GEOPHONE LOC. 2E

WEST DIRECTION

$V_0 = 5'/5.75ms = 870 \text{ ft/sec}$

$V_1 = 24'/8.5ms = 2800 \text{ ft/sec}$

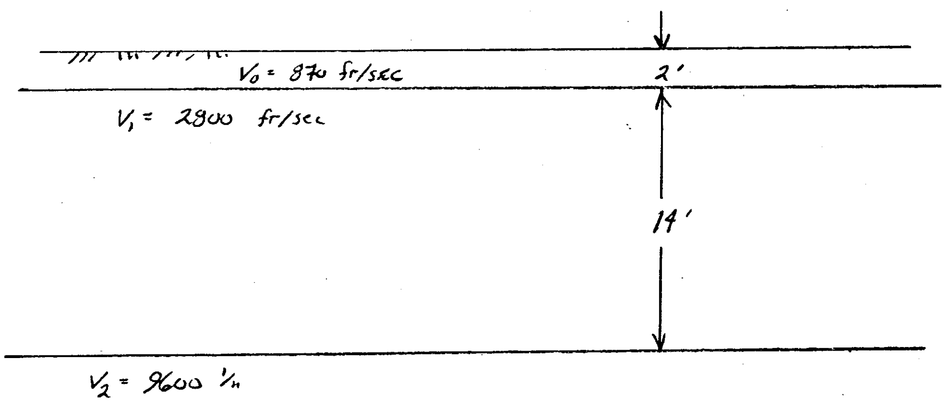
$V_2 = 24'/2.5ms = 9600 \text{ ft/sec}$

$X_c = 5'$

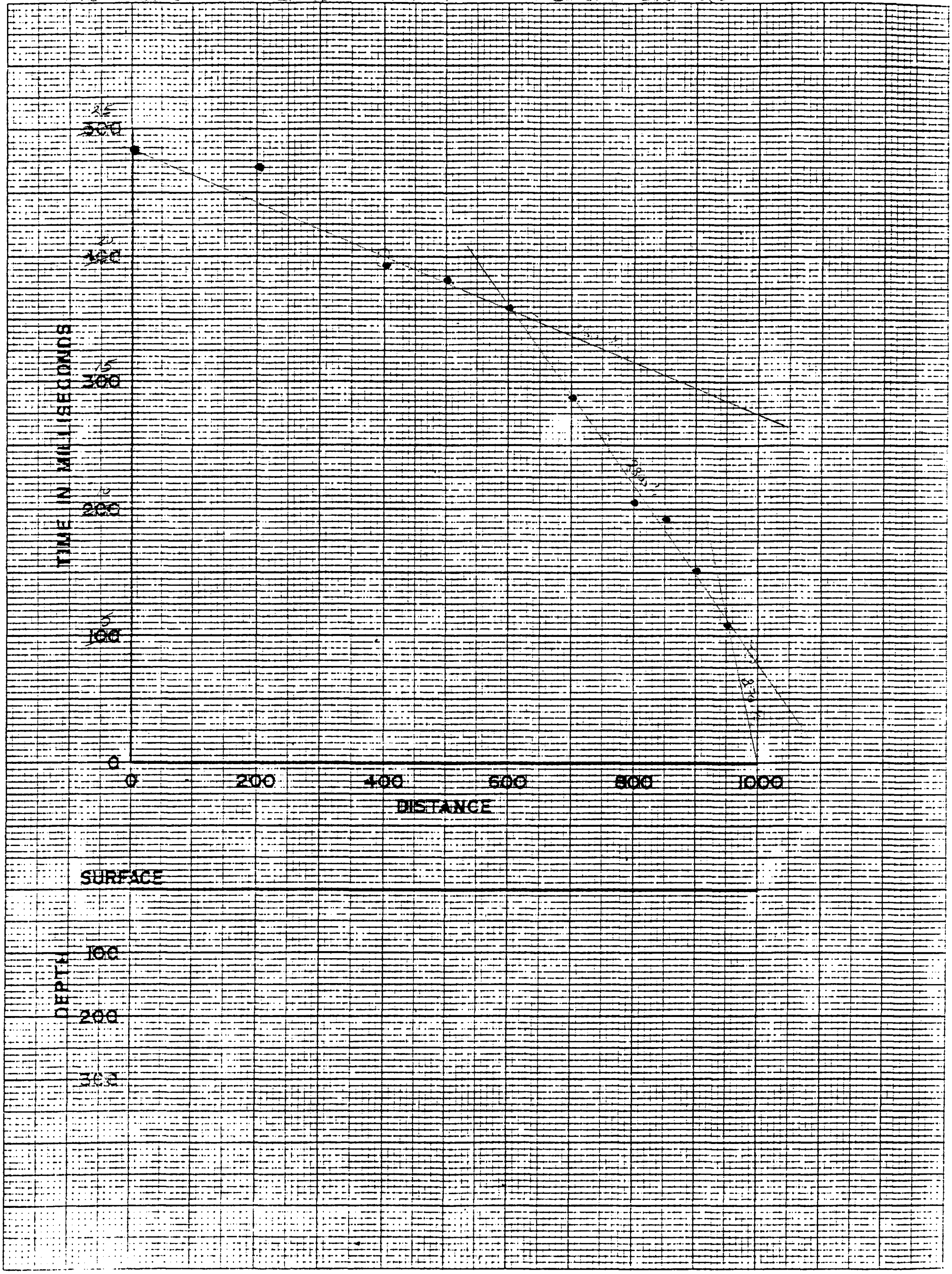
$T_{i_2} = 13.75 \text{ ms}$

$$z_0 = \frac{1}{2}\sqrt{\frac{2800 - 870}{2800 + 870}}\,(5) = 2 \text{ ft} \quad (1.8')$$

$$z_1 = \frac{1}{2}\left(.01375 - 2(1.8)\frac{\sqrt{9600^2 - 870^2}}{9600(870)}\right)\frac{9600(2800)}{\sqrt{9600^2 - 2800^2}} = 14 \text{ ft}$$



GLACIER LAKE CROSS-SECTION "A" 2E



GEOPHONE LOCATION 1W

$$V_0 = 5'/4.75\,ms = 1050 \text{ ft/sec}$$

$$V_1 = 10'/3\,ms = 3333 \text{ ft/sec}$$

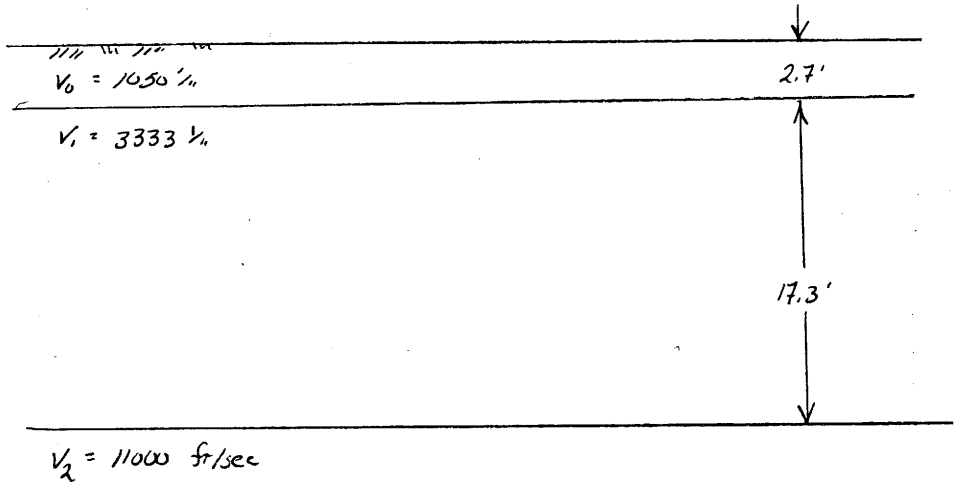
$$V_2 = 22'/2\,ms = 11000 \text{ ft/sec}$$

$$X_c = 7.5 \text{ ft}$$

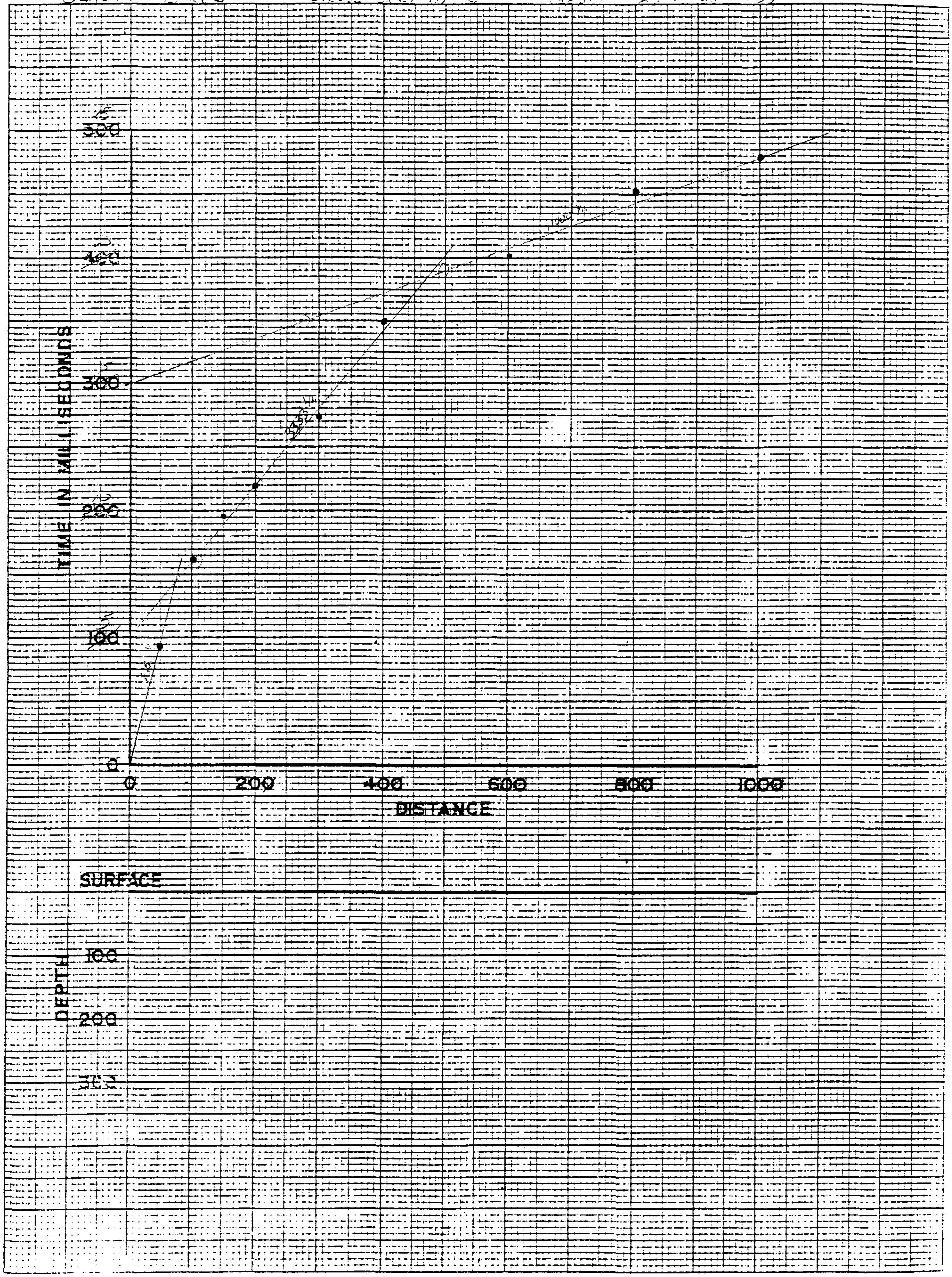
$$T_{i2} = 15\,ms$$

$$Z_0 = \frac{1}{2}\sqrt{\frac{3333-1050}{4383}}\,(7.5) = 2.7 \text{ ft}$$

$$Z_1 = \frac{1}{2}\left(.015 - 2(2.7)\frac{\sqrt{11000^2-1050^2}}{11000(1050)}\right)\frac{11000(3333)}{\sqrt{11000^2-3333^2}} = 17.3'$$



GLACIER LAKES CROSS-SECTION "B" 1(4)



GLACIER LAKES | REFRACTION SURVEY | CROSS-SECTION "B"

GEOPHONE LOCATION 1E

$V_0 = 10'/9.75\,ms = 1025$ ft/sec

$V_1 = 40/5.5\,ms = 7300$ ft/sec

$X_c = 13.5'$

$$Z_0 = \frac{1}{2}\sqrt{\frac{7300-1025}{8325}}\,(13.5) = 5.9'$$

GEOPHONE LOCATION C (POOR DATA AREA ⇒ GEOPHONE NOT PLANTED IN A GOOD LOCATION)

$V_0 = 1100$ ft/sec $= 12'/10.82$ ms

$V_1 = 20/9.25ms = 2160$ ft/sec

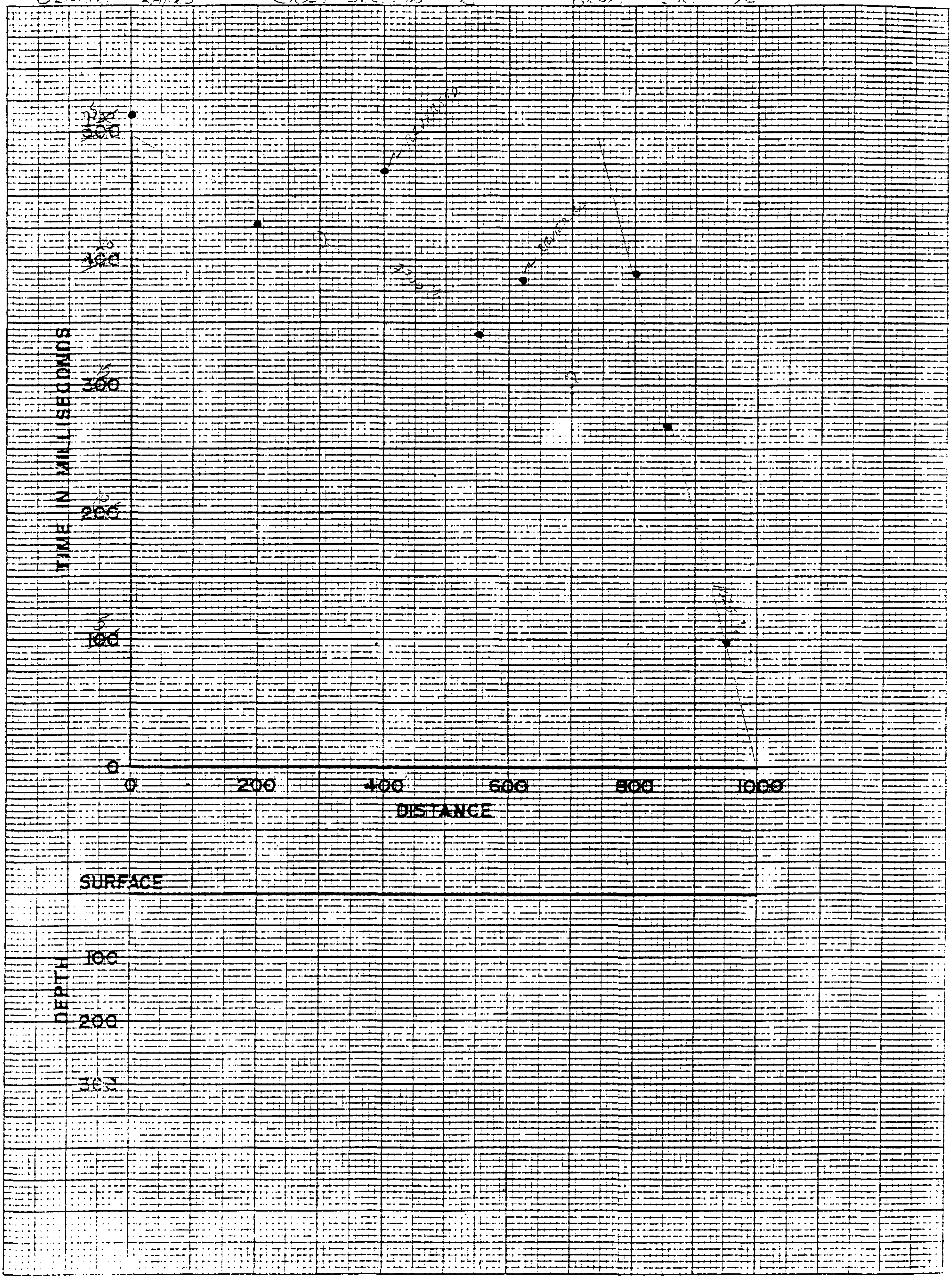
$V_1 = 20/3.75ms = 5333$ ft/sec

AVG. $V_1 = 3750$ ft/sec

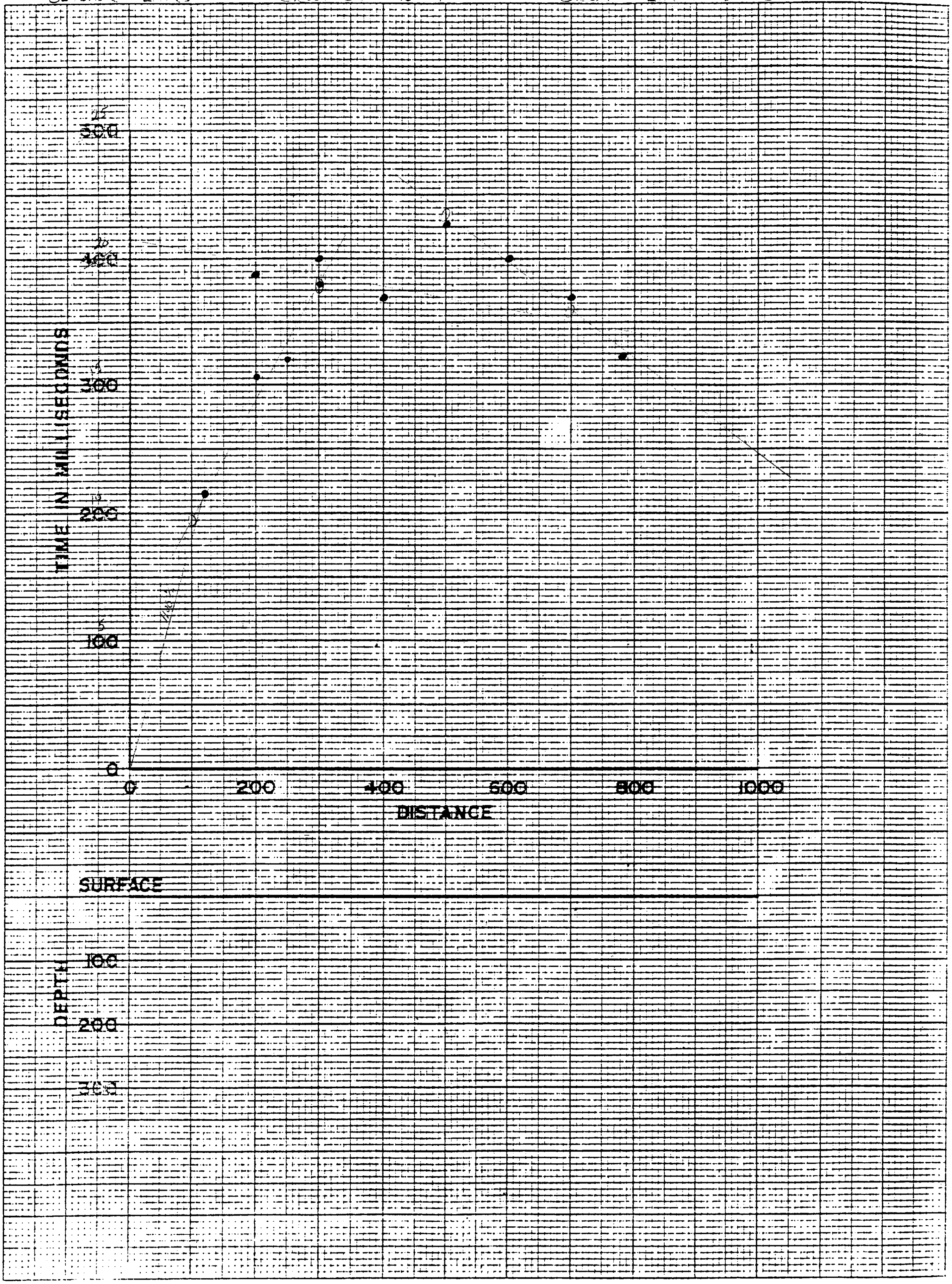
$X_{CROSS} = 12'$

$$Z_6 = \frac{1}{2}\sqrt{\frac{3750-1100}{4850}}\;12' = 4.4'$$

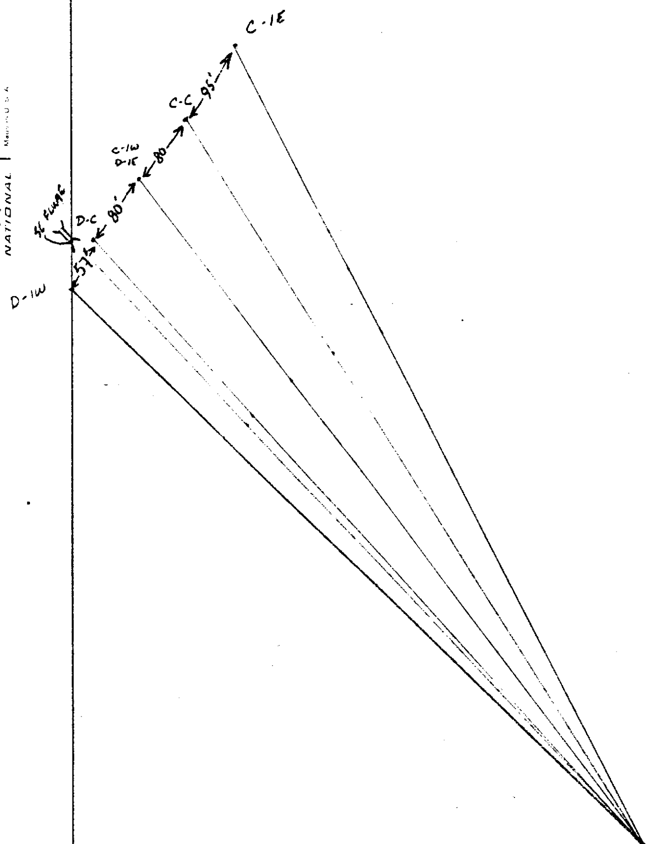
GLACIER LAKES CROSS-SECTION "B" GRAPH NO. 1E



GLACIER LAKE   CROSS-SECTION   GRAPH LOCATION C



GLACIER LAKES | REFRACTION SURVEY | LOCATION OF X-SECT "C & D"



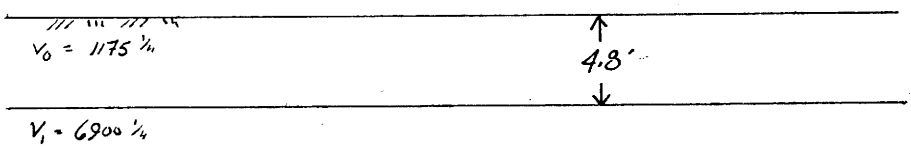
GEOPHONE LOCATION 1E

$V_0 = {}^{10}/_{8.5ms} = 1175$ ft/sec

$V_1 = {}^{50}/_{7.25ms} = 6900$ ft/sec

$X_c = 11.5$ ft

$$Z_0 = \frac{1}{2}\sqrt{\frac{6900-1175}{8075}}\,(11.5) = 4.8 \text{ ft}$$



GEOPHONE LOCATION C

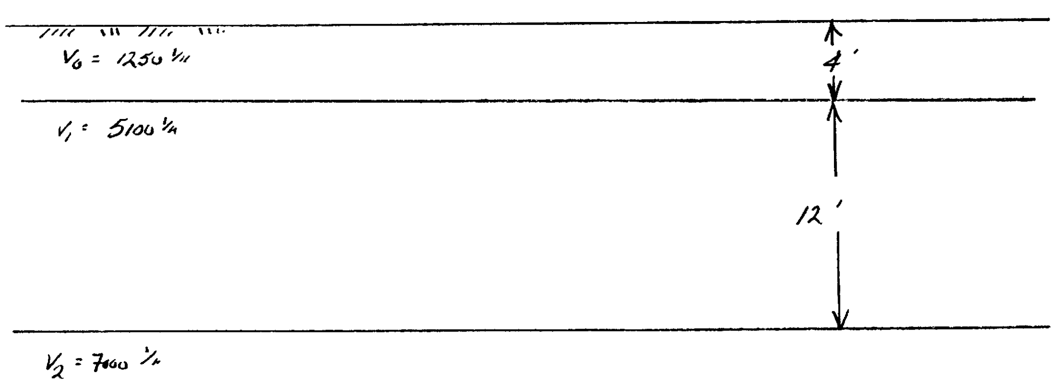
$V_0 = {}^{5}/_{4ms} = 1250$ ft/sec $\qquad X_c = 10'$

$V_1 = {}^{37}/_{7.25ms} = 5100$ ft/sec $\qquad T_{i2} = 9.3$ ms

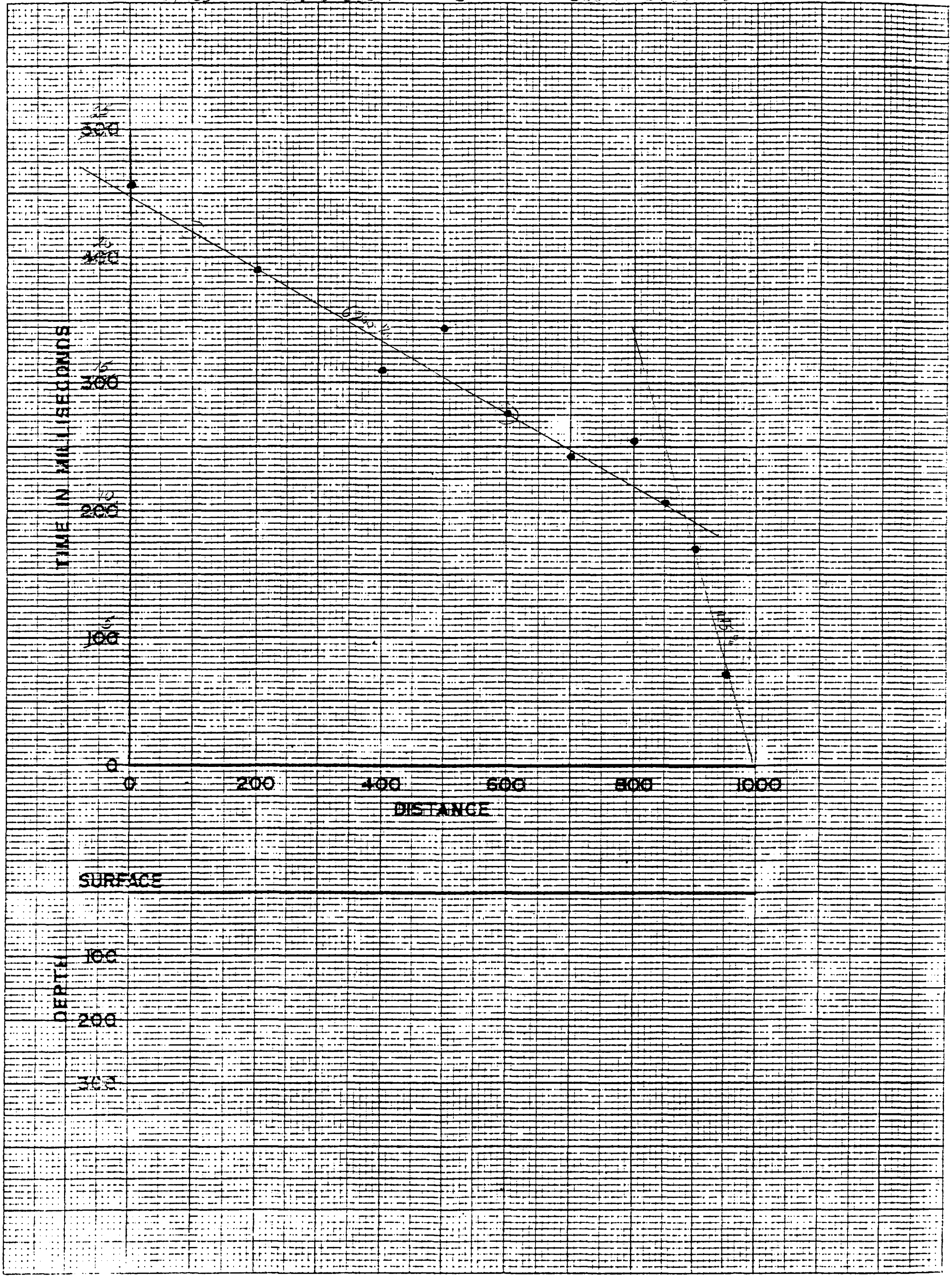
$V_2 = {}^{35}/_{5ms} = 7000$ ft/sec

$$Z_0 = \frac{1}{2}\sqrt{\frac{5100-1250}{6350}}\,(10) = 3.9'$$

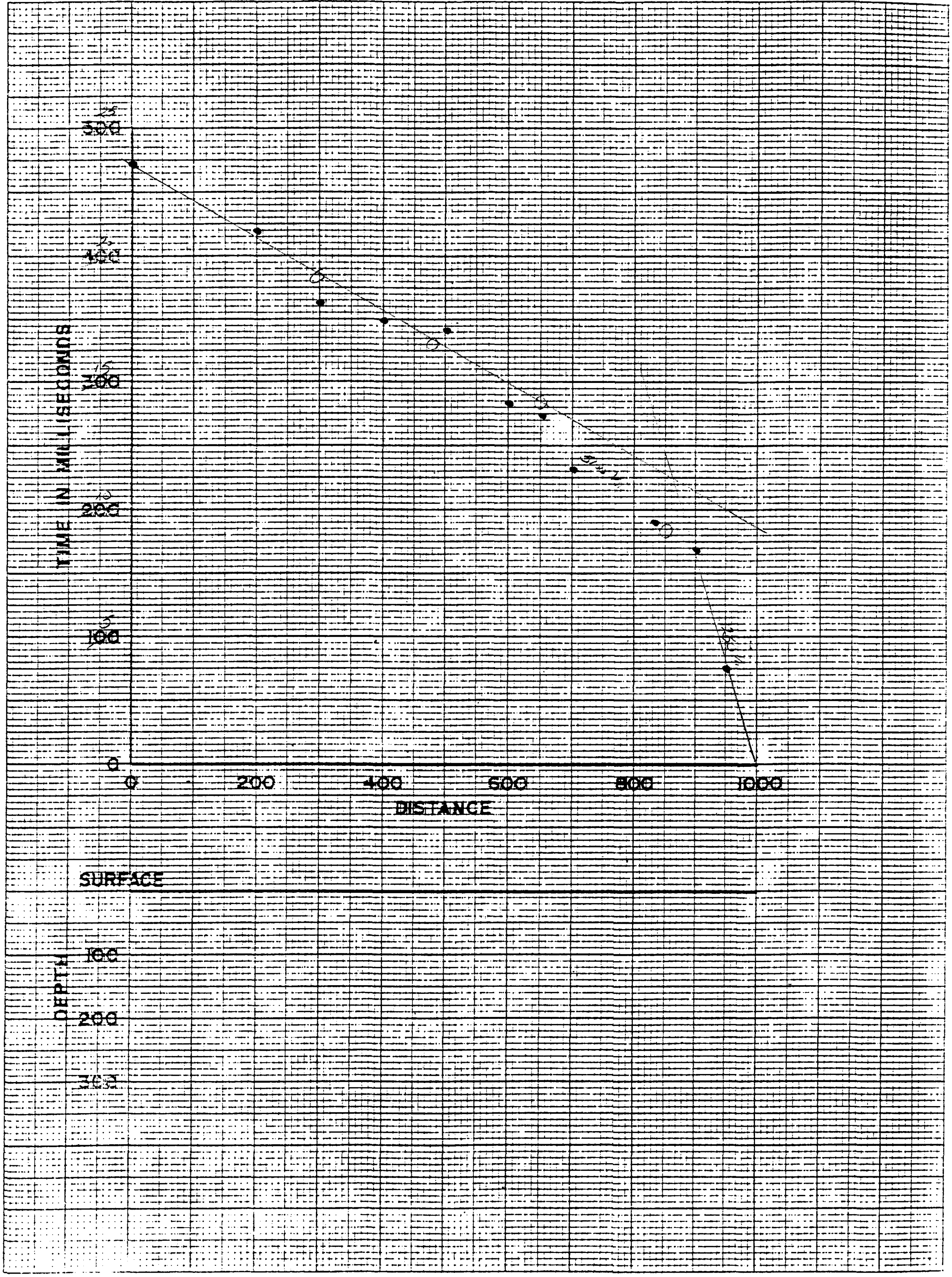
$$Z_1 = \frac{1}{2}\left(.0093 - 2(3.9)\frac{\sqrt{7000^2-1250^2}}{7000(1250)}\right)\frac{7000(5100)}{\sqrt{7000^2-5100^2}} = 11.8' = 12'$$



GLACIER LAKES CROSS-SECTION "C" 1E



GLACIER LAKE: CROSS-SECTION "C" GEOPHONE LOC. "C"



GLACIER LAKE REFRACTION SURVEY CROSS-SECTION D & C

GEOPHONE LOCATION 1E

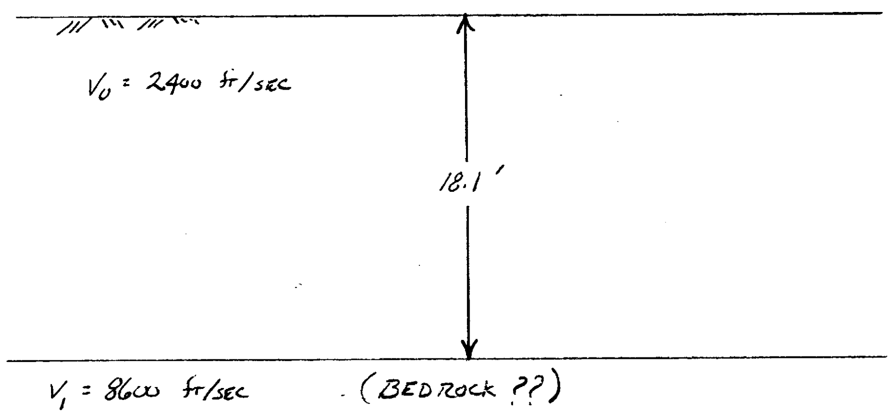
GEOPHONE LOCATION C - 1W

$V_0 = 40'/16.75ms = 2400\ ft/sec$

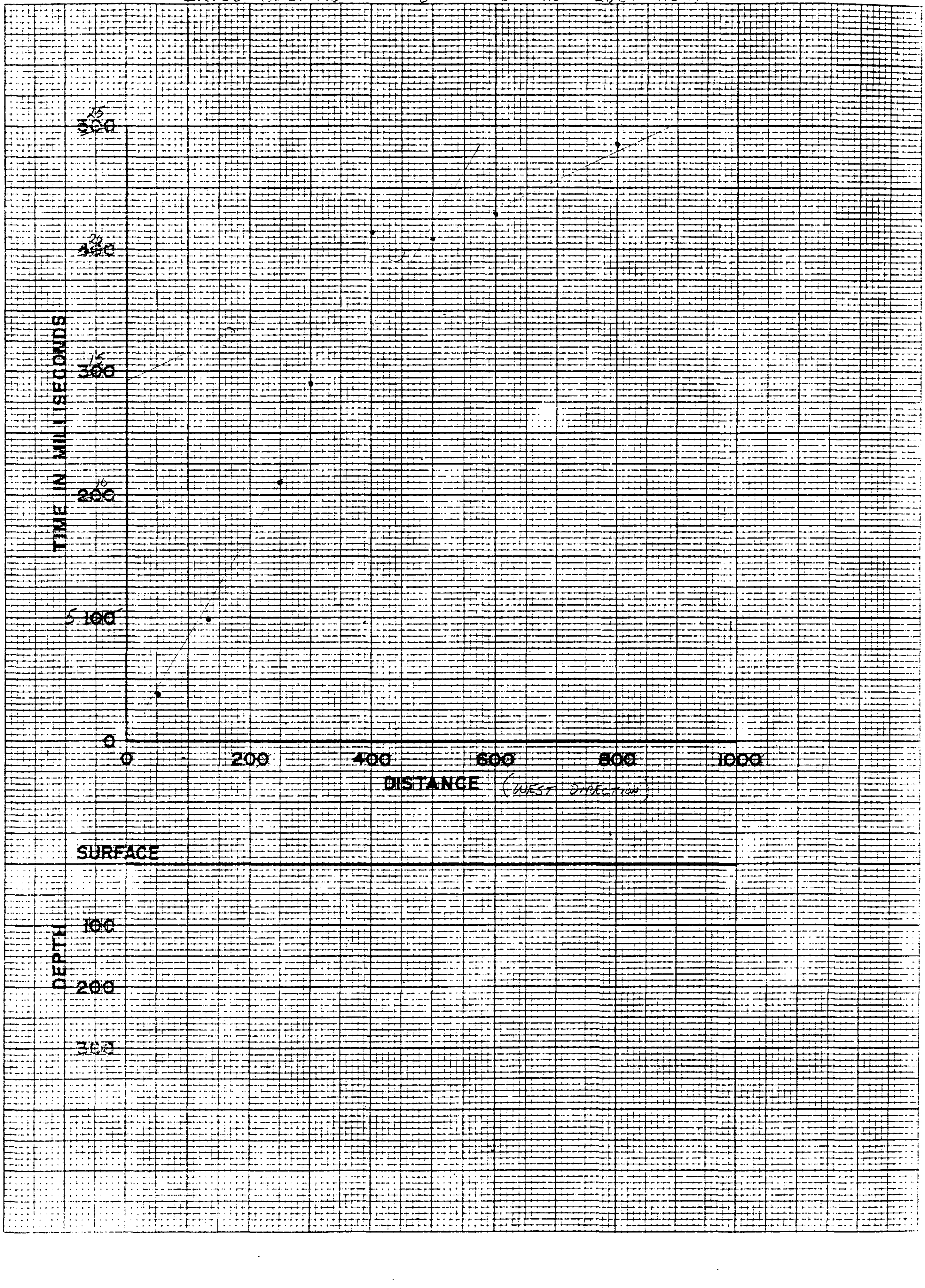
$V_1 = 28'/3.25ms = 8600\ ft/sec$

$X_{cross} = 48.3\ ft$

$$Z = \frac{1}{2}\sqrt{\frac{8600-2400}{11000}}\ (48.3) = 18.1\ ft$$



CROSS-SECTION "C & D" GEOPHONE LOCATION(S) D-1E & C-1W



GEOPHONE LOCATION "CENTER"

$V_0 = {}^{8\,ft}/_{8.75\,ms} = 900$ ft/sec $\qquad X_{cross} = 5.4'$

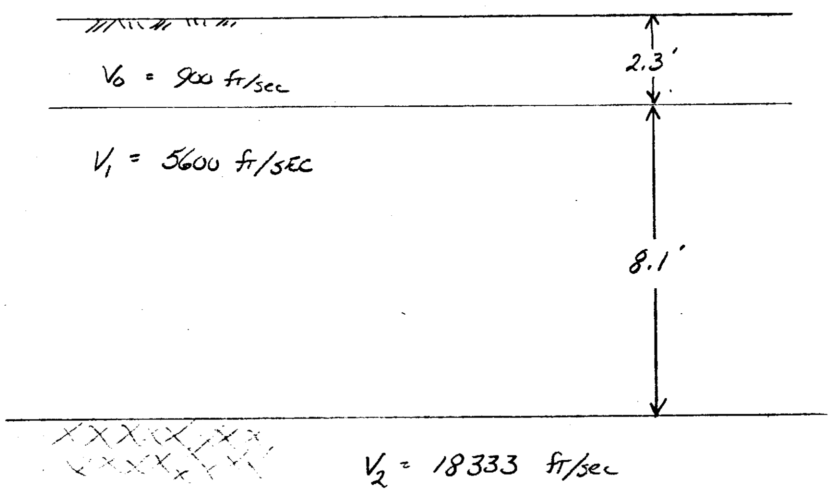
$V_1 = {}^{21\,ft}/_{3.75\,ms} = 5600$ ft/sec $\qquad T_{i_2} = 7.85\,ms$

$V_2 = {}^{55\,ft}/_{3\,ms} = 18333$ ft/sec

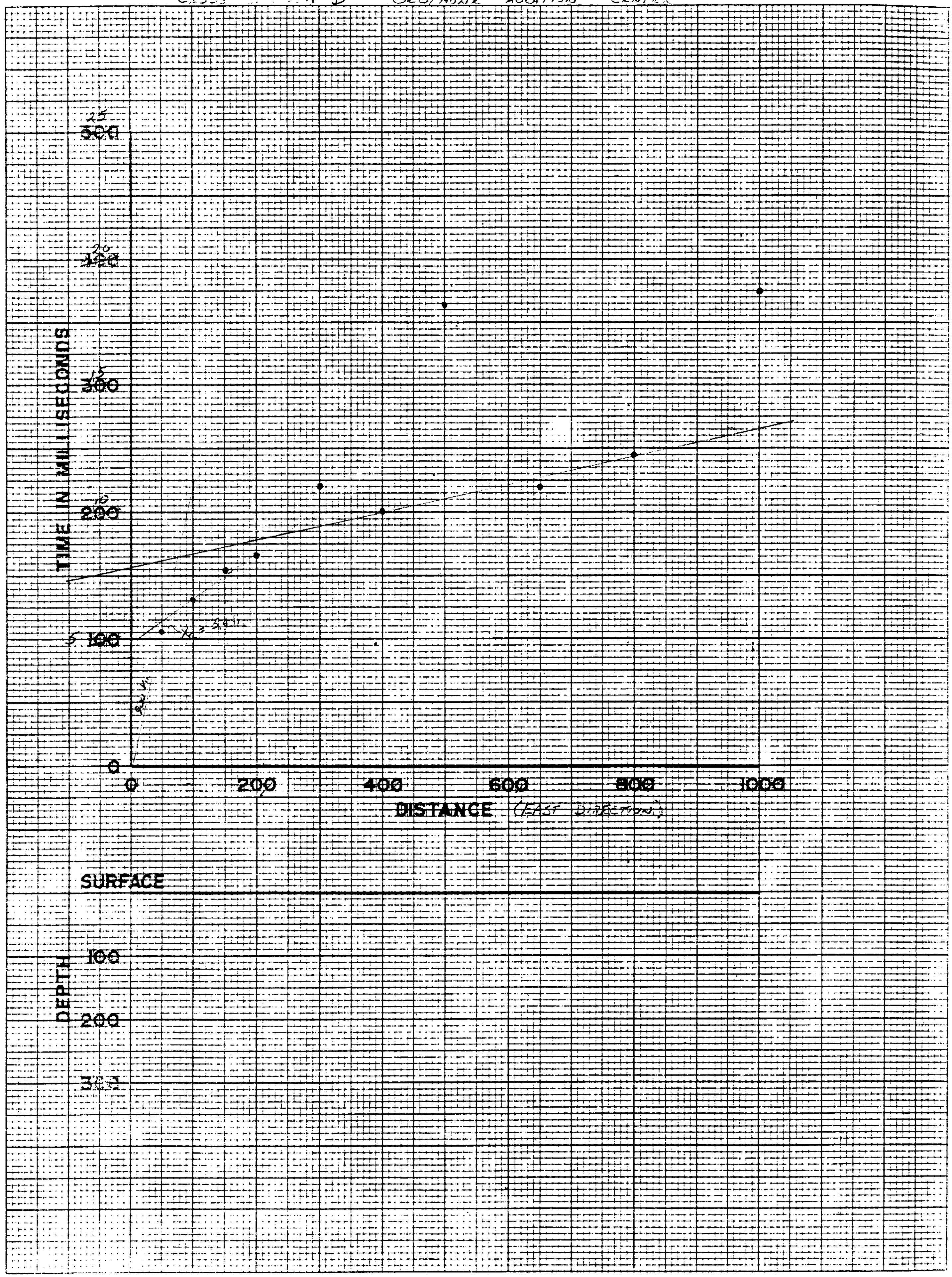
$$Z_0 = \frac{1}{2}\sqrt{\frac{5600-900}{6500}}\,(5.4) = 2.3\ ft$$

$$Z_1 = \frac{1}{2}\left(7.85ms - 2(2.3)\frac{\sqrt{18333^2-900^2}}{18333\,(900)}\right)\frac{18333\,(5600)}{\sqrt{18333^2-5600^2}} = 8.1\ ft$$

TOTAL DEPTH = 2.3 + 8.1 = 10.4 ft



CROSS-SECTION "D" GEOPHONE LOCATION "CENTER"



GLACIER LAKE | REFRACTION SURVEY | CROSS-SECTION D

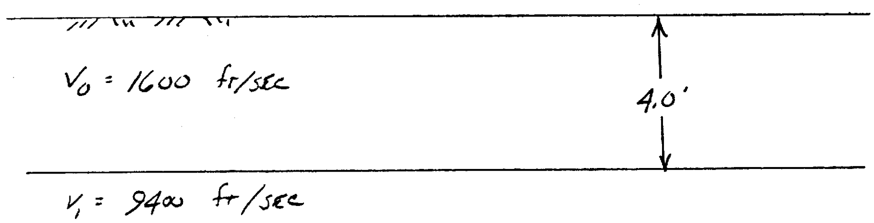
GEOPHONE LOCATION 1W

$V_0 = 10' / 6.25\,ms = 1600$ ft/sec

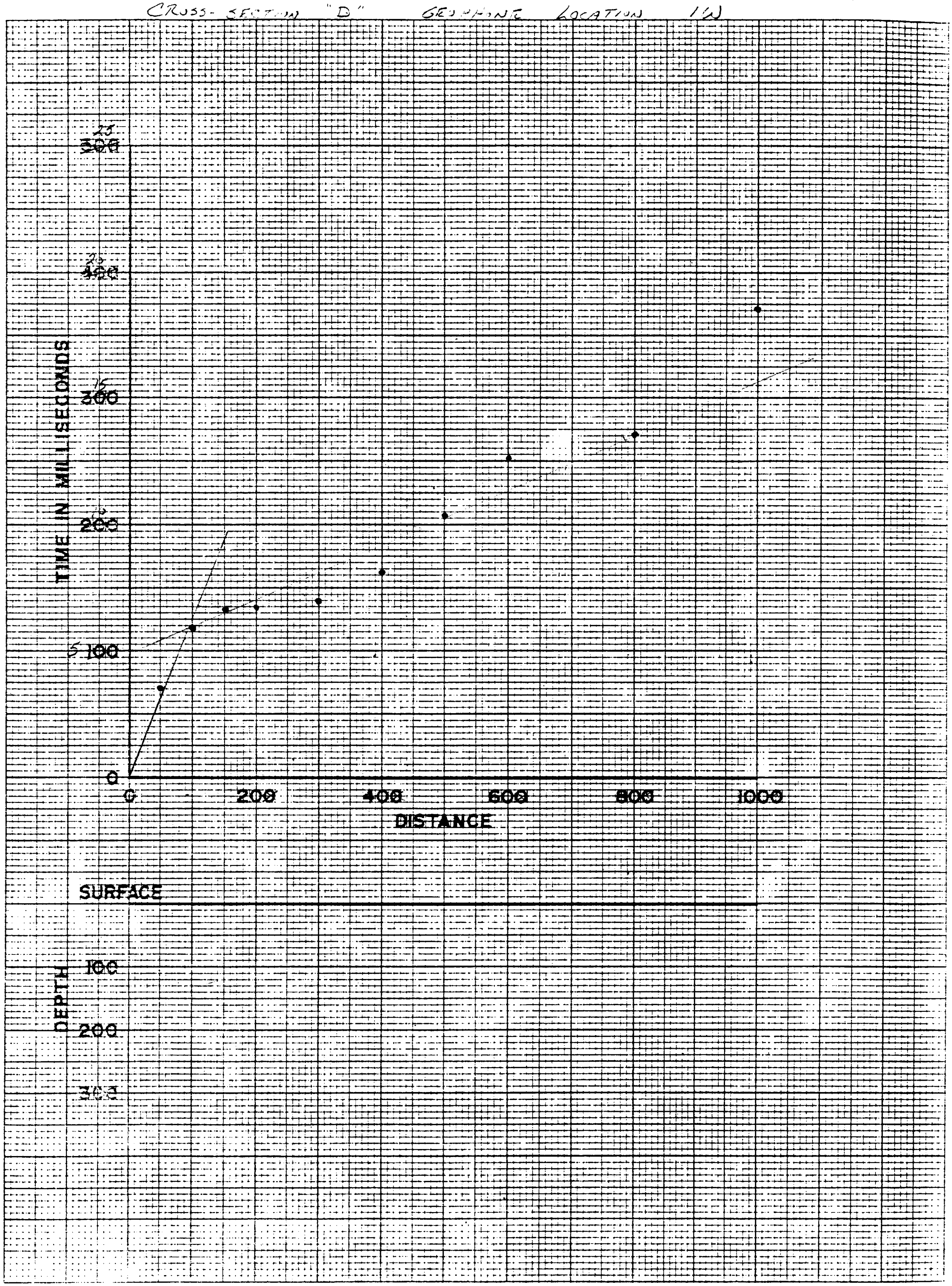
$V_1 = 33' / 3.5\,ms = 9400$ ft/sec

$X_{cross} = 9.4$ ft

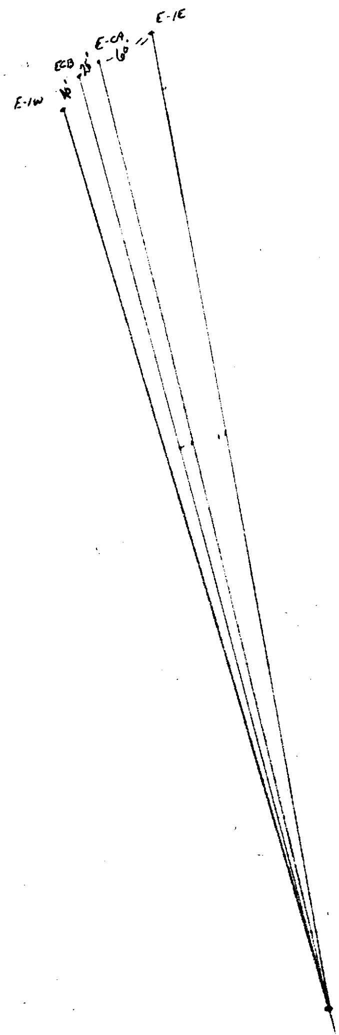
$$Z = \frac{1}{2}\sqrt{\frac{9400 - 1600}{11000}}\,(9.4) = 4.0 \text{ ft}$$



CROSS-SECTION "D" GEOPHONE LOCATION 1W



GLACIER LAKE | REFRACTION SURVEY | CROSS-SECTION "E"

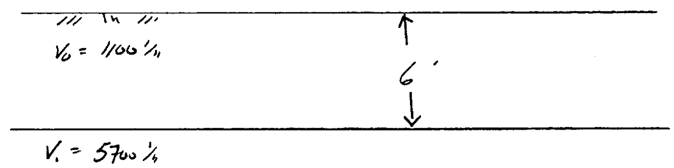


GEOPHONE LOCATION 1W.

$V_0 = {}^{10}/_{9ms} = 1111$ ft/sec
$V_1 = {}^{30}/_{5.25ms} = 5700$ ft/sec

$X_c = 14.5'$

$$Z_0 = \frac{1}{2}\sqrt{\frac{5700-1100}{6800}}\,(14.5) = 6'$$



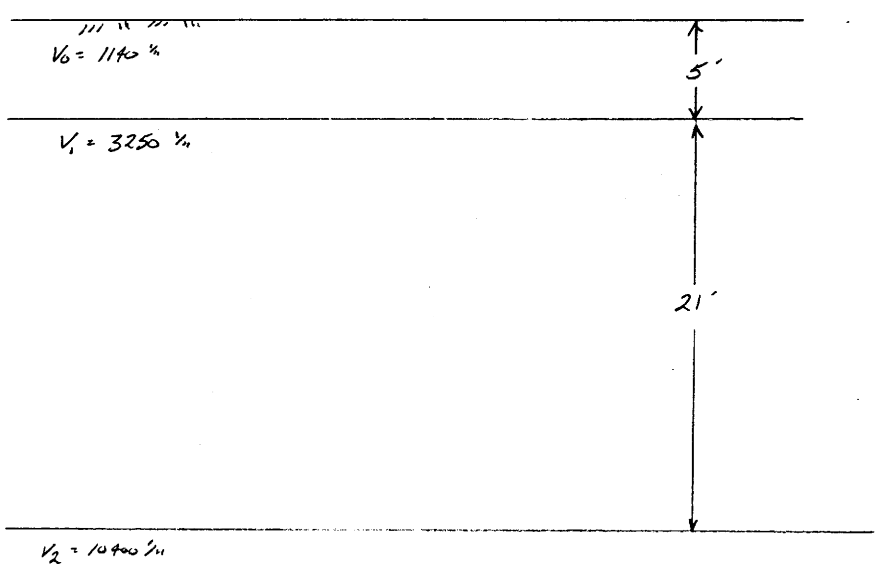
GEOPHONE LOCATION CB

$V_0 = {}^{10}/_{8.8ms} = 1140$ '/s
$V_1 = {}^{13}/_{4ms} = 3250$ '/s
$V_2 = {}^{60}/_{5.75ms} = 10400$ '/s

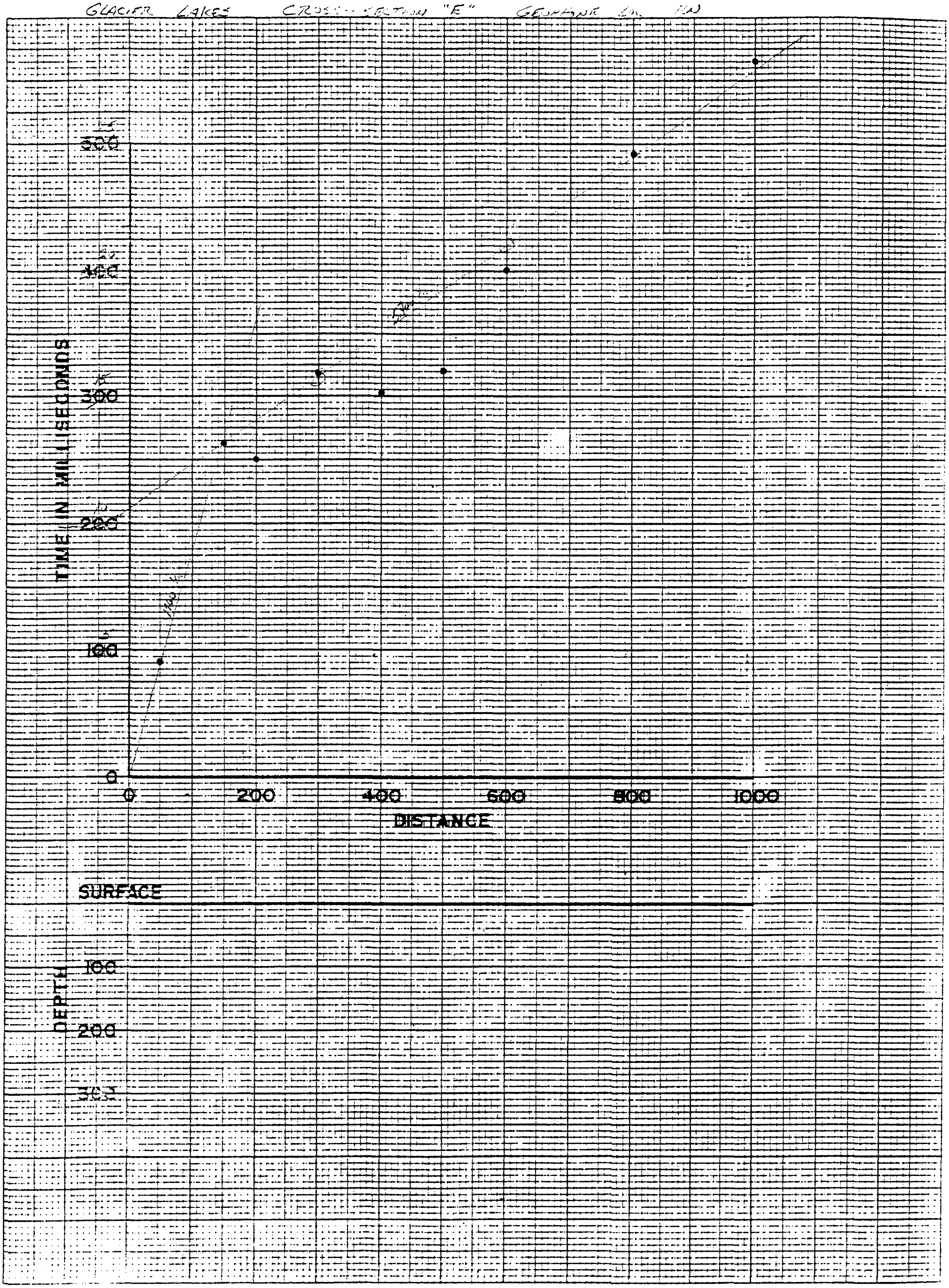
$X_c = 15'$
$T_{i2} = 21.6$ ms

$$Z_0 = \frac{1}{2}\sqrt{\frac{3250-1140}{4390}}\,(15) = 5.2'$$

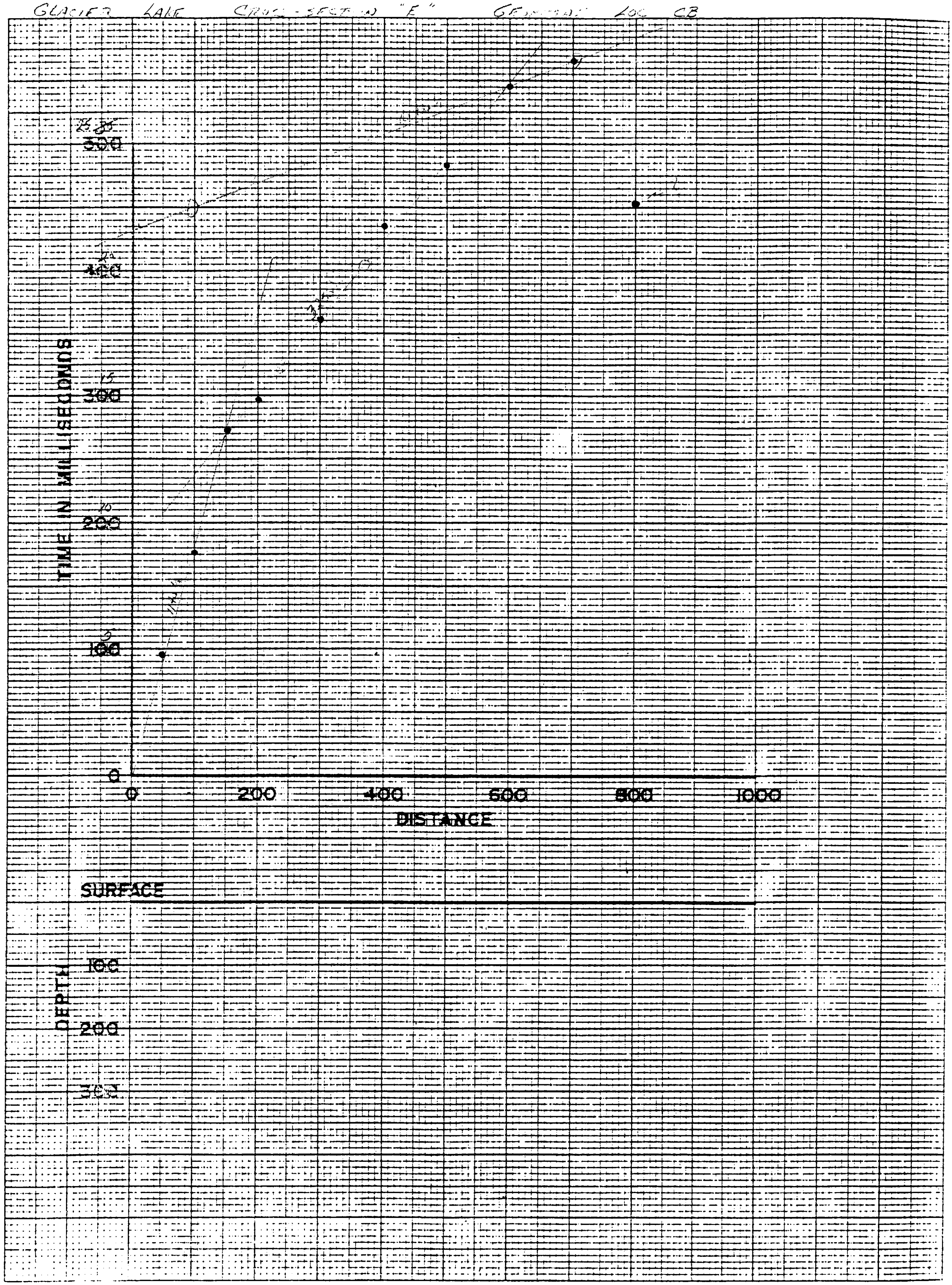
$$Z_1 = \frac{1}{2}\left(.0216 - 2(5.2)\frac{\sqrt{10400^2-1140^2}}{10400(1140)}\right)\frac{10400(3250)}{\sqrt{10400^2-3250^2}} = 21.4'$$



GLACIER LAKES CROSS-SECTION "E"



GLACIER LAKE CROSS-SECTION "E" GEOPHONE LOC CB



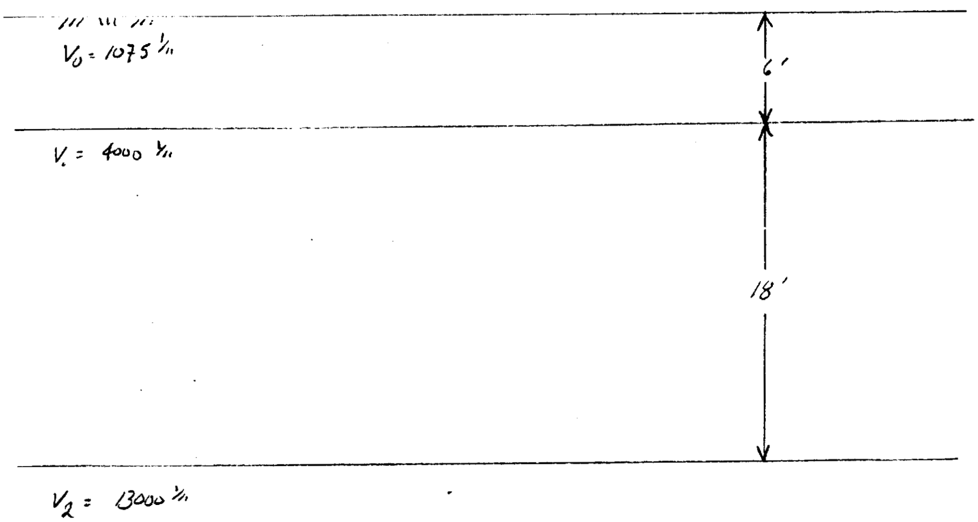
GEOPHONE LOCATION CA

$V_0 = 10/9.3 = 1075$ ft/sec
$V_1 = 10/2.5ms = 4000$ ft/sec
$V_2 = 13/1ms = 13000$ ft/sec

$x_c = 15.5'$
$T_{i2} = 19.3\ ms$

$$Z_0 = \frac{1}{2}\sqrt{\frac{4000-1075}{5075}}\,(15.5) = 5.9'$$

$$Z_1 = \frac{1}{2}\left(.0193 - 2(5.9)\frac{\sqrt{13000^2-1075^2}}{13000(1075)}\right)\frac{13000(4000)}{\sqrt{13000^2-4000^2}} = 17.6'$$



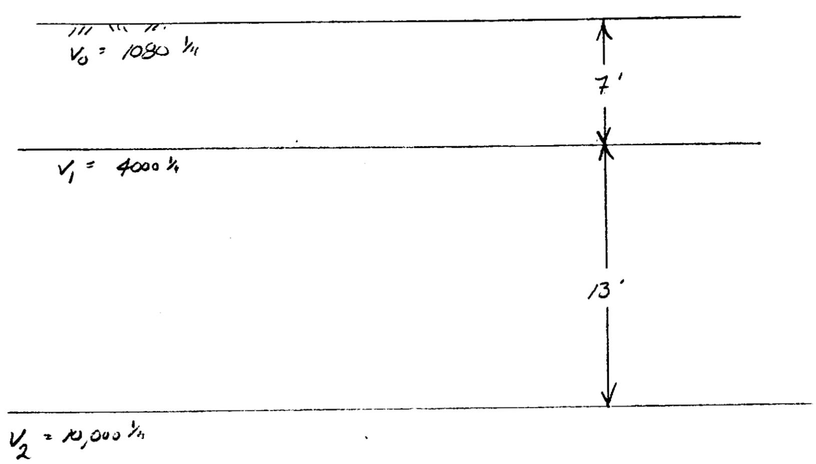
GEOPHONE LOCATION 1E

$V_0 = 10/9.25ms = 1080$ ft/sec
$V_1 = 20/5ms = 4000$ ft/sec
$V_2 = 15/1.5ms = 10000$ ft/sec

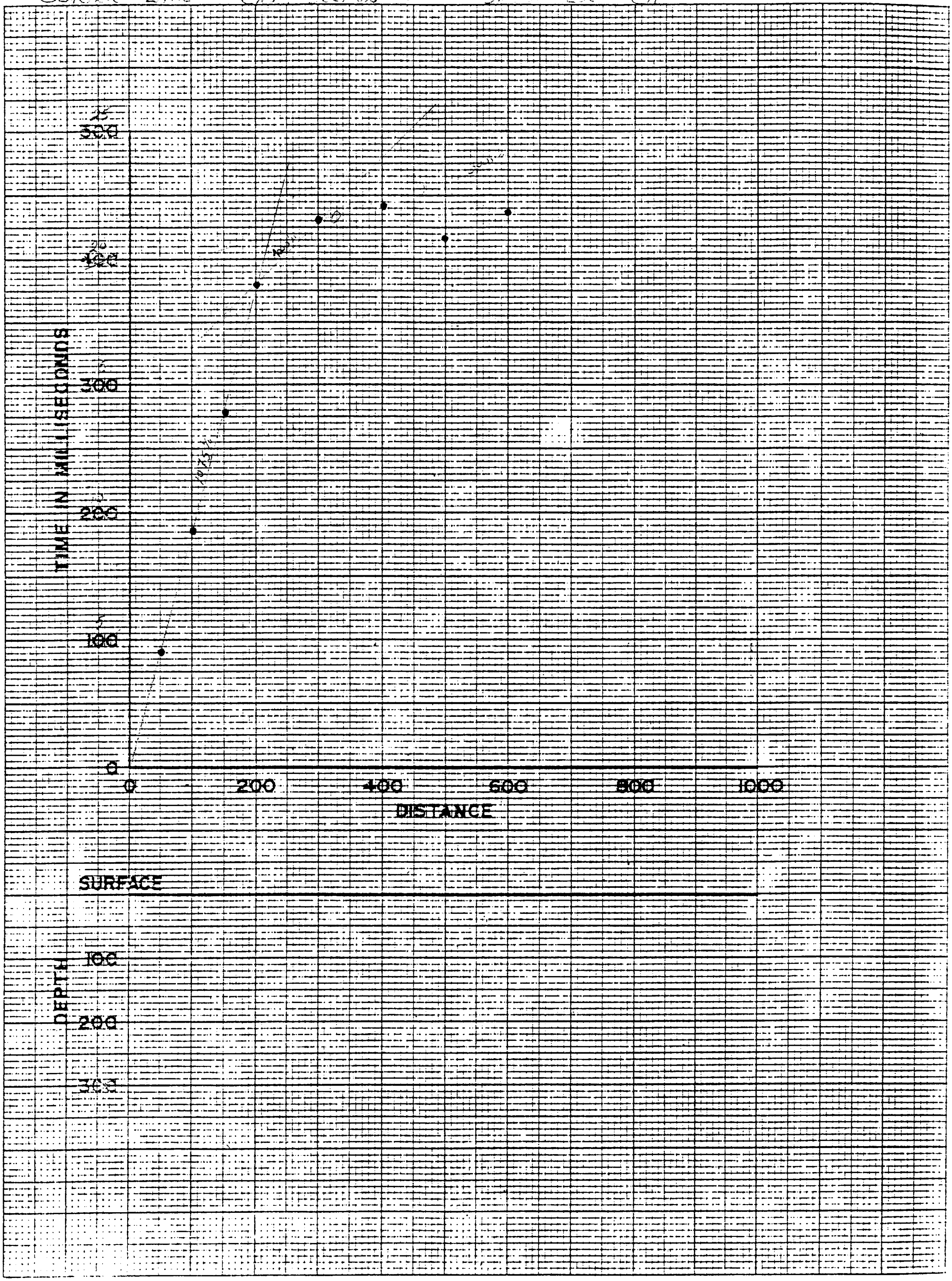
$x_c = 19'$
$T_{i2} = 19.25\ ms$

$$Z_0 = \frac{1}{2}\sqrt{\frac{4000-1080}{5080}}\,(19) = 7.2'$$

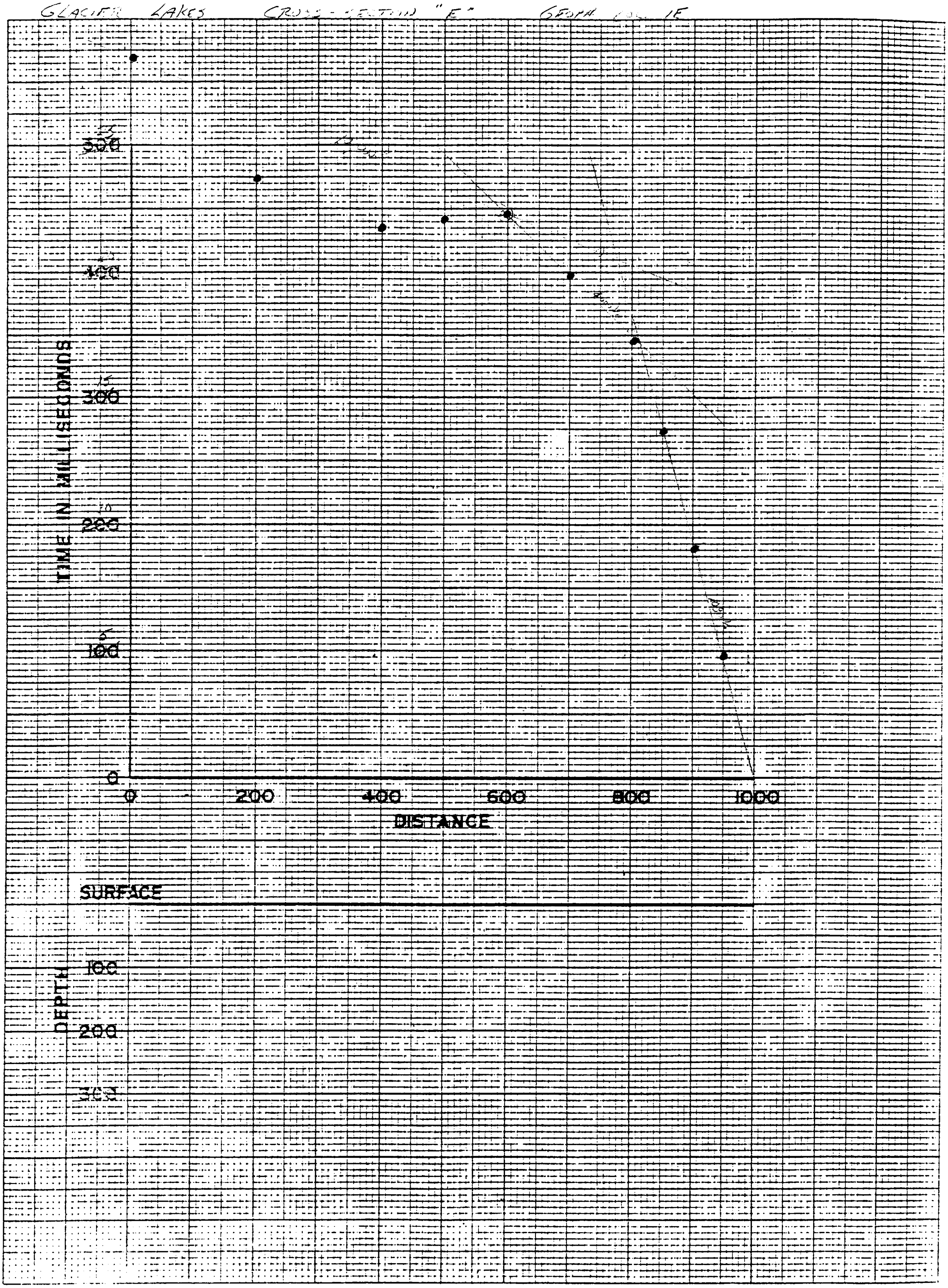
$$Z_1 = \frac{1}{2}\left(.01925 - 2(7.2)\frac{\sqrt{10000^2-1080^2}}{10,000(1080)}\right)\frac{10000(4000)}{\sqrt{10000^2-4000^2}} = 13.1'$$



GLACIER LAKE CROSS SECTION "E" [illegible] CA



GLACIER LAKES CROSS-SECTION "E" GEOPH. ... 1E



GLACIER LAKES — REFRACTION SURVEY — CROSS-SECTION "F"

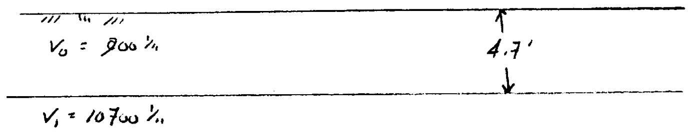
GEOPHONE LOCATION 1W

$V_0 = 5/5.5ms = 900$ ft/sec

$V_1 = 40/3.75ms = 10700$ ft/sec

$X_c = 10.2'$

$$Z_0 = \frac{1}{2}\sqrt{\frac{10700-900}{11600}}\,(10.2) = 4.7'$$



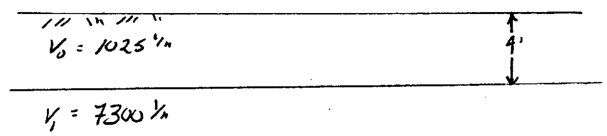
GEOPHONE LOCATION C

$V_0 = 10/9.75ms = 1025$ ft/sec

$V_1 = 20/2.75ms = 7300$ ft/sec

$X_c = 9'$

$$Z_0 = \frac{1}{2}\sqrt{\frac{7300-1025}{8325}}\,(9) = 3.9'$$



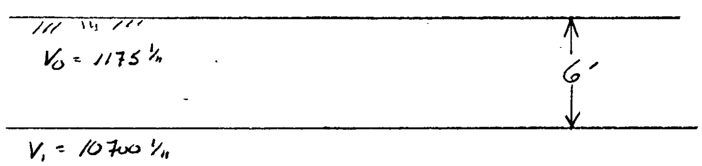
GEOPHONE LOCATION 1E

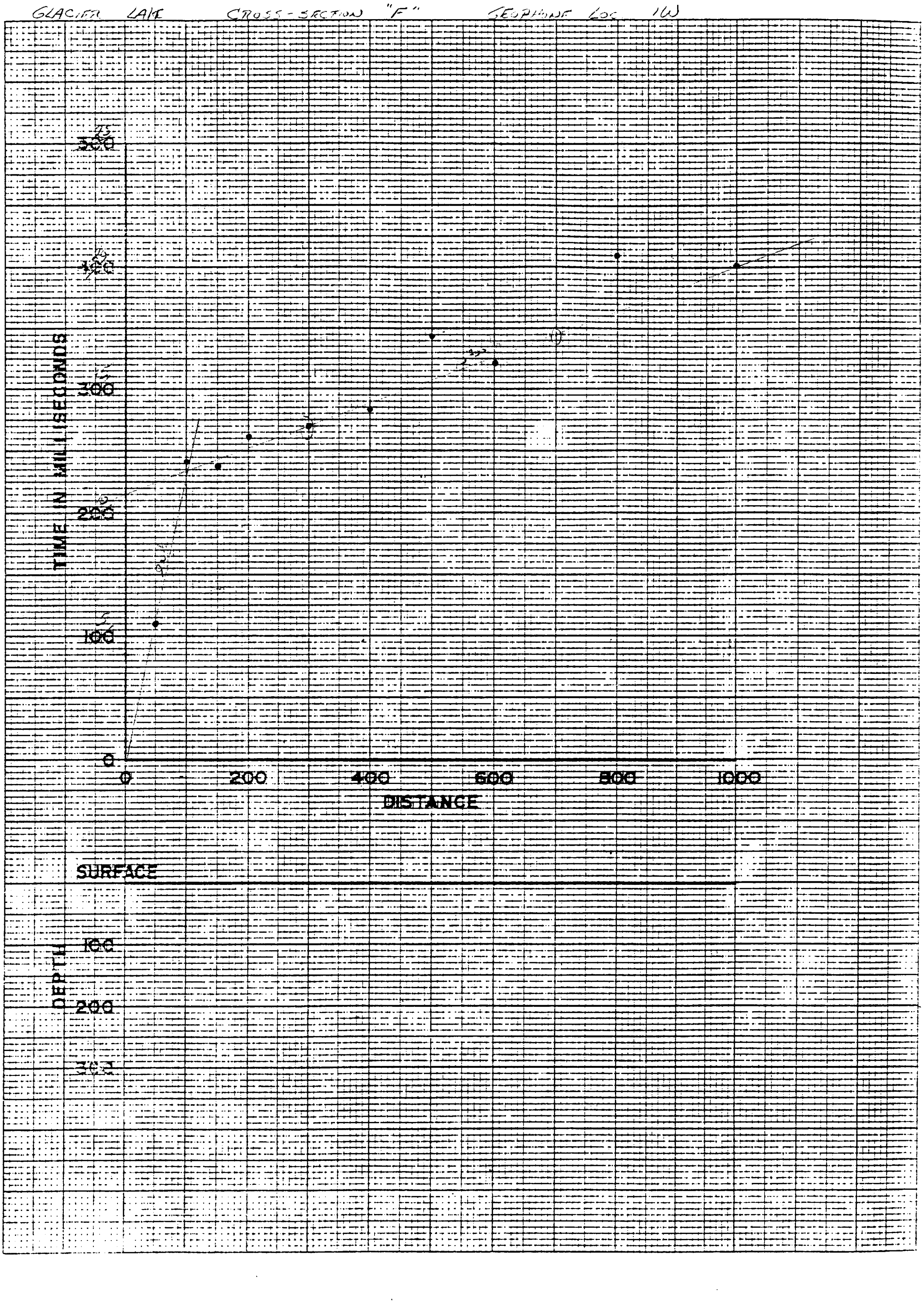
$V_0 = 10/8.5 = 1175$ ft/sec

$V_1 = 40/3.75 = 10700$ ft/se

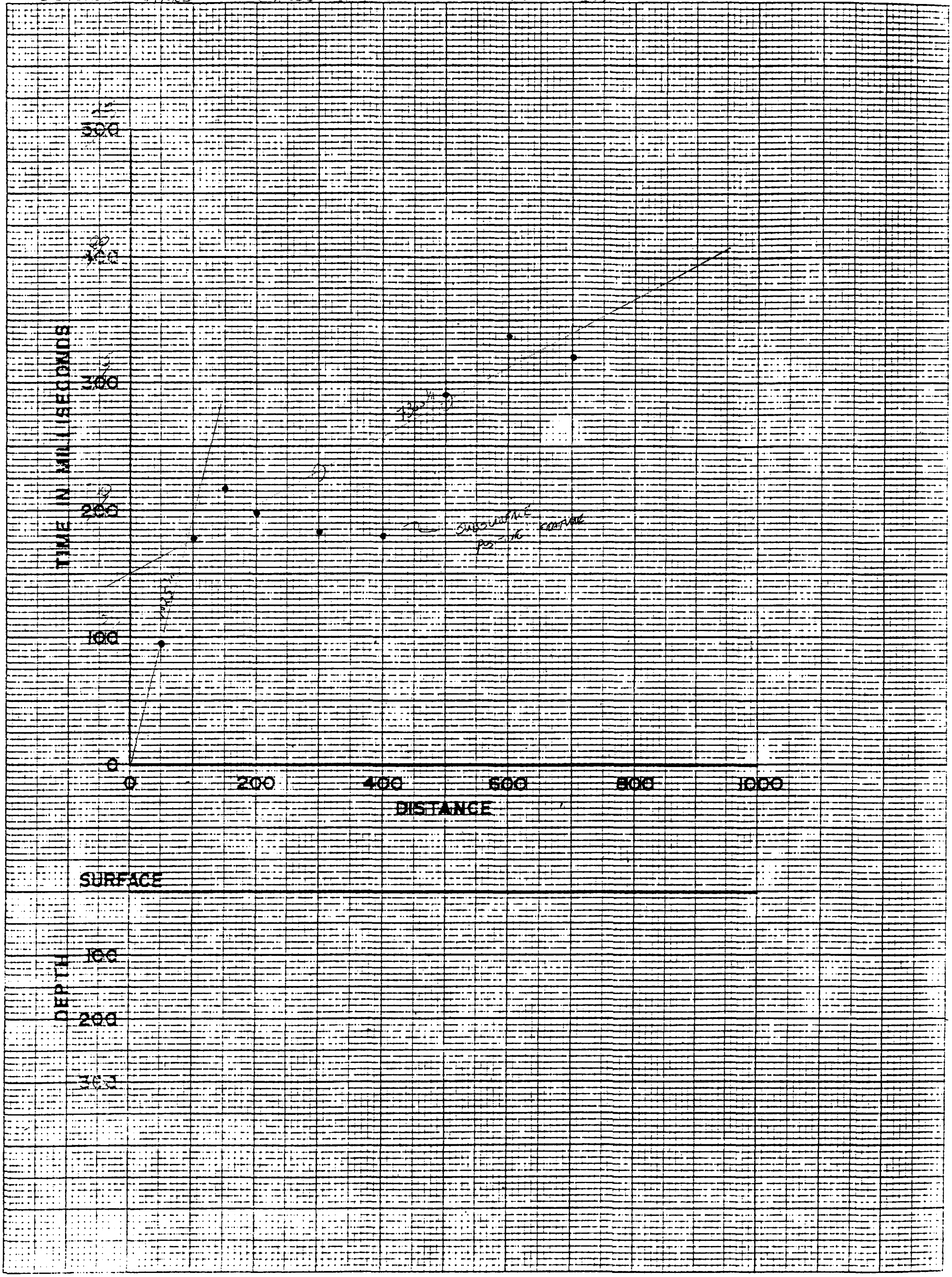
$X_c = 13'$

$$Z_0 = \frac{1}{2}\sqrt{\frac{10700-1175}{11875}}\,(13) = 5.8'$$

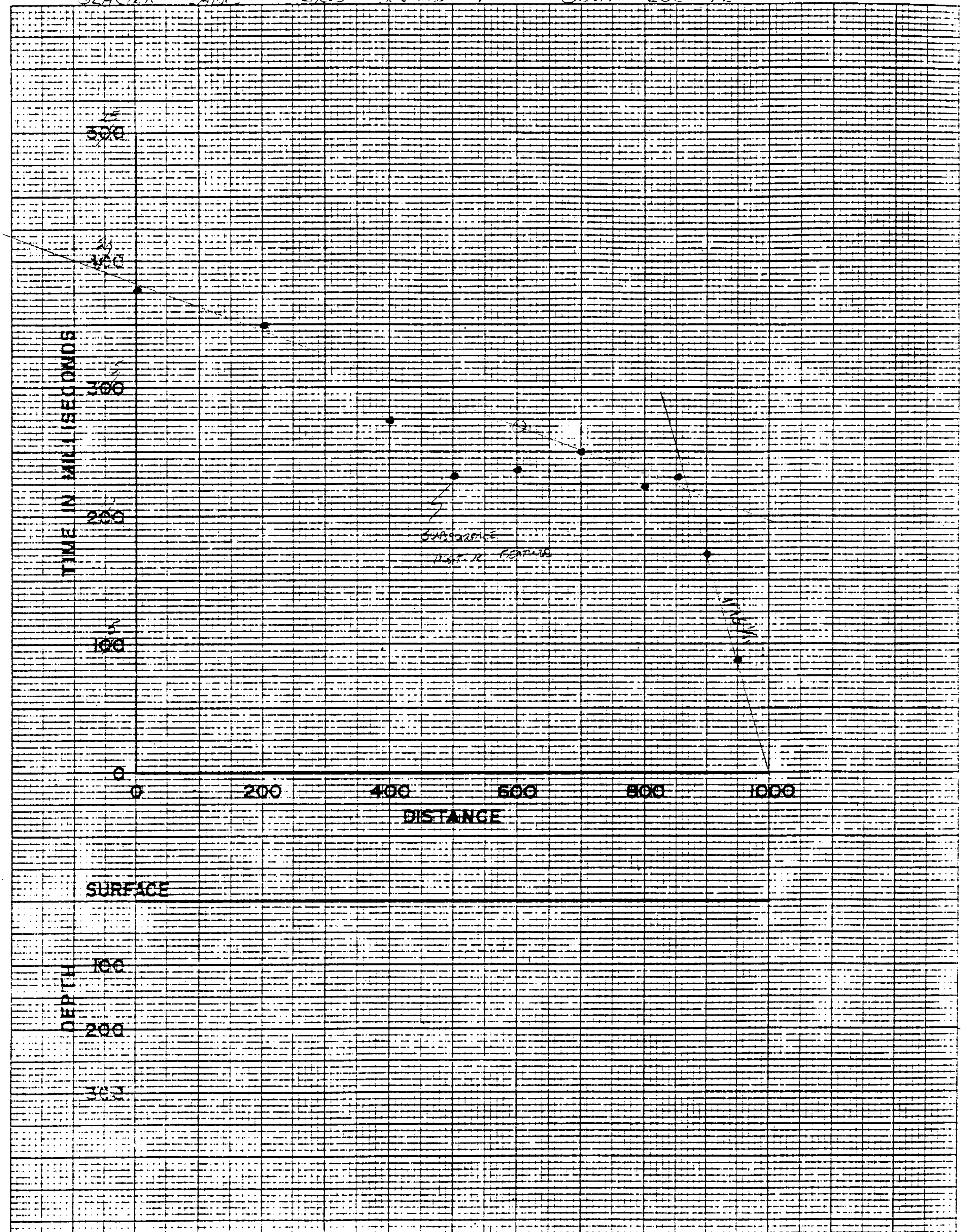



GLACIER LAKE
CROSS-SECTION "F"
GEOPHONE LOC 1W
TIME IN MILLISECONDS
0
100
200
300
400
500
0
200
400
600
800
1000
DISTANCE
SURFACE
DEPTH
100
200
300

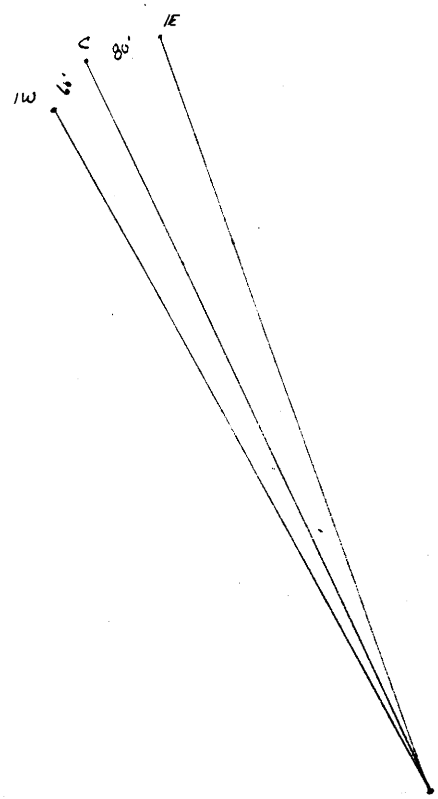
GLACIER LAKES CROSS-SECTION "F"



GLACIER LAKES CROSS-SECTION "F" GEOPH LOC 1E



GLACIER LAKES | REFRACTION SURVEY | CROSS-SECTION "G"



GEOPHONE LOCATION 1W

$V_0 = 5/4.5\,ms = 1110$ ft/sec
$V_2 = 10/1.75\,ms = 5700$ ft/sec
$V_3 = 25/1.75\,ms = 14300$ ft/sec
$X_c = 7'$
$T_{i2} = 4.4$ ms
$V_1 = 10/3\,ms = 3333$

$$Z_0 = \frac{1}{2}\sqrt{\frac{3333-1110}{4443}}\,(7) = 2.5'$$

$$Z_1 = \frac{1}{2}\left(.0044 - 2(2.5)\frac{\sqrt{5700^2-1110^2}}{5700(1110)}\right)\frac{5700(3333)}{\sqrt{5700^2-3333^2}} =$$

$V_0 = 1110$ ft/s
2.5
$V_1 = 3333$ ft/s

GEOPHONE LOCATION C

EAST DIRECTION
$V_0 = 10/9.25\,ms = 1080$ ft/sec
$V_1 = 25/6.5\,ms = 3850$ ft/sec
$V_2 = 10/1\,ms = 10,000$ ft/sec
$X_c = 6'$
$T_{i2} = 11.75$ ms

WEST DIRECTION
$V_0 = 1080$ ft/sec
$V_1 = 25/4.25\,ms = 5900$ ft/s
$X_c = 7'$

AVG.
$V_0 = 1080$ ft/sec
$V_1 = 4900$ ft/sec
$V_2 = 10,000$??
$X_c = 6.5'$
$T_{i2} = 11.75$ ms ??

$$Z_0 = \frac{1}{2}\sqrt{\frac{4900-1080}{5980}}\,(6.5) = 2.6'$$

$$Z_1 = \frac{1}{2}\left(.01175 - 2(2.6)\frac{\sqrt{10,000^2-1080^2}}{10,000(1080)}\right)\frac{10000(4900)}{\sqrt{10,000^2-4900^2}} = 19.6'$$

$V_0 = 1080$ ft/s
2.6'
$V_1 = 4900$ ft/s
20'
$V_2 = 10,000$ ft/s

GLACIER LAKES	REFRACTION SURVEY	CROSS-SECTION "G"

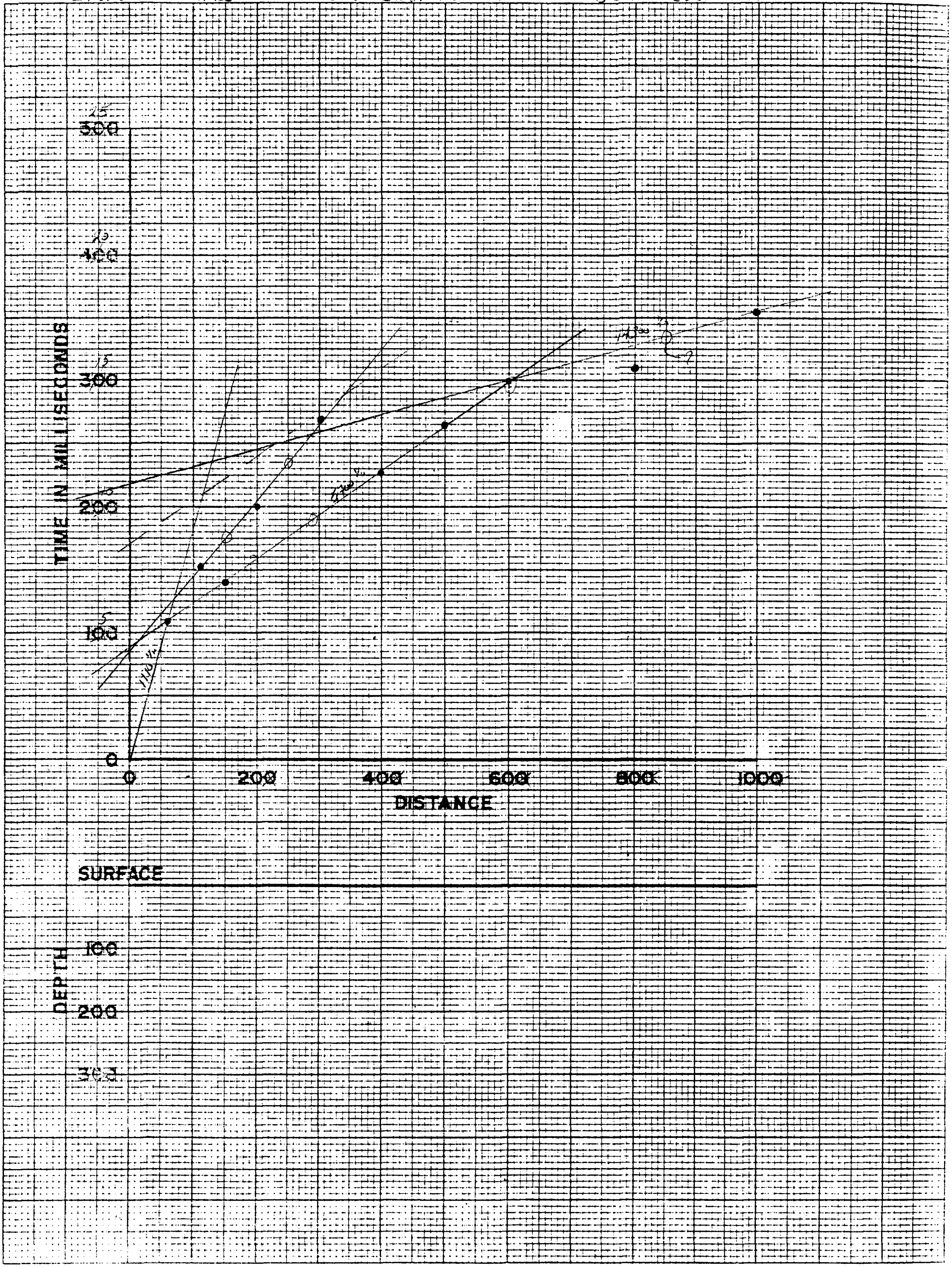
GEOPHONE LOCATION 1E

$V_0 = {}^{10}/_{7.5ms} = 1333$ ft/s
$V_1 = {}^{30}/_{7ms} = 4300$ ft/s
$V_2 = {}^{40}/_{3.75ms} = 10700$ ft/s

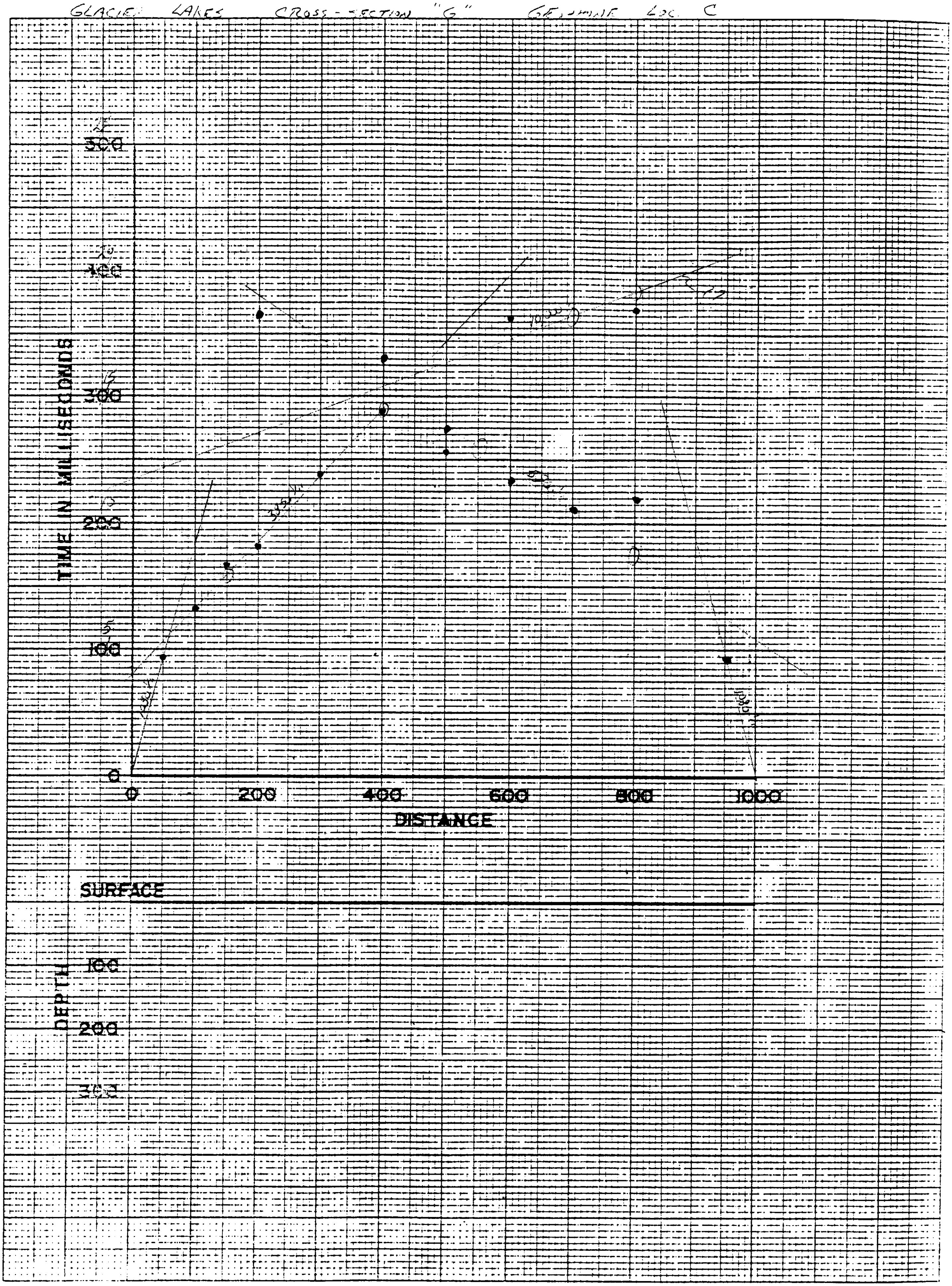
$X_c = ?$

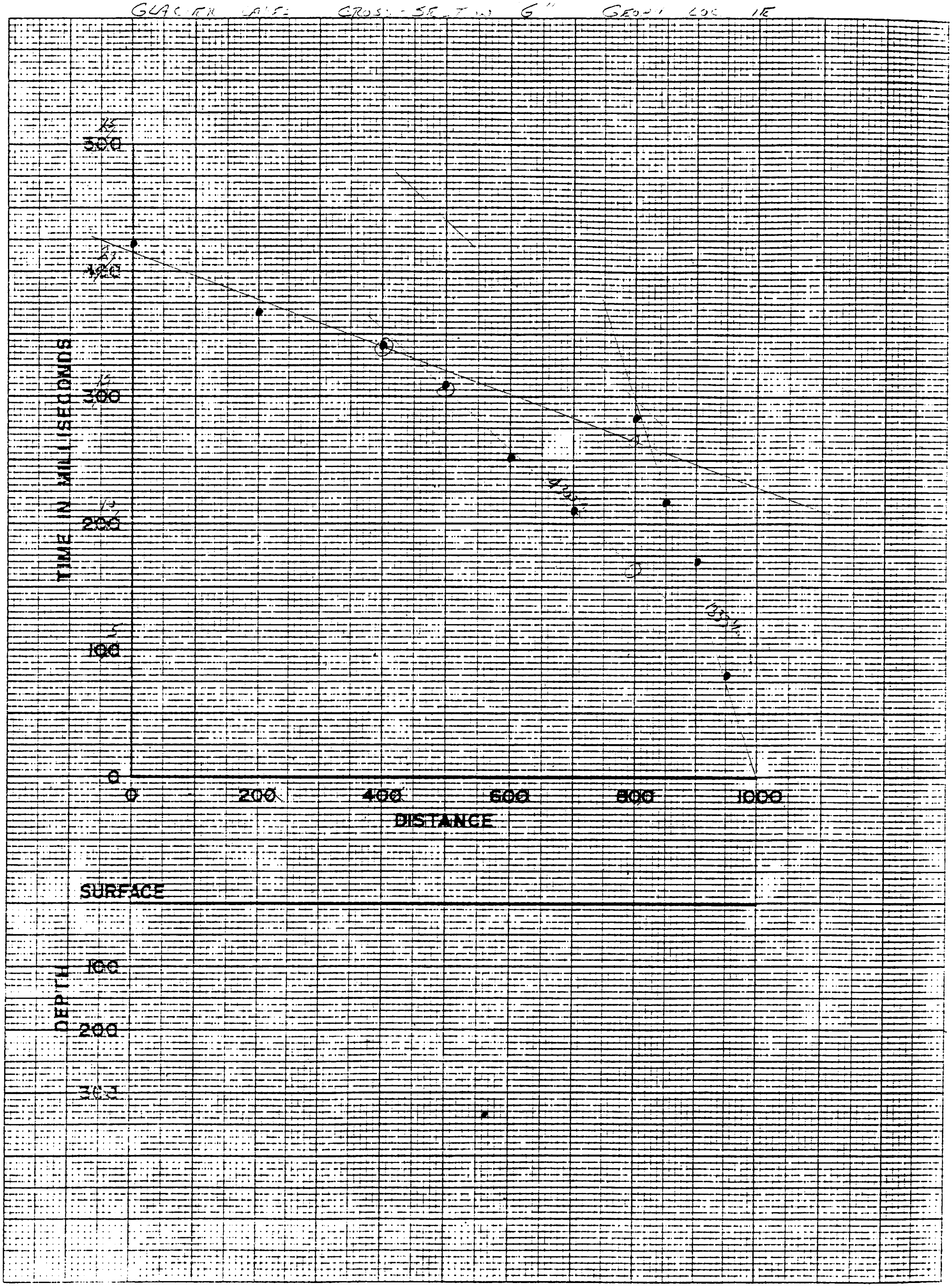
IT APPEARS THAT THE CONSOLIDATED MATERIAL IS DIPPING STEEPLY TOWARD THE LOCATION C AWAY FROM LOCATIONS 1E & 1W, AS DEMONSTRATED BY THE SHARP DECREASE ASSOCIATED W/ THE HAMMER BLOWS 30' (1E) & 40' (1W). I WOULD DISREGARD THIS CROSS-SECTION.

GLACIER LAKE CROSS SECTION "G" GEOPH. LOC. 1W



GLACIER LAKES CROSS-SECTION "G" GEOPHONE LOC C




GLACIER LAKE CROSS-SECTION 6" GEOPH LOC 1E
300
400
300
200
100
0
TIME IN MILLISECONDS
0
200
400
600
800
1000
DISTANCE
SURFACE
DEPTH
100
200
300

SEISMIC DATA

Cross Section L   East side of East Glacier Lake

Bearing of line L:Sta L2S to L2N 332 degrees

Bearing of line L:Sta L2N to L7N 324 degrees

DISTANCE	BETWEEN	STATIONS	feet
L2S	to	L1S	70
L1S	to	L1N	81
L1N	to	L2N	81
L2N	to	L3N	80
L3N	to	L4N	80
L4N	to	L5N	80
L5N	to	L6N	80
L6N	to	L7N	80

STATION	HAMMER POINT	TIME microsec	STATION	HAMMER POINT	TIME microsec
L2S	5N	4.76			
L2S	10N	10.17			
L2S	15N	13.96			
L2S	20N	15.29			
L2S	30N	17.3			
L2S	40N	18.9			
L2S	50N	20.5			
L2S	60N	21.2			
L2S	80N	24.7			
L2S	100N	20.9			
L1S	5N	4.43	L1S	5S	5.15
L1S	10N	8.7	L1S	10S	9.58
L1S	15N	13.82	L1S	15S	14.46
L1S	20N	18.13	L1S	20S	19.14
L1S	30N	15.9	L1S	30S	18.2
L1S	40N	23.9	L1S	40S	21.8
L1S	50N	23.1	L1S	50S	19.5
L1S	60N	27.6	L1S	60S	24.6
L1S	80N	29.4	L1S	80S	25.1
L1S	100N	31			
L1N	5N	5.51	L1N	5S	4.46
L1N	10N	10.41	L1N	10S	9.18
L1N	15N	15	L1N	15S	13.89
L1N	20N	19.6	L1N	20S	17.96
L1N	30N	23.6	L1N	30S	23.6
L1N	40N	24.8	L1N	40S	25.7
L1N	50N	25.9	L1N	50S	20.1
L1N	60N	23.4	L1N	60S	25.9

L1N	80N	25	L1N	80S	28.9
L1N	100N	29.4	L1N	100S	31.1
L2N	5N	4.98	L2N	5S	4.17
L2N	10N	9.38	L2N	10S	8.35
L2N	15N	13.49	L2N	15S	11.77
L2N	20N	14.65	L2N	20S	13.11
L2N	30N	16.84	L2N	30S	15.88
L2N	40N	17.7	L2N	40S	19.2
L2N	50N	17.1	L2N	50S	22.6
L2N	60N	18.7	L2N	60S	21.9
L2N	80N	22.4	L2N	80S	23.3
L2N	100N	26	L2N	100S	25.2
L3N	5N	6.04	L3N	5S	4.6
L3N	10N	8.88	L3N	10S	8.86
L3N	15N	11.63	L3N	15S	11.26
L3N	20N	14.59	L3N	20S	12.18
L3N	30N	16.5	L3N	30S	16.85
L3N	40N	20.7	L3N	40S	19.4
L3N	50N	22.2	L3N	50S	19.8
L3N	60N	22.2	L3N	60S	21.3
L3N	80N	22.4	L3N	80S	21.8
L3N	100N	23.8	L3N	100S	25.1
L4N	5N	9.88	L4N	5S	4.66
L4N	10N	8.69	L4N	10S	8.71
L4N	15N	12.07	L4N	15S	12
L4N	20N	14.51	L4N	20S	14.35
L4N	30N	16.03	L4N	30S	16.1
L4N	40N	16.92	L4N	40S	19.1
L4N	50N	20.2	L4N	50S	20.8
L4N	60N	19.9	L4N	60S	21.8
L4N	80N	21.1	L4N	80S	24
L4N	100N	20.2	L4N	100S	25.5
L5N	5N	4.67	L5N	5S	4.44
L5N	10N	7.18	L5N	10S	8.2
L5N	15N	10.287	L5N	15S	8.72
L5N	20N	7.46	L5N	20S	11.75
L5N	30N	8.55	L5N	30S	14.36
L5N	40N	11.92	L5N	40S	15.09
L5N	50N	14.18	L5N	50S	16.54
L5N	60N	15.49	L5N	60S	18.51
L5N	80N	19.7	L5N	80S	20.8
L5N	100N	17.8	L5N	100S	23.7
L6N	5N	5.21	L6N	5S	4.14
L6N	10N	9.1	L6N	10S	8.59
L6N	15N	11.4	L6N	15S	9.55
L6N	20N	10.7	L6N	20S	10.74
L6N	30N	18.04	L6N	30S	13.46
L6N	40N	20.9	L6N	40S	13.65
L6N	50N	22.8	L6N	50S	11.97
L6N	60N	21.6	L6N	60S	14.02
L6N	80N	23.4	L6N	80S	17.95

L6N	100N	23.3	L6N	100S	21.2
			L7N	5S	4.81
			L7N	10S	9.17
			L7N	15S	11.11
			L7N	20S	13.22
			L7N	30S	18.82
			L7N	40S	23.3
			L7N	50S	24.1
			L7N	60S	19.7
			L7N	80S	23.5
			L7N	100S	23.4

GEOPHONE LOCATION 7N

$V_0 = 10'/10\,ms = 1000\ ft/sec$

$V_1 = 5/2.5\,ms = 2000\ ft/sec$

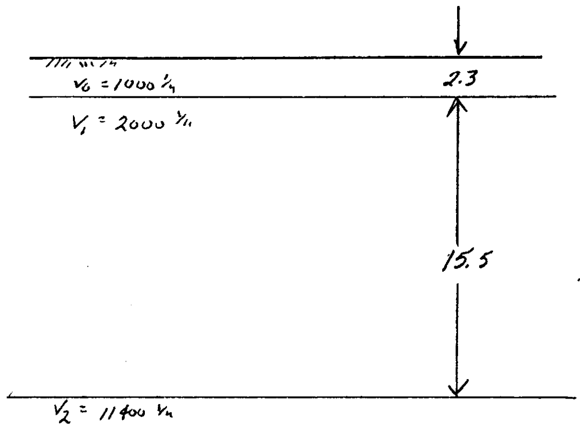
$V_2 = 20/1.75\,ms = 11400\ ft/sec$

$X_c = 8'$

$T_{i2} = 19.8\ ms$

$$Z_0 = \frac{1}{2}\sqrt{\frac{2000-1000}{3000}}\,(8) = 2.3'$$

$$Z_1 = \frac{1}{2}\left(.0198 - 2(2.3)\frac{\sqrt{11400^2-1000^2}}{11400(1000)}\right)\frac{11400(2000)}{\sqrt{11400^2-2000^2}} = 15.5'$$



GEOPHONE LOCATION 6N

SOUTH

$V_0 = 13/11.25\,ms = 1160\ ft/sec$

$V_1 = 21/5.5\,ms = 3800\ ft/sec$

$X_c = 9.3'$

NORTH

$V_0 = 7/7.75\,ms = 900\ ft/sec$

$V_1 = 7/3\,ms = 2330\ ft/sec$

$V_2 = 20/1.25\,ms = 16000\ ft/sec$

$X_c = 7'$

$T_{i2} = 18.375$

AVG.

$V_0 = 1030\ ft/s$

$V_1 = 3050\ ft/s$

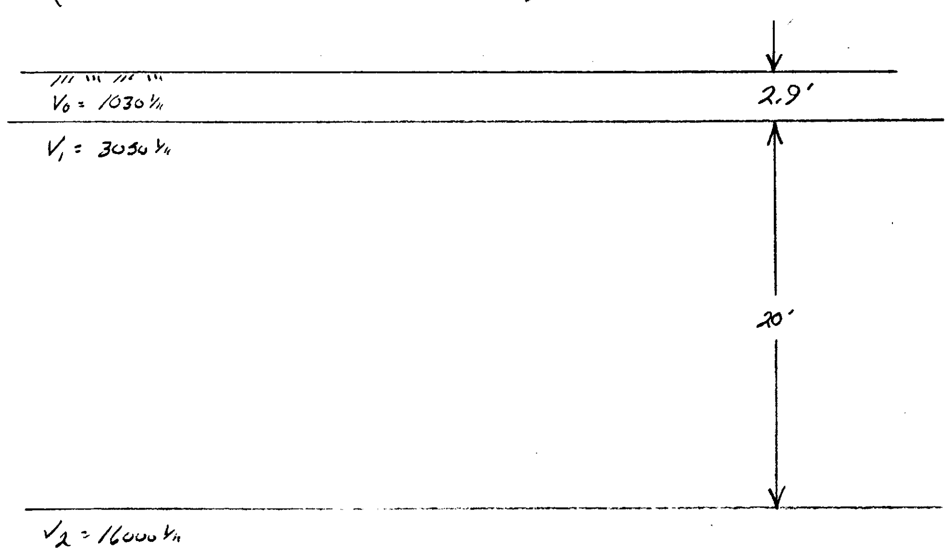
$V_2 = 16000\ ft/s$

$X_c = 8.2$

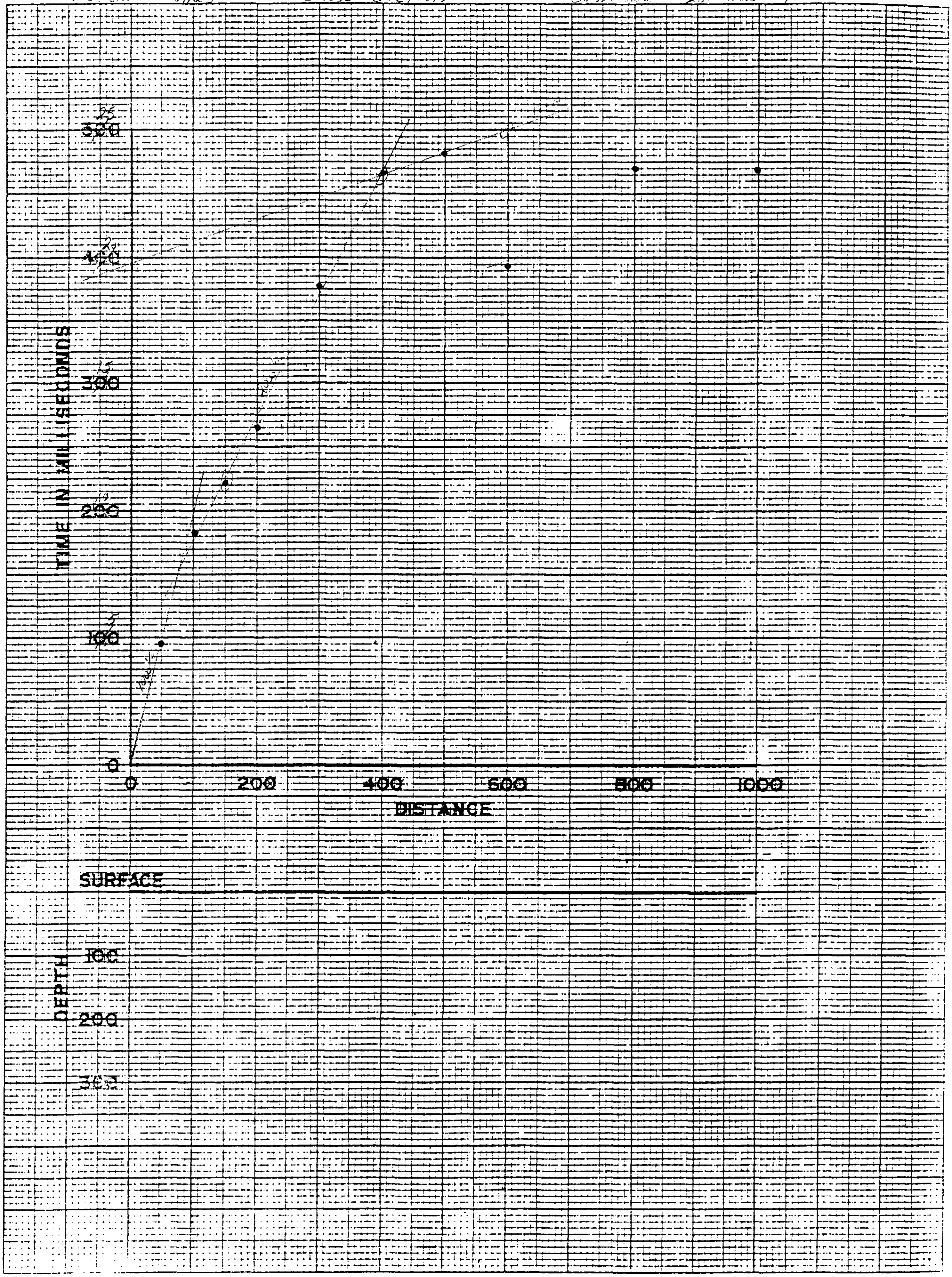
$T_{i2} = 18.375\ ms$

$$Z_0 = \frac{1}{2}\sqrt{\frac{3050-1030}{4080}}\,(8.2) = 2.9'$$

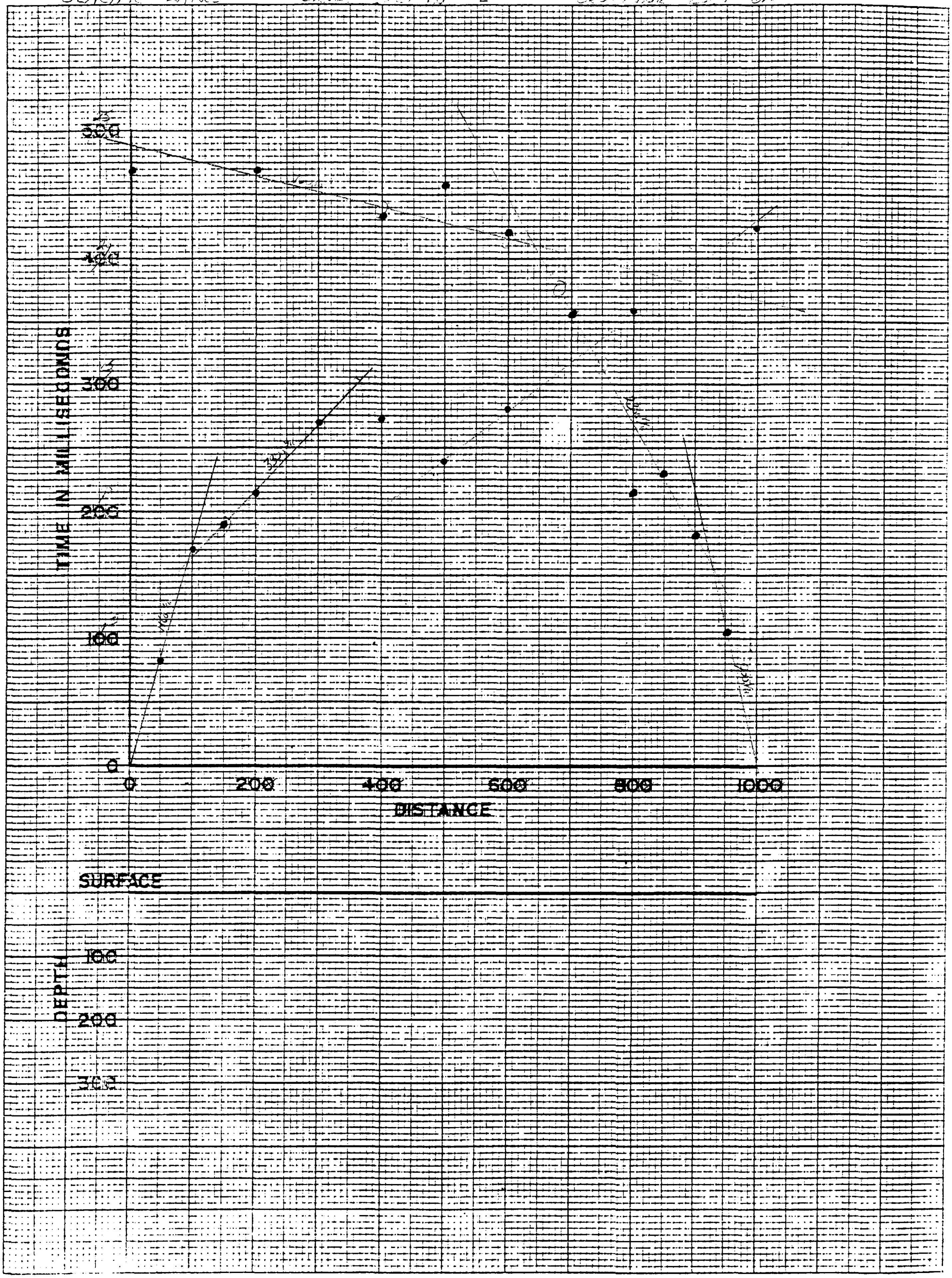
$$Z_1 = \frac{1}{2}\left(.018375 - 2(2.9)\frac{\sqrt{16000^2-1030^2}}{16000(1030)}\right)\frac{16000(3050)}{\sqrt{16000^2-3050^2}} = 19.8'$$



GLACIER LAKES CROSS-SECTION "L" GEOPHONE LOCATION 7N



GLACIER LAKE   CROSS-SECTION "L"   GEOPHONE ... 6N

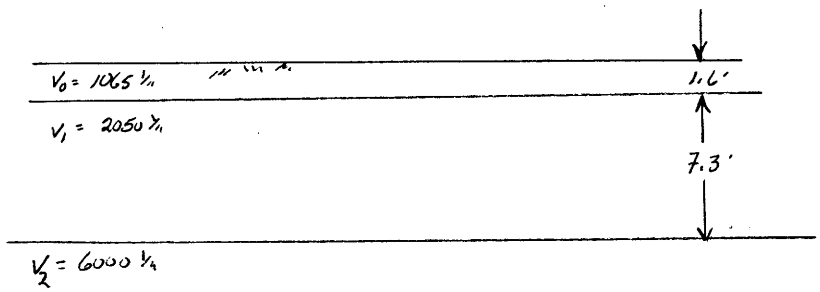


GEOPHONE LOCATION 5N

SOUTH	NORTH	AVG.
$V_0 = {}^{13}/_{12ms} = 1080$ ft/sec	$V_0 = {}^{5}/_{4.75ms} = 1050$ ft/sec	$V_0 = 1065$ '/s
$V_1 = {}^{3}/_{1.25ms} = 2400$ ft/sec	$V_2 = {}^{30}/_{6}$ ms $= 5000$ ft/sec	$V_1 = 2050$ '/s
$V_2 = {}^{35}/_{5ms} = 7000$ ft/sec	$V_1 = {}^{3}/_{1.75ms} = 1700$ ft/sec	$V_2 = 6000$ '/s
$X_c = 6.5'$	$X_c = 5'$	$X_c = 5.75'$
$T_{i2} = 9.625$ ms		$T_{i2} = 9.625$ ms

$$Z_0 = \frac{1}{2}\sqrt{\frac{2050-1065}{3115}}\,(5.75) = 1.6'$$

$$Z_1 = \frac{1}{2}\left(.009625 - 2(1.6)\frac{\sqrt{6000^2-1065^2}}{6000(1065)}\right)\frac{6000(2050)}{\sqrt{6000^2-2050^2}} = 7.3'$$

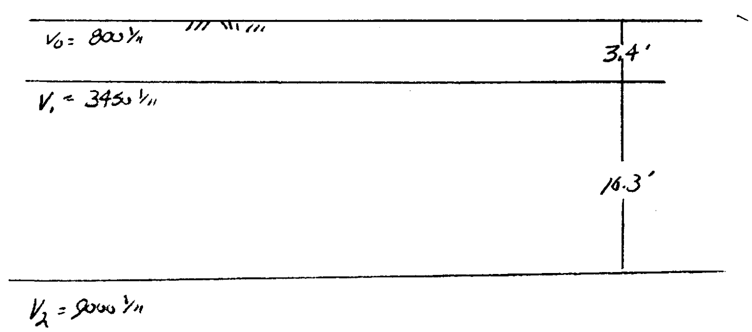


GEOPHONE LOCATION 4N

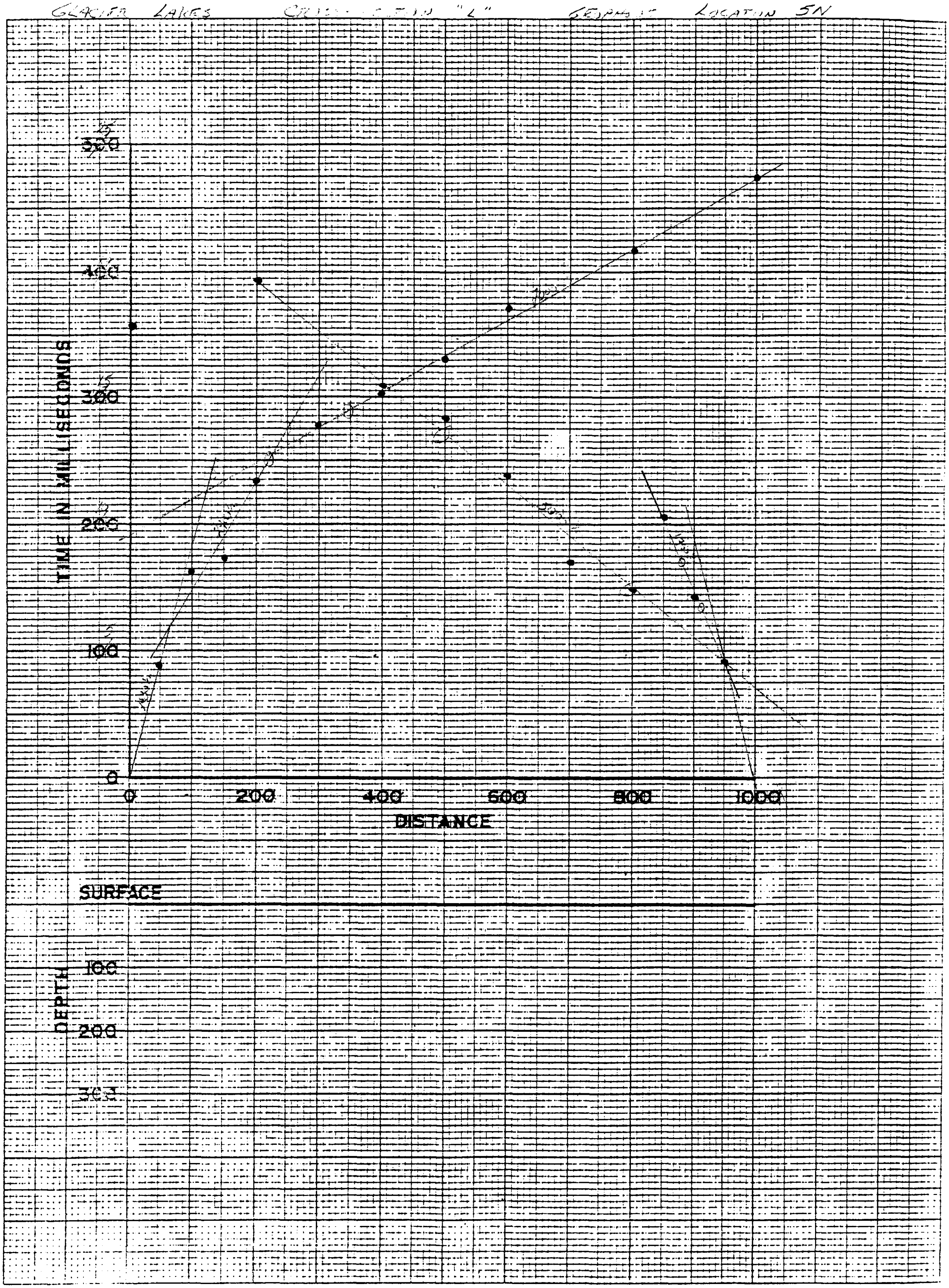
SOUTH	NORTH	AVG.
$V_0 = {}^{11}/_{10ms} = 1100$ ft/sec	$V_0 = {}^{5}/_{10ms} = 500$ ft/sec	$V_0 = 800$ '/s
$V_1 = {}^{6}/_{1.75ms} = 3400$ ft/sec	$V_1 = {}^{7}/_{2ms} = 3500$ ft/sec	$V_1 = 3450$ '/s
$V_2 = {}^{10}/_{1ms} = 10000$ ft/sec	$V_2 = {}^{10}/_{1.25ms} = 8000$ ft/sec	$V_2 = 9000$ '/s
$X_c = 12.25'$	$X_c = 5'$	$X_c = 8.6'$
$T_{i2} = 15.9$ms	$T_{i2} = 12.125$ ms	$T_{i2} = 14$ ms

$$Z_0 = \frac{1}{2}\sqrt{\frac{3450-800}{4250}}\,(8.6) = 3.4'$$

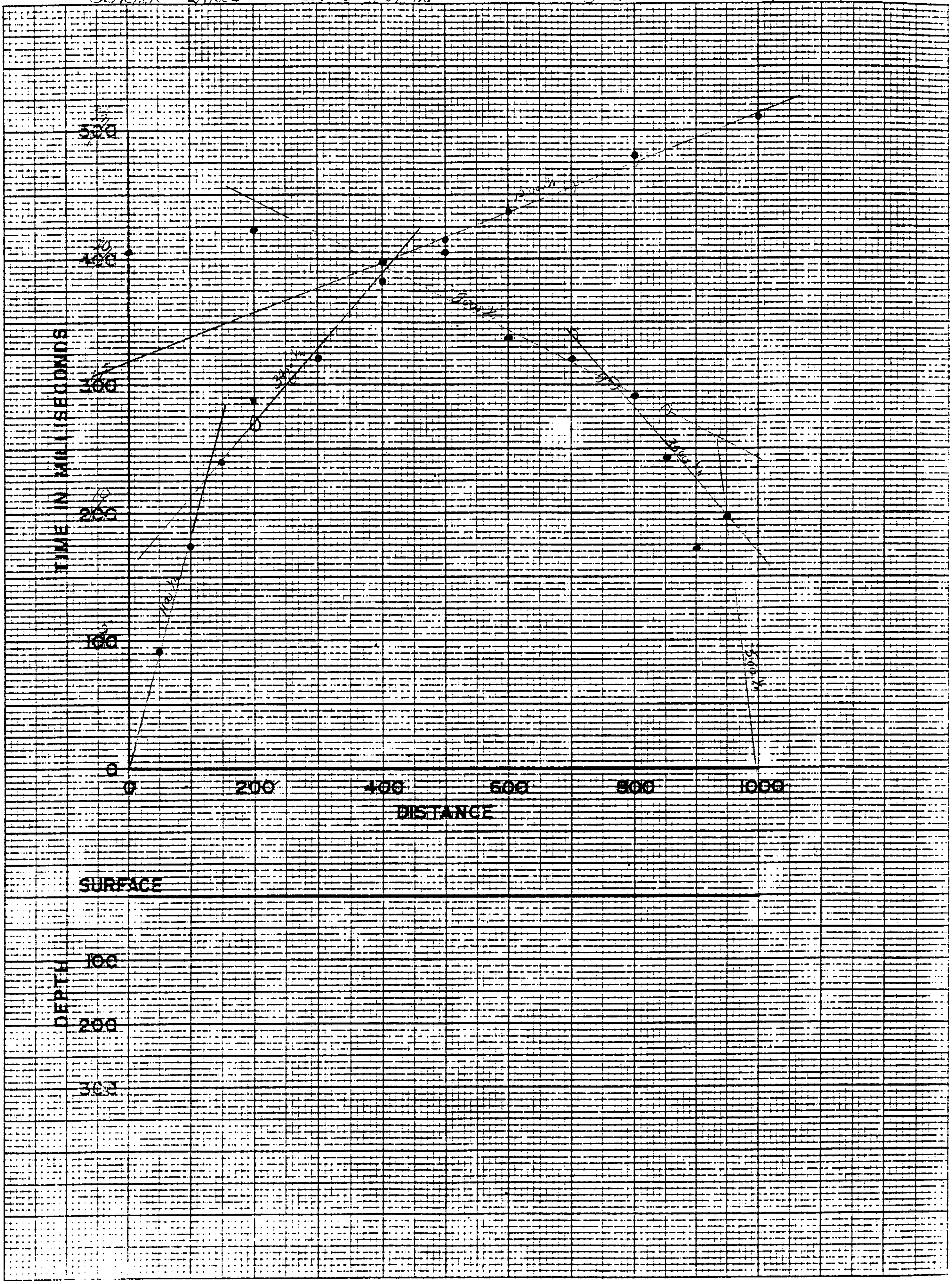
$$Z_1 = \frac{1}{2}\left(.014 - 2(3.4)\frac{\sqrt{9000^2-800^2}}{9000(900)}\right)\frac{9000(3450)}{\sqrt{9000^2-3450^2}} = 10.3'$$



GLACIER LAKES   CROSS SECTION "L"   GEOPHYSIC LOCATION 5N



GLACIER LAKES CROSS-SECTION "L" GEOPHONE LOC 4N



GLACIER LAKES — REFRACTION SURVEY — CROSS-SECTION "C"

GEOPHONE LOCATION 3N

SOUTH

$V_0 = 7/6.25\,ms = 1120$ ft/sec

$V_1 = 20/6.5\,ms = 3100$ ft/sec

$V_2 = 22/2.25\,ms = 9800$ ft/sec

$X_c = 11'$

$T_{i2} = 15\,ms$

NORTH

$V_0 = 6/7.5\,ms = 800$ ft/s

$V_1 = 13/7.5\,ms = 1700$ ft/s

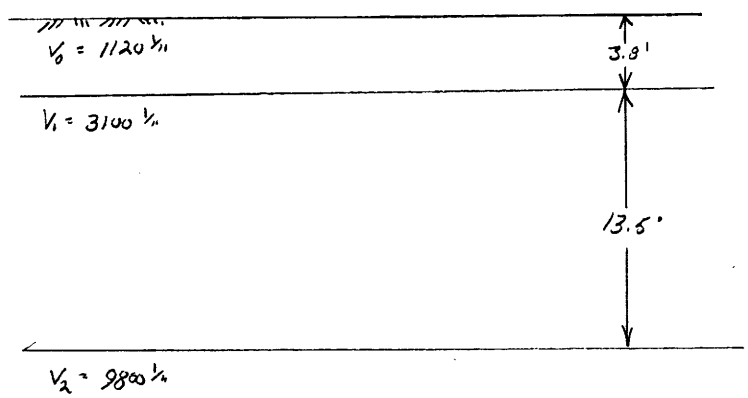
$V_2 = 20/3.75\,ms = 5300$ ft/s

$V_3 = 17/0.75\,ms = 22600$ ft/s

* USING JUST THE SOUTH DIRECTION

$$Z_0 = \frac{1}{2}\sqrt{\frac{3100-1120}{4220}}\,(11) = 3.8'$$

$$Z_1 = \frac{1}{2}\left(.015 - 2(3.8)\frac{\sqrt{9800^2-1120^2}}{9800(1120)}\right)\frac{9800(3100)}{\sqrt{9800^2-3100^2}} = 13.5'$$



GEOPHONE LOCATION 2N

SOUTH

$V_0 = 12/10\,ms = 1200$ ft/s

$V_1 = 6/1.75\,ms = 3400$ ft/s

$V_2 = 19/2\,ms = 9500$ ft/s

$X_c = 13.3'$

$T_{i2} = 15\,ms$

NORTH

$V_0 = 10/9.75\,ms = 1025$ ft/sec

$V_1 = 28/6.75\,ms = 4150$ ft/sec

$X_c = 13.3'$

AVG.

$V_0 = 1112$ ft/s

$V_1 = 3775$ ft/s

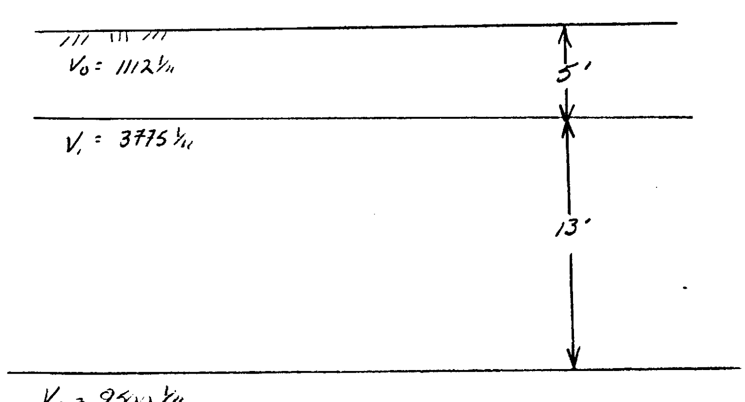
$V_2 = 9500$ ft/s

$X_c = 13.3'$

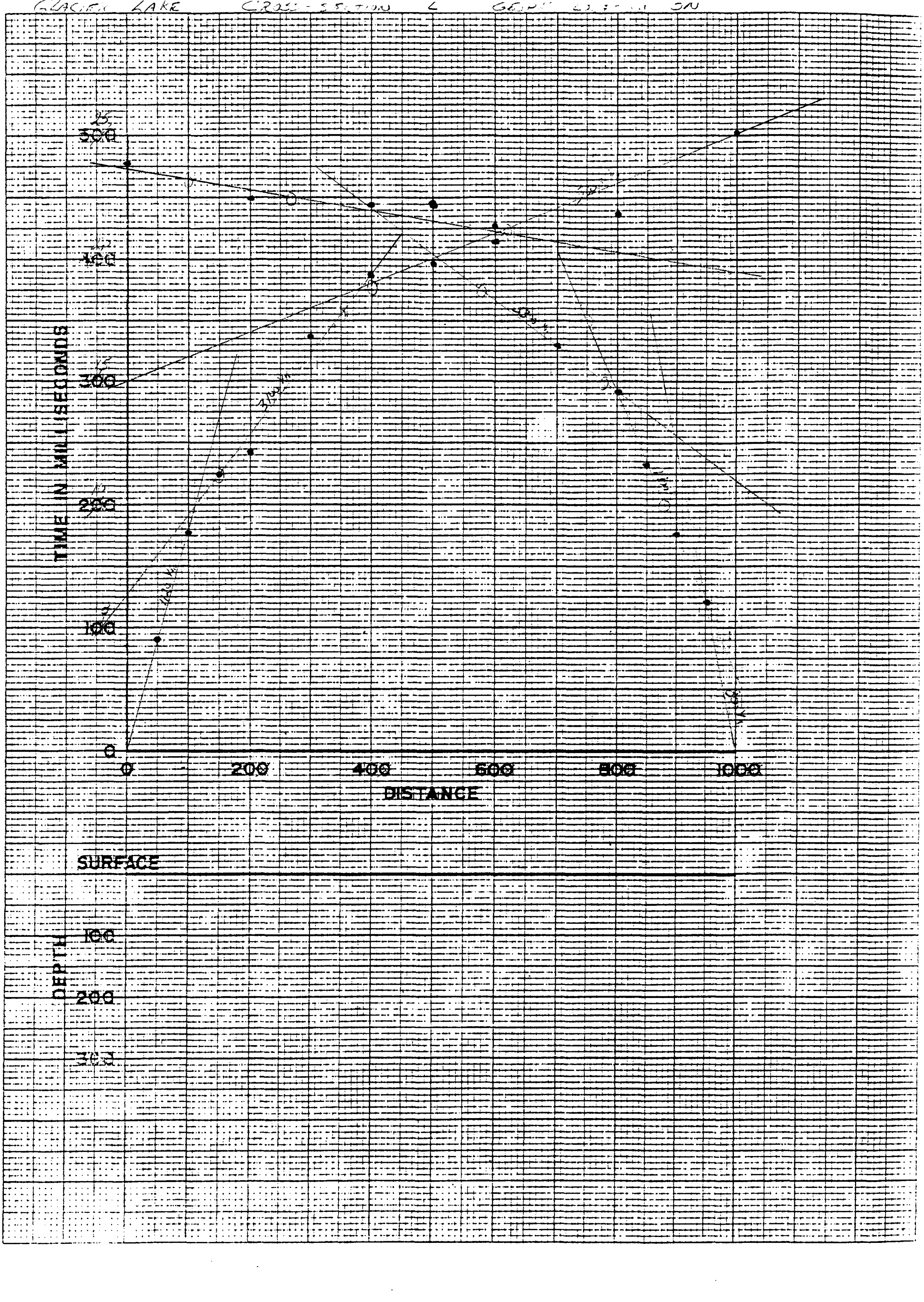
$T_{i2} = 15\,ms$

$$Z_0 = \frac{1}{2}\sqrt{\frac{3775-1112}{4887}}\,(13.3) = 4.9'$$

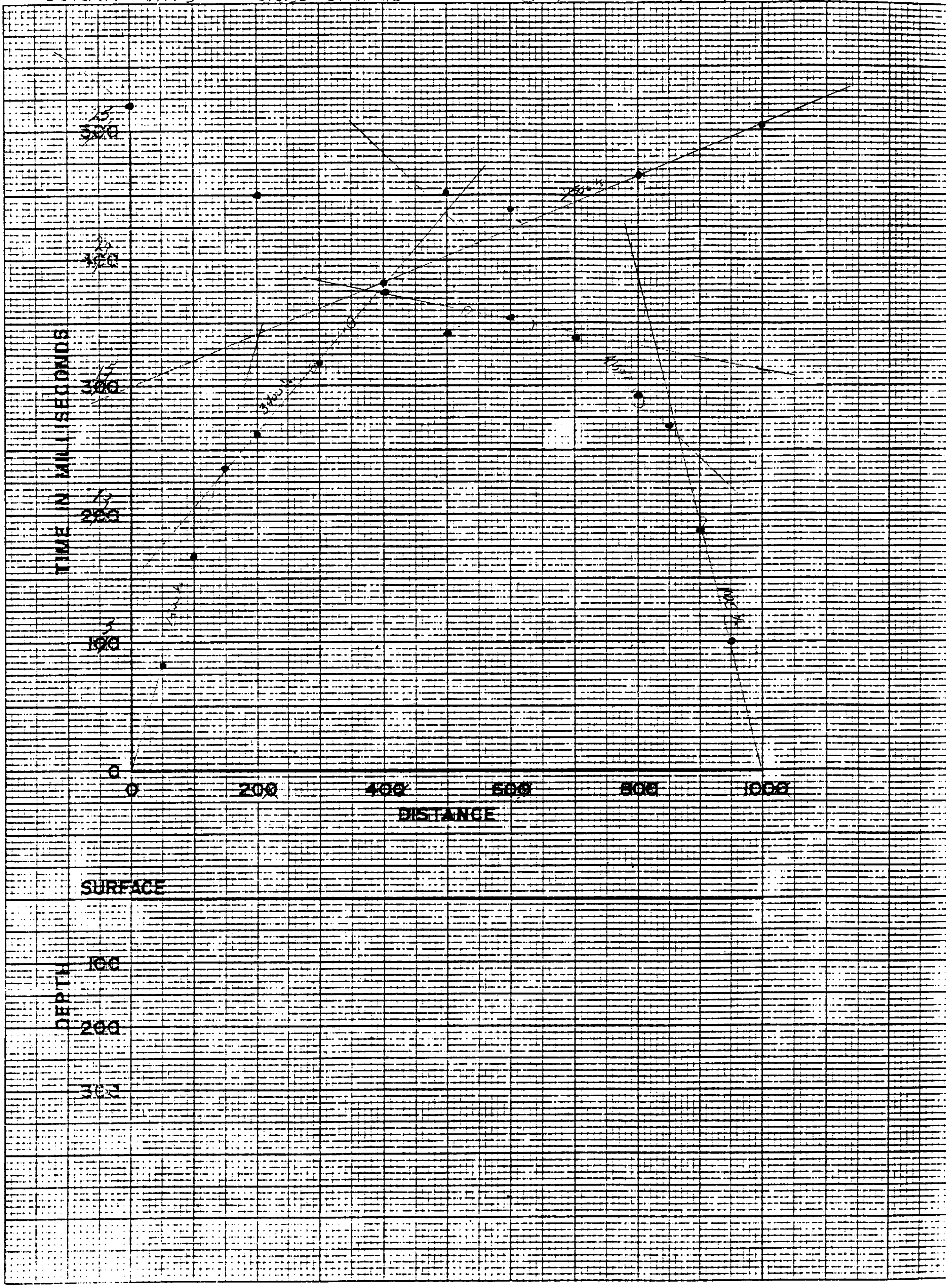
$$Z_1 = \frac{1}{2}\left(.015 - 2(4.9)\frac{\sqrt{9500^2-1112^2}}{9500(1112)}\right)\frac{9500(3775)}{\sqrt{9500^2-3775^2}} = 12.8'$$



GLACIER LAKE CROSS-SECTION [illegible]



GLACIER LAKES CROSS-SECTION "2" GEOPH. LOCATION 2N



GLACIER LAKES | REFRACTION SURVEY | CROSS-SECTION "L"

GEOPHONE LOCATION 1N

SOUTH

$V_0 = 14/12.5\ ms = 1120$ '/s

$V_1 = 16/1.75\ ms = 9150$ '/s

$X_c = 25.8'$

NORTH

$V_0 = 5/5.25\ ms = 950$ ft/sec

$V_1 = 16/1.75 = 9150$ '/s

$X_c = 21.25$

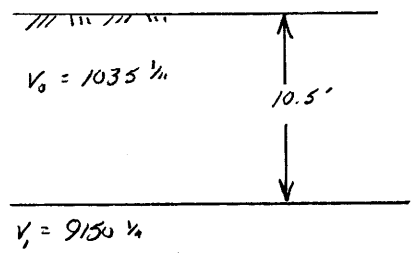
AVG.

$V_0 = 1035$ '/s

$V_1 = 9150$ '/s

$X_c = 23.5'$

$$Z_0 = \frac{1}{2}\sqrt{\frac{9150-1035}{10185}}\,(23.5) = 10.5'$$



GEOPHONE LOCATION 15

SOUTH

$V_0 = 8/7.5\ ms = 1070$ '/s

$V_1 = 15/2\ ms = 7500$ '/s

$X_c = 20.5'$

NORTH

$V_0 = 15/13.25\ ms = 1130$ ft/sec

$V_1 = 20/3.5\ ms = 5700$ ft/sec

$V_2 = 17/1.25 = 13600$ ft/sec

$X_c = 23'$

$T_{i2} = 23.6\ ms$

AVG.

$V_0 = 1100$ '/s

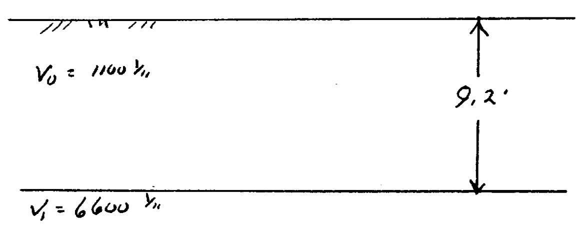
$V_1 = 6600$ '/s

$V_2 = 13600$ '/s

$X_c = 21.75'$

$T_{i2} = 23.6\ ms$

$$Z_0 = \frac{1}{2}\sqrt{\frac{6600-1100}{7700}}\,(21.75) = 9.2'$$



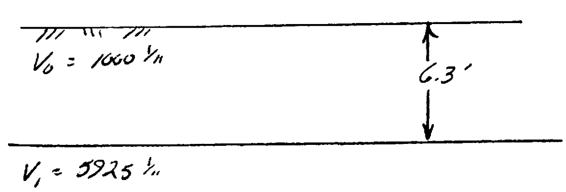
GEOPHONE LOCATION 25

$V_0 = 1000$ '/s

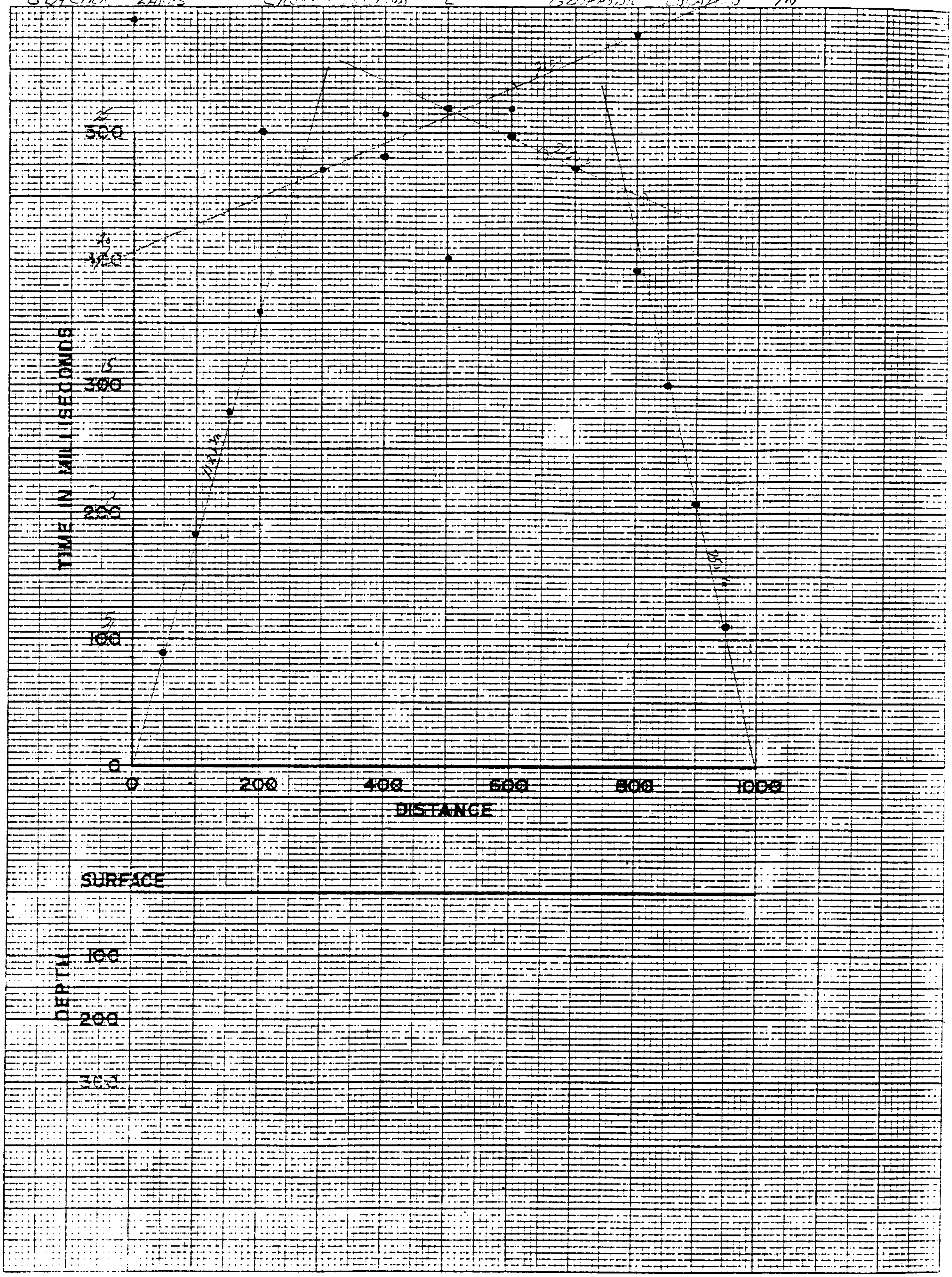
$V_1 = 40/6.75\ ms = 5925$ ft/sec

$X_c = 15'$

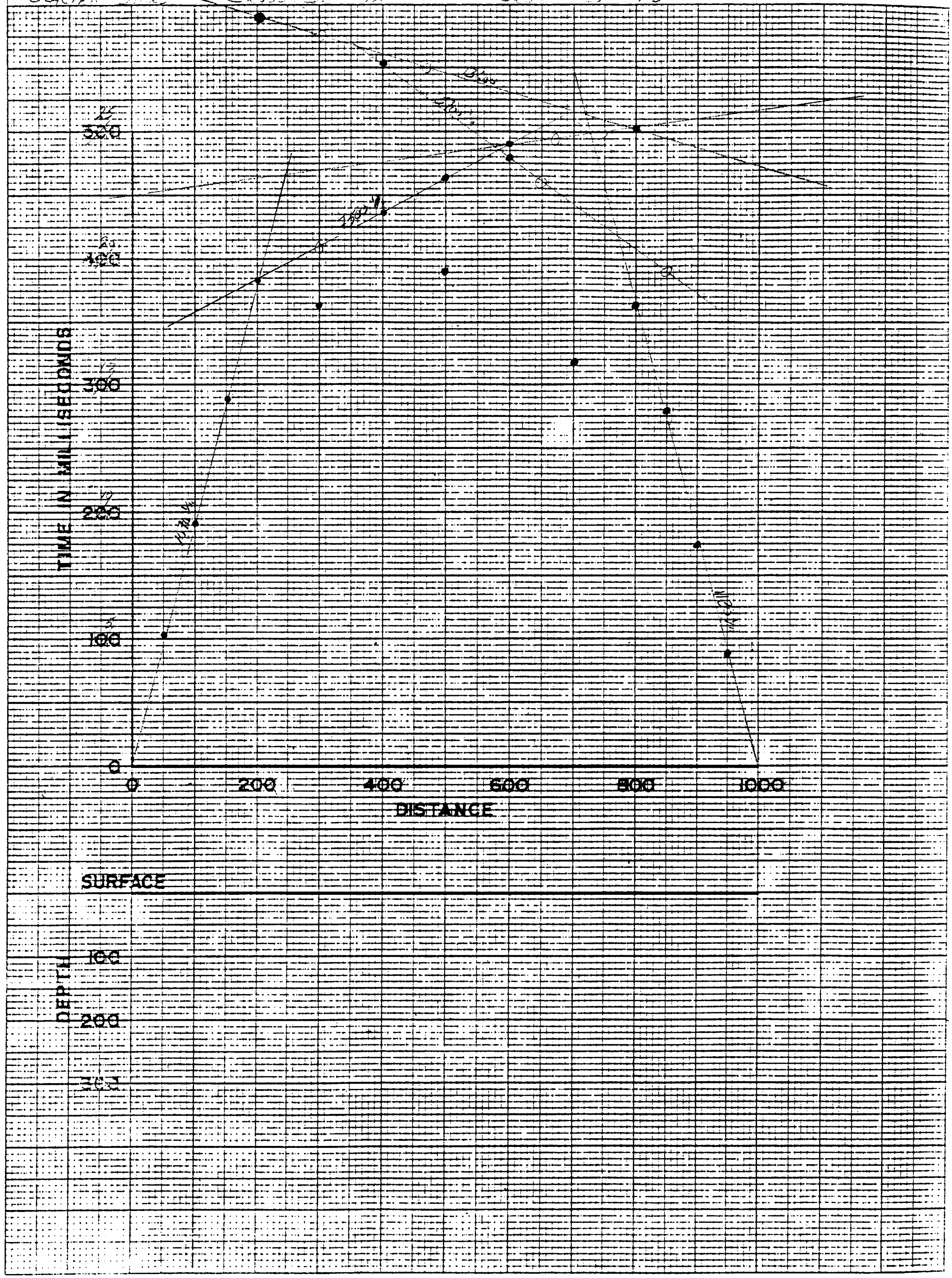
$$Z_0 = \frac{1}{2}\sqrt{\frac{5925-1000}{6925}}\,(15') = 6.3'$$



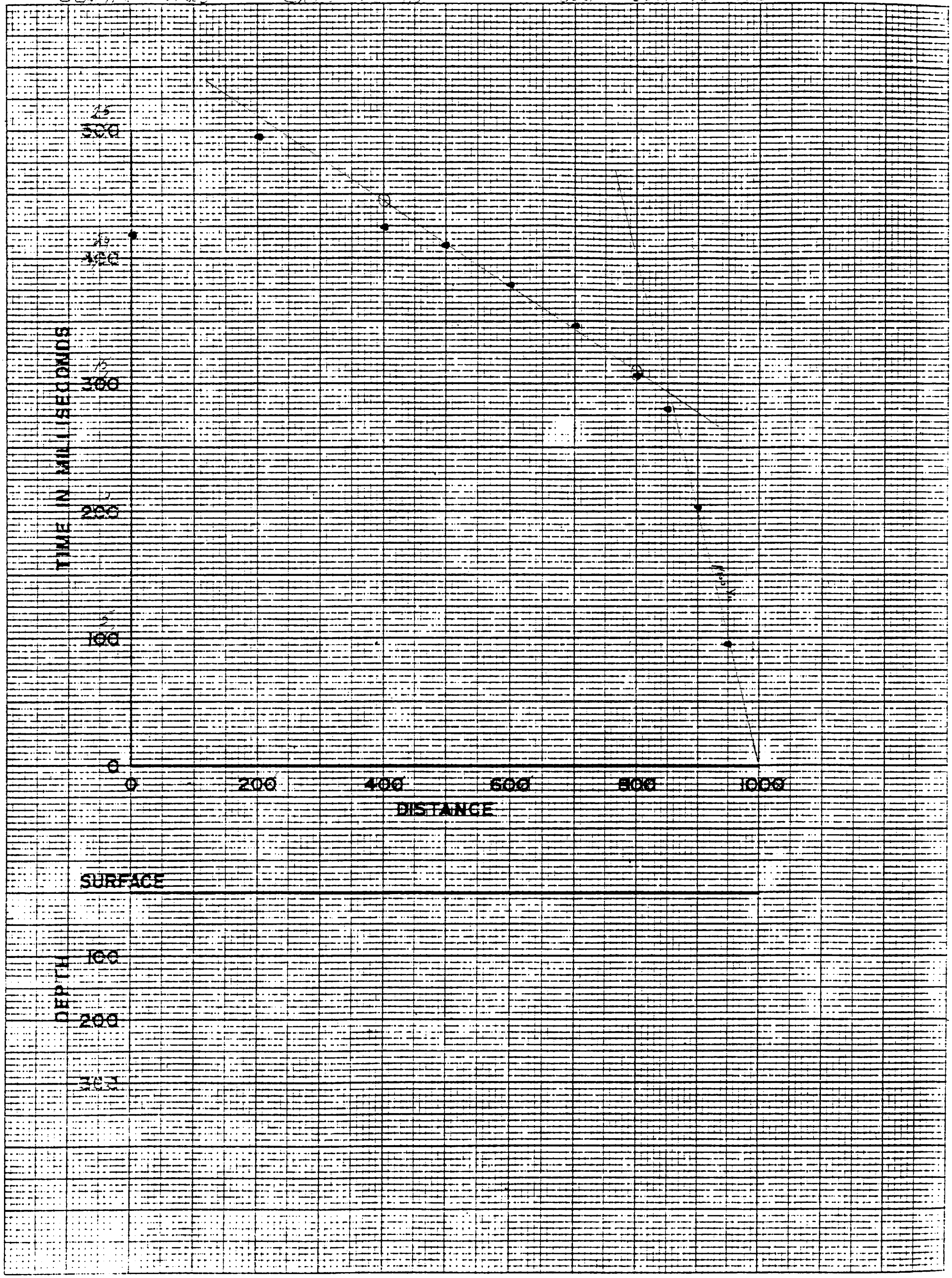
GLACIER LAKES CROSS-SECTION "L" GEOPHONE LOCATION IN

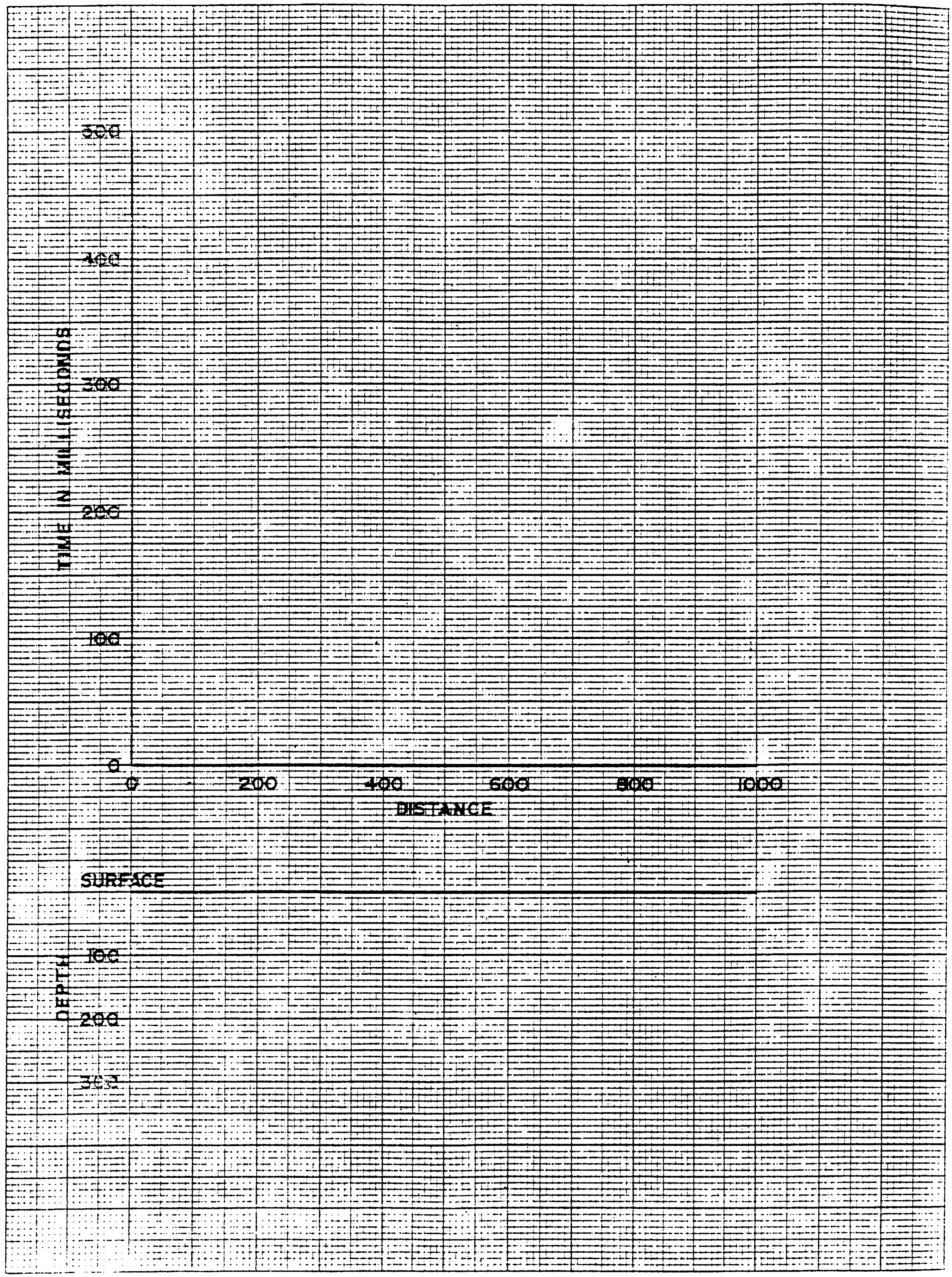


GLACIER LAKES CROSS 15



GLACIER LAKES CROSS-SECTION "L" GEOPH LOCATION 25




TIME IN MILLISECONDS
500
400
300
200
100
0
0
200
400
600
800
1000
DISTANCE
SURFACE
DEPTH
100
200
300

APPENDIX E

DETERMINATION OF HYDRAULIC CONDUCTIVITY

WEST GLACIER LAKE:

$$Q = KIA \Rightarrow K = \frac{Q}{IA}$$

WHERE:

- Q = VOLUMETRIC FLOW RATE gal/day
- I = HYDRAULIC GRADIENT
- A = AREA PERPENDICULAR TO FLOW
- K = HYDRAULIC CONDUCTIVITY

ASSUME:

- ALL NON-CHANNELIZED FLOW MOVES IN THE GROUNDWATER AQUIFER, I.E. NO SUBCONC. SURFACE FLOW.
  Q = 939400 gal/d FROM SECTION 14
- THE HYDRAULIC GRADIENT IS UNITY I.E. 1 ft/ft
- THE AREA PERPENDICULAR TO FLOW CAN BE COMPLETELY ACCOUNTED FOR FROM THE SIESMIC PROFILES. FOR WGL SHOT LINES "C-D", "F", AND "G" APPLY AND THE ENTIRE THICKNESS IS SATURATED.

$$K = \frac{939400 \text{ gal/d}}{(1 \text{ ft/ft})(6425 \text{ ft}^2)}$$

$$K = 146.2 \ \frac{\text{GPD}}{\text{ft}^2}$$

EVALUATION OF HYDRAULIC CONDUCTIVITY ANALYSIS.

THE HYDRAULIC CONDUCTIVITY CALCULATED FALLS AT THE UPPER LIMIT OF CONDUCTIVITIES FOR GLACIAL TILLS (10^{-6} - 10^{2}).

THE PROBLEM WITH THE ABOVE ANALYSIS IS THAT NONE OF THE ASSUMPTIONS USED IN PREFORMING THE CALCULATION CAN TRULY BE JUSTIFIED. THERE IS NO REASON TO BELIEVE, FOR EXAMPLE, THAT ALL OF THE NON-CHANNELIZED FLOW MOVES IN THE GROUND-WATER SYSTEM OR THAT THE HYDRAULIC GRADIENT IS UNITY. THE AREA PERPENDICULAR TO FLOW IS CERTAINLY MUCH GREATER THAN THAT CALCULATED FROM THE REFRACTION SURVEY AS THE SHOT LINES COVER ONLY A FRACTION OF THE POTENTIAL CONTRIBUTING AREA (REFER TO SURVEY MAP).

HOWEVER, IN SPITE OF THESE SHORTCOMINGS THE K VALUE CALCULATED MAY NOT BE TOTALLY ERRONEOUS WHEN THE FOLLOWING OBSERVATIONS ARE TAKEN INTO ACCOUNT:

1. IF THE FRACTION OF NON-CHANNELIZED FLOW ENTERING THE GROUNDWATER SYSTEM IS ONLY 10% OF THE TOTAL NON-CHANNELIZED FLOW (93940 gal/d) THE RESULTING CONDUCTIVITY IS ONLY DECREASED BY 1 ORDER OF MAGNITUDE.

2. ALTHOUGTH THE HYD. GRADIENT IS MOST LIKELY SOME FRACTION OF UNITY IT IS DEFINITELY KNOWN THAT THE AQUIFER AREA PERPENDICULAR TO FLOW IS MUCH GREATER THAN THE 6425 ft^2 VALUE USED. THEREFORE, THE EFFECTS OF DECREASED GRADIENT AND INCREASED AREA WILL TEND TO OFFSET EACH OTHER RESULTING IN MINIMAL CHANGES IN THE CONDUCTIVITY. FOR EXAMPLE, IF $I = .5$ ft/ft AND $2A = 12850$ ft^2 THERE WILL BE NO CHANGE AT ALL IN THE CONDUCTIVITY.

IN CONCLUSION, ALTHOUGH THE INDIVIDUAL ASSUMUPTIONS MAY NOT BE JUSTIFIABLE THE OVERALL AFFECT MAY BE NEGLIGIBLE. THEREFORE, THE HYDRAULIC CONDUCTIVITY VALUE OF $K = 146.2$ GPD/ft^2 FOR THIS AQUIFER MAY BE VERY CLOSE TO THE TRUE VALUE WHICH CAN ONLY BE DETERMINED WITH FURTHER AND MORE EXTENSIVE STUDY.

EAST GLACIER LAKE:

AS THERE IS NO MEASURED SURFACE FLOW INTO EGL OUTFLOW = GROUND-WATER FLOW.

$$\text{OUTFLOW} = 86.99 \text{ AC. FT}$$

$$= 2.835 \times 10^{7} \text{ GAL}$$

USING A 130 DAY FLOW PERIOD:

$$\frac{2.83 \times 10^{7} \text{ GAL}}{130 \text{ d}} = 2.18 \times 10^{5} \text{ GPD}$$

$$K = \frac{Q}{IA}$$

$$A = 8542.5 \text{ ft}^{2}$$
$$I = 1 \text{ ft/ft}$$

$$K = \frac{2.18 \times 10^{5} \text{ GPD}}{8542.5 \text{ ft}^{2} (1 \text{ ft/ft})}$$

$$= 25.5 \frac{\text{GPD}}{\text{ft}^{2}}$$

SECTION "C-D" WEST GLACIER LAKE

SUBUNIT #	LENGTH (ft)	DEPTH (ft)	AREA (ft^2)
1	5	5.0	25
2	10	7.0	70
3	10	8.0	80
4	10	9.0	90
5	10	9.5	95
6	10	9.0	90
7	10	11.0	110
8	10	11.0	110
9	10	12.5	125
10	10	15.0	150
11	10	16.5	165
12	10	17.5	175
13	10	18.0	180
14	10	18.5	185
15	10	19.0	190
16	10	19.0	190
17	10	18.0	180
18	10	18.0	180
19	10	18.0	180
20	10	17.0	170
21	10	16.0	160
22	10	15.0	150
23	10	14.0	140
24	10	13.5	135
25	10	13.0	130
26	10	11.0	110
27	10	10.0	100
28	10	9.0	90
29	10	8.0	80
30	10	6.5	65
31	10	5.5	55
32	10	4.0	40

$\Sigma A = 3995$

SECTION "F"   WEST GLACIER LAKE

SUBUNIT #	LENGTH (ft)	DEPTH (ft)	AREA (ft^2)
1	10	5.75	57.5
2	10	4.0	40
3	10	2.5	25
4	10	1.5	15
5	10	2.0	20
6	10	2.5	25
7	10	3.5	35.
8	10	4.0	40
9	10	4.0	40
10	10	4.0	40
11	10	4.0	40
12	5	4.5	22.5
			ΣA = 400

SECTION "G" WEST GLACIER LAKE

SUBUNIT #	LENGTH (ft)	DEPTH (ft)	AREA (ft^2)
1	10	9.5	95
2	10	10.5	105
3	10	10.5	105
4	10	11.0	110
5	10	13.0	130
6	10	16.5	165
7	10	19.0	190
8	10	22.5	225
9	10	21.5	215
20	10	19.0	190
11	10	17.5	175
12	10	15.5	155
13	10	14.5	145
14	10	12.5	125

$\Sigma A = 2030$

SECTION "L" - EAST GLACIER LAKE

SUBUNIT #	LENGTH (ft)	DEPTH (ft)	AREA (ft^2)
1	10	6.5	65
2	10	7.0	70
3	10	7.0	70
4	10	7.0	70
5	10	7.25	72.5
6	10	8.0	80
7	10	9.0	90
8	10	9.5	95
9	10	10.0	100
10	10	10.0	100
11	10	10.5	105
12	10	10.5	105
13	10	10.5	105
14	10	9.5	95
15	10	10.0	100
16	10	10.5	105
17	10	11.5	115
18	10	12.0	120
19	10	12.5	125
20	10	14.0	140
21	10	15.0	150
22	10	16.5	165
23	10	18.5	185
24	10	20.0	200
25	10	19.5	195
26	10	19.5	195
27	10	19.0	190
28	10	19.0	190
29	10	18.5	185
30	10	17.5	175
31	10	17.5	175
32	10	17.0	170
33	10	16.5	165
34	10	16.5	165
35	10	16.5	165
36	10	15.0	150
37	10	14.5	145
38	10	14.0	140
39	10	14.0	140
40	10	13.0	130
41	10	11.0	110
42	10	9.0	90
43	10	8.0	80
44	10	7.5	75
45	10	7.0	70

SECTION 'L'

SUBUNIT #	LENGTH (ft)	DEPTH (ft)	AREA (ft²)
46	10	8.0	80
47	10	8.5	85
48	10	9.0	90
49	10	9.0	90
50	10	8.5	85
51	10	8.5	85
52	10	11.0	110
53	10	15.0	150
54	10	20.0	200
55	10	23.5	235
56	10	23.0	230
57	10	22.0	220
58	10	22.0	220
59	10	21.5	215
60	10	20.0	200
61	10	18.0	180
62	10	17.0	170
63	10	17.0	170

$\Sigma A = 8542.5$