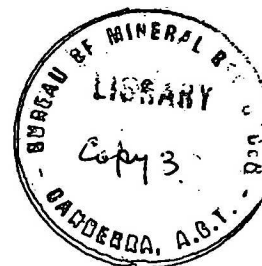


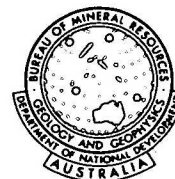
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DEPARTMENT OF
NATIONAL DEVELOPMENT
BUREAU OF MINERAL
RESOURCES, GEOLOGY
AND GEOPHYSICS



Record 1972/83

COMPUTER PROGRAM FOR CALCULATING SEISMIC
VELOCITIES FROM EXPANDED AND OFFSET REFLECTION
SPREADS

by

G.R. Pettifer

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SUMMARY

The use of expanded and offset reflection spreads in seismic prospecting to determine average vertical velocities involves the fitting of a straight line to time squared versus horizontal distance squared data. The theory, mathematical background, and limitations of the method are discussed and comments on its application are given. A BMR computer program VELSPRED, to determine the line by the method of least-squares and to provide a statistical evaluation of the error of fit, is presented. The program is used to compute average velocities, interval velocities, and depths. Estimates of the errors in these quantities have been made from the fit of the line, but no estimates of the errors due to other limitations are given.

INTRODUCTION

In seismic reflection surveys, vertical velocity information is essential at many stages in processing and interpretation. If no wells have been drilled in a survey area this information can be obtained only from an analysis of normal moveout on reflection records. The expanded spread method (Musgrave, 1962) involves the progressive movement of shot and geophone spread so that reflections are obtained from the same portion of subsurface but with continuously increasing shot to geophone distance. In this way continuously increasing normal moveout can be measured from zero to large values for each reflection event and the effects of dip in a reflector can be removed by averaging reflection times from opposite sides of the expanded spread. Provided the data quality is fair, a reasonably accurate determination of vertical velocity may be made over a localized area.

In the offset reflection method measurements are made and vertical velocity is derived over an extended distance of subsurface. The removal of dip effects is not inherent in the computation, but dip may be measured from a reflection section over the same line and allowed for in the computation. On land, the method involves the use of a stationary shot-point and an increasing offset of the geophone spread. An application of the method at sea using sonobuoys is now widespread. The ship, firing shots or using another energy source at regular time intervals, steams away from a floating sonobuoy, which receives the signal and transmits it to the ship (Houtz, et al., 1968; Le Pichon et al., 1968).

The visual fitting of a straight line to a set of experimental time squared versus horizontal distance squared points can result in significant error which is difficult to estimate. A normal method of obtaining a best fitting line is by least-squares analysis. At the same time, a measure of goodness of fit is obtained. The least-squares computation is fairly onerous and merits the use of a digital computer. The computer programme described here calculates average vertical velocities, interval velocities, and depths from several reflections from a number of velocity probes and presents the results graphically with errors indicated, and numerically in a line printer output.

2. MATHEMATICAL BACKGROUND

Basic Formulae

The method of analysis assumes straight line ray paths to a particular reflecting horizon and back to the surface. Using Pythagoras' theorem we find that:

$$t^2 = \frac{1}{V_a^2} x^2 + \frac{(2D)^2}{V_a^2} \quad (1)$$

where x = Distance between shot and geophone

t = Time of travel of the reflected ray from shot to geophone

V_a = Average vertical velocity to the reflector

D = Depth to the reflector

For t^2 data plotted against x^2 data, this is the equation of a straight line and thus (1) can be rewritten as follows.

$$t^2 = (\text{SLOPE}) x^2 + (\text{INTERCEPT}) \quad (2)$$

where $\text{SLOPE} = \frac{1}{v_a^2}$ (3)

$$\text{INTERCEPT} = \frac{(2D)^2}{v_a^2} \quad (4)$$

Thus average velocity and depth can be calculated from the parameters of the line. Solving (3) for average velocity

$$v_a = 1/\sqrt{\text{SLOPE}} \quad (5)$$

If t_o represents the two-way reflection time at zero offset ($x = 0$) for the particular reflecting horizon, then from (2)

$$t_o^2 = \text{INTERCEPT} \quad (6)$$

and solving for depth in (4)

$$D = \frac{1}{2} v_a t_o \quad (7)$$

For two reflectors, denoted say by subscripts 1 and 2, the interval velocity between them, v_i , is given by

$$v_i = \frac{D_2 - D_1}{\frac{1}{2}(t_{o2} - t_{o1})} = \frac{v_{a2} t_{o2} - v_{a1} t_{o1}}{t_{o2} - t_{o1}} \quad (8)$$

where t_{o1} and t_{o2} are the two way reflection times at zero offset for reflectors 1 and 2 respectively.

The least-squares model for the line represented by equation (2) is

$$t_i^2 = (\text{SLOPE}) x_i^2 + (\text{INTERCEPT}) + \epsilon_i \quad (9)$$

where i denotes the i^{th} data point and i ranges from 1 to n (the number of data points) and ϵ_i represents the deviation of the i^{th} data point from the fitted line.

To obtain a least-squares fit, the basic criterion of least squares states that $\sum \epsilon_i^2$ should be minimized. From (9):

$$\epsilon_i^2 = (t_i^2 - (\text{SLOPE}) x_i^2 - (\text{INTERCEPT}))^2 \quad (10)$$

This least-squares criterion is satisfied if

$$\frac{\partial (\sum \epsilon_i^2)}{\partial (\text{SLOPE})} = \frac{\partial (\sum \epsilon_i^2)}{\partial (\text{INTERCEPT})} = 0 \quad (11)$$

Differentiation of (10) and substitution in (11) yields

$$\text{SLOPE} = \frac{(\sum x_i^2 t_i^2) - (\sum x_i^2) (\sum t_i^2)/n}{(\sum x_i^4) - (\sum x_i^2)^2/n} \quad (12)$$

$$\text{INTERCEPT} = (\sum t_i^2 - (\text{SLOPE}) (\sum x_i^2))/n \quad (13)$$

Equations (5), (6), (7), (8), (9), (12), and (13) give the solution for average velocity, depth, and interval velocity from the parameters of the least-squares fitted line.

Computations of Errors

A reliable measure of the error in the fit can be obtained from the standard deviation, σ , which is the square root of the variance. Assuming that the deviations follow a normal distribution, then the variance of the fit, σ^2 , is defined as

$$\sigma^2 = \sum \epsilon_i^2 / (n - 2) \quad (14)$$

Substituting (10) in (14)

$$\sigma^2 = \sum (t_i^2 - (\text{SLOPE}) x_i^2 - (\text{INTERCEPT}))^2 / (n - 2) \quad (15)$$

The variances of the slope and of the intercept can then be derived from the variance of the fit following the method of Draper and Smith (1966). The variance of the slope, σ_1^2 , is given by

$$\sigma_1^2 = \frac{\sigma^2}{\sum (x_i^2 - (\sum x_i^2)/n)^2} = \frac{\sigma^2}{\sum (x_i^2)^2 - (\sum x_i^2)^2/n} \quad (16)$$

and the variance of the intercept, σ_2^2 , is given by

$$\sigma_2^2 = \frac{\sigma^2 \sum (x_i^2)^2}{n (\sum (x_i^2)^2 - (\sum x_i^2)^2/n)} = \frac{\sigma_1^2 \sum (x_i^2)^2}{n} \quad (17)$$

It follows theoretically, from equations (16) and (17), that the possible distribution of values of SLOPE and INTERCEPT also follow a normal distribution. For the normal distribution the probability P that the true value of an estimated parameter, μ , lies in the range $\mu \pm k\sigma$ (where k is a constant; 1, 2, 3 etc and σ is the standard deviation), is readily obtainable from statistical tables and is given in Table 1.

Table 1

k	1	2	3	4	∞
P(x 100%)	68.27	95.45	99.73	99.99	100

In practice two standard deviations ($k = 2$) have been found to give useful error range estimates for the parameters SLOPE and INTERCEPT so that:

$$(\text{SLOPE}) = 2\sigma_1 \quad (18)$$

$$(\text{INTERCEPT}) = 2\sigma_2 \quad (19)$$

Because the least squares linear model (equation (9)) for the $t^2 - x^2$ data is a good approximation, the variance σ^2 is low and hence the magnitude of the errors in the parameters of the line are much less than the magnitude of the parameters themselves. Thus it is possible to use the approximation from differential calculus:

$$\delta y \approx \frac{\partial y}{\partial x_1} \delta x_1 + \frac{\partial y}{\partial x_2} \delta x_2 + \frac{\partial y}{\partial x_3} \delta x_3 + \dots \quad (20)$$

where y is an arbitrary function of any number of variables $x_1, x_2, x_3, \dots$. Substituting into this from equations (5) and (18) yields the average velocity error magnitude, δV_a , given by:

$$|\delta V_a| = |V_a \sigma_1 / \text{SLOPE}| \quad (21)$$

Similarly, using equations (3), (4), (18), and (19), the depth error δD is given by:

$$|\delta D| = D \left| \frac{\sigma_2}{\text{INTERCEPT}} - \frac{\sigma_1}{\text{SLOPE}} \right| \quad (22)$$

The interval velocity error calculated from equation (8) is given by

$$|\delta V_i| = \frac{t_{01} |\delta V_{a1}| + t_{02} |\delta V_{a2}|}{t_{02} - t_{01}} \quad (23)$$

Equations (21), (22), and (23) give a complete solution for the errors involved.

3. COMMENTS, AND LIMITATIONS OF VELOCITY PROBES

In the following discussion the term velocity probe is used to include expanded spreads, offset reflection spreads, and sonobuoy velocity probes. Specific comments refer to each particular method.

(1) The reliability of the information derived depends heavily on the quality and character of the input data. The accuracy of visual picking of seismic reflections may be seriously affected by the presence of interfering noise events or lateral changes in reflection character. This may introduce systematic errors, into the $t^2 - x^2$ line, which are not eliminated by least-squares fit nor are the contributions by these errors included in the error estimates obtained.

(2) In offset reflection methods where reflecting interfaces dip or are non-planar, errors may be produced in computing velocities. More complicated computing procedures are required for an exact solution of the dipping layer case (Sattlegger, 1965). Approximate corrections for the effect of dip (Brown, 1969) can be made to the velocity calculated.

(3) The assumption of straight ray-path geometry, on which the formulae are based, may not always be warranted. Because average velocity generally increases with depth, the seismic ray is refracted at each velocity layer interface. For small offset distances between the shot and the receiver, the seismic ray deviates only slightly from a straight line path and the approximation holds good. As the offset x increases, the seismic ray deviates more from a straight line path and because of refraction effects, an increasingly greater proportion of the actual travel path is spent in the deeper higher-velocity layers. This causes an increase in the apparent velocity as the offset increases and with good quality field data this may be seen as a decrease in slope of the $t^2 - x^2$ plot.

This effect may become appreciable in marine work and in deep crustal studies where often large offsets are employed. The true vertical velocity can be found by fitting a tangent to the $t^2 - x^2$ curve at zero offset (Dix, 1955, Grant and West, 1965). The computer program presented fits an overall straight line to all the $t^2 - x^2$ data and may yield a greater velocity than the time vertical velocity. The effect is often not detectable, being dependent on such factors as data quality, the nature of the vertical velocity distribution, and the thickness of formation encountered in the geological section. A preliminary analysis of the velocities and depths involved before full scale recording is carried out in the field may permit choice of an acceptable maximum offset.

In sedimentary basin investigations on land a maximum offset of the order of 1.5 to 2 times the depth of the reflector gives reasonably straight ray-paths. In deep crustal investigations this would be significantly less, since for offsets equal to 30 km or more, lateral inhomogeneities become important.

In marine sonobuoy work a large proportion of data is available out to offsets of several times the depth of the reflections and use of this large offset data in a $t^2 - x^2$ analysis may produce significant errors. The deviation of the actual ray path from a straight line is greatly increased where large velocity contrasts occur. This is generally the case in the marine environment where the sediments have a significantly higher velocity than the overlying water layer. In deep-water areas where the water depth is of the same order of magnitude as the thickness of the sub-bottom sedimentary section the ray-path deviation effect may become very significant.

Brown (1969) discusses the effect of large offset and gives an approximate method of correcting velocities deduced from $t^2 - x^2$ data using large offsets.

(4) An even spread of data points in the x^2 domain is desirable. Theoretically a minimum variance fit is obtained if bias is given to data points at both ends of the range. Because of the maximum offset considerations, (3) above, a reasonable compromise is to include a few more data points for small offsets to define the intercept as accurately as possible.

(5) Interval velocity resolution decreases with depth and interval velocity errors increase. Equations (8) and (25) indicate that as the error in interval velocity is inversely proportional to the time difference ($t_{02} - t_{01}$) between successive reflections, then for a uniform resolution of interval velocity with depth the time difference ($t_{02} - t_{01}$) must increase linearly with time t . This does not occur generally in actual geological sections. Plate 8 illustrates the increase in interval velocity error with depth and illustrates how significantly larger errors occur where interval velocity is measured over a small time interval.

Resolution of interval velocity is reported to be better with marine data (Le Pichon et al., 1968).

4. COMPUTATIONAL METHOD

The computer program presented consists of a main program VELSPRED, with one least-squares fitting subroutine SQSPITER, and two plot subroutines T2X2PLOT and PLOT25XX. Flow diagrams for these are shown in Plates 1, 2, 3, and 4. The program accepts t and x values read manually from seismic sections. The times have been averaged from both sides of the shot to remove dip effects in the case of expanded spreads. Output from the program consists of a table of all parameters calculated and their errors, together with a printout of all basic input data for checking purposes. A $t^2 - x^2$ plot for visual inspection of fit, an average velocity versus time plot, a depth versus time plot, and an interval velocity versus depth plot comprise the graphical output. Appendix 1 contains a listing of the program as used for land seismic expanded spreads. Minor modification of graphical headings only is needed for application to offset reflection spreads. Appendix 2 contains a sample line printer output. Plates 5, 6, 7, and 8 show sample graphical outputs.

The program may be used in a number of ways. In preliminary assessment of the input data, where only a $t^2 - x^2$ plot and an output table is required, the subroutine PLOT25XX and its call card in VELSPRED may be excluded. The program is designed to handle a number of velocity probes from different surveys with up to 15 reflections for each velocity probe and 50 data points per reflection. This capacity can be extended by altering the appropriate DIMENSION statement.

The program has provision for arbitrary specification of graph scales on input and this enables the program to accept all types of velocity probes including deep crustal velocity spreads. For the interval velocity versus time plot, anomalously large interval velocities which lie outside a reasonable range, which is specified on input, are plotted at the extreme of the range.

The input x values are scaled before input by an appropriate factor, called 'STNINT'. In expanded spread and offset reflection work on land, STNINT represents the geophone station interval so that the input x values are the geophone number (i.e. seismic trace number) from the centre of the expanded spread, or from the shot in offset reflection work. In marine reflection work using the offset reflection method with sonobuoys, the actual distance from the sonobuoy to the shooting-recording boat (i.e. the true x value), is determined from the time of arrival of the direct water wave, which is easily measured on the sonobuoy seismic record. Consequently, in this case the factor 'STNINT' becomes the velocity of sound in sea water and the input x values represent the direct water wave arrival times. In summary, for land seismic work:

$$\text{Input } x = \frac{\text{Actual } x}{\text{STNINT}} = \frac{\text{Actual } x}{\text{Geophone Spacing}} = \text{Geophone number from zero offset}$$

and for marine sonobuoy velocity probes:

$$\text{Input } x = \frac{\text{Actual } x}{\text{STNINT}} = \frac{\text{Actual } x}{\text{Water wave velocity}} = \text{Direct wave arrival time}$$

The program accepts the input scale factor STNINT and corrects for scaling after the least squares fit has been made. This reduces the possibility of numbers becoming too large for their storage positions during the least-square calculation.

A possible improvement in the program would lie in the use of a digitizing machine for automatic picking of the reflection times. These generally have some form of punched tape output which could be made compatible to the program by minor modification of input formats in VELSPRED. Use of an automatic picking process has several advantages; the tedious strain involved in manual picking of seismic sections would be reduced; the number of data points per reflection could be increased greatly; in surveys involving a large number of velocity probes such as marine surveys, where for each picked trace on each sonobuoy record, two times (the direct water wave arrival time and the two reflection times) are read off, the use of an automatic picking process is almost essential to process the large volume of data.

5. INSTRUCTIONS FOR USE OF COMPUTER PROGRAM(1) CHOICE OF SCALES

PLOT	ABSCISSA SCALE	MAX. VALUE OF ABSCISSA	ORDINATE SCALE	MAX. VALUE OF ORDINATE
$t^2 - x^2$	XSQSCALE	10X XSQSCALE	TSQSCALE	20X TSQSCALE
$V_a - t$	TSCALE	10X TSCALE	AVSCALE	15X AVSCALE
$D - t$	TSCALE	10X TSCALE	DSCALE 1	10X DSCALE 1
$V_i - D$	DSCALE 2	10X DSCALE 2	VINTSCAL	VINTMAX

NOTE:

- Scales are in units/inch, (for use with Calcomp 10-inch-wide paper).
- x^2 scale is in (geophone number)² units - numbered from zero offset or (direct waterwave travel time)² units

(2) DATA CARD DECK

	Card No.	Col. Nos	Format	Comments
1st Survey	1	1-64	8A8	Survey (Survey name and year)
	2	1-8	A8	UNITS (Either m, km, ft - Right justified)
		9-13	F5.0	AVSCALE (Average velocity scale)
		14-16	F3.1	TSCALE (Time scale)
		17-21	F5.0	DSCALE 1 (Depth ordinate scale)
		22-26	F5.0	DSCALE 2 (Depth abscissa scale)
		27-31	F5.0	VINTSCAL (Interval velocity)
		32-37	F6.0	VINTMAX (Maximum interval velocity)
		38-41	F4.1	TSQSCALE (t^2 Scale)
		42-46	F6.0	SQSCALE (x^2 scale)
1st Velocity probe	3	1-64 65-80	8A8 2A8	SURVEY (Survey name and year) TRAVERSE (Velocity probe name and identifier)
	4	1-2	I2	NRFLNS (No. of reflections in this probe)
		6-11	F6.2	STNINT (Geophone station interval or water velocity)
		15-16	I2	NSTDEVNS (No. of standard deviations in the statistical fit - generally 2)

	EOF	After last survey
1	0.0000	0.0000
2	0.0000	0.0000
3	0.0000	0.0000
4	0.0000	0.0000
5	0.0000	0.0000
6	0.0000	0.0000
7	0.0000	0.0000
8	0.0000	0.0000
9	0.0000	0.0000
10	0.0000	0.0000
11	0.0000	0.0000
12	0.0000	0.0000
13	0.0000	0.0000
14	0.0000	0.0000
15	0.0000	0.0000
16	0.0000	0.0000
17	0.0000	0.0000
18	0.0000	0.0000
19	0.0000	0.0000
20	0.0000	0.0000
21	0.0000	0.0000
22	0.0000	0.0000
23	0.0000	0.0000
24	0.0000	0.0000
25	0.0000	0.0000
26	0.0000	0.0000
27	0.0000	0.0000
28	0.0000	0.0000
29	0.0000	0.0000
30	0.0000	0.0000
31	0.0000	0.0000
32	0.0000	0.0000
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38	0.0000	0.0000
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42	0.0000	0.0000
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47	0.0000	0.0000
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87	0.0000	0.0000
88	0.0000	0.0000
89	0.0000	0.0000
90	0.0000	0.0000
91	0.0000	0.0000
92	0.0000	0.0000
93	0.0000	0.0000
94	0.0000	0.0000
95	0.0000	0.0000
96	0.0000	0.0000
97	0.0000	0.0000
98	0.0000	0.0000
99	0.0000	0.0000
100	0.0000	0.0000

EOF

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APPENDIX 1

20

PROGRAM LISTING

16/09/70

PROGRAM VELSPED LAND SEISMIC EXPANDED SPREAD

VD 1

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C PROGRAM VELSPED COMPUTES FROM A STATISTICAL LEAST SQUARES FIT OF A
C STRAIGHT LINE TO T SQUARED - X SQUARED DATA , AVERAGE VELOCITIES ,
C DEPTHS(AND ERRORS) TO EACH REFLECTING HORIZON, INTERVAL VELOCITIES(AND
C ERRORS) ARE ALSO CALCULATED, ANY NUMBER OF EXPANDED SPREADS FORM ONE
C OR MORE SURVEYS CAN BE ANALYSED, UP TO 50 DATA POINTS PER REFLECTION
C AND 15 REFLECTIONS PER EXPANDED SPREAD CAN BE HANDLED
C NOTE... HAVE ASSUMED DEPTH OF REFLECTOR IS VERY MUCH GREATER THAN THE OFFSET
C NOTE... IN ALL ERROR ANALYSIS , HAVE ASSUMED RELATIVE ERRORS VERY MUCH LESS
C THAN UNITY
      DIMENSION X(50),T(50),AVVELY(15),VINTVL(15),VINTVLHX(15),VINTVLHN(15),
      115),AVVELMAX(15),AVVELMIN(15),DEPTH(15),DEPTERR(15),TNOUGHT(15),DVD
      2ELTAV(15),SURVEY(6),EXPDSPD(3),TRAVERSE(2),DEPTHMAX(15),DEPTHMIN(15)
      351
      DATA(NREAD = 0), (NPRINT = 61), (NPUNCH = 62)
      DATA(EXPSPD = 24H EXPANDED SPREAD)
      10 FORMAT(12,3X,F5.2,3X,12)
      20 FORMAT(1X,F7.3)
      30 FORMAT(10F7.3)
      40 FORMAT(8A8,2A5)
      50 FORMAT(26H TSO XSD RESULTS ASSUMING ,12.49M STANDARD DEVIATIONS INVD
      1 THE SLOPE AND INTERCEPTS,///,1H ,113(=S),///,1H ,*REFL,N SS TWO-WAY
      2AY SS DEPTH TO S ERROR IN SS AVERAGE S MAXIM AV S MINIM AV SS INVD
      3INTERVAL S MAX, INT S MIN, INT SS,///,1H ,* NO, SS TIME SS REFLVD
      4LECTOR S DEPTH SS,2(3(= VELOCITY S),S),///,1H ,7X,SS (SECS,VD
      5) SS (1(=R2,=) S (1(=R2,=) SS,2(3(= (1(=R2,=/SEC) S),S),VD
      6///,1H ,113(=S),/)
      60 FORMAT(15, SS,F8.3, SS,F8.0, SS,F7.0, SS,2(3(F8.0, VD
      1 S),S),///,1H ,7X,SS,10X,SS,11X,SS,10X,SS,2(3(10X,SS),S),VD
      2)
      70 FORMAT(1H ,//, REFLECTION NO,12,4X,TNOUGHT =,F6.3,4X,NPTS =,VD
      113)
      80 FORMAT(10F7.3)
      90 FORMAT(1H,EX,9A8,///,1H ,10X,*EXPANDED SPREAD=,3X,2A8,////,1HVD
      1)
      100 FORMAT(1H ,INPUT DATA FOR ,8A8,2A8,///,1H ,*GEOPHONE STN INTERVALVD
      1 SS,F5.0, R2 ,///,1H ,*VALUES TABULATED ARE GEOPHONE STN, NO, (X1)VD
      2),J1,NPTS) AND TWO-WAY TIME (T1),J1,NPTS) OR THE CORRESPONDINGVD
      3X(J),//, 48H NOTE 1 THE TRUE SHOT-RECEIVER DISTANCE = X(J) * F5.0,VD
      4 R2 ,//,80H 2 THE TIMES T1(J) HAVE BEEN AVERAGED FROM TIMES FVD
      5FROM BOTH SIDES OF THE SHOT,/)
      110 FORMAT(15, SS,F8.3, SS,F8.0, SS,F7.0, SS,2(3(F8.0, VD
      1 S),S),///,1H ,7X,SS,10X,SS,11X,SS,10X,SS,2(3(10X,SS),S),VD
      2),///,1H ,113(=S),//,1H)
      120 FORMAT(8A8)
      130 FORMAT(AB,F5.0,13.1,3F5.0,F6.0,F4.1,F6.0)
      140 FORMAT(*DATA ERROR IN TRAVERSE =,2A8)
      GO TO 200
      150 READ(NREAD,120) SURVEY
      160 IF(EOF,NREAD) 170,190
      170 READ(NREAD,40) SURVEY,TRAVERSE
      180 IF(EOF,NREAD) 180,230
      180 READ(NREAD,120) SURVEY
      190 IF(EOF,NREAD) 290,210
      190 WRITE(NPRINT,140) EXPDSPD
      200 READ(NREAD,120) SURVEY
      210 READ(NREAD,130) UNITS,AVSCALE,TSCALE,DESCALE1,DSCALE2,VINTSCALE,VINTVD
      1MAX,TSCALE,XSCALE
      220 READ(NREAD,40) SURVEY,TRAVERSE
      C SPECIFY THE NO. OF REFLECTIONS, STN INTERVAL AND THE NO. OF STANDARD DEVIATION
      C S IN THE INTERCEPT AND SLOPE
      230 READ(NREAD,10) NRFLNS,STNINT,NSTDVNS
      C START COMPUTING DO LOOP (EACH REFL,N DONE IN TURN)
      DO 270 J=1,NRFLNS
      NA = J
      C READ IN NO. OF PTS ON TSO XSD LINE AND TWO WAY TIME
      READ(NREAD,20) NPTS,TNOUGHT(NA)
      C READ IN X(I) = TRACE NOS FROM CENTRE OF SPREAD AND T(I) = AVERAGED REFLECTION
      C TIMES AT TRACES X(I) BOTH SIDES OF CENTRE
      C THE MAXIMUM VALUE OF ALL THE X(I) IS X(NPTS)
      READ(NREAD,30) X(1),1 = 1,NPTS)
      READ(NREAD,30) T(1),1 = 1,NPTS)
      IF(NA,NE,1) GO TO 240
      WRITE(NPRINT,100) SURVEY,TRAVERSE,(SYNINT,6NPTS, K = 1,2)
      240 CONTINUE
      WRITE(NPRINT,70) NA,TNOUGHT(NA),NPTS
      WRITE(NPRINT,80) 1(X(1),1 = 1,NPTS)
      WRITE(NPRINT,80) 1(T(1),1 = 1,NPTS)
      C FOR EASE SQUARE X AND Y AND STORE IN X AND T RESPECTIVELY
      DO 250 I = 1,NPTS
      X(I) = X(1)+I-1
      250 T(I) = T(1)+I-1
      C MAKE LEAST SQUARES FIT IN SUBROUTINE SOSFITER
      CALL SOSFITER(NPTS,X,T,SLOPE,DEVSLOPE,TINTER,DEVINTER)
      C PLOT T SQUARED-X SQUARED GRAPH - SUBROUTINE T2X2PLOT
      CALL T2X2PLOT(SURVEY,EXPDSPD,TRAVERSE,STNINT,UNITS,NPTS,X,T,XSCALEVD
      1E,TSCALE,TINTER,SLOPE,NA,NRFLNS)
      C CORRECT FOR SCALING OF X(I), IN SLOPE AND DEVSLOPE
      SLOPE = SLOPE/(STNINT)**2
      DEVSLOPE = DEVSLOPE/(STNINT)**2
      C CALCULATE AV. VELY AND RANGE OF ERROR
      AVVELY(J) = 1.0/SORT(SLOPE)
      A = FLOAT(NSTDVNS)*DEVSLOPE*AVVELY(J)
      DELTAV(J) = A/(FLOAT(2)*SLOPE)
      AVVELMAX(J) = AVVELY(J) + DELTAV(J)
      AVVELMIN(J) = AVVELY(J) - DELTAV(J)
      C CALCULATE DEPTHS AND ERROR
      DEPTH(J) = 0.5 * SORT (TINTER/SLOPE)
      A = 0.5 * DEPTH(J) * NSTDVNS
      B = (DEVINTER/TINTER) * (DEVSLOPE/SLOPE)
      DEPTERR(J) = A+B
      DEPTERR(J) = ABS(DEPTERR(J))
      DEPTHMAX(J) = DEPTH(J) + DEPTERR(J)
      DEPTHMIN(J) = DEPTH(J) - DEPTERR(J)
      C CALCULATE INTERVAL VELOCITIES AND ERROR
      IF(J,GT,1)GO TO 260
      VINTVL(1) = AVVELY(1)
      VINTVLHX(1) = AVVELMAX(1)
      VINTVLHN(1) = AVVELMIN(1)
      GO TO 270
      260 A = AVVELY(J) * TNOUGHT(J) - AVVELY(J-1) * TNOUGHT(J-1)

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      N = TNOUGHT(J) - TNOUGHT(J-1)          VD 90
      VINTVL(J) = A/Z          VD 91
      VINTVLMX(J) = (AVVELMAX(J)*TNOUGHT(J) - AVVELMIN(J-1)*TNOUGHT(J-1))VD 92
      1/P          VD 93
      VINTVLMN(J) = (AVVELMIN(J)*TNOUGHT(J) - AVVELMAX(J-1)*TNOUGHT(J-1))VD 94
      1/H          VD 95
      270 CONTINUE          VD 96
      WRITE(PPRINT,90) SURVEY, TRAVERSE          VD 97
C PRINT OUT 1/2" TABLE HEADINGS          VD 98
      WRITE(PPRINT,51) NSTOPVMS, (UNITS,K = 1,8)          VD 99
      DO 280 J = 1, NRFLMS          VD 100
      N = J          VD 101
      IF (N, EP, NRFLMS) GO TO 280          VD 102
C PRINT 1/2" VALUES IN TABLE          VD 103
      WRITE(PPRINT,60) J, TNOUGHT(N), DEPTH(N), DEPTHERR(N), AVVELY(N), AVVEVD 104
      1LMAX(N), AVVELMIN(N), VINTVL(N), VINTVLMX(N), VINTVLMN(N)          VD 105
      280 CONTINUE          VD 106
      N = NRFLMS          VD 107
      WRITE(PPRINT,110) J, TNOUGHT(N), DEPTH(N), DEPTHERR(N), AVVELY(N), AVVEVD 108
      1LMAX(N), AVVELMIN(N), VINTVL(N), VINTVLMX(N), VINTVLMN(N)          VD 109
C PLOT GRAPHS OF RESULTS - SURROUTINE PLOT25XX          VD 110
      CALL PLOT25XX(SURVEY, EXPOS, THAVERSE, STNINT, UNITS, TNOUGHT, TSCALE, VD 111
      1AVSCALE, AVVELY, AVVELMIN, AVVELMAX, DSCALE1, DSCALE2, DEPTH, DEPTHMAX, DEVD 112
      2PTHMIN, VINTSCALE, VINTMAX, VINTVL, VINTVLMX, VINTVLMN, NRFLMS)          VD 113
C REDIRECT TO COMPUTE NEXT EXPANDED SPREAD IF ANY          VD 114
      GO TO 150          VD 115
      290 STOP          VD 116
      END          VD 117

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      SURROUTINE SOSFITER(N,X,T,SLOPE,DFVSLOPE,TINTER,DEVINTER)          SQ 1
C PROVIDES LEAST SQUARES FIT AND STD DEVN OF SLOPE AND INTERCEPT          SQ 2
      DIMENSION X(50),T(50)          SQ 3
      XSUM=0, T SUM=0, XSOSUM=0, XYSUM=0, & VARSUM=0.          SQ 4
C COMPUTE SUMS          SQ 5
      DO 10 I = 1,N          SQ 6
      XSUM = XSUM + X(I)          SQ 7
      T SUM = T SUM + T(I)          SQ 8
      XSOSUM = XSOSUM + X(I) ** 2          SQ 9
      10 XYSUM = XYSUM + X(I) * T(I)          SQ 10
C SOLVE FOR SLOPE AND TANGENT          SQ 11
      DIVIDEND = XYSUM - (XSUM * T SUM/N)          SQ 12
      DIVISOR = XSOSUM - ((XSUM ** 2)/N)          SQ 13
      SLOPE = DIVIDEND/DIVISOR          SQ 14
      TINTER = (T SUM - (XSUM * SLOPE))/N          SQ 15
C COMPUTE VARIANCE (MEASURE OF SUMS OF DEVS SQUARED)          SQ 16
      DO 20 I = 1,N          SQ 17
      20 VARSUM = VARSUM + (T(I) - SLOPE * X(I) - TINTER) ** 2          SQ 18
      VARSUM = VARSUM / (N - 2)          SQ 19
C COMPUTE VARIANCE OF SLOPE AND INTERCEPT, THEN TAKE SQRT FOR STD DEVS          SQ 20
      VARSLP = VARSUM/DIVISOR          SQ 21
      DEVSLP = SQRT(VARSLP)          SQ 22
      VARINTER = (VARSUM * XSOSUM)/(DIVISOR * N)          SQ 23
      DEVINTER = SQRT(VARINTER)          SQ 24
      RETURN          SQ 25
      END          SQ 26

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SURROUTINE PLOT25XX(SURVEY,EXPSPD,TRAVERSE,STNINT,UNITS,TNUGHT,TPL
1SCALE,AVSCALE,AVVEL,AVVELMIN,AVVELMAX,DSCALE1,DSCALE2,DEPTH,DEPTMPL
2MAX,DEPTHMIN,VINTSCALE,VINTMAX,VINTVL,VINTVLMX,VINTVLMN,NRFLNS) PL 1
C SURROUTINE PLOT25XX PRODUCES THREE GRAPHS PL 2
C (1) AVERAGE VELOCITY VS TWO-WAY TIME (WITH ERROR BARS) PL 3
C (2) DEPTH VS TWO-WAY TIME (WITH ERROR BARS) PL 4
C (3) INTERVAL VELOCITY VS DEPTH HISTOGRAM (WITH ERROR BARS) PL 5
C SCALES OF THE GRAPHS ARE ARBITRARY AND ARE INPUTED IN THE MAIN PROGRAM PL 6
DIMEVSTON SURVEY(8),EXPSPD(3),TRAVERSE(2),AVVEL(15),AVVELMAX(15) PL 7
1,AVVELMIN(15),DEPTH(15),DEPTHMAX(15),DEPTHMIN(15),VINTVL(15),VINTVPL 8
2MAX(15),VINTVLMN(15),A(15),B(15),C(15),D(15),E(15),F(15),AVVELVER(PL 9
3H),VELTGRPH(5),TIMEHOR(7),DEPTGRPH(4),DEPTMVER(7),VINTGRPH(8),VELPL 10
4VFR(9),DEPTMHOR(7),BUF(9),XTEXT(9),TNUGHT(15) PL 11
DATA(VELTGRPH = 40M AVERAGE VELOCITY VERSUS TWO-WAY TIME ),(AVVPL 12
1PLVER = 64H VELOCITY SCALE (VERT. SCALE 1 INCH REPS. PL 13
2 /SEC. ),(TIMEHOR = 56H TIME SCALE (HOR. SCALE 1 INCH REPS. PL 14
3S, SECS. ),(DEPTGRPH = 32H DEPTH VERSUS TWO-WAY TIME PL 15
4 ),(DEPTMHOR = 54H DEPTH SCALE (HOR. SCALE 1 INCH REPS. PL 16
5 ),(DEPTMVER = 54H DEPTH SCALE (VERT. SCALE 1 INCH PL 17
REPS. ),(VINTGRPH = 64H INTERVAL VELOCITY (RANGE PL 18
7 TO /SEC.) VERSUS DEPTH ),(VELINVER = 72H INTERVAL VEPL 19
LOCITY SCALE (VERT. SCALE 1 INCH REPS. /SEC. ) PL 20
A(1) = 0, B(1) = 0, PL 21
10 FORMAT(9A6) PL 22
20 FORMAT(2A8) PL 23
30 FORMAT(5A8) PL 24
40 FORMAT(7A8) PL 25
50 FORMAT(4A8) PL 26
60 FORMAT(3A8) PL 27
70 FORMAT(5,0) PL 28
80 FORMAT(2) PL 29
90 FORMAT(3,1) PL 30
100 FORMAT(6,0) PL 31
110 FORMAT(9A8) PL 32
120 FORMAT(7,1) PL 33
C AV. VEL. VS TIME BRANCH OF PLOT ROUTINE PL 34
C SET SCALES PL 35
XSCALE = YSCALE PL 36
YSCALE = AVSCALE PL 37
XMAX = 10.0 * XSCALE PL 38
YMAX = 15.0 * YSCALE PL 39
DO 140 J = 1,NRFLNS PL 40
A(J) = AVVEL(J) PL 41
B(J) = AVVELMIN(J) PL 42
C(J) = AVVELMAX(J) PL 43
140 CALL PLOT(XSCALE,YSCALE,2) PL 44
CALL PLOT(0,0,1) PL 45
C PRINT SURVEY AND TRAVERSE HEADINGS PL 46
150 CALL PLOT(0,0,1,YSCALE,3) PL 47
ENCODE(64,10,BUF) SURVEY PL 48
CALL TEXT(BUF,64,3) PL 49
CALL PLOT(0,0,1,5*YSCALE,3) PL 50
ENCODE(24,60,XTEXT) EXPSPD PL 51
CALL TEXT(XTEXT,24,3) PL 52
CALL PLOT(4,0,XSCALE,-1,5*YSCALE,3) PL 53
ENCODE(16,20,BUF) TRAVERSE PL 54
CALL TEXT(BUF,16,3) PL 55
C INSERT REDIRECTION CARDS PL 56
IF(A(1).EQ. DEPTH(1))GO TO 230 PL 57
IF(D(1).EQ.VINTVL(1))GO TO 320 PL 58
C PRINT SCALES FOR AV. VEL. VS TIME GRAPH PL 59
160 CALL PLOT(XSCALE,-2.0*YSCALE,3) PL 60
ENCODE(40,30,XTEXT) VELTGRPH PL 61
CALL TEXT(XTEXT,40,3) PL 62
CALL PLOT(XSCALE,-2.5*YSCALE,3) PL 63
ENCODE(64,10,XTEXT) AVVELVER PL 64
CALL TEXT(XTEXT,64,2) PL 65
CALL PLOT(5,0,XSCALE,-2.5*YSCALE,3) PL 66
ENCODE(5,70,BUF) AVSCALE PL 67
CALL TEXT(BUF,5,2) PL 68
CALL PLOT(6,0,XSCALE,-2.5*YSCALE,3) PL 69
ENCODE(12,80,XTEXT) UNITS PL 70
CALL TEXT(XTEXT,12,2) PL 71
CALL PLOT(XSCALE,-3.0*YSCALE,3) PL 72
ENCODE(56,40,XTEXT) TIMEHOR PL 73
CALL TEXT(XTEXT,56,2) PL 74
CALL PLOT(5,2,XSCALE,-3.0*YSCALE,3) PL 75
ENCODE(13,90,BUF) YSCALE PL 76
CALL TEXT(BUF,13,2) PL 77
C MAIN PLOT ROUTINE FOR AV. VEL. VS TIME AND DEPTH VS TIME PL 78
170 CALL PLOT(0,0,3) PL 79
C PLOT AXES AND SCALES PL 80
180 CALL PLOT(0,YMAX,4) PL 81
NY = (YMAX/YSCALE) * 1 PL 82
DO 190 M = 1,NY PL 83
XY = FLOAT(NY-M) - 0.03 PL 84
AY = (NY - 0.03)*YSCALE PL 85
CALL PLOT(0,40,XSCALE,XY*YSCALE,3) PL 86
ENCODE(17,120,BUF) AY PL 87
CALL TEXT(BUF,17,1) PL 88
CALL PLOT(0,0,XSCALE,AY,3) PL 89
CALL TEXT(1H=0.1) PL 90
190 CONTINUE PL 91
CALL PLOT(0,0,3) PL 92
CALL PLOT(XMAX,0,4) PL 93
DO 200 M = 1,11 PL 94
XX = FLOAT(11-M) - 0.17 PL 95
AX = (XX - 0.17)*XSCALE PL 96
CALL PLOT(XX,XSCALE,-0.5*YSCALE,3) PL 97
ENCODE(17,120,BUF) AX PL 98
CALL TEXT(BUF,17,1) PL 99
AX = AX - 0.01*XSCALE PL 100
CALL PLOT(AX,-0.05*YSCALE,3) PL 101
CALL TEXT(1H=0.1) PL 102
200 CONTINUE PL 103
CALL PLOT(0,0,3) PL 104
IF(D(1).EQ.VINTVL(1))GO TO 330 PL 105
DO 210 J=1,NRFLNS PL 106
CALL PLOT(TNUGHT(J),C(J),3) PL 107
CALL TEXT(1H=0.1) PL 108
CALL PLOT(TNUGHT(J),A(J),4) PL 109
CALL TEXT(1H=0.2) PL 110

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CALL PLOT(THOUGHT(J),B(J),4)
CALL TEXT(TH-0.4)
210 CONTINUE
IF(A(1).EQ.DEPTH(1)).GO TO 240
CALL PLOT(0,YMAX*.4*YSCALE,3)
C DEPTH VS TIME BRANCH OF PLOT ROUTINE
C SET DEPTH SCALE
YSCALE = DSCALE1
YMAX = 10.0 * YSCALE
CALL PLOT(YSCALE,YSCALE,2)
CALL PLOT(0,0,1)
DO 220 J = 1,NRFLNS
A(J) = DEPTH(J)
IF(A(J).GT.YMAX) A(J) = YMAX
B(J) = DEPTHMIN(J)
IF(B(J).GT.YMAX) B(J) = YMAX
C(J) = DEPTHMAX(J)
220 IF(C(J).GT.YMAX) C(J) = YMAX
GO TO 150
C PRINT SCALES FOR DEPTH VS TIME GRAPH
230 CALL PLOT(XSCALE,-2.*YSCALE,3)
ENCODE(32,50,XTEXT) DEPTORPH
CALL TEXT(XTEXT,32,3)
CALL PLOT(XSCALE,-2.*YSCALE,3)
ENCODE(56,40,XTEXT) DEPTHVER
CALL TEXT(XTEXT,56,2)
CALL PLOT(5,2*XSCALE,-7.5*YSCALE,3)
ENCODE(15,70,XTEXT) DSCALE1
CALL TEXT(XTEXT,5,2)
CALL PLOT(5,8*XSCALE,-2.5*YSCALE,3)
ENCODE(2,80,XTEXT) UNITS
CALL TEXT(XTEXT,2,2)
CALL PLOT(XSCALE,-3.0*YSCALE,3)
ENCODE(56,40,XTEXT) TIMEHOR
CALL TEXT(XTEXT,56,2)
CALL PLOT(5,2*XSCALE,-3.0*YSCALE,3)
ENCODE(3,90,BUF) YSCALE
CALL TEXT(BUF,3,2)
C GO TO MAIN PLOT ROUTINE
GO TO 170
240 CALL PLOT(0,YMAX*.4*YSCALE,3)
C INTERVAL VELOCITY VS DEPTH HISTOGRAM PLOT ROUTINE (ERRORS INCLUDED)
C SET SCALES
XSCALE = DSCALE2
XMAX = 10.0 * XSCALE
YSCALE = VINTSCALE
YMAX = VINTMAX
CALL PLOT(0,0,1)
CALL PLOT(XSCALE,YSCALE,2)
C LIMIT INTERVAL VELOCITY TO REALISTIC, PREDETERMINED RANGE (I.E. 0 TO
C VINTMAX)
DO 300 J = 1,NRFLNS
IF(VINTVLN(J).GE.0.) GO TO 250
VINTVLN(J) = 0.
250 IF(VINTVL(J).GE.0.100 TO 260
VINTVL(J) = 0.
260 IF(VINTVLX(J).GE.0.100 TO 270
VINTVLX(J) = 0.
270 IF(VINTVLX(J).LE.VINTMAX) GO TO 280
VINTVLX(J) = YMAX
280 IF(VINTVL(J).LE.VINTMAX) GO TO 290
VINTVL(J) = YMAX
290 IF(VINTVLN(J).LE.VINTMAX) GO TO 300
VINTVLN(J) = YMAX
300 CONTINUE
DO 310 J = 1,NRFLNS
B(J) = VINTVL(J)
C(J) = VINTVLX(J)
310 F(J) = VINTVLX(J)
A(J) = 0.
C PRINT SURVEY AND TRAVERSE HEADINGS
GO TO 150
C PRINT SCALES FOR INTERVAL VELOCITY VS DEPTH GRAPH
320 CALL PLOT(XSCALE,-2.*YSCALE,3)
ENCODE(64,80,XTEXT) VINTORPH
CALL TEXT(XTEXT,64,3)
CALL PLOT(4,77*XSCALE,-2.0*YSCALE,3)
ENCODE(16,100,XTEXT) VINTMAX
CALL TEXT(XTEXT,6,3)
CALL PLOT(5,85*XSCALE,-2.0*YSCALE,3)
ENCODE(2,80,XTEXT) UNITS
CALL TEXT(XTEXT,2,3)
CALL PLOT(XSCALE,-2.0*YSCALE,3)
ENCODE(72,110,XTEXT) VELINVER
CALL TEXT(XTEXT,72,2)
CALL PLOT(6,3*XSCALE,-2.5*YSCALE,3)
ENCODE(5,70,XTEXT) VINTSCALE
CALL TEXT(XTEXT,5,2)
CALL PLOT(6,9*XSCALE,-7.5*YSCALE,3)
ENCODE(2,80,XTEXT) UNITS
CALL TEXT(XTEXT,2,2)
CALL PLOT(XSCALE,-3.0*YSCALE,3)
ENCODE(56,40,XTEXT) DEPTHVER
CALL TEXT(XTEXT,56,2)
CALL PLOT(5,0*XSCALE,-8.0*YSCALE,3)
ENCODE(5,70,XTEXT) DSCALE2
CALL TEXT(XTEXT,5,2)
CALL PLOT(5,6*XSCALE,-3.0*YSCALE,3)
ENCODE(2,80,XTEXT) UNITS
CALL TEXT(XTEXT,2,2)
C PLOT AXES
CALL PLOT(0,0,1)
GO TO 180
C PLOT INTERVAL VELOCITY VS DEPTH HISTOGRAM
330 A(1) = DEPTH(1)
CALL PLOT(0,A(1),3)
DO 340 J = 2,NRFLNS
CALL PLOT(A(J)-1,B(J)-1,4)
340 CALL PLOT(A(J)-1,B(J),4)
CALL PLOT(A(NRFLNS),B(NRFLNS),4)
CALL PLOT(A(NRFLNS),0,4)
C PLOT ERROR BARS
NERR = NRFLNS - 1
DO 350 J = 1,NERR
NB = NRFLNS+1-J
CALL PLOT(0.5*(A(NB)+A(NB+1)),B(NB),3)
CALL TEXT(TH-0.3)
CALL PLOT(0.5*(A(NB)+A(NB+1)),F(NB),4)
350 CALL TEXT(TH-0.3)
CALL PLOT(A(1),B(1),3)
CALL TEXT(TH-0.3)
CALL PLOT(0.5*(A(1)+A(2)),F(1),4)
CALL TEXT(TH-0.3)
CALL PLOT(0,YMAX*.4*YSCALE,3)
RETURN
END

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SUBROUTINE T2X2PLOT(SURVEY,EXPDSPD,TRAVERSE,STNINT,UNITS,NPTS,X,T,TP
1
1X$OSCALE,TS$OSCALE,TINTER,SLOPE,NA,NRFLNS) TP 2
C SURROUTINE T2X2PLOT PRODUCES A Y SQUARED - X SQUARED PLOT OF ALL TP 3
C REFLECTIONS ANALYZED. THE VERTICAL AND HORIZONTAL SCALES ARE ARBITRARY TP 4
C AND SPECIFIED IN THE MAIN PROGRAM. THE X SQUARED SCALE IS IN SQUARED TP 5
C TRACE NO. UNITS TP 6
C T$O-X$O PLOT ROUTINE TP 7
  DIMENSION SURVEY(8),EXPDSPD(3), TRAVERSE(2),X(50),T(50),BUF(9),TSQTP
  1X$T(4),TSQVERT(8),XSQHOR(8),XNOTE(8),XTEXT(9) TP 8
  DATA(T$OXS2 = 324 T SQUARED - X SQUARED PLOT 1,(TSQVERT = 64HTP
  1 TSQUARED SCALE (VERT. SCALE 1 INCH REPS. SQUARED SECS.) 1TP
  2,(XSQHOR = 64H X SQUARED SCALE (HOR. SCALE 1 INCH REPS. SQUPT
  3ARED UNITS) 1,XNOTE = 64H NOTE TRUE SHOT-RECEIVER DISTANCE 1TP
  4 THE NO. OF UNITS 1 TP
  10 FORMAT(8A8) TP 14
  20 FORMAT(2A8) TP 15
  30 FORMAT(7A8) TP 16
  40 FORMAT(4A8) TP 17
  50 FORMAT(3A8) TP 18
  60 FORMAT(5,1) TP 19
  70 FORMAT(4,1) TP 20
  80 FORMAT(5,0) TP 21
  90 FORMAT(42) TP 22
  100 FORMAT(7,1) TP 23
  IF(NA,NE,1) GO TO 130 TP 24
C SET SCALES TP 25
  XSCALE = XS$OSCALE TP 26
  YSCALE = TS$OSCALE TP 27
  XMAX = 10. * XSCALE TP 28
  YMAX = 20. * YSCALE TP 29
  CALL PLOT(0,0,1) TP 30
  CALL PLOT(XSCALE,YSCALE,2) TP 31
C PRINT SURVEY AND TRAVERSE AND SCALE HEADINGS TP 32
  CALL PLOT(0,2,*YSCALE,3) TP 33
  ENCODE(64,10,3UF) SURVEY TP 34
  CALL TEXT(3UF,54,3) TP 35
  CALL PLOT(0,1.5*YSCALE,3) TP 36
  ENCODE(24,50,XTEXT) EXPDSPD TP 37
  CALL TEXT(XTEXT,24,3) TP 38
  CALL PLOT(4,0*XSCALE,1.5*YSCALE,3) TP 39
  ENCODE(16,20,3UF) TRAVERSE TP 40
  CALL TEXT(3UF,16,3) TP 41
  CALL PLOT(1,0*XSCALE,1.0*YSCALE,3) TP 42
  ENCODE(32,40,3UF) TSQXSQ TP 43
  CALL TEXT(3UF,32,3) TP 44
  CALL PLOT(1,0*XSCALE,0.5*YSCALE,3) TP 45
  ENCODE(64,10,3UF) TSQVERT TP 46
  CALL TEXT(3UF,64,2) TP 47
  CALL PLOT(5,35*XSCALE,0.5*YSCALE,3) TP 48
  ENCODE(4,70,3UF) YSCALE TP 49
  CALL TEXT(3UF,4,2) TP 50
  CALL PLOT(1,0*XSCALE,0,3) TP 51
  ENCODE(64,10,3UF) XSQHOR TP 52
  CALL TEXT(3UF,64,2) TP 53
  CALL PLOT(5,30*XSCALE,0,3) TP 54
  ENCODE(8,80,3UF) XSCALE TP 55
  CALL TEXT(3UF,8,2) TP 56
  CALL PLOT(1,0*XSCALE,-0.5*YSCALE,3) TP 57
  ENCODE(64,10,3UF) XNOTE TP 58
  CALL TEXT(3UF,64,2) TP 59
  CALL PLOT(6,5*XSCALE,-0.5*YSCALE,3) TP 60
  ENCODE(8,60,3UF) STNINT TP 61
  CALL TEXT(3UF,8,2) TP 62
  CALL PLOT(7,2*XSCALE,-0.5*YSCALE,3) TP 63
  ENCODE(12,90,XTEXT) UNITS TP 64
  CALL TEXT(XTEXT,2,2) TP 65
  CALL PLOT(10,3.0*YSCALE,3) TP 66
C PLOT AXES AND SCALES TP 67
  CALL PLOT(0,0,1) TP 68
  CALL PLOT(0,YMAX,4) TP 69
  NY = (YMAX/XSCALE) * 1 TP 70
  DO 130 M = 1,NY TP 71
  YY = FLOAT(NY-M) * 0.03 TP 72
  AY = (YY * 0.03)*YSCALE TP 73
  CALL PLOT(-0.48*XSCALE,YY*YSCALE,3) TP 74
  ENCODE(7,100,3UF) AY TP 75
  CALL TEXT(3UF,7,1) TP 76
  CALL PLOT(-0.02*XSCALE,AY,3) TP 77
  CALL TEXT(1H,-0,1) TP 78
  110 CONTINUE TP 79
  CALL PLOT(0,0,3) TP 80
  CALL PLOT(XMAX,0,4) TP 81
  DO 120 M = 1,11 TP 82
  XX = FLOAT(11-M) * 0.17 TP 83
  AX = (XX * 0.17)*XSCALE TP 84
  CALL PLOT(XX*XSCALE,-0.3*YSCALE,3) TP 85
  ENCODE(7,100,3UF) AX TP 86
  CALL TEXT(3UF,7,1) TP 87
  AX = AX - 0.01*XSCALE TP 88
  CALL PLOT(AX,-0.05*YSCALE,3) TP 89
  CALL TEXT(1H,0,1) TP 90
  120 CONTINUE TP 91
  CALL PLOT(0,0,3) TP 92
  130 CONTINUE TP 93
C PLOT INDIVIDUAL DATA POINTS TP 94
  DO 140 NX = 1,8 TP 95
  IF(NA,PQ,2-NX-1) GO TO 150 TP 96
  IF(NA,EQ,2-NX) GO TO 170 TP 97
  140 CONTINUE TP 98
  150 DO 160 I = 1,NPTS TP 99
  CALL PLOT(X(I),T(I),3) TP 100
  160 CALL TEXT(1H,0,3) TP 101
  GO TO 190 TP 102
  170 DO 180 I = 1,NPTS TP 103
  CALL PLOT(X(I),T(I),3) TP 104
  180 CALL TEXT(1H,0,2) TP 105
C PLOT LINE OF BEST FIT TP 106
  190 XSQMAX = X(NPTS) * XSCALE TP 107
  IF(XSQMAX,GT,XMAX) XSQMAX = XMAX TP 108
  TSQMAX = TINTER * XSQMAX * SLOPE TP 109
  CALL PLOT(XSQMAX,TSQMAX,3) TP 110
  CALL PLOT(0,TINTER,4) TP 111
  IF(NA,NE,NRFLNS) GO TO 200 TP 112
  TP = YMAX * 4.0 * YSCALE TP 113
  CALL PLOT(0,TP,3) TP 114
  200 CONTINUE TP 115
  RETURN TP 116
  END TP 117

```

INPUT DATA FOR GOSSES BLUFF SEISMIC SURVEY 1969

G6/8A (SE)

APPENDIX 2
LONG BLIND TEST AREA

GEOPHONE S & INTERVAL = 110FT

VALUES TABULATED ARE GEOPHONE STN. NO. (X(I),J=1,NPTS) AND TWO-WAY TIME (T(I),J=1,NPTS) FOR THE CORRESPONDING(I,J)

NOTE 1 THE TRUE SHOT-RECEIVER DISTANCE = X(I,J) * 110FT

2 THE TIMES T(I,J) HAVE BEEN AVERAGED FROM TIMES FROM BOTH SIDES OF THE SHOT

REFLECTION NO. 1 TNOUGHT = 1.315 NPTS = 30
1.000 2.000 3.000 4.000 5.000 6.000 7.000 8.000 9.000 10.000
13.000 16.000 20.000 24.000 28.000 32.000 36.000 40.000 45.000 50.000
56.000 62.000 68.000 74.000 76.000 80.000 83.000 86.000 90.000 93.000
1.315 1.315 1.315 1.316 1.316 1.317 1.317 1.318 1.318 1.319
1.321 1.322 1.325 1.327 1.333 1.339 1.344 1.350 1.357 1.359
1.391 1.397 1.412 1.430 1.437 1.449 1.460 1.472 1.488 1.499

REFLECTION NO. 2 TNOUGHT = 1.668 NPTS = 30
1.000 2.000 3.000 4.000 5.000 6.000 7.000 8.000 9.000 10.000
19.000 28.000 37.000 46.000 55.000 64.000 73.000 82.000 91.000 98.000
50.000 100.000 109.000 118.000 127.000 136.000 145.000 154.000 163.000 172.000
1.670 1.669 1.667 1.667 1.664 1.664 1.666 1.668 1.669 1.668
1.672 1.683 1.685 1.705 1.717 1.737 1.766 1.780 1.809 1.837
1.713 1.841 1.728 1.954 1.743 1.865 1.781 1.872 1.800 1.880

REFLECTION NO. 3 TNOUGHT = 1.878 NPTS = 30
1.000 2.000 3.000 4.000 5.000 6.000 7.000 8.000 9.000 10.000
19.000 28.000 37.000 46.000 55.000 64.000 73.000 82.000 91.000 98.000
50.000 100.000 109.000 118.000 127.000 136.000 145.000 154.000 163.000 172.000
1.883 1.882 1.884 1.883 1.884 1.882 1.880 1.881 1.882 1.882
1.888 1.898 1.899 1.913 1.916 1.937 1.958 1.974 1.998 2.028
1.914 2.026 1.930 2.135 1.948 2.043 1.959 2.050 1.995 2.057

REFLECTION NO. 4 TNOUGHT = 2.380 NPTS = 30
1.000 2.000 3.000 4.000 5.000 6.000 7.000 8.000 9.000 10.000
19.000 28.000 37.000 46.000 55.000 64.000 73.000 82.000 91.000 98.000
50.000 100.000 109.000 118.000 127.000 136.000 145.000 154.000 163.000 172.000
2.380 2.380 2.380 2.380 2.381 2.381 2.381 2.382 2.382 2.382
2.382 2.385 2.391 2.400 2.409 2.420 2.438 2.451 2.468 2.476
2.403 2.484 2.415 2.487 2.427 2.495 2.444 2.497 2.459 2.502

REFLECTION NO. 5 TNOUGHT = 2.635 NPTS = 30
1.000 2.000 3.000 4.000 5.000 6.000 7.000 8.000 9.000 10.000
19.000 28.000 37.000 46.000 55.000 64.000 73.000 82.000 91.000 98.000
50.000 100.000 109.000 118.000 127.000 136.000 145.000 154.000 163.000 172.000
2.640 2.638 2.636 2.635 2.634 2.634 2.633 2.639 2.636 2.635
2.637 2.637 2.645 2.653 2.664 2.672 2.686 2.695 2.716 2.732
2.657 2.730 2.670 2.735 2.680 2.741 2.693 2.742 2.711 2.745

REFLECTION NO. 6 TNOUGHT = 2.990 NPTS = 30
1.000 2.000 3.000 4.000 5.000 6.000 7.000 8.000 9.000 10.000
19.000 28.000 37.000 46.000 55.000 64.000 73.000 82.000 91.000 98.000
50.000 100.000 109.000 118.000 127.000 136.000 145.000 154.000 163.000 172.000
2.990 2.990 2.990 2.990 2.990 2.990 2.990 2.991 2.991 2.992
2.992 2.993 2.997 3.000 3.007 3.020 3.030 3.043 3.058 3.089
3.004 3.070 3.012 3.075 3.039 3.080 3.037 3.088 3.058 3.087

GOSSES BLUFF SEISMIC SURVEY 1969

EXPANDED SPREAD G9/8A (SE)

TSQ XSQ RESULTS ASSUMING 2 STANDARD DEVIATIONS IN THE SLOPE AND INTERCEPTS.

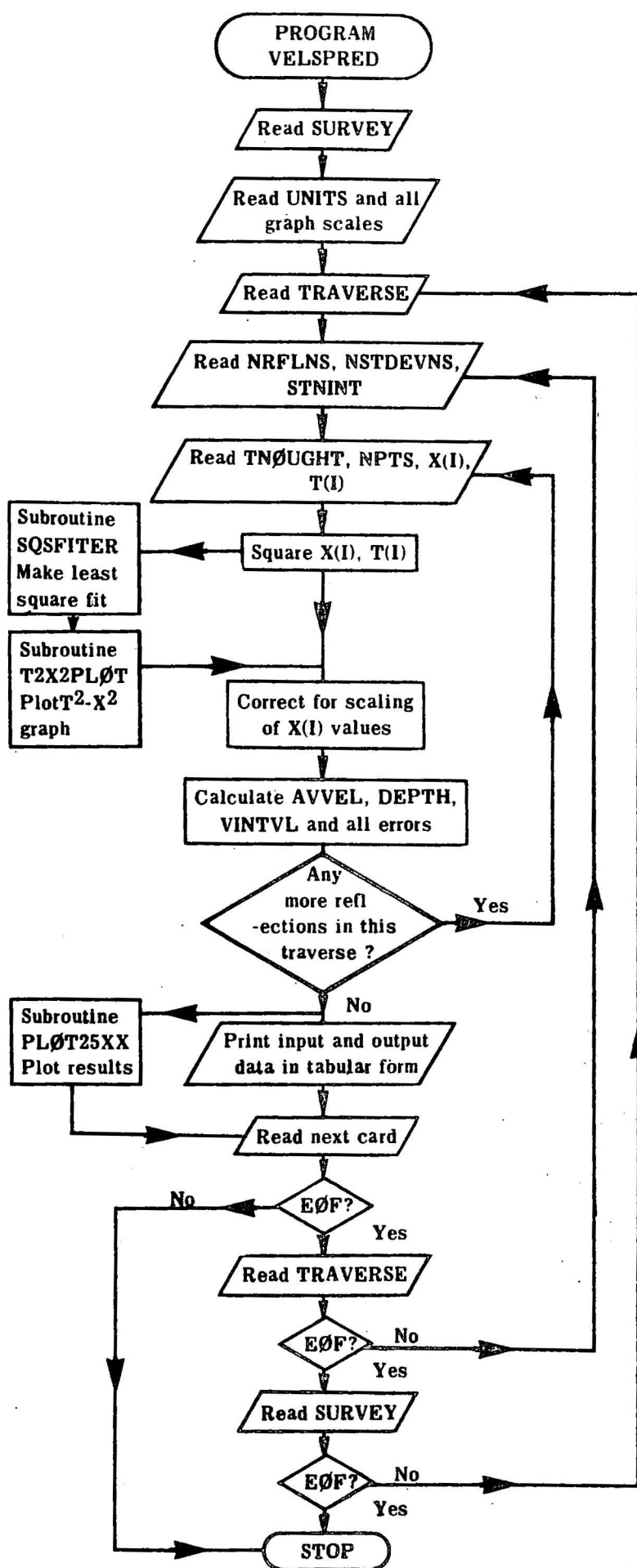
=====

REFLN NO. TWO-WAY TIME DEPTH TO REFLECTOR DEPTH AVERAGE VELOCITY MAXIMUM AV MINIMUM AV INTERVAL MAX. INT MIN. INT
\$ (SECS.) \$ (FT.) \$ (FT.) \$ (FT/SEC) \$ (FT/SEC) \$ (FT/SEC) \$ (FT/SEC) \$ (FT/SEC) \$ (FT/SEC)

=====

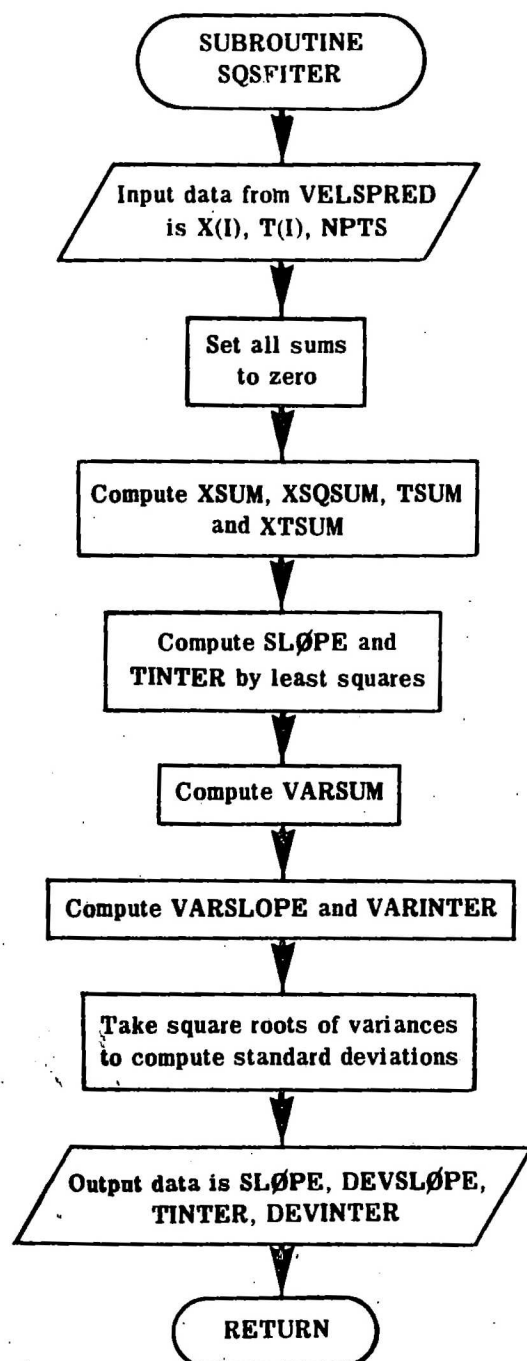
1	1.315	9450	41	14369	14440	14299	14369	14440	14299
2	1.668	11504	101	13821	13960	13682	11776	12696	10857
3	1.878	13593	173	14461	14665	14258	19550	22474	16627
4	2.380	18331	141	15409	15534	15284	18956	20310	17601
5	2.635	20099	235	15259	15445	15072	13854	16749	10759
6	2.990	23138	345	15489	15727	15250	17194	20586	13802

=====



UNITS: Metres, kilometres or feet
 SURVEY: Survey name and year
 TRAVERSE: Velocity probe name and details
 NRFLNS: The number of reflections analyzed in the probe
 NSTDEVNS: The number of standard deviations taken as an estimate of error
 STNINT: Geophone station interval or P-wave velocity in sea-water
 TNØUGHT: Two-way reflection time at the centre of the expanded spread or at shot-point
 NPTS: The number of data points for that particular reflection
 X(I): Geophone station number or direct water-wave arrival time
 T(I): Corresponding reflected wave arrival time
 AVVEL: Average velocity
 VINTVL: Interval velocity
 EOF: (End of file card)

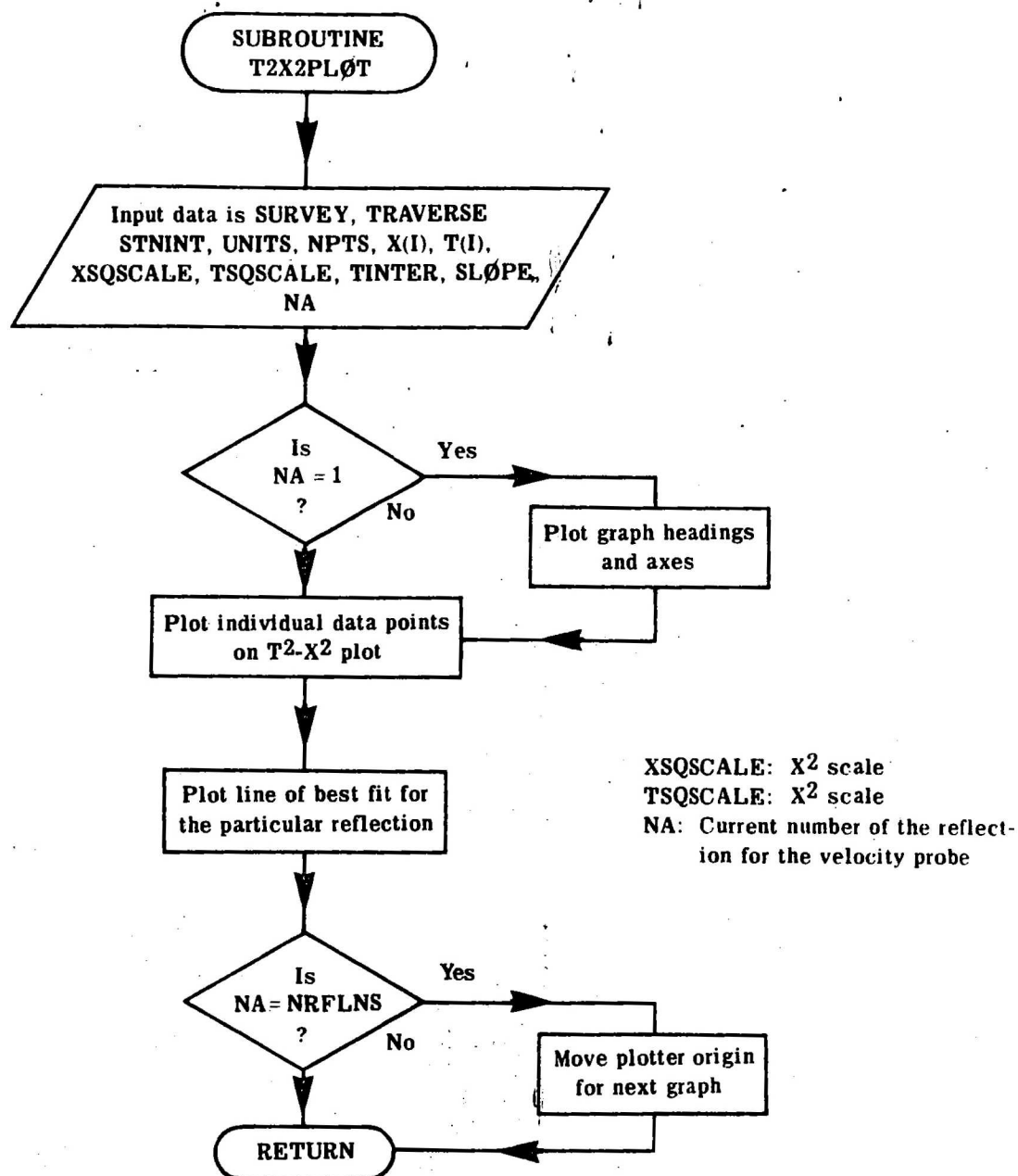
FLOW DIAGRAM
 PROGRAM VELSPRED



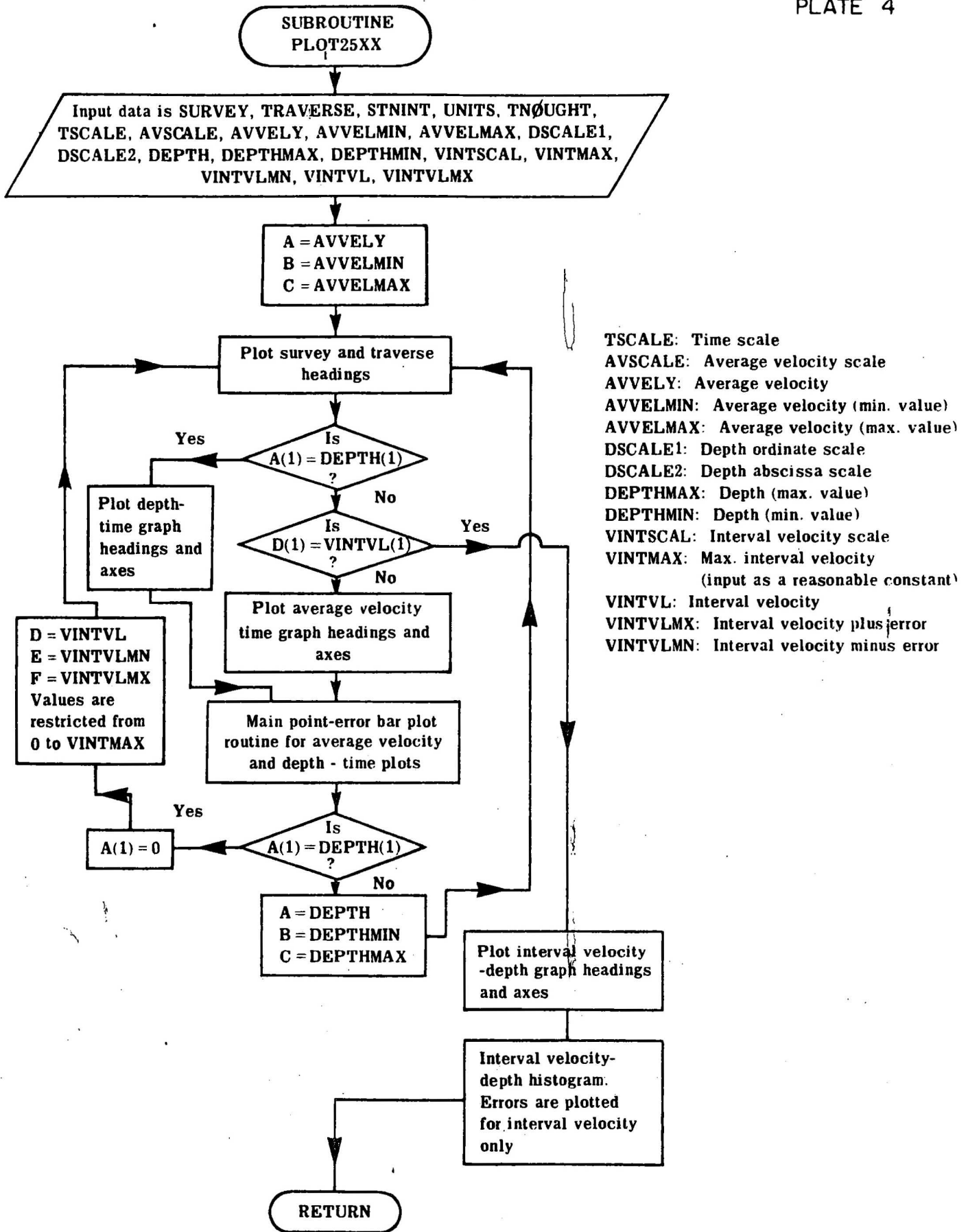
XSUM: Sum of $X^2(I)$
 TSUM: Sum of $T^2(I)$
 XSQSUM: Sum of $X^4(I)$
 XTSUM: Sum of $X^2(I) \cdot T^2(I)$
 SLOPE: Slope of plot
 TINTER: Intercept of plot
 VARSUM: Variance of least squares fit
 VARSLOPE: Variance of slope
 VARINTER: Variance of intercept
 DEVSLOPE: Standard deviation of the slope
 DEVINTER: Standard deviation of the intercept

FLOW DIAGRAM

SUBROUTINE SQSFITER

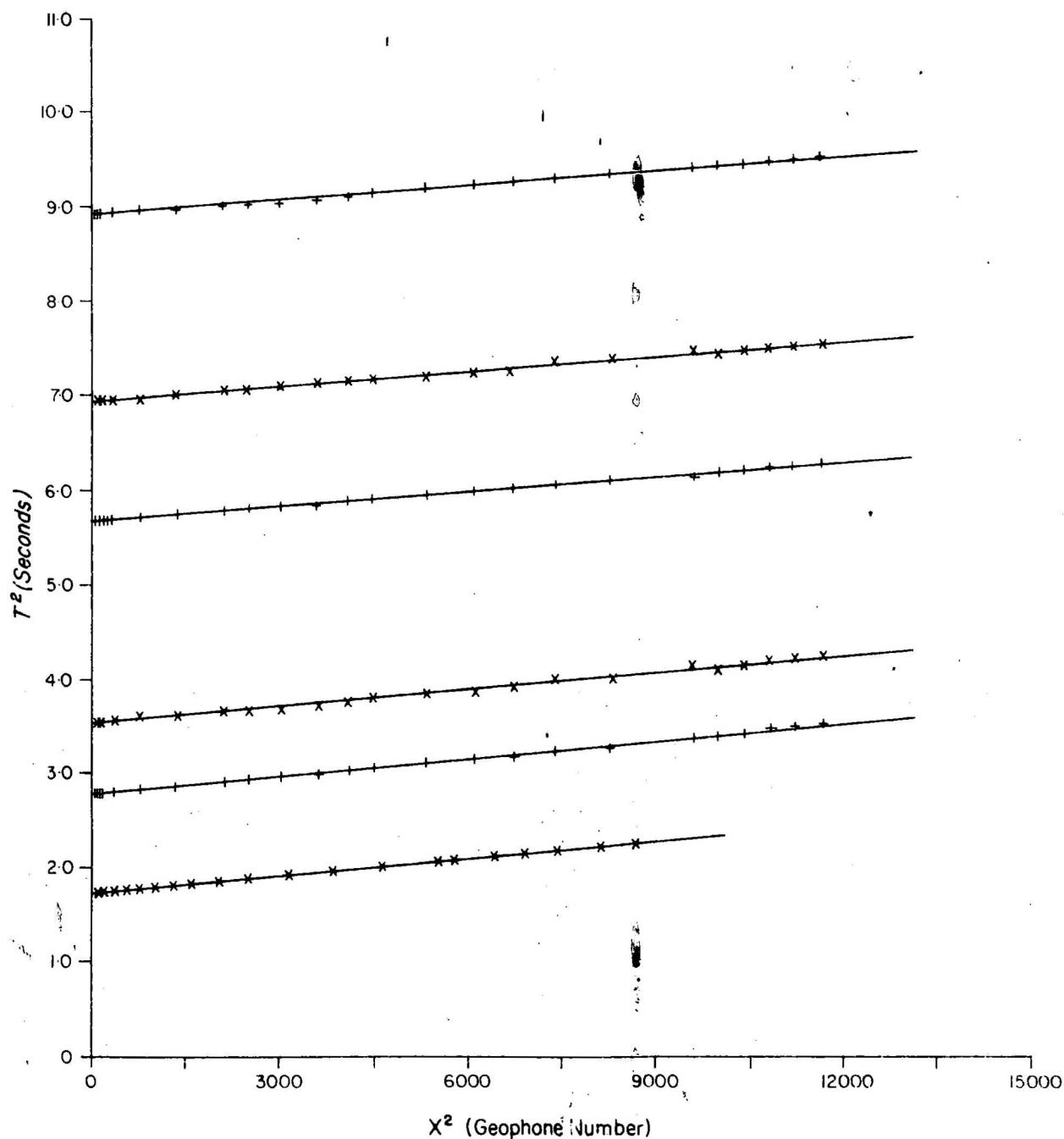


FLOW DIAGRAM
SUBROUTINE T2X2PLOT



FLOW DIAGRAM
SUBROUTINE PLOT25XX

NOTE: This is a $\frac{3}{5}$ reduction from the original computer printout.



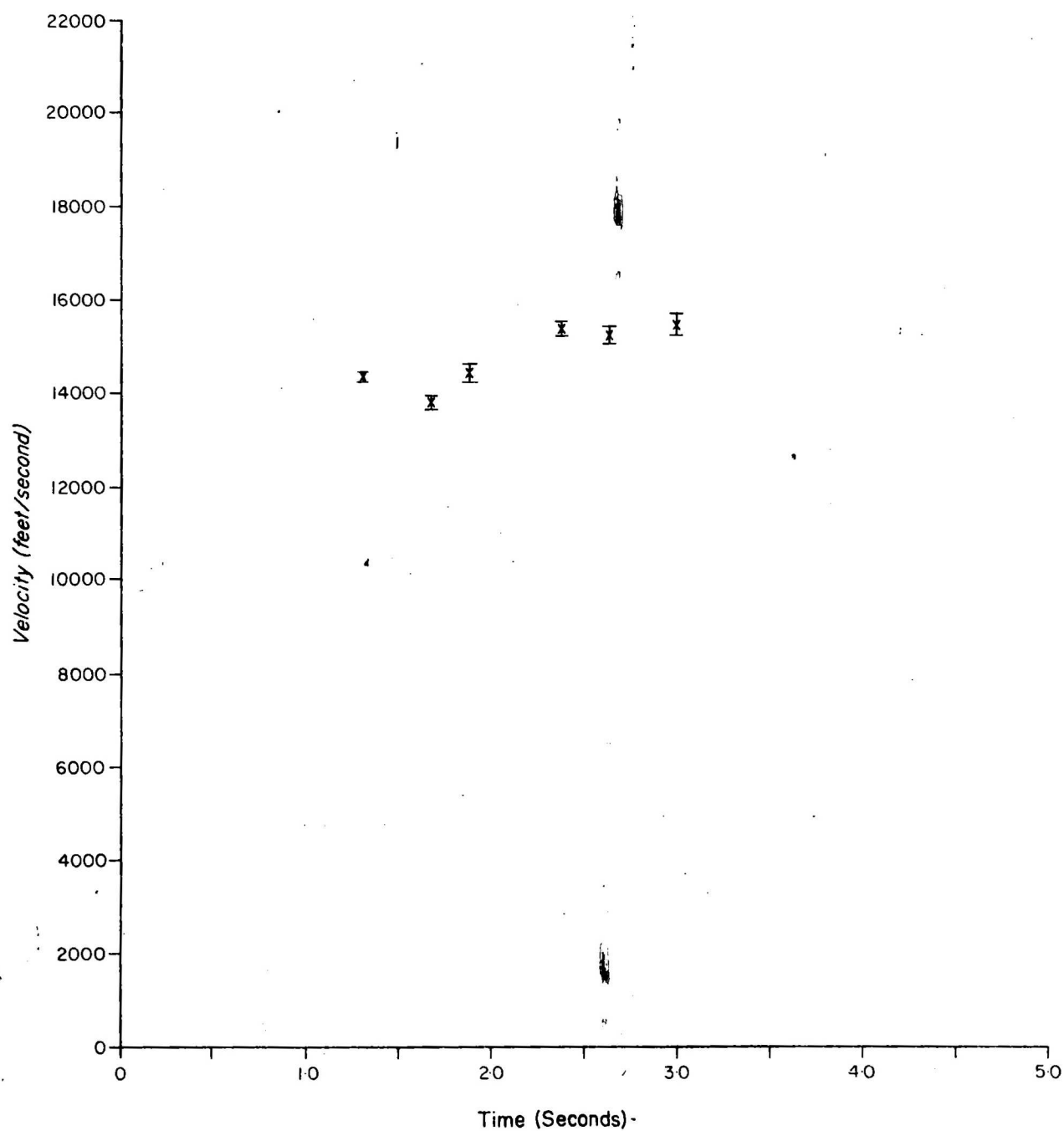
NOTE: True shot-receiver distance = Number of units x 110.0 feet

GOSSES BLUFF SEISMIC SURVEY 1969

EXPANDED SPREAD GB/BA (SE)

T SQUARED - X SQUARED PLOT

NOTE: This is a $\frac{3}{5}$ reduction from the original computer printout.

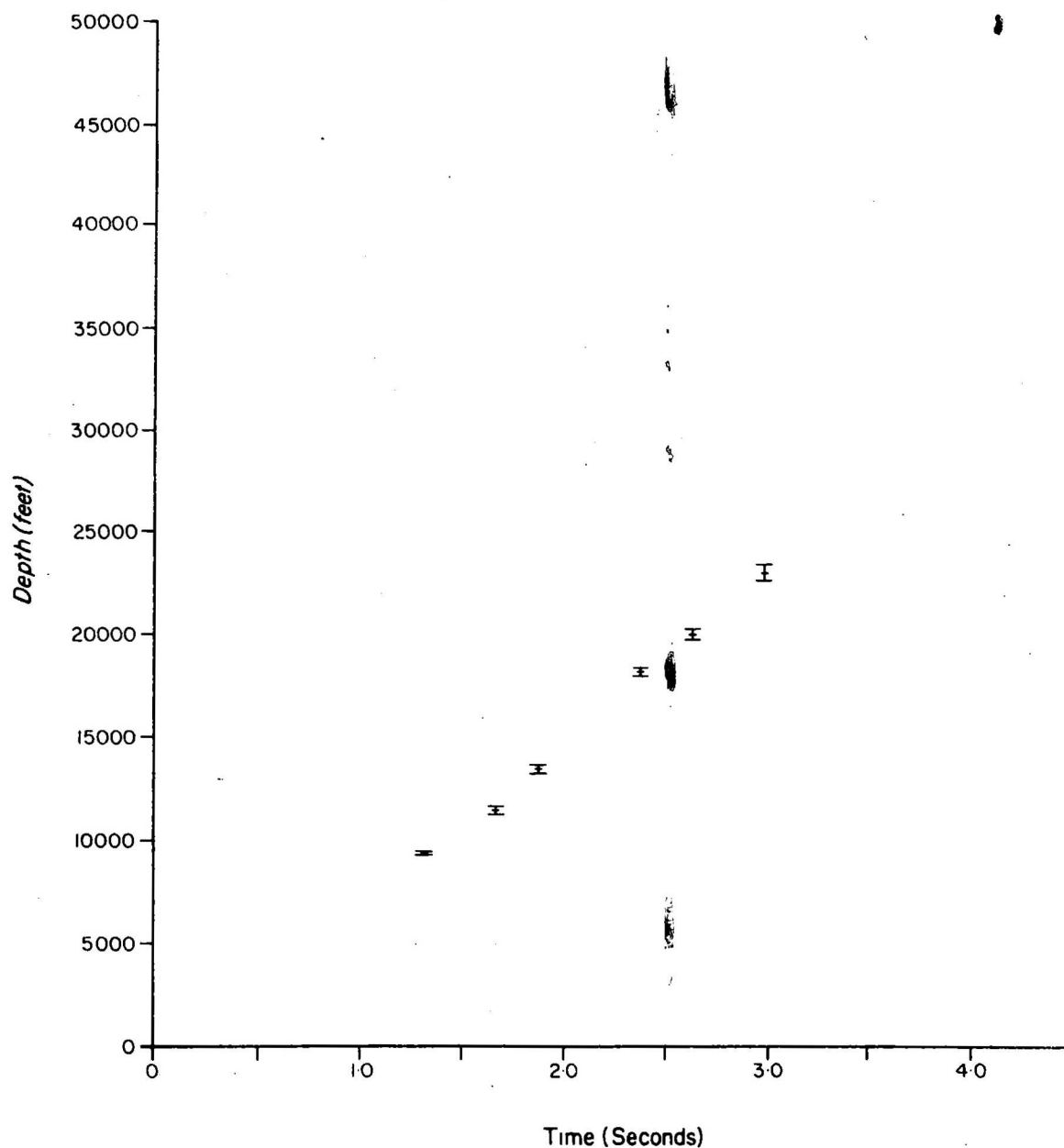


GOSSES BLUFF SEISMIC SURVEY 1969

EXPANDED SPREAD GB/BA (SE)

AVERAGE VELOCITY Vs. TWO-WAY TIME

NOTE: This is a $\frac{3}{5}$ reduction from the original computer printout.

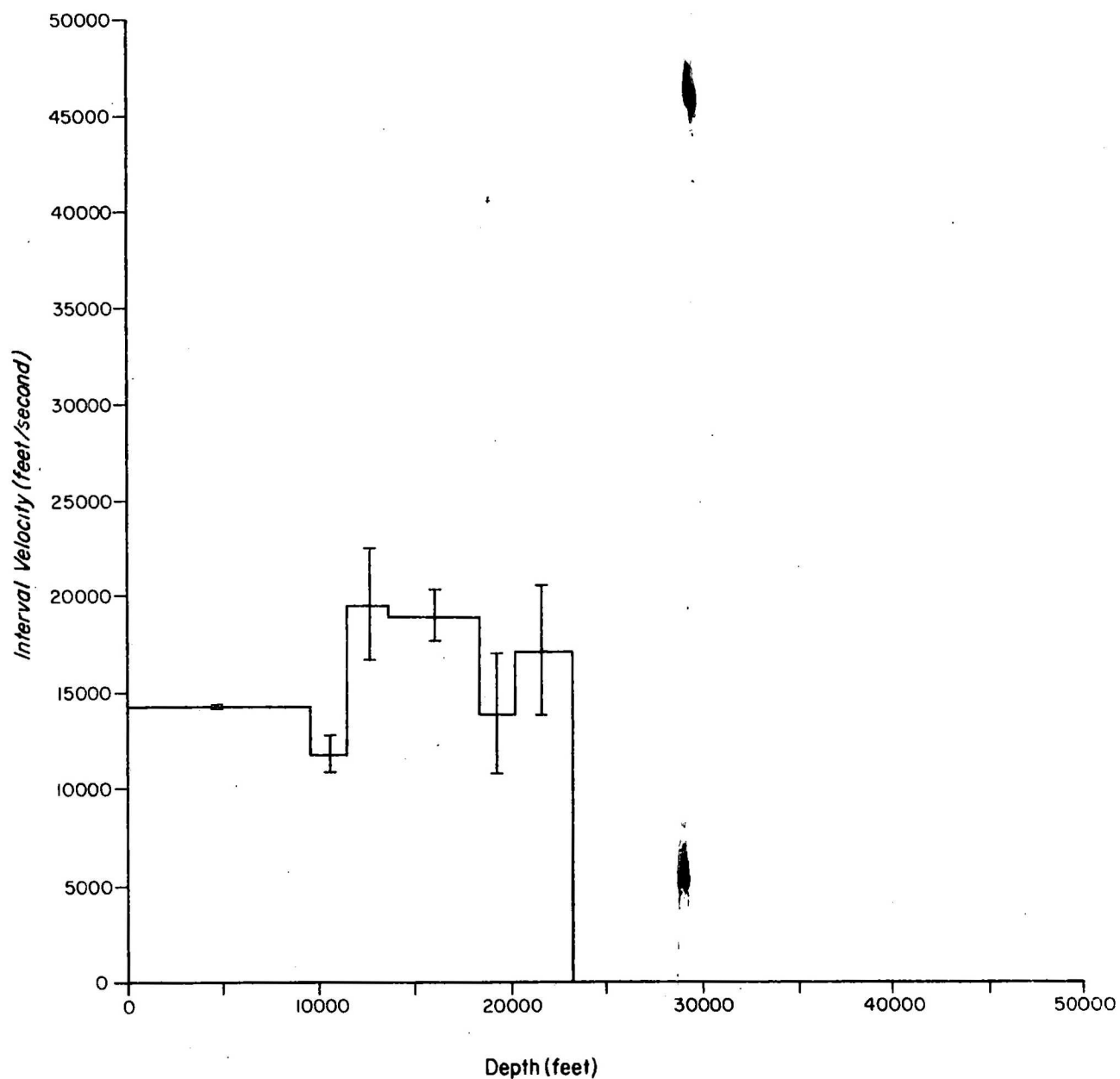


GOSSES BLUFF SEISMIC SURVEY 1969

EXPANDED SPREAD GB/BA (SE)

DEPTH Vs. TWO-WAY TIME

NOTE: This is a $\frac{3}{5}$ reduction from the original computer printout.



GOSSES BLUFF SEISMIC SURVEY 1969
EXPANDED SPREAD GB/BA (SE)

INTERVAL VELOCITY Vs. DEPTH