Seismic Lateral Studies

Velocity vs Azimuth and Depth

at WNRE No. 1

by

J.A. Mair and C.P. Lam

AECL Radioactive Waste Disposal Program

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Introduction

The propagation velocity of seismic compressional or shear energy depends on the elastic properties of the rock medium. The presence of cracks, even in extremely small fractional volumes, the state of fluid saturation and the permeability within the rock body exert a major effect on these properties. The in-situ measurement of these velocities and their directional variations may, therefore, be useful in qualifying rock bodies as to their potential for a radioactive waste disposal site.

A survey to determine seismic compressional velocity as a function of azimuth and depth was carried out at the Whiteshell Nuclear Research Establishment (WNRE) grounds, Pinawa, Manitoba in November, 1978.

Field Procedure

Fig. 1 shows the schematic layout of the test site. BH is the central borehole (WNRE - drill site No. 1). JY, KX, JW, SY, BW, CX, CY and NY are the shot locations, at various offset positions, around the borehole. Approximately 3 kg of 46% Forcite, detonated in augured holes of 1.2 m depth, provided the energy source for each shot. Recordings were obtained at 10 m intervals, using a string of twelve hydrophones (Mark Products P-27) lowered within the borehole. A total of three shots were detonated at each shot location and recorded by the hydrophone string at 29-127, 117-215 and 205-309 meter depth intervals within the borehole. The 10 m overlap allowed travel time checks between successive shots, reducing however the number of depth positions for recording from 36 to 32.

Table 1 lists the overburden thickness and overburden compressional (P) velocity below the eight shot locations. These values were provided by a surface refraction survey, performed in the same area, by the Geological Survey of Canada. Borehole direction was provided by the directional survey report from Sperry Sun. The coordinates of the hydrophone locations, within the non-vertical hole, were calculated relative to a three coordinate system with the top center of the borehole as the origin. Positive x direction runs from the borehole to the east, positive y to the south and positive z vertically downwards. Table 2 gives the coordinates of the 32 hydrophone locations while tables 3 to 10 give the x and y coordinates of each shot-point and the horizontal distances from the shot-point to each hydrophone.

Field measurement errors

Distance between the eight shot points and the borehole was measured to within ±0.5 m by AECL's survey crew. Surface topography is flat to within ±1m. The x, y and z coordinates of the hydrophone locations within the non-vertical hole have errors of ±.3 meter. Picking error of first events from the high speed (2 m/s) paper monitors, using a tangent method, is estimated to be ±.0005 sec.

The combined error, due to these parameters, is estimated to be less than .001 seconds in travel time, representing, for typical distances and velocities of this survey, an error in calculated velocity of about 1%.

Interpretation

1. The seismic traces recorded by the hydrophones over the 205-309 meter depth interval from a shot detonated at shot point CX are reproduced in the upper half of Figure 2. The first arrivals, marked P, are the direct compressional energy. The second event, marked S, is the interpreted shear wave arrival. The arrival time ratio of P and S is a constant 1.67, indicating an in-situ Poisson's ratio of 0.22 for the rock material traversed to these depths. Of the 24 shots recorded, the 12 trace segment of Fig. 2 is the only one showing a correlatable shear-wave phase.

2. The phase, marked W, is a dominant arrival on all recordings. The interpretation of this arrival is shown as an inset on Fig. 2 and can be briefly described as follows:

   The compressional wave, travelling within the rock body from shotpoint CX, over-pressures a water-filled shear zone, known from drill logs to exist at about 400 meters depth. The over-pressure is released, where the shear-zone intersects the drilled hole, with an origin time corresponding to the arrival of the compressional wave. This energy propagates upwards, as a "tube-wave", within the inclined, water-filled borehole, producing phase W. The propagation velocity of this phase is dependent on the compressional velocity of the fluid and the modulus of rigidity of the surrounding rock material. For the indicated depth interval this velocity is 1340 m/s. Event WR is the "tube-wave" after propagating downwards and reflecting from the bottom of the borehole.

The dominant high frequency component of the P first events is about 200 Hz, while that of the tube-wave is about 100 Hz. The thickness of the shear zone provides a line rather than a point source, contributing to the lower frequency of the highly correlatable, tube-wave transient.

3. The main thrust of the experiment was to determine seismic compressional velocity as a function of azimuth around the borehole at all depths. The results from the GSC vertical-velocity survey for the WNRE No. 1 bore-hole are shown in Fig. 3. It appears from this figure that a 3 layer earth section (Model No. 1) might be an appropriate simplification. Beneath a 20 meter thickness of low-velocity sediment a rock material having an average vertical velocity of 5.265 km/s is assumed to exist to a depth of 150m. Below this, a material with an average vertical velocity of 5.593 km/s is assumed. We allow these two lower layers to have a simple velocity anisotropy i.e. the velocity in any horizontal direction may be higher or lower than the velocity in the vertical direction. The contact at 150m is assumed to be horizontal. The upper, low velocity layer, is given the depths and velocities of Table 1 and is assumed to be isotropic in the immediate area of each shot point.

We define the velocity in any direction, Vs, in one of these anisotropic layers as;

$$Vs = Vx/A \qquad (1)$$

where $A = (k^2 \cos^2\theta + \sin^2\theta)^{1/2}$

θ is the angle from vertical of the ray path

$k = V_x/V_z$ the ratio of horizontal to vertical velocity

Snell's law of refraction at an interface is modified from the familiar form;

$$\frac{\sin\theta_1}{V_1} = \frac{\sin\theta_2}{V_2}$$

to;

$$\frac{\sin\theta_1}{Vx1.A_1} = \frac{\sin\theta_2}{Vx2.A_2} \qquad (2)$$

where $A_1 = (k_1^2 \cos^2\theta_1 + \sin^2\theta_1)^{1/2}$

$A_2 = (k_2^2 \cos^2\theta_2 + \sin^2\theta_2)^{1/2}$

An iterative, ray tracing procedure, developed from equations 1 and 2, has been employed to satisfy the measured travel times, horizontal distances and hydrophone depths and the assumed horizontal layering and vertical velocities of Model No. 1 (Fig. 2). Listings of these programs are given in Appendix A.

Figure 4 shows the calculated horizontal velocity, at 32 depths, obtained from shot-point JW. Figure 5 shows the value of "k" the ratio of these horizontal velocities to the vertical velocity of Model No. 1. The discontinuity at 150 m in Figure 5 has been caused by the assumed step in the vertical velocity for the model and this step is obviously not justified.

A simpler assumption, Model No. 2 of Figure 2 has, therefore, been employed i.e. a two layer model with the same low velocity layer but now overlying a uniform layer of 5.5 km/s, vertical velocity material. The "k" factor determined from this model is plotted in Figure 6 for shot-point JW. The discontinuity at 150m is avoided and Model No. 2 has been assumed for all the remaining calculations. For this simpler model plots of k factor vs depth become redundant and are not included as plots for this report. Figures 7 to 13, tables 11-18 give calculated horizontal velocities vs depth for the remaining seven shot points.

It is difficult to form any ideas as to velocity trends from these figures. A scatter of $\pm$.05 km/s is to be expected from the error analysis. The discontinuities occurring at about 120m and 200m depths must be ignored as they are due to slight mis-ties of the overlapping segments.

A series of plots of horizontal velocity vs. azimuth at, roughly, 30m depth intervals are shown in Figures 14 to 18. Figure 19 summarizes the gradual trend, from what appears to be a random scatter of velocity with azimuth, 5.4 $\pm$.05 km/s, at shallow depths to what may be a meaningful, anisotropic, distribution of velocity at depths greater than about 250m.

The sinusoidal function (Fig. 19), sketched upon the velocity vs. azimuth results at the 309.9 meter depth is;

$$V(\phi) = 5.45 - 0.09 \cos(\phi - 97) - 0.10 \cos 2(\phi - 38)$$

The form of this equation has been chosen for the following reasons:

1. Suppose there to be, within the crystalline rock body, a uniform trend of decreasing velocity at some azimuthal angle "a". This trend could be due, for example, to a series of plane, parallel, dipping beds in which velocity incrementally increases or, in the limit, a dipping layer in which velocity increases with depth, the layer or layers having been truncated, horizontally at the surface. It could, as well, be simply due to a decrease in the "quality" of the rock in direction "a", possibly indicating an increasing fracture density in that direction. Velocities measured at a given depth within the borehole, for raypaths travelling substantially horizontal paths from different directions should show a variation with azimuthal angle ϕ of approximately;

$$V(\varnothing) = Vo - A\cos(\varnothing - a)$$

where $V(\varnothing)$ - velocity at azimuthal angle $\varnothing$

Vo - average velocity

A - velocity variation amplitude

a - azimuthal angle of minimum velocity

2. A horizontal layer, having transverse, velocity anisotropy about a vertical axis, possibly due to past or present anisotropic stress and a resulting non-random foliation or crack pattern will exhibit a velocity variation with azimuthal angle $\varnothing$ of approximately;

$$V(\varnothing) = Vo - B\cos 2(\varnothing - b)$$

where B - velocity variation due to transverse anisotropy

b - azimuthal angle of minimum velocity

The combined form of these equations has five unknowns and we have only 8 data points at each depth, each of these with an estimated error of 1% or about $\pm$.05 km/s. In spite of these errors and the poor statistical sample a trend may be indicated by the calculated curve indicated in Figure 19.

The first velocity trend term indicates an amplitude variation of 0.09 km/s with the minimum direction to the east (97°) and a maximum to the west. The transverse anisotropy term indicates an amplitude variation of 0.1 km/s with the directions of minimum value to the northeast (38°) and southwest (218°). An anisotropy factor of about 4% is thus indicated which is certainly well within typical values for laboratory and field measurements of many crystalline rocks.

Discussion

For the shallow depths of this survey it may be more appropriate to assign the velocity variations to crack patterns rather than to rock formation or recrystallization under anisotropic, paleo-stress fields. A crack pattern, of course, results from stress relief, and, in general, the cracks will propagate in a direction, normal to the least compressive stress. The presence of cracks even in extremely small fractional volumes, can exert a major effect on the elastic properties and therefore, seismic velocities of a rock body. The state of fluid saturation and the permeability will also influence these properties. The dominant cause of energy dissipation, at seismic frequencies, within water-saturated, crystalline rocks, probably results from fluid flow along and between cracks (O'Connell and Budiansky, 1977). This mechanism should be most effective to a compressional wave-front advancing in-line with the long axis of a system of water filled cracks. Attenuation should be highest and seismic velocity lowest in this direction even though boundary stress conditions are hydrostatic. The same directional effect would be obtained if an initially random crack pattern, within a rock material, was altered by a presently active anisotropic stress field. Minimum velocities would be obtained in the direction of minimum stress, but, as before, the crack pattern, now altered in response to the stress, would have a long dimension also in this direction.

The variational velocity terms of the equation appear to be large enough to be significant relative to the estimated errors. If significant, they can only be assumed valid for a region within a radius of a few hundred meters around the borehole. A more regional interpretation would, of course, require an extended experiment. We speculate, however, that;

1. A crack pattern with a long dimension running NE-SW may exist at depths of 250-310m beneath the survey site at WNRE No. 1.

2. This direction may also be the direction of least compressive stress.

3. Rock "quality" may improve to the west of the drill hole, or alternatively, iso-velocity planes within the crystalline rock dip to the east.

Conclusions and Recommendations

1. The correlatable shear wave, evident in Figure 2, allows a calculation of in-situ Poisson's ratio for the rock material, traversed by seismic energy from shotpoint CX. The value of 0.22 for this ratio is not surprising although indicating rather competent material considering the shallow depth of the trajectory.

Far more interesting, would be a measure of the variation of this parameter, as a function of azimuth about the bore-hole, unfortunately denied us by the nature of the shot pulse. The dynamite blasts, act approximately as point sources of compressional energy with little generation of shear-wave energy and as stated previously, only one shot out of the 24 recorded produced a correlatable shear wave event. Horizontal shear waves (SH) can be produced by explosive charges, for example, by using three horizontal, linear charges. These are aligned in the direction of the borehole and the center one shot first. The charges on either side of the center are then detonated, separately, producing an increased amount of polarized shear energy due to the discontinuity of overburden properties created by the center shot. While quite possible at WNRE, Pinawa, where over burden might respond to a plow, it would be an impractical technique in areas of exposed crystalline rock. An alternative method, may be provided by repetitive, pulses from a suitable mechanical device with recordings "stacked" until a sufficient signal to noise ratio has been achieved. We have recommended a trial, for what may prove to be a suitable mechanical device, for an experiment at Chalk River, Ont. in the fall of 1979. The "Mini-Sosie" recording and field stacking capability may prove to be a suitable partner for this energy source.

2. The "tube wave" of Figure 2, originating from the shear zone at 400m is interesting as its velocity within the bore-hole should vary with the modulus of rigidity of the rock material in the immediate area surrounding the bore-hole. Other experiments, such as the vertical velocity surveys carried out by the G.S.C., have noted many such events and are better designed to analyze this waveform. It's efficient generation at certain points within the borehole may relate to rock permeability. We will be watching for it in subsequent surveys.

3. In the area of borehole WNRE No. 1, variations of compressional velocity as a function of azimuth and depth are apparent but are rather close to our estimated errors. A well organized fracture or foliation pattern or lateral change in rock type would be expected to produce significantly larger variations. This may prove to be true for other locations, certainly at Chalk River there appears to be a variation of 10-20% around borehole CR-1. It is suggested, therefore, that additional surveys of this type be funded for other locations of interest to the Radwaste Disposal Program. The technique will be much more valuable when shear waves can be generated and detected. Hole-to-hole ray path trajectories rather

than from surface-to-hole would probably be more diagnostic of rock properties, as the surface, low-velocity-layer would thus be eliminated from the calculations.

Reference

O'Connell, R.J. and Budiansky, B. Viscoelastic Properties of Fluid-Saturated Cracked Solids. Journal of Geophysical Research, 82, 1977, pp 5719-5735.

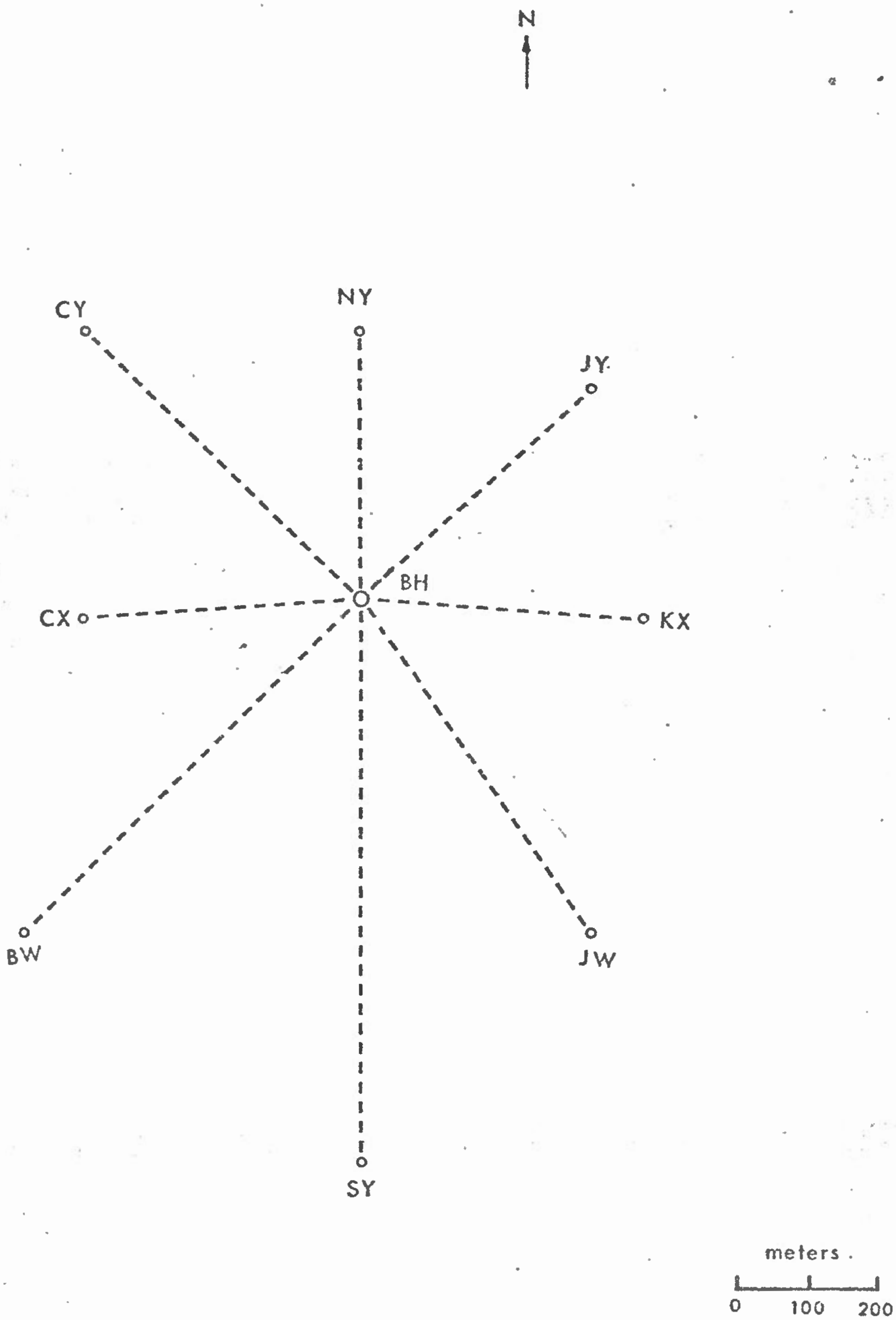


Fig. 1

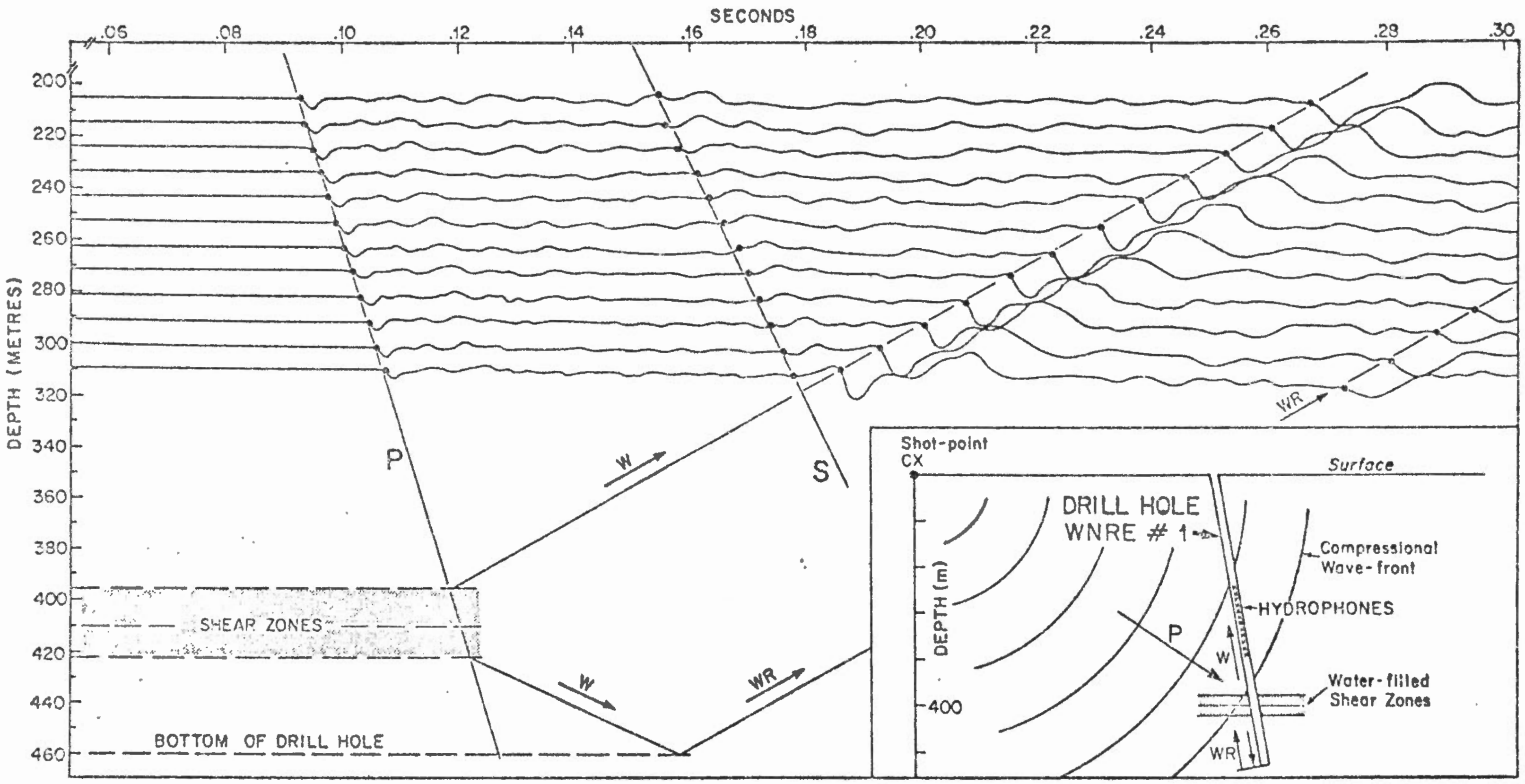
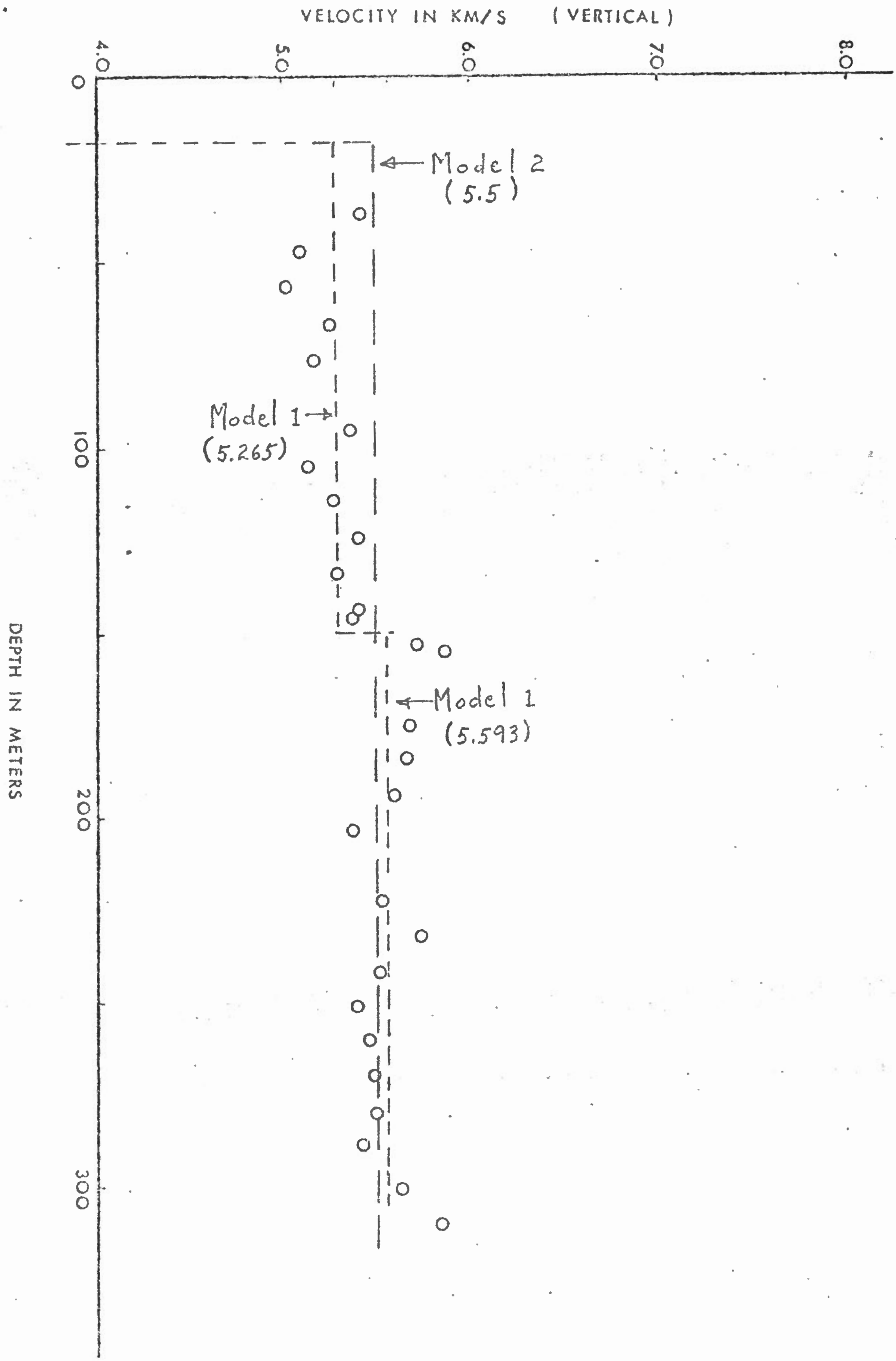

SECONDS
.05
.08
.10
.12
.14
.16
.18
.20
.22
.24
.26
.28
.30
DEPTH (METRES)
200
220
240
260
280
300
320
340
360
380
400
420
440
460
P
S
W
WR
SHEAR ZONES
BOTTOM OF DRILL HOLE
Shot-point
CX
Surface
DRILL HOLE
WNRE # 1
Compressional
Wave-front
HYDROPHONES
DEPTH (m)
400
Water-filled
Shear Zones

Figure 2



VELOCITY IN KM/S (VERTICAL)
4.0
5.0
6.0
7.0
8.0
0
100
200
300
DEPTH IN METERS
Model 2
(5.5)
Model 1
(5.265)
Model 1
(5.593)

Figure 3

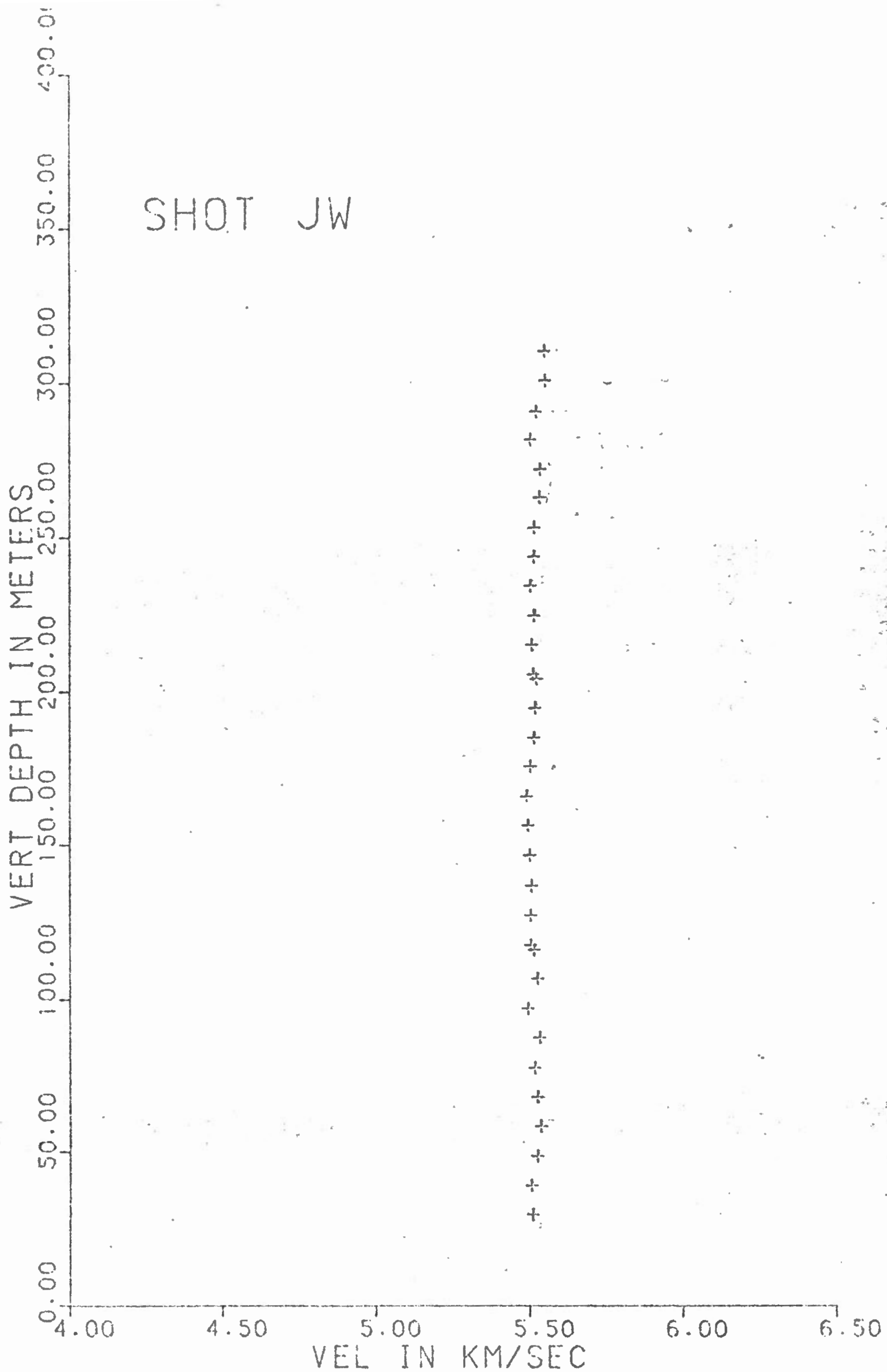

SHOT JW
VERT DEPTH IN METERS
VEL IN KM/SEC
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
4.00
4.50
5.00
5.50
6.00
6.50

Fig. 4

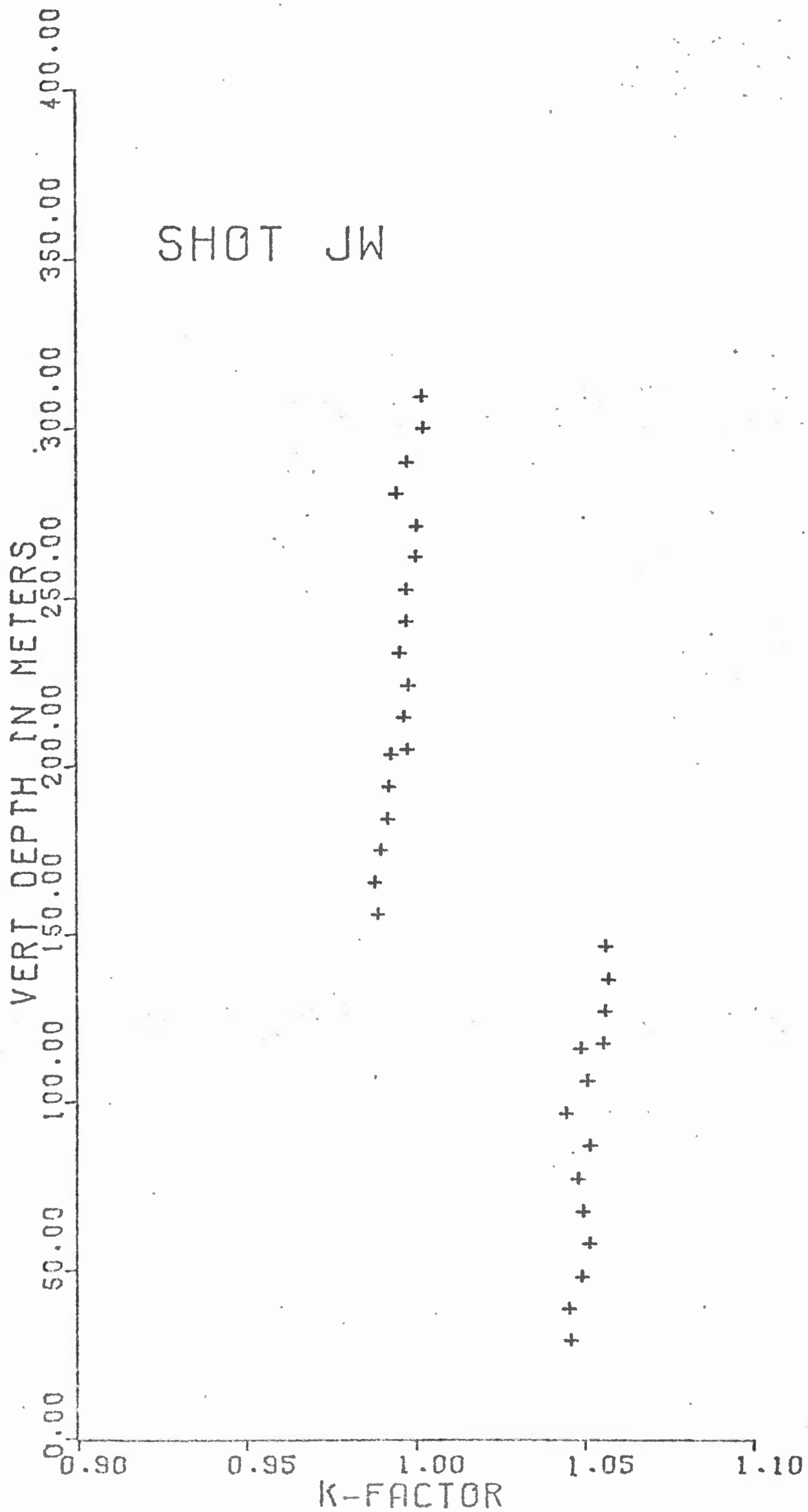
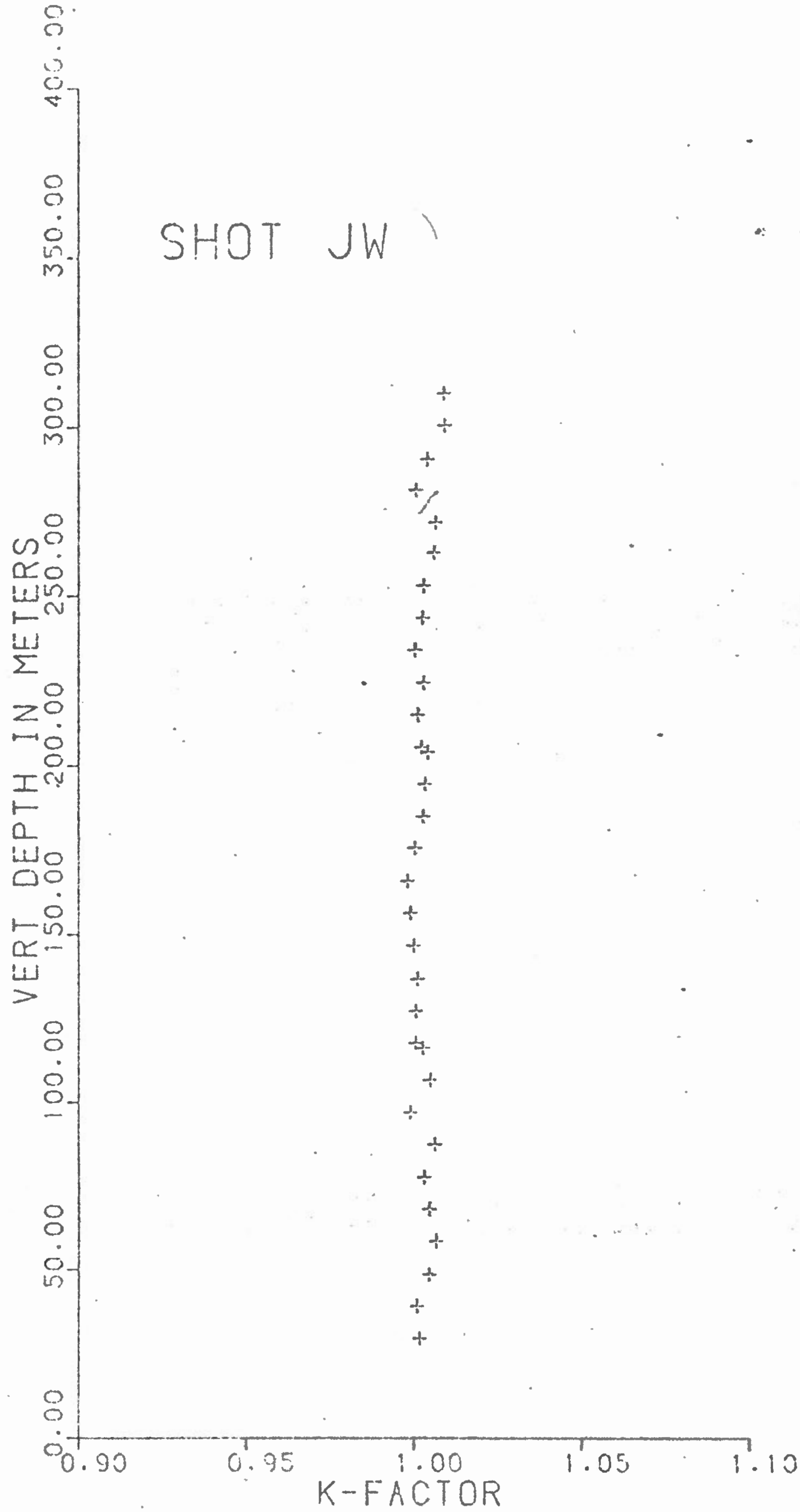

SHOT JW
VERT DEPTH IN METERS
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
0.90
0.95
1.00
1.05
1.10
K-FACTOR
(Model 1)

Fig. 5


SHOT JW
VERT DEPTH IN METERS
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
0.90
0.95
1.00
1.05
1.10
K-FACTOR

(Model 2)

Fig. 6

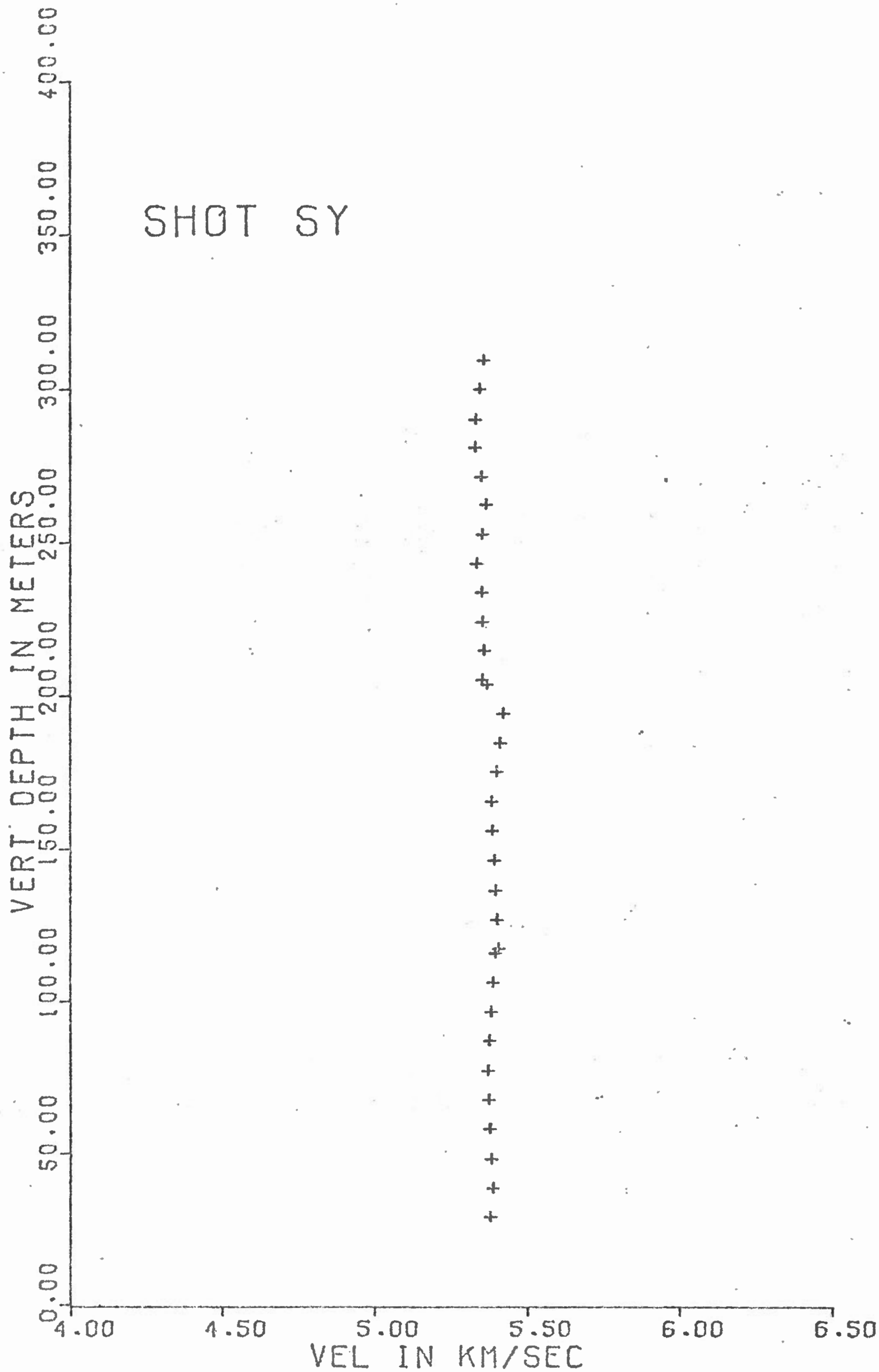

SHOT SY
VERT DEPTH IN METERS
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
4.00
4.50
5.00
5.50
6.00
6.50
VEL IN KM/SEC

Fig. 7

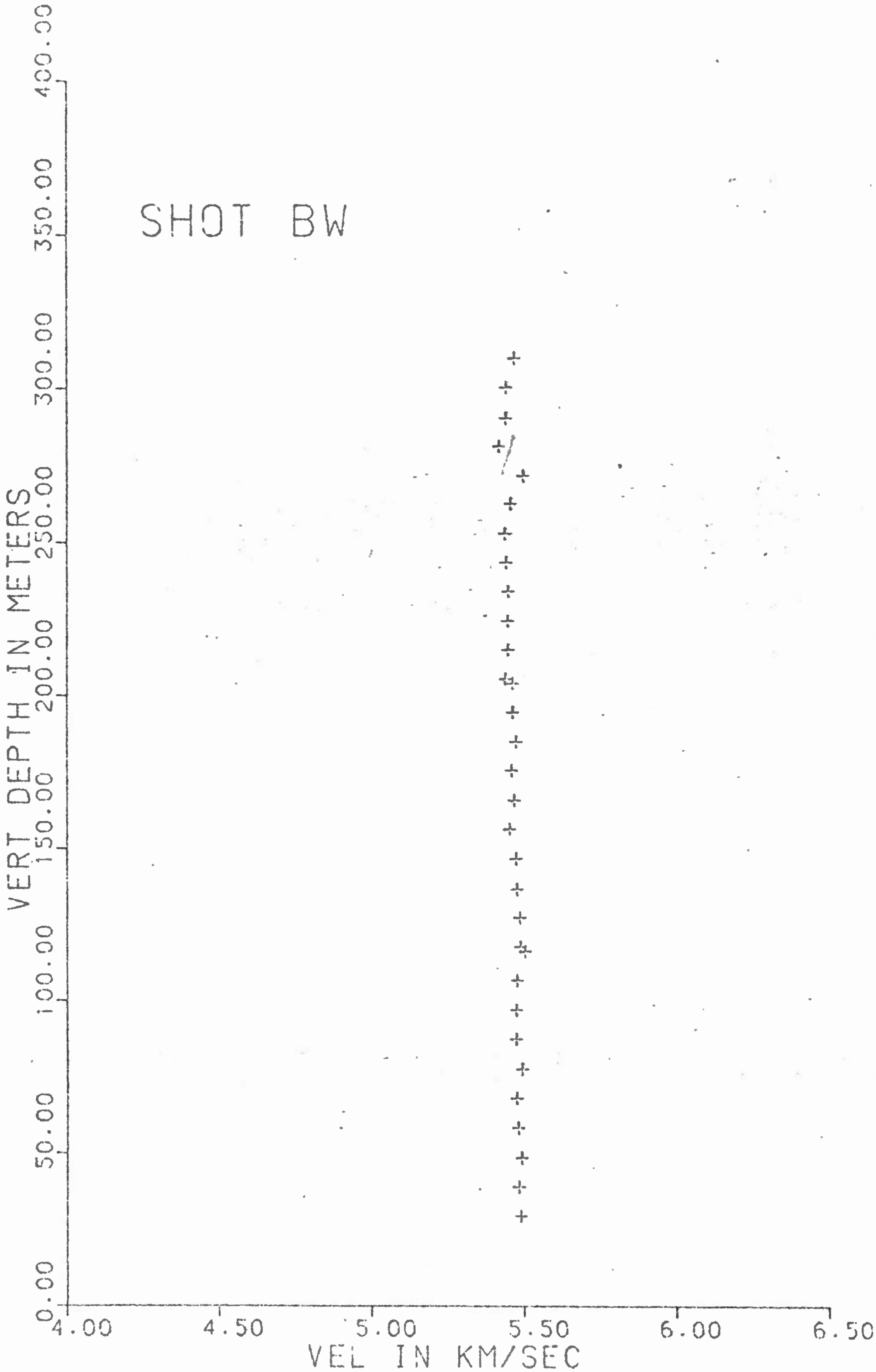
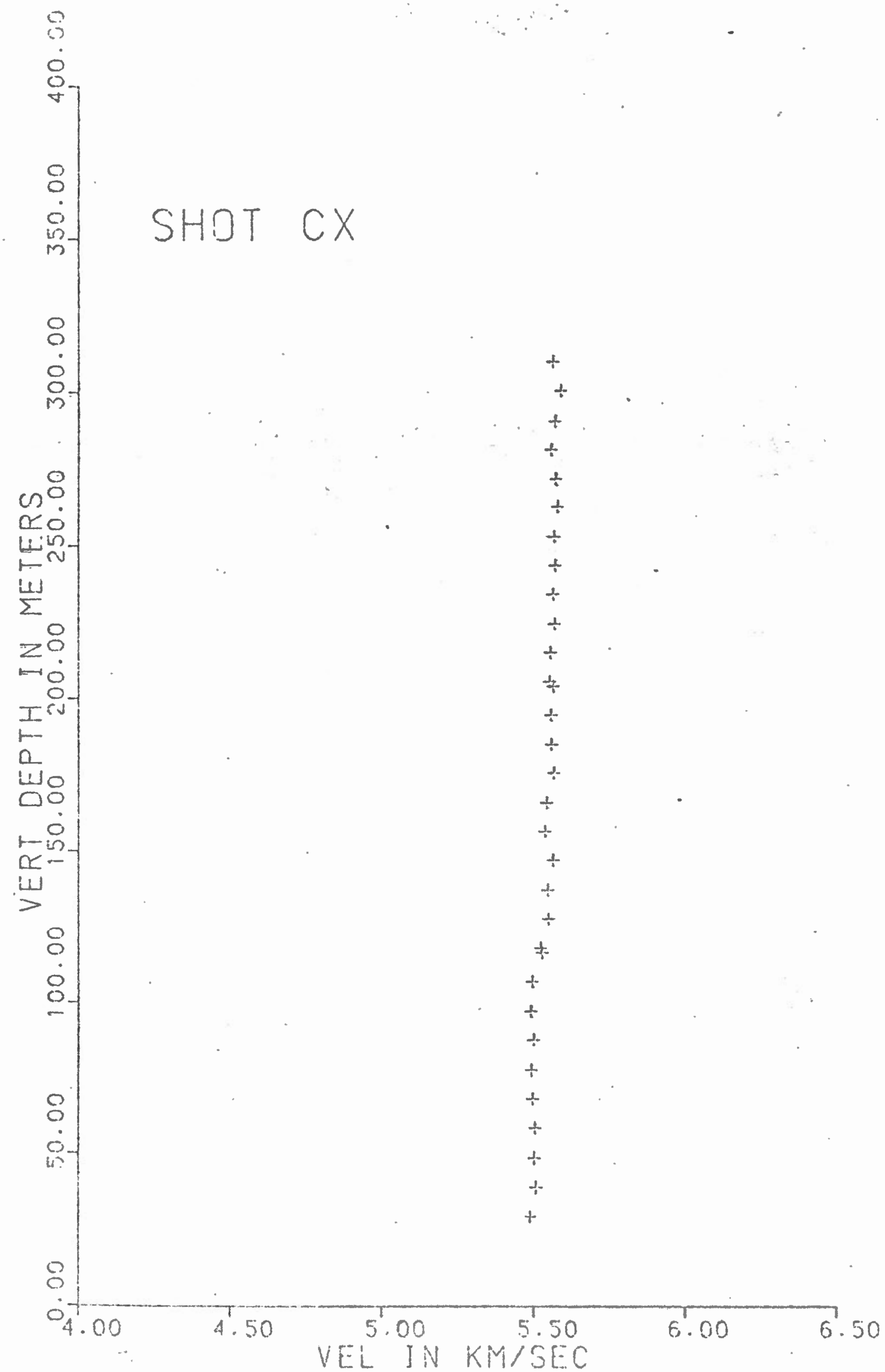

SHOT BW
VERT DEPTH IN METERS
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
4.00
4.50
5.00
5.50
6.00
6.50
VEL IN KM/SEC

Fig. 8



SHOT CX
VERT DEPTH IN METERS
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
4.00
4.50
5.00
5.50
6.00
6.50
VEL IN KM/SEC

Fig. 9

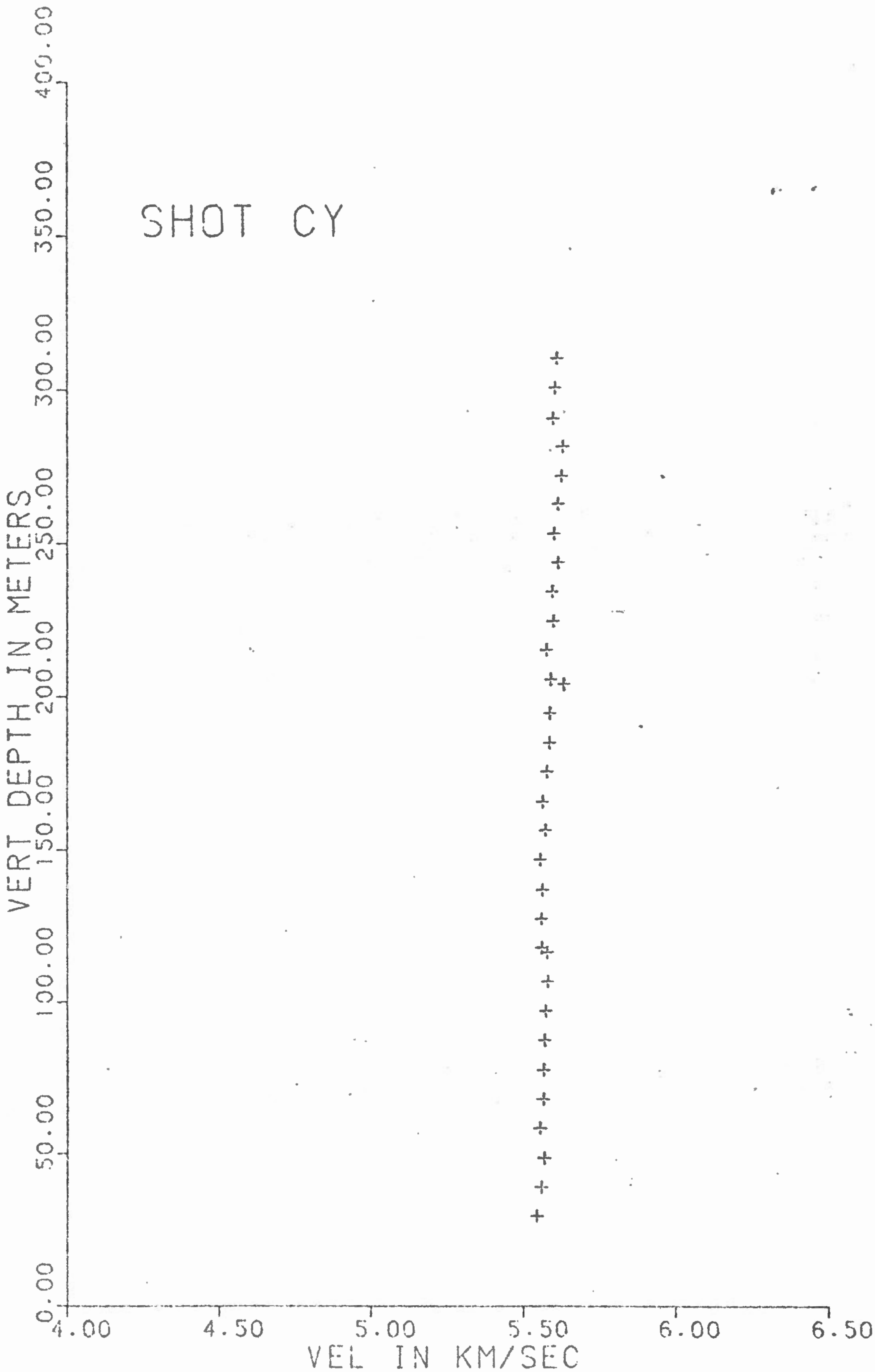

SHOT CY
VERT DEPTH IN METERS
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
4.00
4.50
5.00
5.50
6.00
6.50
VEL IN KM/SEC

Fig. 19

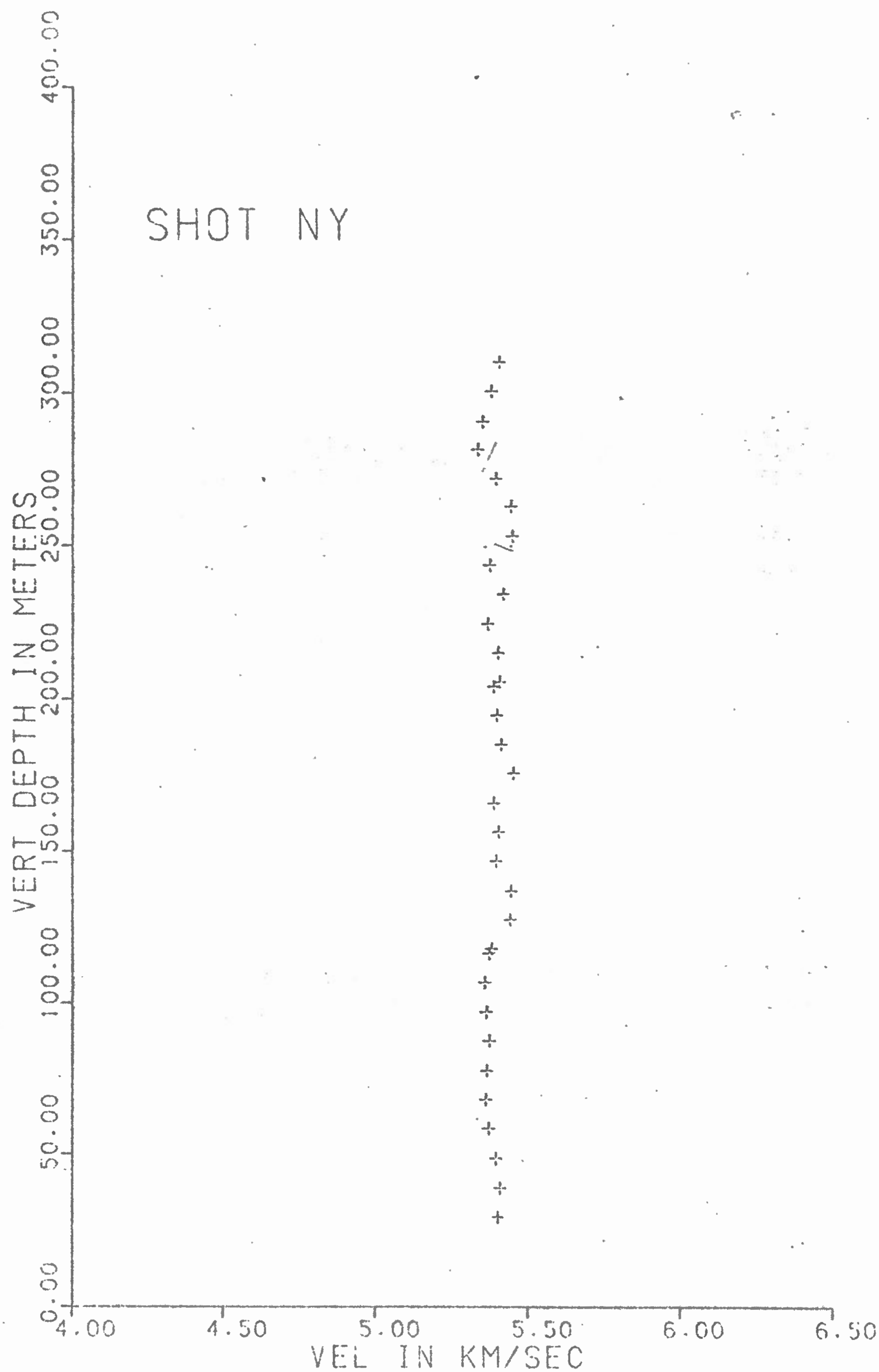

SHOT NY
VERT DEPTH IN METERS
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
4.00
4.50
5.00
5.50
6.00
6.50
VEL IN KM/SEC

Fig. 11

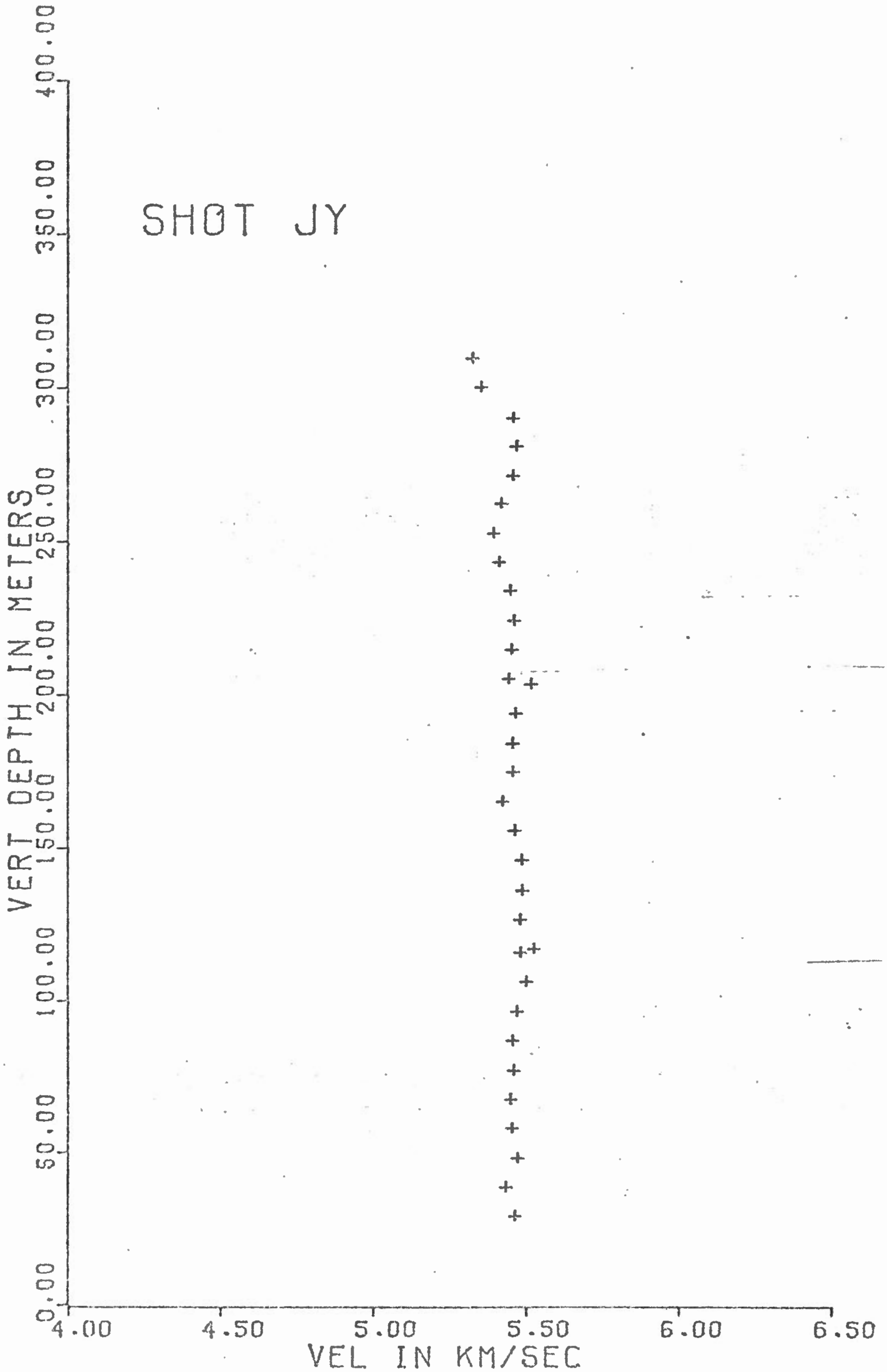
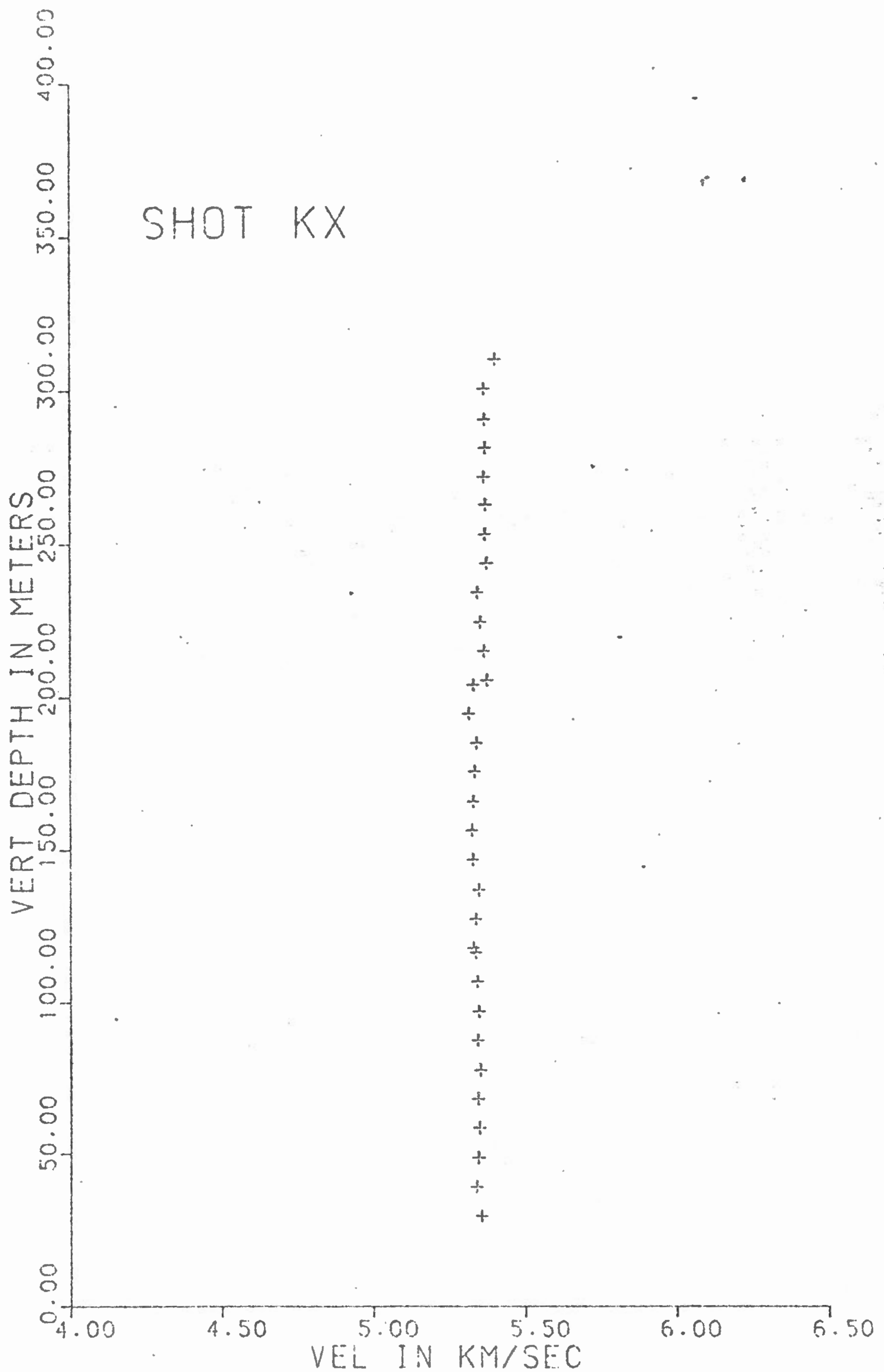
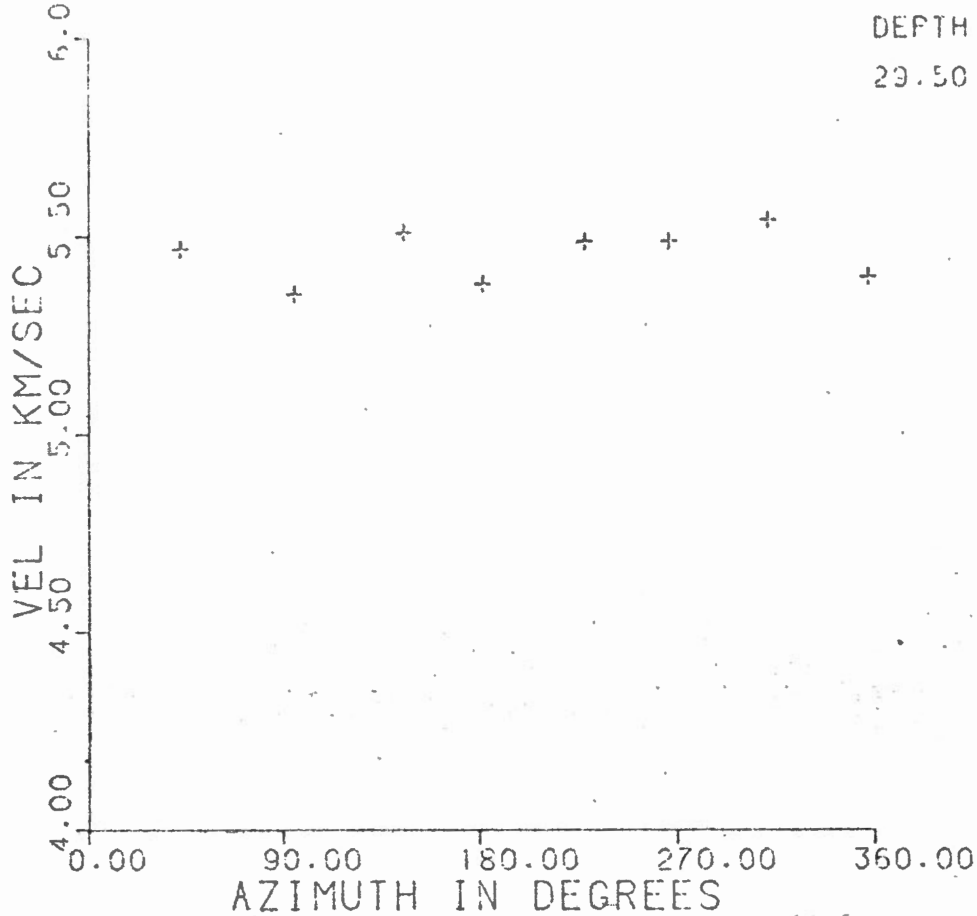

SHOT JY
VERT DEPTH IN METERS
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
4.00
4.50
5.00
5.50
6.00
6.50
VEL IN KM/SEC

Fig. 12



SHOT KX
VERT DEPTH IN METERS
0.00
50.00
100.00
150.00
200.00
250.00
300.00
350.00
400.00
4.00
4.50
5.00
5.50
6.00
6.50
VEL IN KM/SEC

Fig. 13


DEPTH
29.50
VEL IN KM/SEC
6.0
5.50
5.00
4.50
4.00
0.00
90.00
180.00
270.00
360.00
AZIMUTH IN DEGREES

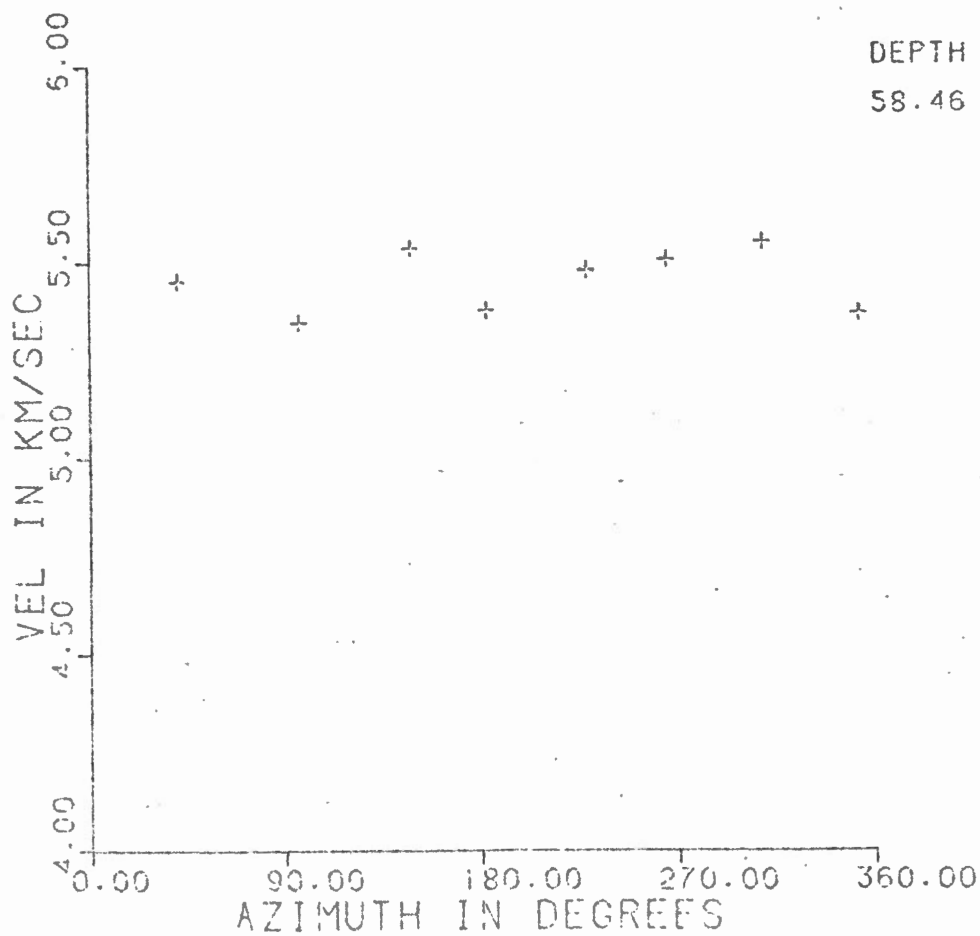
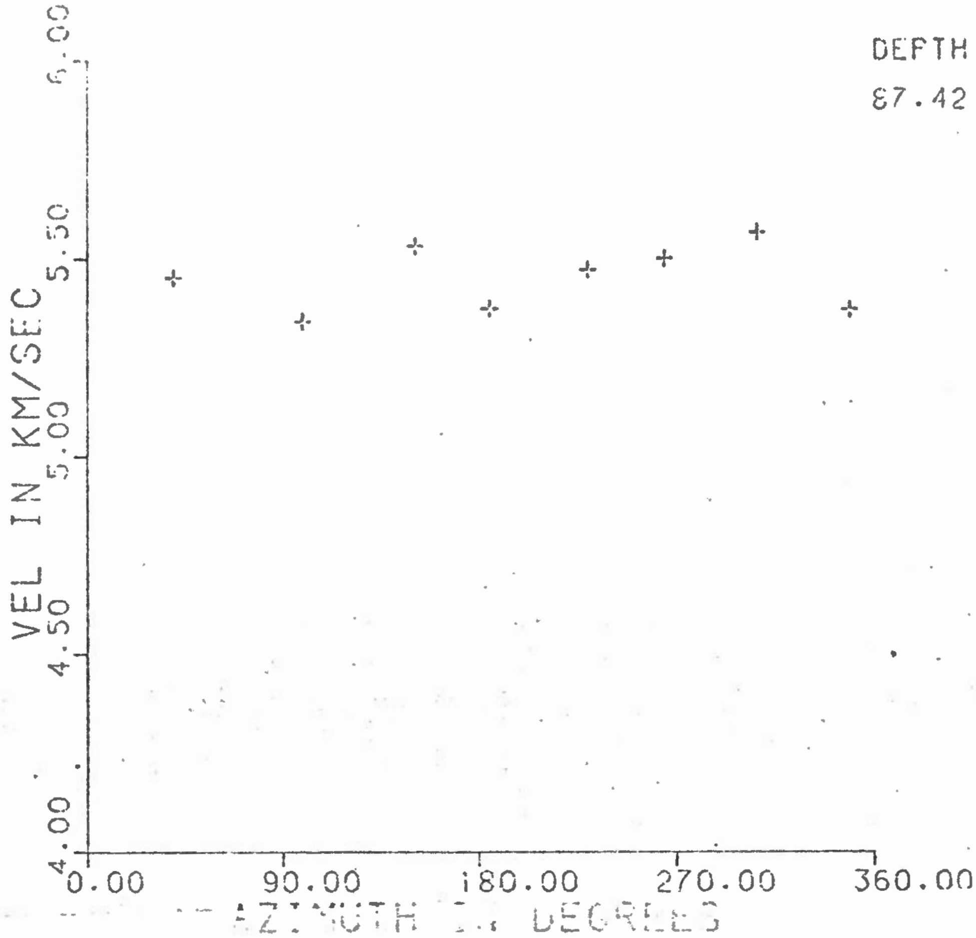

DEPTH
58.46
VEL IN KM/SEC
6.00
5.50
5.00
4.50
4.00
0.00
90.00
180.00
270.00
360.00
AZIMUTH IN DEGREES

Fig. 14


DEPTH
87.42
VEL IN KM/SEC
6.00
5.50
5.00
4.50
4.00
0.00
90.00
180.00
270.00
360.00
AZIMUTH IN DEGREES

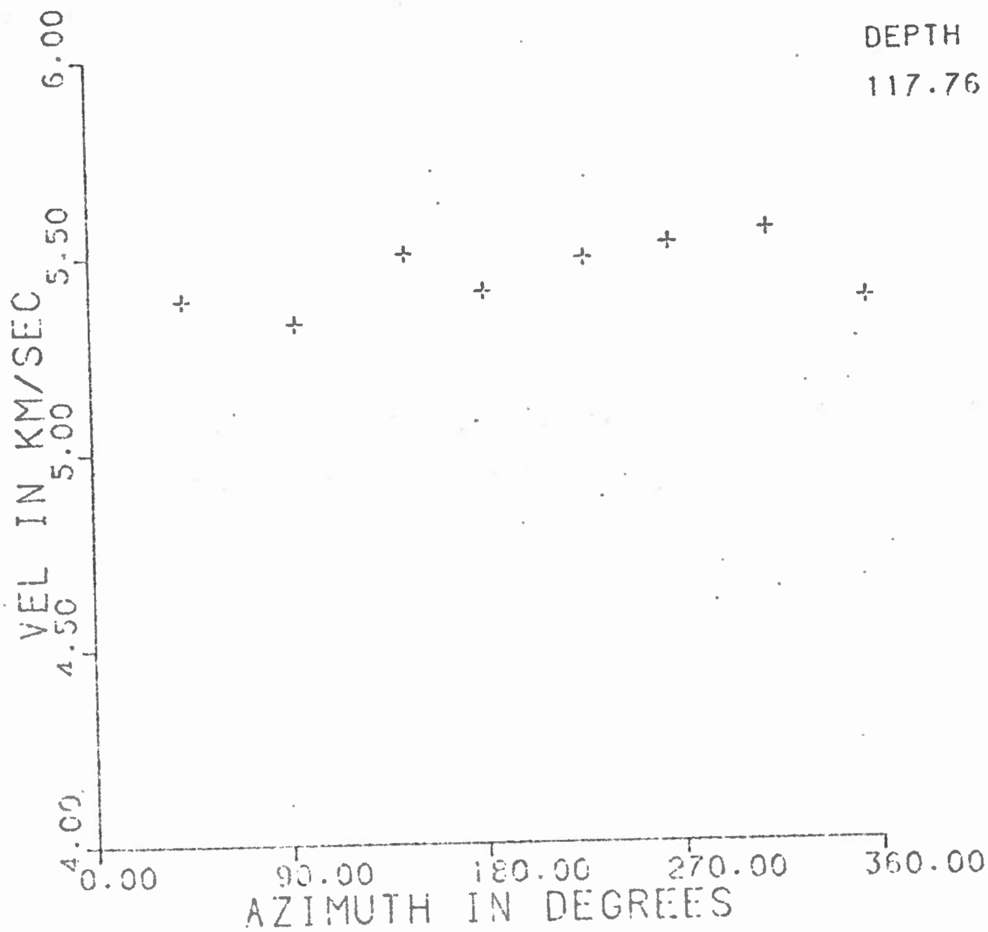

DEPTH
117.76
VEL IN KM/SEC
6.00
5.50
5.00
4.50
4.00
0.00
90.00
180.00
270.00
360.00
AZIMUTH IN DEGREES

Fig. 15

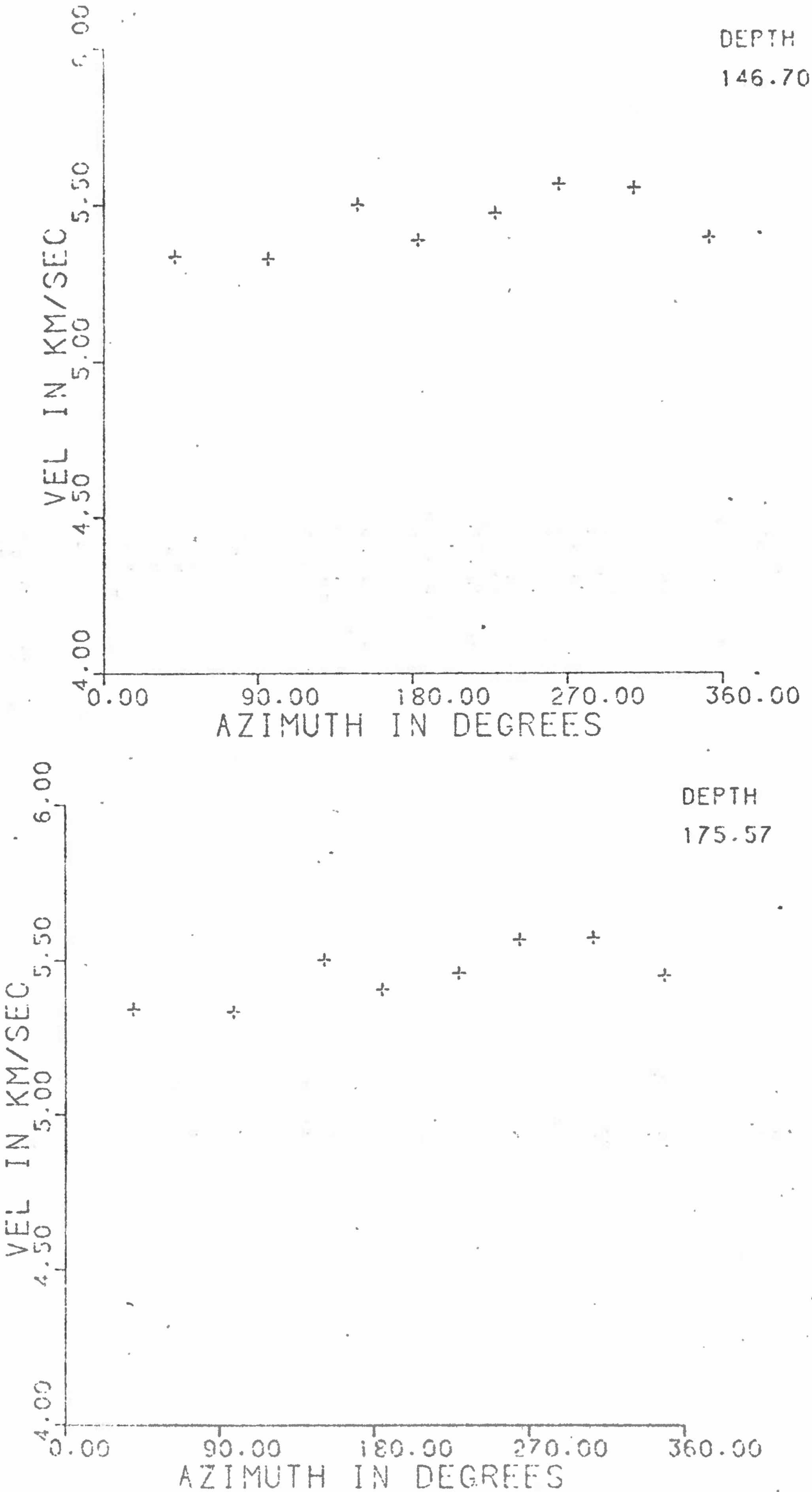

DEPTH
146.70
VEL IN KM/SEC
4.00
4.50
5.00
5.50
6.00
0.00
90.00
180.00
270.00
360.00
AZIMUTH IN DEGREES
DEPTH
175.57
VEL IN KM/SEC
4.00
4.50
5.00
5.50
6.00
0.00
90.00
180.00
270.00
360.00
AZIMUTH IN DEGREES

Fig. 16

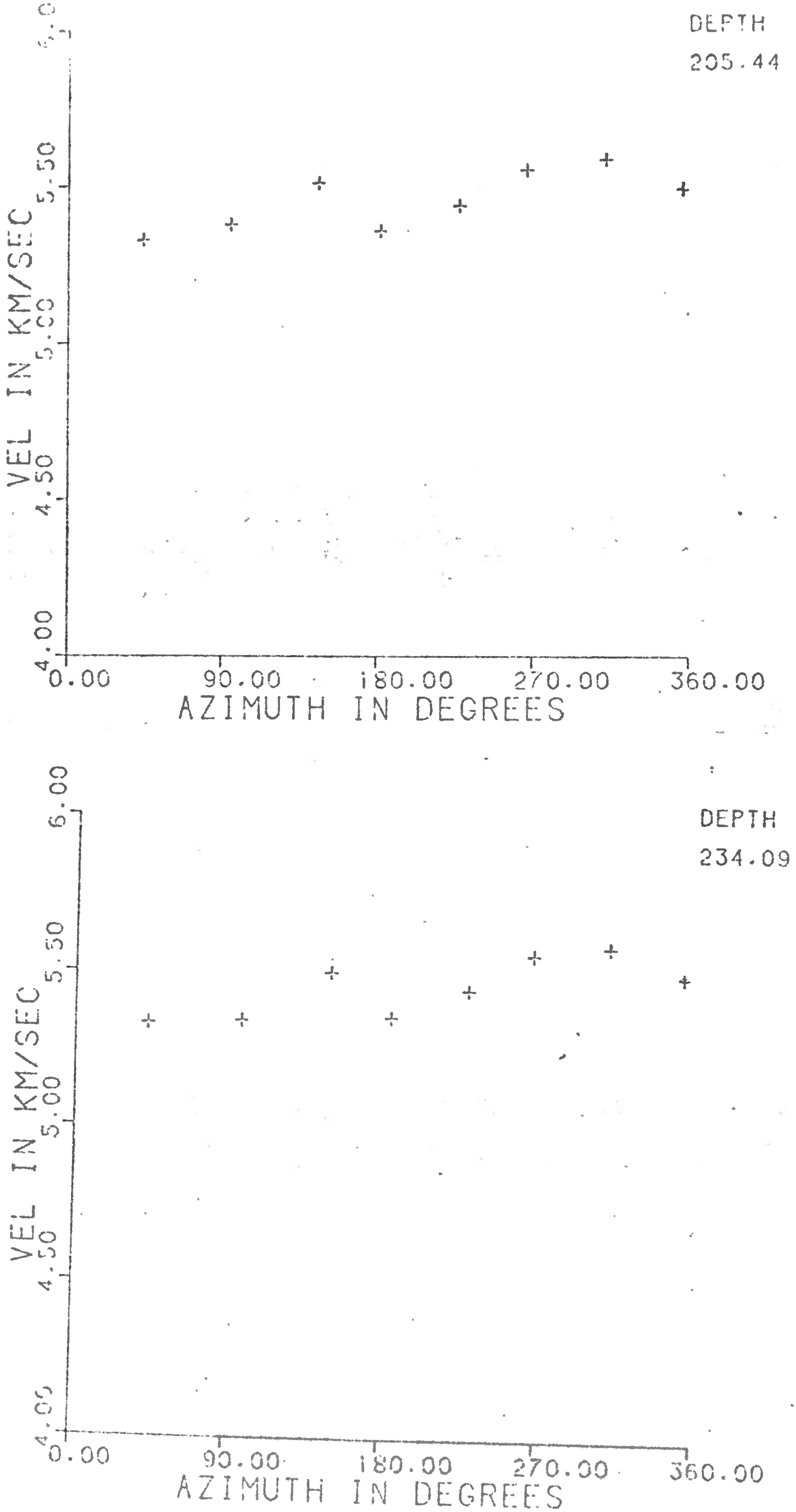
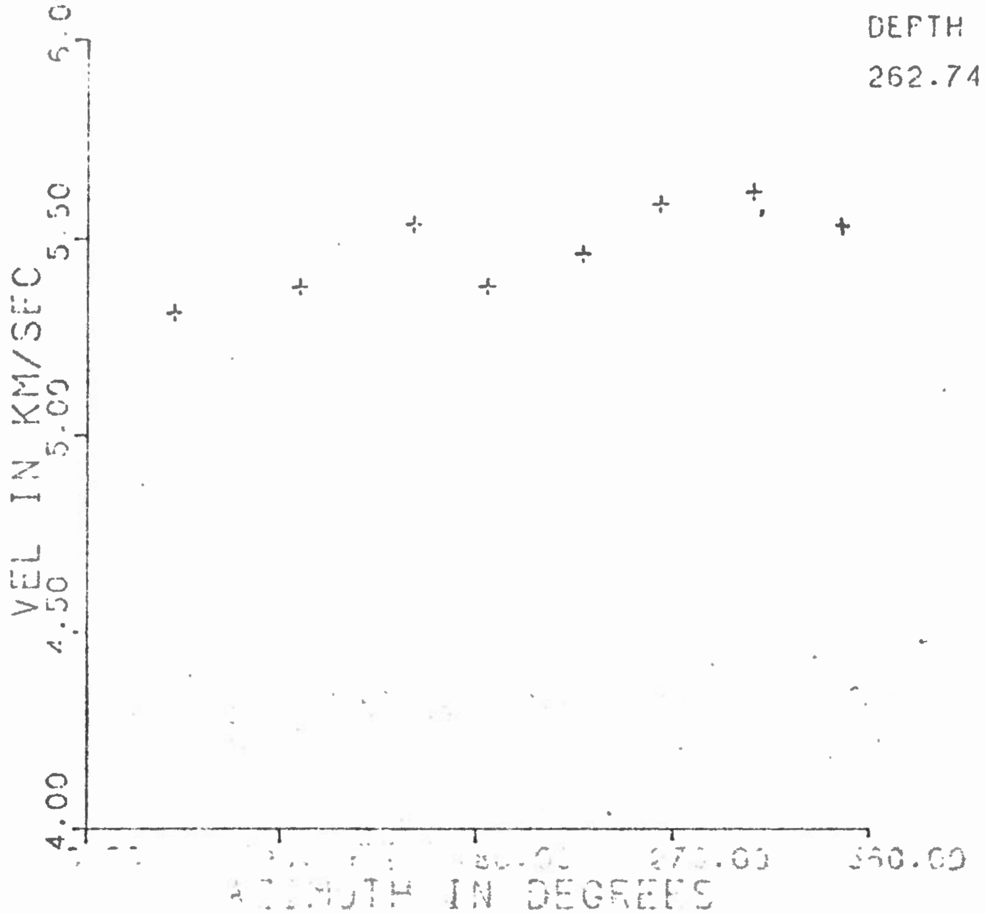

DEPTH
205.44
VEL IN KM/SEC
4.00
4.50
5.00
5.50
6.00
0.00
90.00
180.00
270.00
360.00
AZIMUTH IN DEGREES
DEPTH
234.09
VEL IN KM/SEC
4.00
4.50
5.00
5.50
6.00
0.00
90.00
180.00
270.00
360.00
AZIMUTH IN DEGREES

Fig. 17


DEPTH
262.74
VEL IN KM/SEC
4.00
4.50
5.00
5.50
6.00
AZIMUTH IN DEGREES
270.00
360.00

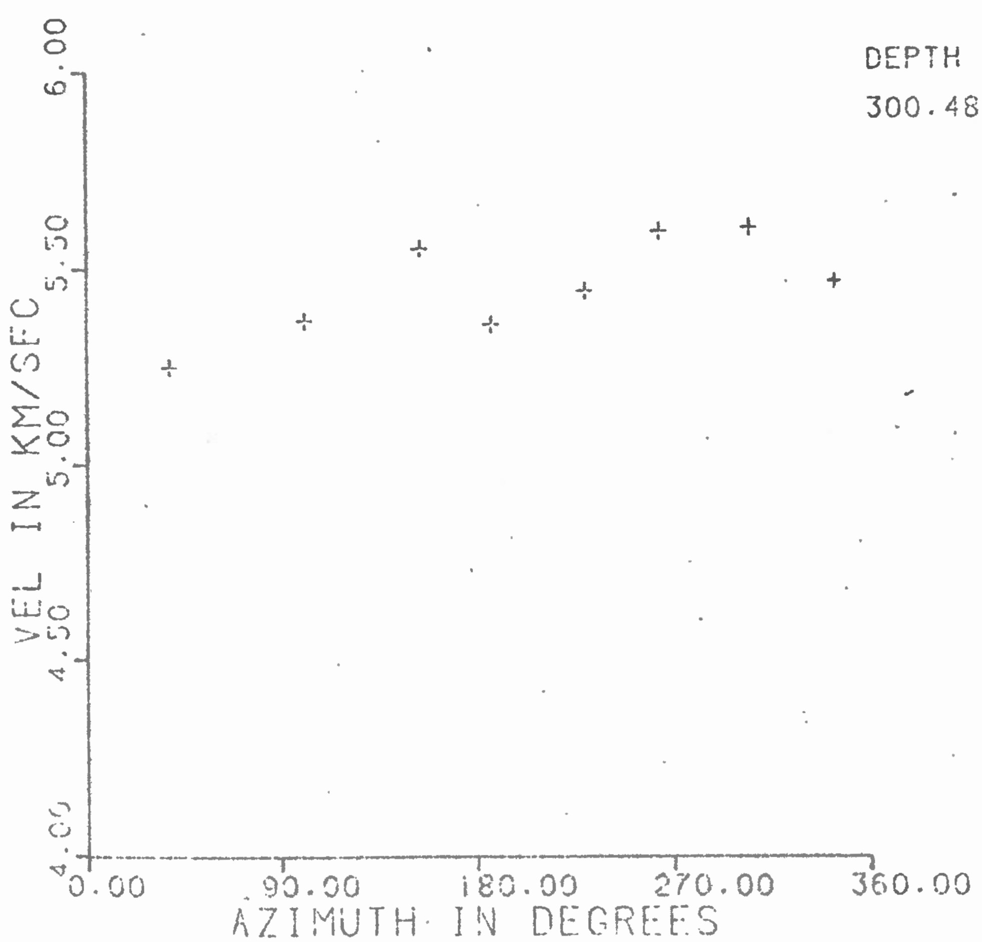
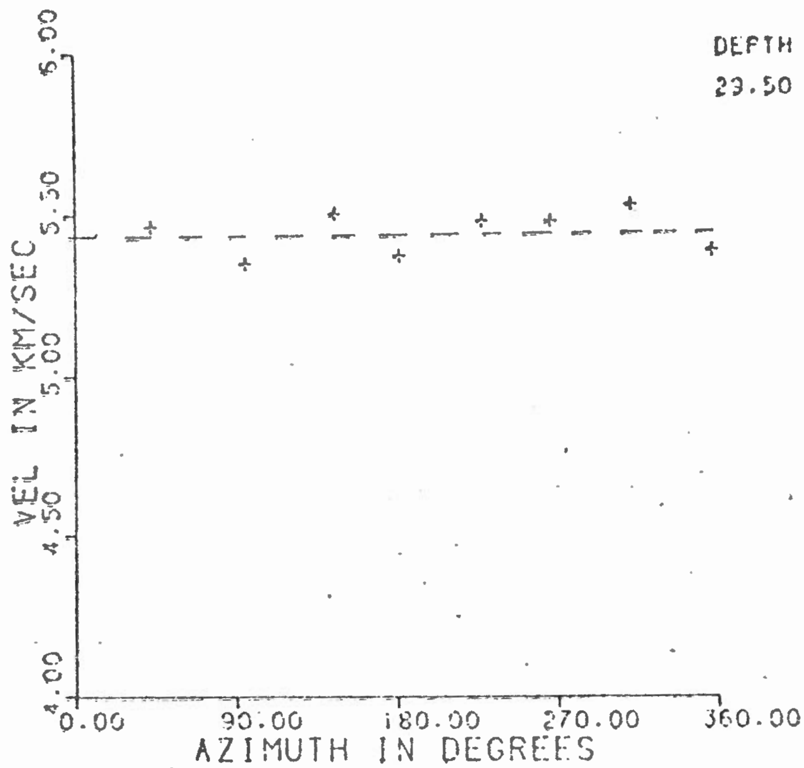

DEPTH
300.48
VEL IN KM/SEC
4.50
5.00
5.50
6.00
0.00
90.00
180.00
270.00
360.00
AZIMUTH IN DEGREES

Fig. 18


DEPTH
29.50
VEL IN KM/SEC
4.00
4.50
5.00
5.50
6.00
0.00
90.00
180.00
270.00
360.00
AZIMUTH IN DEGREES

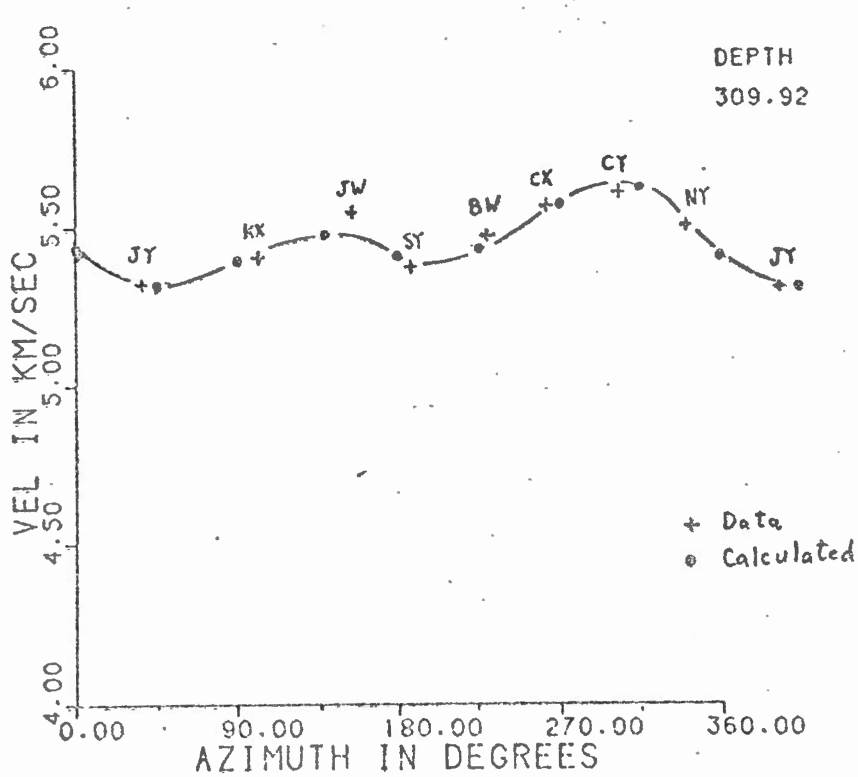

DEPTH
309.92
VEL IN KM/SEC
4.00
4.50
5.00
5.50
6.00
JY
KX
JW
SY
BW
CX
CY
NY
JY
+ Data
• Calculated
0.00
90.00
180.00
270.00
360.00
AZIMUTH IN DEGREES

Fig. 19.

SHOT LOCATION	OVERBURDEN THICKNESS (METERS)	OVERBURDEN VELOCITY (KM/S)
NY	24.38	1.798
JY	17.00	1.768
KX	16.00	1.920
JW	20.00	1.737
SY	15.35	1.710
BW	10.00	1.798
CX	10.00	1.676
CY	14.00	1.493

Table 1 Overburden thickness and overburden velocity at the shot locations

COORDINATES OF THE HYDROPHONES

PHONE	X-COORDIN	Y-COORDIN	Z-COORDIN
1	7.24	-2.55	29.50
2	9.72	-3.57	39.05
3	12.10	-4.45	48.52
4	14.48	-5.30	58.46
5	16.92	-6.16	67.97
6	19.39	-7.07	77.51
7	21.85	-7.99	87.42
8	24.29	-8.84	96.93
9	26.82	-9.78	106.68
10	29.26	-10.67	116.22
11	29.67	-10.78	117.76
12	32.28	-11.67	127.35
13	34.90	-12.56	136.86
14	37.58	-13.47	146.70
15	40.23	-14.36	156.36
16	42.98	-15.24	165.81
17	45.66	-16.15	175.57
18	48.31	-17.22	184.92
19	51.15	-18.23	194.56
20	53.86	-19.20	203.97
21	54.19	-19.28	205.44
22	57.06	-20.33	215.01
23	59.86	-21.34	224.40
24	62.67	-22.28	234.09
25	65.62	-23.32	243.54
26	68.58	-24.38	252.99
27	71.57	-25.39	262.74
28	74.74	-26.46	271.73
29	77.85	-27.46	281.33
30	80.93	-28.50	290.48
31	84.00	-29.63	300.48
32	87.17	-30.72	309.92

TABLE - 2

THE FOLLOWING TABLE IS THE HORIZONTAL DISTANCE FROM SHOT POINT NY TO THE CORRESPONDING HYDROPHONE

PHONE *****	X-COORDIN *********	Y-COORDIN *********	HORZ DIST *********
1	2.500	-372.000	369.482
2	2.500	-372.000	368.505
3	2.500	-372.000	367.675
4	2.500	-372.000	366.892
5	2.500	-372.000	366.127
6	2.500	-372.000	365.319
7	2.500	-372.000	364.528
8	2.500	-372.000	363.814
9	2.500	-372.000	363.032
10	2.500	-372.000	362.322
11	0.000	-372.000	362.433
12	0.000	-372.000	361.769
13	0.000	-372.000	361.132
14	0.000	-372.000	360.492
15	0.000	-372.000	359.900
16	0.000	-372.000	359.339
17	0.000	-372.000	358.763
18	0.000	-372.000	358.053
19	0.000	-372.000	357.451
20	0.000	-372.000	356.885
21	-4.000	-372.000	357.492
22	-4.000	-372.000	356.931
23	-4.000	-372.000	356.432
24	-4.000	-372.000	356.017
25	-4.000	-372.000	355.566
26	-4.000	-372.000	355.112
27	-4.000	-372.000	354.752
28	-4.000	-372.000	354.400
29	-4.000	-372.000	354.125
30	-4.000	-372.000	353.843
31	-4.000	-372.000	353.502
32	-4.000	-372.000	353.245

TABLE - 3

THE FOLLOWING TABLE IS THE HORIZONTAL DISTANCE FROM SHOT POINT JY TO THE CORRESPONDING HYDROPHONE

PHONE	X-COORDIN	Y-COORDIN	HORZ DIST
*****	*********	*********	*********
1	324.300	-334.300	458.900
2	324.300	-334.300	456.446
3	324.300	-334.300	454.169
4	324.300	-334.300	451.916
5	324.300	-334.300	449.625
6	324.300	-334.300	447.271
7	324.300	-334.300	444.920
8	324.300	-334.300	442.639
9	324.300	-334.300	440.231
10	324.300	-334.300	437.933
11	324.300	-325.700	431.251
12	324.300	-325.700	428.823
13	324.300	-325.700	426.392
14	324.300	-325.700	423.902
15	324.300	-325.700	421.460
16	324.300	-325.700	418.960
17	324.300	-325.700	416.484
18	324.300	-325.700	413.919
19	324.300	-325.700	411.282
20	324.300	-325.700	408.753
21	324.300	-318.800	403.328
22	324.300	-318.800	400.627
23	324.300	-318.800	398.009
24	324.300	-318.800	395.443
25	324.300	-318.800	392.712
26	324.300	-318.800	389.965
27	324.300	-318.800	387.250
28	324.300	-318.800	384.377
29	324.300	-318.800	381.597
30	324.300	-318.800	378.822
31	324.300	-318.800	375.983
32	324.300	-318.800	373.117

TABLE-4

THE [illegible]LLOWING TABLE IS THE HORIZONTAL DISTANCE [illegible]ROM SHOT POINT KX TO THE CORRESPONDING H[illegible] .OPHONE

PHONE *****	X-COORDIN *********	Y-COORDIN *********	HORZ DIST *********
1	399.110	26.000	392.912
2	399.110	26.000	390.508
3	399.110	26.000	388.205
4	399.110	26.000	385.904
5	399.110	26.000	383.544
6	399.110	26.000	381.162
7	399.110	26.000	378.783
8	399.110	26.000	376.433
9	399.110	26.000	374.003
10	399.110	26.000	371.662
11	401.860	23.500	373.763
12	401.860	23.500	371.251
13	401.860	23.500	368.727
14	401.860	23.500	366.149
15	401.860	23.500	363.602
16	401.860	23.500	360.968
17	401.860	23.500	358.401
18	401.860	23.500	355.886
19	401.860	23.500	353.188
20	401.860	23.500	350.611
21	404.110	26.000	352.836
22	404.110	26.000	350.130
23	404.110	26.000	347.486
24	404.110	26.000	344.839
25	404.110	26.000	342.060
26	404.110	26.000	339.291
27	404.110	26.000	336.490
28	404.110	26.000	333.523
29	404.110	26.000	330.614
30	404.110	26.000	327.748
31	404.110	26.000	324.903
32	404.110	26.000	321.972

TABLE-5

THE [illegible]LLOWING TABLE IS THE HORIZONTAL DISTANCE [illegible]ROM SHOT POINT JW TO THE CORRESPONDING H[illegible] OPHONE

PHONE *****	X-COORDIN *********	Y-COORDIN *********	HORZ DIST *********
1	326.550	430.400	537.964
2	326.550	430.400	537.314
3	326.550	430.400	536.631
4	326.550	430.400	535.935
5	326.550	430.400	535.215
6	326.550	430.400	534.538
7	326.550	430.400	533.874
8	326.550	430.400	533.189
9	326.550	430.400	532.540
10	326.550	430.400	531.904
11	324.300	430.400	530.517
12	324.300	430.400	529.817
13	324.300	430.400	529.116
14	324.300	430.400	528.422
15	324.300	430.400	527.732
16	324.300	430.400	527.008
17	324.300	430.400	526.357
18	324.300	430.400	525.866
19	324.300	430.400	525.242
20	324.300	430.400	524.672
21	321.550	430.400	523.153
22	321.550	430.400	522.602
23	321.550	430.400	522.059
24	321.550	430.400	521.479
25	321.550	430.400	520.920
26	321.550	430.400	520.406
27	321.550	430.400	519.842
28	321.550	430.400	519.263
29	321.550	430.400	518.681
30	321.550	430.400	518.159
31	321.550	430.400	517.738
32	321.550	430.400	517.269

TABLE - 6

THE [illegible]LLOWING TABLE IS THE HORIZONTAL DISTANCE [illegible]ROM SHOT POINT SY TO THE CORRESPONDING H[illegible] .OPHONE

PHONE	X-COORDIN	Y-COORDIN	HORZ DIST
*****	*********	*********	*********
1	3.740	802.700	805.256
2	3.740	802.700	806.288
3	3.740	802.700	807.193
4	3.740	802.700	808.075
5	3.740	802.700	808.964
6	3.740	802.700	809.923
7	3.740	802.700	810.888
8	3.740	802.700	811.800
9	3.740	802.700	812.812
10	3.740	802.700	813.768
11	0.000	800.700	812.026
12	0.000	800.700	813.015
13	0.000	800.700	814.006
14	0.000	800.700	815.039
15	0.000	800.700	816.049
16	0.000	800.700	817.071
17	0.000	800.700	818.130
18	0.000	800.700	819.347
19	0.000	800.700	820.523
20	0.000	800.700	821.670
21	-4.000	799.700	821.041
22	-4.000	799.700	822.300
23	-4.000	799.700	823.516
24	-4.000	799.700	824.680
25	-4.000	799.700	825.957
26	-4.000	799.700	827.274
27	-4.000	799.700	828.543
28	-4.000	799.700	829.901
29	-4.000	799.700	831.202
30	-4.000	799.700	832.542
31	-4.000	799.700	833.983
32	-4.000	799.700	835.414

TABLE-7

THE [illegible]LLOWING TABLE IS THE HORIZONTAL DISTANC[illegible] ROM SHOT POINT BW TO THE CORRESPONDING H[illegible] OPHONE

PHONE	X-COORDIN	Y-COORDIN	HORZ DIST
*****	*********	*********	*********
1	-477.700	445.300	660.099
2	-477.700	445.300	662.618
3	-477.700	445.300	664.966
4	-477.700	445.300	667.295
5	-477.700	445.300	669.671
6	-477.700	445.300	672.112
7	-477.700	445.300	674.554
8	-477.700	445.300	676.934
9	-477.700	445.300	679.444
10	-477.700	445.300	681.848
11	-475.700	445.300	680.745
12	-475.700	445.300	683.277
13	-475.700	445.300	685.818
14	-475.700	445.300	688.426
15	-475.700	445.300	690.993
16	-475.700	445.300	693.631
17	-475.700	445.300	696.244
18	-475.700	445.300	698.938
19	-475.700	445.300	701.730
20	-475.700	445.300	704.411
21	-470.700	445.300	700.957
22	-470.700	445.300	703.805
23	-470.700	445.300	706.574
24	-470.700	445.300	709.305
25	-470.700	445.300	712.212
26	-470.700	445.300	715.141
27	-470.700	445.300	718.056
28	-470.700	445.300	721.150
29	-470.700	445.300	724.160
30	-470.700	445.300	727.170
31	-470.700	445.300	730.241
32	-470.700	445.300	733.364

TABLE - 8

THE FOLLOWING TABLE IS THE HORIZONTAL DISTANCE FROM SHOT POINT CX TO THE CORRESPONDING HYDROPHONE

PHONE	X-COORDIN	Y-COORDIN	HORZ DIST
1	-391.350	21.000	399.281
2	-391.350	21.000	401.825
3	-391.350	21.000	404.253
4	-391.350	21.000	406.680
5	-391.350	21.000	409.169
6	-391.350	21.000	411.694
7	-391.350	21.000	414.220
8	-391.350	21.000	416.713
9	-391.350	21.000	419.304
10	-391.350	21.000	421.802
11	-390.320	18.000	420.978
12	-390.320	18.000	423.639
13	-390.320	18.000	426.317
14	-390.320	18.000	429.058
15	-390.320	18.000	431.768
16	-390.320	18.000	434.570
17	-390.320	18.000	437.315
18	-390.320	18.000	440.043
19	-390.320	18.000	442.950
20	-390.320	18.000	445.734
21	-388.320	18.500	444.121
22	-388.320	18.500	447.069
23	-388.320	18.500	449.950
24	-388.320	18.500	452.828
25	-388.320	18.500	455.866
26	-388.320	18.500	458.909
27	-388.320	18.500	461.978
28	-388.320	18.500	465.235
29	-388.320	18.500	468.427
30	-388.320	18.500	471.593
31	-388.320	18.500	474.769
32	-338.320	18.500	478.035

TABLE-9

THE [illegible]LLOWING TABLE IS THE HORIZONTAL DISTANCE [illegible]ROM SHOT POINT CY TO THE CORRESPONDING H[illegible] OPHONE

PHONE *****	X-COORDIN *********	Y-COORDIN *********	HORZ DIST *********
1	-395.110	-372.000	546.239
2	-395.110	-372.000	547.388
3	-395.110	-372.000	548.556
4	-395.110	-372.000	549.753
5	-395.110	-372.000	551.005
6	-395.110	-372.000	552.249
7	-395.110	-372.000	553.503
8	-395.110	-372.000	554.783
9	-395.110	-372.000	556.082
10	-395.110	-372.000	557.361
11	-392.110	-372.000	555.318
12	-392.110	-372.000	556.723
13	-392.110	-372.000	558.154
14	-392.110	-372.000	559.623
15	-392.110	-372.000	561.098
16	-392.110	-372.000	562.653
17	-392.110	-372.000	564.153
18	-392.110	-372.000	565.543
19	-392.110	-372.000	567.125
20	-392.110	-372.000	568.642
21	-389.110	-372.000	566.507
22	-389.110	-372.000	568.101
23	-389.110	-372.000	569.686
24	-389.110	-372.000	571.320
25	-389.110	-372.000	573.029
26	-389.110	-372.000	574.733
27	-389.110	-372.000	576.509
28	-389.110	-372.000	578.407
29	-389.110	-372.000	580.306
30	-389.110	-372.000	582.174
31	-389.110	-372.000	584.000
32	-389.110	-372.000	585.931

TABLE - 10

EXPLANATION OF THE SYMBOLS AND UNITS USED FOR THE PARAMETERS IN THE FOLLOWING TABLES

SYMBOLS

CO-ORDIN	-	CO-ORDINATE
HORZ DIST	-	HORIZONTAL DISTANCE
PHONE	-	HYDROPHONE
ARR TIME	-	ARRIVAL TIME
GAMA	-	ANGLE OF REFRACTION AT LOWEST LAYER
H-VEL	-	HORIZONTAL P VELOCITY
VELOC	-	AVERAGE VELOCITY
K-FACTOR	-	ANISOTROPY FACTOR

UNITS

CO-ORDIN	-	METERS
HORZ DIST	-	METERS
DEPTH	-	METERS
ARR TIME	-	MILLISECONDS
GAMA	-	DEGREES
VEL	-	KM/SEC
H-VEL	-	KM/SEC
VELOC	-	KM/SEC

…LLOWING TABLE GIVES THE PERTINENT RE… …FROM SHOT POINT KX TO THE CORRESPOND…NG …DROPHO…

PHONE	HOR DIST	DEPTH.	ARR TIME	GAMA.	VELOC	H-VEL	K-FACTOR
1	392.91	29.50	81.21	88.00	5.354	5.354	.9734
2	390.51	39.05	81.05	86.57	5.339	5.338	.9706
3	388.21	48.52	80.66	85.13	5.345	5.344	.9717
4	385.90	58.46	80.35	83.62	5.350	5.348	.9724
5	383.54	67.97	80.19	82.16	5.346	5.343	.9715
6	381.16	77.51	79.88	80.69	5.356	5.352	.9731
7	378.78	87.42	79.88	79.15	5.347	5.342	.9713
8	376.43	96.93	79.73	77.68	5.353	5.347	.9721
9	374.00	106.68	79.73	76.16	5.351	5.342	.9713
10	371.66	116.22	79.80	74.68	5.348	5.337	.9703
11	373.76	117.76	80.35	74.54	5.341	5.329	.9689
12	371.25	127.35	80.27	73.05	5.350	5.337	.9703
13	368.73	136.86	80.19	71.58	5.363	5.348	.9724
14	366.15	146.70	80.55	70.06	5.347	5.328	.9687
15	363.60	156.36	80.74	68.58	5.347	5.325	.9682
16	360.97	165.81	80.86	67.14	5.354	5.329	.9690
17	358.40	175.57	81.05	65.66	5.361	5.334	.9699
18	355.89	184.92	81.25	64.26	5.370	5.341	.9711
19	353.19	194.56	81.84	62.82	5.352	5.315	.9664
20	350.61	203.97	82.03	61.43	5.367	5.330	.9690
21	352.84	205.44	82.03	61.40	5.404	5.376	.9774
22	350.13	215.01	82.53	60.01	5.398	5.366	.9756
23	347.49	224.40	83.08	58.67	5.392	5.354	.9734
24	344.84	234.09	83.67	57.30	5.388	5.344	.9717
25	342.06	243.54	83.86	55.98	5.413	5.375	.9772
26	339.29	252.99	84.45	54.67	5.412	5.369	.9762
27	336.49	262.74	85.03	53.35	5.416	5.371	.9766
28	333.52	271.73	85.62	52.12	5.414	5.365	.9754
29	330.61	281.33	86.21	50.85	5.421	5.370	.9765
30	327.75	290.48	86.87	49.66	5.422	5.368	.9759
31	324.90	300.48	87.65	48.40	5.424	5.366	.9757
32	321.97	309.92	88.08	47.22	5.447	5.403	.9824

Table 11

TH LLOWING TABLE GIVES THE PERTINENT RES FROM SHOT POINT JW TO THE CORRESPOND ROPHONE

PHONE	HOR DIST	DEPTH.	ARR TIME	GAMA.	VELOC	H-VEL	K-FACTOR
1	537.96	29.50	108.59	88.98	5.509	5.509	1.0017
2	537.31	39.05	108.59	87.94	5.505	5.505	1.0009
3	536.63	48.52	108.20	86.92	5.525	5.525	1.0045
4	535.94	58.46	108.00	85.84	5.536	5.536	1.0065
5	535.22	67.97	108.20	84.81	5.525	5.525	1.0045
6	534.54	77.51	108.40	83.78	5.516	5.516	1.0030
7	533.87	87.42	108.20	82.71	5.533	5.533	1.0061
8	533.19	96.93	108.98	81.69	5.495	5.494	.9990
9	532.54	106.68	108.59	80.64	5.526	5.526	1.0048
10	531.90	116.22	108.98	79.62	5.514	5.514	1.0026
11	530.52	117.76	108.98	79.43	5.503	5.503	1.0005
12	529.82	127.35	109.18	78.41	5.503	5.503	1.0006
13	529.12	136.86	109.37	77.40	5.506	5.506	1.0011
14	528.42	146.70	109.76	76.36	5.500	5.500	1.0000
15	527.73	156.36	110.16	75.34	5.495	5.494	.9990
16	527.01	165.81	110.55	74.35	5.491	5.490	.9982
17	526.36	175.57	110.74	73.34	5.502	5.502	1.0003
18	525.87	184.92	110.94	72.39	5.514	5.515	1.0027
19	525.24	194.56	111.33	71.41	5.516	5.518	1.0033
20	524.67	203.97	111.72	70.46	5.520	5.522	1.0041
21	523.15	205.44	111.72	70.27	5.511	5.512	1.0022
22	522.60	215.01	112.31	69.31	5.506	5.507	1.0012
23	522.06	224.40	112.70	68.39	5.513	5.515	1.0028
24	521.48	234.09	113.48	67.44	5.501	5.502	1.0003
25	520.92	243.54	113.87	66.53	5.512	5.514	1.0025
26	520.41	252.99	114.46	65.63	5.513	5.515	1.0028
27	519.84	262.74	114.85	64.72	5.527	5.533	1.0059
28	519.26	271.73	115.43	63.88	5.528	5.535	1.0064
29	518.68	281.33	116.60	63.00	5.502	5.503	1.0006
30	518.16	290.48	117.00	62.17	5.517	5.522	1.0040
31	517.74	300.48	117.38	61.29	5.539	5.551	1.0092
32	517.27	309.92	118.17	60.46	5.537	5.549	1.0089

Table 12

TI OLLOWING TABLE GIVES THE PERTINENT RES FROM SHOT POINT SY TO THE CORRESPOND DROPHONE

PHONE	HOR DIST	DEP!H.	ARR TIME	GAMA.	VELOC	H-VEL	K-FACTOR
1	805.26	29.50	158.20	88.99	5.380	5.380	.9782
2	806.29	39.05	158.20	88.31	5.389	5.389	.9798
3	807.19	48.52	158.59	87.63	5.383	5.383	.9787
4	808.08	58.46	158.98	86.93	5.378	5.378	.9778
5	808.96	67.97	159.38	86.25	5.373	5.373	.9769
6	809.92	77.51	159.77	85.58	5.370	5.370	.9763
7	810.69	87.42	159.96	84.89	5.375	5.374	.9772
8	811.80	96.93	160.16	84.23	5.380	5.379	.9780
9	812.81	106.68	160.35	83.55	5.387	5.386	.9792
10	813.77	116.22	160.55	82.89	5.394	5.392	.9804
11	812.03	117.76	159.92	82.77	5.406	5.405	.9826
12	813.02	127.35	160.55	82.11	5.398	5.396	.9812
13	814.01	136.86	161.13	81.46	5.393	5.391	.9801
14	815.04	146.70	161.72	80.79	5.389	5.386	.9793
15	816.05	156.36	162.11	80.14	5.392	5.389	.9798
16	817.07	165.81	162.62	79.50	5.392	5.388	.9796
17	818.13	175.57	162.66	78.85	5.409	5.406	.9828
18	819.35	184.92	162.89	78.24	5.421	5.417	.9850
19	820.52	194.56	163.16	77.61	5.432	5.429	.9870
20	821.67	203.97	165.23	76.99	5.380	5.374	.9771
21	821.04	205.44	165.63	76.89	5.365	5.358	.9741
22	822.30	215.01	166.02	76.27	5.373	5.366	.9756
23	823.52	224.40	166.80	75.67	5.369	5.360	.9746
24	824.68	234.09	167.50	75.06	5.367	5.358	.9742
25	825.96	243.54	168.67	74.47	5.351	5.340	.9710
26	827.27	252.99	168.75	73.88	5.373	5.362	.9750
27	828.54	262.74	169.14	73.28	5.384	5.374	.9772
28	829.90	271.73	170.31	72.74	5.370	5.358	.9741
29	831.20	281.33	171.60	72.16	5.353	5.338	.9705
30	832.54	290.48	172.27	71.61	5.356	5.341	.9710
31	833.98	300.48	172.66	71.02	5.371	5.356	.9739
32	835.41	309.92	173.05	70.47	5.385	5.372	.9766

Table 13

TH OLLOWING TABLE GIVES THE PERTINENT RES FROM SHOT POINT BW TO THE CORRESPOND DROPHONE

PHONE	HOR DIST	DEPTH.	ARR TIME	GAMA.	VELOC	H-VEL	K-FACTOR
1	660.10	29.50	125.59	88.30	5.488	5.488	.9978
2	662.62	39.05	126.25	87.48	5.482	5.482	.9967
3	664.97	48.52	126.56	86.67	5.491	5.491	.9984
4	667.30	58.46	127.34	85.82	5.480	5.480	.9964
5	669.67	67.97	128.05	85.03	5.474	5.474	.9952
6	672.11	77.51	128.24	84.23	5.493	5.493	.9986
7	674.55	87.42	129.30	83.42	5.474	5.473	.9952
8	676.93	96.93	129.92	82.65	5.475	5.474	.9953
9	679.44	106.68	130.56	81.86	5.477	5.477	.9958
10	681.85	116.22	130.66	81.10	5.503	5.503	1.0006
11	680.75	117.76	130.86	80.96	5.488	5.487	.9977
12	683.28	127.35	131.64	80.21	5.486	5.485	.9973
13	685.82	136.86	132.62	79.47	5.476	5.476	.9956
14	688.43	146.70	133.48	78.71	5.474	5.473	.9951
15	690.99	156.36	134.77	77.98	5.454	5.452	.9913
16	693.63	165.81	135.27	77.28	5.468	5.467	.9940
17	696.24	175.57	136.33	76.56	5.460	5.458	.9924
18	698.94	184.92	136.88	75.88	5.475	5.473	.9951
19	701.73	194.56	138.05	75.20	5.465	5.462	.9931
20	704.41	203.97	138.98	74.53	5.464	5.462	.9931
21	700.96	205.44	138.98	74.35	5.442	5.438	.9887
22	703.81	215.01	139.76	73.69	5.451	5.447	.9903
23	706.57	224.40	140.74	73.04	5.451	5.446	.9902
24	709.31	234.09	141.71	72.39	5.452	5.448	.9905
25	712.21	243.54	142.89	71.77	5.447	5.441	.9893
26	715.14	252.99	144.06	71.15	5.443	5.436	.9883
27	718.06	262.74	144.72	70.53	5.460	5.455	.9917
28	721.15	271.73	144.84	69.97	5.498	5.497	.9995
29	724.16	281.33	147.77	69.37	5.427	5.417	.9850
30	727.17	290.48	148.35	68.82	5.448	5.440	.9892
31	730.24	300.48	149.53	68.22	5.449	5.441	.9892
32	733.36	309.92	150.07	67.67	5.473	5.468	.9943

Table 14

TH[illegible]LLOWING TABLE GIVES THE PERTINENT RES[illegible] FROM SHOT POINT CX TO THE CORRESPOND[illegible] [illegible]ROPHONE

PHONE	HOR DIST	DEPTH.	ARR TIME	GAMA.	VELOC	H-VEL	K-FACTOR
1	399.28	29.50	78.52	87.18	5.488	5.488	.9979
2	401.83	39.05	78.83	85.83	5.508	5.508	1.0014
3	404.25	48.52	79.49	84.51	5.502	5.502	1.0004
4	406.68	58.46	80.08	83.15	5.505	5.505	1.0010
5	409.17	67.97	80.86	81.87	5.497	5.497	.9995
6	411.69	77.51	81.64	80.62	5.493	5.493	.9987
7	414.22	87.42	82.30	79.33	5.501	5.501	1.0001
8	416.71	96.93	83.20	78.13	5.492	5.492	.9985
9	419.30	106.68	83.98	76.92	5.497	5.497	.9994
10	421.80	116.22	84.38	75.77	5.529	5.530	1.0055
11	420.98	117.76	84.38	75.54	5.523	5.525	1.0045
12	423.64	127.35	84.96	74.41	5.547	5.550	1.0092
13	426.32	136.86	85.94	73.32	5.544	5.548	1.0087
14	429.06	146.70	86.72	72.21	5.559	5.565	1.0119
15	431.77	156.36	88.09	71.15	5.535	5.539	1.0070
16	434.57	165.81	89.06	70.15	5.539	5.545	1.0081
17	437.32	175.57	89.84	69.14	5.559	5.568	1.0123
18	440.04	184.92	91.02	68.19	5.552	5.560	1.0110
19	442.95	194.56	92.19	67.25	5.550	5.559	1.0107
20	445.73	203.97	93.24	66.35	5.555	5.566	1.0120
21	444.12	205.44	93.24	66.11	5.545	5.554	1.0098
22	447.07	215.01	94.41	65.23	5.547	5.557	1.0103
23	449.95	224.40	95.43	64.38	5.557	5.571	1.0128
24	452.83	234.09	96.75	63.53	5.552	5.565	1.0118
25	455.87	243.54	97.93	62.73	5.556	5.572	1.0130
26	458.91	252.99	99.25	61.96	5.554	5.569	1.0126
27	461.98	262.74	100.43	61.18	5.562	5.581	1.0148
28	465.24	271.73	101.83	60.50	5.556	5.575	1.0136
29	468.43	281.33	103.39	59.78	5.545	5.560	1.0109
30	471.59	290.48	104.57	59.12	5.553	5.573	1.0132
31	474.77	300.48	105.74	58.40	5.567	5.593	1.0170
32	478.04	309.92	107.50	57.75	5.547	5.566	1.0121

Table 15

TI[illegible]OLLOWING TABLE GIVES THE PERTINENT RES[illegible] FROM SHOT POINT CY TO THE CORRESPOND[illegible] [illegible]ROPHONE

PHONE	HOR DIST	DEPTH.	ARR TIME	GAMA.	VELOC	H-VEL	K-FACTOR
1	546.24	29.50	107.66	88.36	5.541	5.541	1.0074
2	547.39	39.05	107.66	87.36	5.556	5.556	1.0102
3	548.56	48.52	107.81	86.37	5.565	5.565	1.0118
4	549.75	58.46	108.40	85.34	5.551	5.551	1.0093
5	551.01	67.97	108.59	84.37	5.561	5.562	1.0112
6	552.25	77.51	108.98	83.39	5.562	5.563	1.0114
7	553.50	87.42	109.38	82.39	5.565	5.566	1.0120
8	554.78	96.93	109.77	81.44	5.569	5.570	1.0128
9	556.08	106.68	110.16	80.47	5.575	5.577	1.0141
10	557.36	116.22	110.74	79.54	5.572	5.575	1.0136
11	555.32	117.76	110.74	79.34	5.555	5.557	1.0104
12	556.72	127.35	111.36	78.41	5.553	5.555	1.0100
13	558.15	136.86	111.91	77.50	5.556	5.559	1.0107
14	559.62	146.70	112.69	76.57	5.549	5.552	1.0095
15	561.10	156.36	113.08	75.67	5.565	5.569	1.0126
16	562.10	165.81	113.86	74.79	5.555	5.560	1.0108
17	564.15	175.57	114.45	73.92	5.568	5.574	1.0135
18	565.54	184.92	115.03	73.08	5.575	5.583	1.0150
19	567.13	194.56	115.81	72.23	5.576	5.584	1.0152
20	568.64	203.97	115.81	71.42	5.617	5.631	1.0238
21	566.51	205.44	116.28	71.22	5.578	5.587	1.0158
22	568.10	215.01	117.37	70.40	5.564	5.573	1.0132
23	569.69	224.40	117.84	69.61	5.584	5.596	1.0174
24	571.32	234.09	118.81	68.81	5.580	5.592	1.0167
25	573.03	243.54	119.40	68.05	5.596	5.612	1.0203
26	574.73	252.99	120.57	67.30	5.583	5.598	1.0179
27	576.51	262.74	121.35	66.53	5.593	5.611	1.0202
28	578.41	271.73	122.13	65.85	5.602	5.623	1.0224
29	580.31	281.33	123.11	65.14	5.604	5.627	1.0231
30	582.17	290.48	124.67	64.46	5.577	5.595	1.0172
31	584.00	300.48	125.65	63.74	5.581	5.602	1.0185
32	585.93	309.92	126.63	63.07	5.585	5.608	1.0197

Table 16

T[illegible]LLOWING TABLE GIVES THE PERTINENT RES[illegible]FROM SHOT POINT NY TO THE CORRESPOND[illegible]ROPHONE

PHONE	HOR DIST	DEPTH.	ARR TIME	GAMA.	VELOC	H-VEL	K-FACTOR
1	369.48	29.50	81.25	89.19	5.397	5.397	.9813
2	368.51	39.05	81.02	87.67	5.405	5.405	.9827
3	367.68	48.52	81.13	86.15	5.391	5.391	.9802
4	366.89	58.46	81.41	84.57	5.369	5.368	.9760
5	366.13	67.97	81.56	83.05	5.361	5.359	.9744
6	365.32	77.51	81.60	81.53	5.365	5.362	.9750
7	364.53	87.42	81.64	79.96	5.374	5.370	.9764
8	363.81	96.93	81.95	78.46	5.365	5.360	.9745
9	363.03	106.68	82.23	76.93	5.363	5.355	.9737
10	362.32	116.22	82.34	75.45	5.377	5.369	.9762
11	362.43	117.76	82.34	75.23	5.385	5.377	.9776
12	361.77	127.35	81.95	73.76	5.444	5.439	.9890
13	361.13	136.86	82.31	72.33	5.447	5.442	.9894
14	360.49	146.70	83.32	70.86	5.404	5.392	.9804
15	359.90	156.36	83.71	69.44	5.412	5.400	.9819
16	359.34	165.81	84.41	68.07	5.400	5.384	.9789
17	358.76	175.57	84.26	66.70	5.457	5.450	.9908
18	358.05	184.92	85.27	65.38	5.424	5.409	.9834
19	357.45	194.56	85.06	64.05	5.414	5.394	.9808
20	356.89	203.97	86.84	62.79	5.407	5.383	.9788
21	357.49	205.44	86.84	62.64	5.424	5.404	.9825
22	356.93	215.01	87.62	61.39	5.421	5.398	.9814
23	356.43	224.40	88.71	60.18	5.397	5.364	.9753
24	356.02	234.09	88.98	58.98	5.438	5.416	.9848
25	355.57	243.54	90.27	57.82	5.406	5.370	.9764
26	355.11	252.99	90.35	56.70	5.462	5.446	.9903
27	354.75	262.74	91.33	55.58	5.460	5.441	.9892
28	354.40	271.73	92.70	54.55	5.426	5.390	.9800
29	354.13	281.33	94.26	53.49	5.388	5.330	.9690
30	353.84	290.48	95.04	52.52	5.401	5.346	.9720
31	353.50	300.48	95.82	51.48	5.422	5.374	.9771
32	353.25	309.92	96.60	50.53	5.440	5.401	.9820

Table 17

THE [illegible]LLOWING TABLE GIVES THE PERTINENT RESUL[illegible]ROM SHOT POINT JY TO THE CORRESPONDIN[illegible]ROPHONE

PHONE	HOR DIST	DEPTH.	ARR TIME	GAMA.	VELOC	H-VEL
1	458.90	29.50	93.05	88.42	5.468	5.468
2	456.45	39.05	93.16	87.20	5.436	5.436
3	454.17	48.52	92.27	85.98	5.474	5.475
4	451.92	58.46	92.30	84.69	5.455	5.456
5	449.63	67.97	92.15	83.45	5.449	5.451
6	447.27	77.51	91.80	82.20	5.458	5.462
7	444.92	87.42	91.72	80.89	5.453	5.458
8	442.64	96.93	91.42	79.63	5.465	5.472
9	440.23	106.68	90.94	78.34	5.491	5.502
10	437.93	116.22	91.21	77.07	5.470	5.482
11	431.25	117.76	87.62	76.69	5.644	5.668
12	428.82	127.35	88.24	75.39	5.599	5.624
13	426.39	136.86	88.24	74.11	5.601	5.631
14	423.90	146.70	88.40	72.78	5.595	5.630
15	421.46	156.36	88.28	69.10	5.606	5.608
16	418.96	165.81	88.91	67.81	5.571	5.568
17	416.48	175.57	88.67	66.47	5.601	5.602
18	413.92	184.92	88.86	65.19	5.600	5.602
19	411.28	194.56	88.98	63.88	5.608	5.612
20	408.75	203.97	88.67	62.64	5.647	5.662
21	403.33	205.44	90.47	62.12	5.476	5.444
22	400.63	215.01	90.63	60.83	5.486	5.454
23	398.01	224.40	90.86	59.57	5.494	5.461
24	395.44	234.09	91.41	58.29	5.486	5.447
25	392.71	243.54	92.19	57.05	5.463	5.411
26	389.97	252.99	92.81	55.81	5.453	5.392
27	387.25	262.74	92.97	54.55	5.476	5.419
28	384.38	271.73	92.97	53.42	5.504	5.457
29	381.60	281.33	93.36	52.19	5.515	5.469
30	378.82	290.48	93.98	51.04	5.510	5.458
31	375.98	300.48	95.70	49.80	5.448	5.351
32	373.12	309.92	96.56	48.66	5.436	5.323

Table 18

Computer programs

Program HORDIST calculates the horizontal distance between a shot point and hydrophone pair. It requires the x and y coordinates of the shot points and hydrophones.

AZIMUTH is the program used to compute the azimuths of the shot point and hydrophone pair. Zero azimuth is along the negative y direction and runs clockwise. Input to this program are the x and y coordinates of the shot points and hydrophones.

Program INCIDIS determines the average compressional velocity, horizontal P velocity and anisotropy factor,k. After initialization and inputting the horizontal distance of the shot point-hydrophone pair, hydrophone depth and travel time, it calls subroutine LAYER to determine the value of horizontal P velocity, average P velocity and anisotropy factor, k. The solution is iterated to within .0001 of the k value.

The result of horizontal P velocity and anisotropy factor vs depth and azimuth are plotted by PROTOR. Input to this program are the horizontal P velocity, anisotropy factor, depth and azimuth of each shot point-hydrophone pair.

```
      PROGRAM HORDIST(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT)
      COMMON SPCX(32),SPCY(32),DHCX(32),DHCY(32),DHCZ(32),SLOC(8)
      READ(1,1)DHCX
    1 FORMAT(10F8.2)
      READ(1,1)DHCY
      READ(1,1)DHCZ
      READ(1,20)SLOC
   20 FORMAT(A10)
      DO 2 I=1,32
      DHCX(I)=DHCX(I)/3.2808
      DHCZ(I)=DHCZ(I)/3.2808
    2 DHCY(I)=DHCY(I)/3.2808
      WRITE(2,7)
    7 FORMAT(1H1,*COORDINATES OF THE HYDROPHONES*)
      WRITE(2,8)
    8 FORMAT(1X,"********************************",///)
      WRITE(2,9)
    9 FORMAT(1X,*PHONE*,3X,*X-COORDIN*,3X,*Y-COORDIN*,3X,*Z-COORDIN*)
      WRITE(2,10)
   10 FORMAT(1X,"******",3X,"**********",3X,"**********",3X,"**********",/)
      DO 12 I=1,32
      WRITE(2,11)I,DHCX(I),DHCY(I),DHCZ(I)
   11 FORMAT(2X,I2,4X,3(F9.2,3X))
   12 CONTINUE
      DO 30 K=1,8
      READ(1,40)SPCX
   40 FORMAT(F8.2)
      READ(1,40)SPCY
      WRITE(2,21)SLOC(K)
   21 FORMAT(1H1,46HTHE FOLLOWING TABLE IS THE HORIZONTAL DISTANCE,
     110H FROM SHOT,A10,31HTO THE CORRESPONDING HYDROPHONE,///)
      WRITE(2,22)
   22 FORMAT(1X,*PHONE*,3X,*X-COORDIN*,3X,*Y-COORDIN*,3X,*HORZ DIST*)
      WRITE(2,10)
      DO 5 I=1,32
      HOX=SPCX(I)-DHCX(I)
      HOX2=HOX*HOX
      HOY=SPCY(I)-DHCY(I)
      HOY2=HOY*HOY
      SPDH=SQRT(HOY2+HOX2)
      WRITE(2,4)I,SPCX(I),SPCY(I),SPDH
    4 FORMAT(2X,I2,4X,3(F9.3,3X))
    5 CONTINUE
   30 CONTINUE
      END
```

```
      PROGRAM AZIMUTH(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT)
      COMMON DHX(32),DHY(32),SP(8,2)
      READ(1,1)DHX
      READ(1,1)DHY
    1 FORMAT(10F8.2)
      M=0
    2 CONTINUE
      READ(1,3)N
    3 FORMAT(I3)
      IF(N.EQ.0)STOP
      READ(1,4)SP
    4 FORMAT(8F8.3)
      DO 10 I=1,N
      M=M+1
      DO 8 J=1,8
      X=SP(J,1)-DHX(I)
      Y=SP(J,2)-DHY(I)
      IF(ABS(Y).LT.0.01)GO TO 20
      TANG=ABS(X)/ABS(Y)
      THETA=ATAN(TANG)
      THET=THETA*180./3.1415926
      GO TO 9
   20 THET=90.
    9 IF(X.GT.0.)GO TO 30
      IF(Y.GT.0.)GO TO 31
      AZIM=360.-THET
      GO TO 40
   31 AZIM=180.+THET
      GO TO 40
   30 IF(Y.GT.0.)GO TO 32
      AZIM=THET
      GO TO 40
   32 AZIM=180.-THET
   40 WRITE(2,13)M,AZIM
   13 FORMAT(1X,I3,3X,F8.3)
    8 CONTINUE
      WRITE(2,14)
   14 FORMAT(1X,3H   )
   10 CONTINUE
      GO TO 2
      END
```

```
      PROGRAM INCIDIS(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT)
      COMMON V1,V2,H1,DELT,ALPH,DJ(32)
      COMMON V3,ANF(32),JJ,H2,X1,X2,X3,TANG,TANF,TIJ,VS1
      COMMON ANFAC,MM
      COMMON VEL,VELH,AN2
      READ(1,3)V3,H2
    3 FORMAT(2F8.3)
      READ(1,6)DJ
    6 FORMAT(10F8.2)
    1 CONTINUE
      DO 2 II=1,32
    2 ANF(II)=1.
      READ(1,4)V1,V2,H1,SLOC
    4 FORMAT(3F8.3,A10)
      IF(V2.LT.1.)STOP
      WRITE(2,10)SLOC
   10 FORMAT(1H1,*THE FOLLOWING TABLE GIVES THE PERTINENT RESULTS*,
     1* FROM SHOT*,A10,*TO THE CORRESPONDING HYDROPHONE*,///)
      WRITE(2,11)
   11 FORMAT(1X,*PHONE*,3X,*HOR DIST*,3X,*DEPTH.*,3X,*ARR TIME*,3X,
     1 *GAMA.*,3X,*VELOC*,3X,*H-VEL*,3X,*K-FACTOR*)
      WRITE(2,12)
   12 FORMAT(1X,*-----*,3X,*--------*,3X,*------*,3X,*--------*,3X,
     1 *-----*,3X,*-----*,3X,*-----*,3X,*--------*,/)
      DO 20 I=1,32
      JJ=I
      READ(1,5)DELT,TIJ
    5 FORMAT(2F8.3)
      ALPH=10.
   28 CONTINUE
      MM=0
      CALL LAYER
      IF(ABS(ANFAC-ANF(I)).LE.0.0001)GO TO 26
      ANF(I)=ANFAC
      GO TO 28
   26 CONTINUE
      ANF(I)=ANFAC
      IF(DJ(I).LT.150.)GO TO 33
      ALPH=10.
      MM=1
      AN2=1.
   29 CONTINUE
      CALL LAYER
      IF(ABS(ANFAC-AN2).LE.0.0001)GO TO 32
      AN2=ANFAC
      GO TO 29
   32 ANF(I)=ANFAC
      GAMA=180.*ATAN(TANF)/3.1415926
      GO TO 34
   33 CONTINUE
      GAMA=180.*ATAN(TANG)/3.1415926
   34 CONTINUE
      WRITE(2,30)I,DELT,DJ(I),TIJ,GAMA,VEL,VELH,ANFAC
   30 FORMAT(1X,2X,I2,5X,3(F6.2,4X),F5.2,3X,F5.3,3X,F5.3,5X,F6.4)
   20 CONTINUE
      GO TO 1
      END
```

```
      SUBROUTINE LAYER
      COMMON V1,V2,H1,DELT,ALPH,DJ(32)
      COMMON V3,ANF(32),JJ,H2,X1,X2,X3,TANG,TANF,TIJ,VS1
      COMMON ANFAC,MM
      COMMON VEL,VELH,AN2
      N=M=0
      STEP=1.
      SIGN=1.
    1 CONTINUE
      ALPH=ALPH+SIGN*STEP
      ALPHA=ALPH*3.1415926/180.
      TANA=TAN(ALPHA)
      ANF2=ANF(JJ)*ANF(JJ)
      SINA=SIN(ALPHA)
      COSEA=1./SINA
      COSEA2=COSEA*COSEA
      V22=V2*V2
      DNUM=ANF2*V2
      FACT=(V1*V1*COSEA2-ANF2*V22)
      IF(FACT.LT.0.)GO TO 21
      DEN=SQRT(FACT)
      TANG=DNUM/DEN
      IF(MM.EQ.1)GO TO 40
      X1=H1*TANA
      X2=(DJ(JJ)-H1)*TANG
      DIST=X1+X2
      GO TO 38
   40 CONTINUE
      X1=H1*TANA
      X2=(H2-H1)*TANG
      V32=V3*V3
      AN22=AN2*AN2
      COTG=1./TANG
      COTG2=COTG*COTG
      FFACT=(ANF2*V22*(1.+ANF2*COTG2)-AN22*V32)
      IF(FFACT.LT.0.)GO TO 21
      DFEN=SQRT(FFACT)
      TANF=AN22*V3/DFEN
      X3=(DJ(JJ)-H2)*TANF
      DIST=X1+X2+X3
   38 CONTINUE
      IF(ABS(DIST-DELT).LE.0.00001)GO TO 23
      IF(DIST.GT.DELT)GO TO 21
      N=1
      SIGN=1.
      IF(M.EQ.1)GO TO 20
      GO TO 1
   20 CONTINUE
      STEP=STEP/2.
      GO TO 1
   21 CONTINUE
      SIGN=-1.
      M=1
      IF(N.EQ.1)GO TO 22
      GO TO 1
   22 CONTINUE
      STEP=STEP/2.
```

```
      GO TO 1
   23 IF(MM.EQ.1)GO TO 42
      TDUL=SQRT(H1*H1+X1*X1)
      TDLL=SQRT((DJ(JJ)-H1)*(DJ(JJ)-H1)+X2*X2)
      T1=TDUL/V1
      T2=TIJ-T1
      VEL=TDLL/T2
      TANG2=TANG*TANG
      VSVZ=VEL/V2
      VSVZ2=VSVZ*VSVZ
      DEN=TANG2-VSVZ2+1.
      VELH=SQRT(VEL*VEL*TANG2/DEN)
      ANFAC=VELH/V2
      GO TO 45
   42 CONTINUE
      FLAYER=SQRT(H1*H1+X1*X1)
      SLAYER=SQRT((H2-H1)*(H2-H1)+X2*X2)
      TLAYER=SQRT((DJ(JJ)-H2)*(DJ(JJ)-H2)+X3*X3)
      VS1=ANF(JJ)*V2*SQRT((1.+TANG*TANG)/(ANF2+TANG*TANG))
      T1=FLAYER/V1
      T2=SLAYER/VS1
      T3=TIJ-T1-T2
      VEL=TLAYER/T3
      TANF2=TANF*TANF
      VSVZ=VEL/V3
      VSVZ2=VSVZ*VSVZ
      DEN=TANF2-VSVZ2+1.
      VELH=SQRT(VEL*VEL*TANF2/DEN)
      ANFAC=VELH/V3
   45 CONTINUE
      RETURN
      END
```

```
      PROGRAM PROTOR(INPUT,OUTPUT,TAPE1=INPUT)
      DIMENSION IBUF(1024),XARRAY(34),ZARRAY(34),DEPTH(34)
      READ(1,2)(DEPTH(I),I=1,32)
    2 FORMAT(10F8.2)
      DO 50 K=1,32
      DEPTH(K)=DEPTH(K)/3.2808
   50 CONTINUE
      CALL PLOTS(IBUF,1024)
      CALL PLOT(0.0,-30.,-3)
      CALL PLOT(4.0,4.0,-3)
   10 CONTINUE
      READ(1,7)SP
    7 FORMAT(A7)
      READ(1,5)MM
    5 FORMAT(I2)
      IF(MM.EQ.99)GO TO 40
      READ(1,6)(ZARRAY(I),XARRAY(I),I=1,32)
    6 FORMAT(2F7.3)
      XARRAY(33)=0.9
      DEPTH(33)=0.0
      XARRAY(34)=.05
      DEPTH(34)=50.
      ZARRAY(33)=4.0
      ZARRAY(34)=.5
      CALL AXIS(0.0,0.0,8HK-FACTOR,-8,4.0,0.0,XARRAY(33),XARRAY(34))
      CALL AXIS(0.,0.,20HVERT DEPTH IN METERS,20,8.,90.,DEPTH(33),
     4 DEPTH(34))
      CALL LINE(XARRAY,DEPTH,32,1,-1,3)
      CALL SYMBOL(0.5,7.0,.2,SP,0.0,7)
      CALL PLOT(0.0,12.,-3)
      CALL AXIS(0.,0.,13HVEL IN KM/SEC,-13,5.,0.,ZARRAY(33),ZARRAY(34))
      CALL AXIS(0.,0.,20HVERT DEPTH IN METERS,20,8.,90.,DEPTH(33),
     4 DEPTH(34))
      CALL LINE(ZARRAY,DEPTH,32,1,-1,3)
      CALL SYMBOL(0.5,7.0,.2,SP,0.0,7)
      CALL PLOT(10.,-12.,-3)
      GO TO 10
   40 CONTINUE
      CALL PLOT(4.,4.,-3)
      CALL PLOT(0.,0.,999)
      END
```

```
      PROGRAM PLOTOR(INPUT,OUTPUT,TAPE1=INPUT,TAPE2=OUTPUT)
      DIMENSION IBUF(1024),XARRAY(10),YARRAY(10),ZARRAY(10)
      DIMENSION DEPTH(32)
      READ(1,2)DEPTH
    2 FORMAT(10F8.2)
      DO 3 I=1,32
    3 DEPTH(I)=DEPTH(I)/3.2808
      CALL PLOTS(IBUF,1024)
      M=0
      CALL PLOT(0.0,-30.0,-3)
      CALL PLOT(4.0,4.0,-3)
   10 CONTINUE
      M=M+1
      READ(1,8)(ZARRAY(I),XARRAY(I),I=1,8)
    8 FORMAT(F7.3,F7.4)
      IF(XARRAY(1).GT.900.)GO TO 40
      READ(1,1)(YARRAY(I),I=1,8)
    1 FORMAT(F7.3)
      XARRAY(9)=.9
      YARRAY(9)=0.0
      XARRAY(10)=.05
      YARRAY(10)=90.
      CALL AXIS(0.0,0.0,8HK-FACTOR,8,4.0,90.,XARRAY(9),XARRAY(10))
      CALL AXIS(0.0,0.0,18HAZIMUTH IN DEGREES,-18,4.,0.,YARRAY(9),
     1 YARRAY(10))
      CALL LINE(YARRAY,XARRAY,8,1,-1,3)
      WRITE(2,6)DEPTH(M)
    6 FORMAT(1H1,6HDEPTH=,F8.3,//)
      WRITE(2,9)
    9 FORMAT(1X,*K-FACTOR*,3X,*AZIMUTH*)
      WRITE(2,14)
   14 FORMAT(1X,*--------*,3X,*-------*,/)
      WRITE(2,5)(XARRAY(I),YARRAY(I),I=1,8)
    5 FORMAT(1X,1X,F5.3,5X,F6.2)
      WRITE(2,7)
    7 FORMAT(1X,///)
      CALL PLOT(0.0,5.5,-3)
      ZARRAY(9)=4.0
      ZARRAY(10)=.5
      CALL AXIS(0.0,0.0,13HVEL IN KM/SEC,13,4.,90.,ZARRAY(9),
     5 ZARRAY(10))
      CALL AXIS(0.0,0.0,18HAZIMUTH IN DEGREES,-18,4.,0.,YARRAY(9),
     1 YARRAY(10))
      CALL LINE(YARRAY,ZARRAY,8,1,-1,3)
      CALL SYMBOL(4.,4.,.1,5HDEPTH,0.,5)
      CALL NUMBER(4.,3.75,.1,DEPTH(M),0.,2)
      WRITE(2,15)
   15 FORMAT(1X,*HOR. VEL*,3X,*AZIMUTH*)
      WRITE(2,14)
      WRITE(2,5)(ZARRAY(I),YARRAY(I),I=1,8)
      CALL PLOT(7.,-5.5,-3)
      GO TO 10
   40 CONTINUE
      CALL PLOT(4.0,4.0,-3)
      CALL PLOT(0.0,0.0,999)
      END
```