Miscellaneous Paper GL-94-10
March 1994

US Army Corps
of Engineers
Waterways Experiment
Station

Seismic Refraction and Electromagnetic Surveys at Fort Detrick, Maryland

by José L. Llopis, Janet E. Simms

WES

Prepared for U.S. Army Environmental Center

Miscellaneous Paper GL-94-10
March 1994

Seismic Refraction and Electromagnetic Surveys at Fort Detrick, Maryland

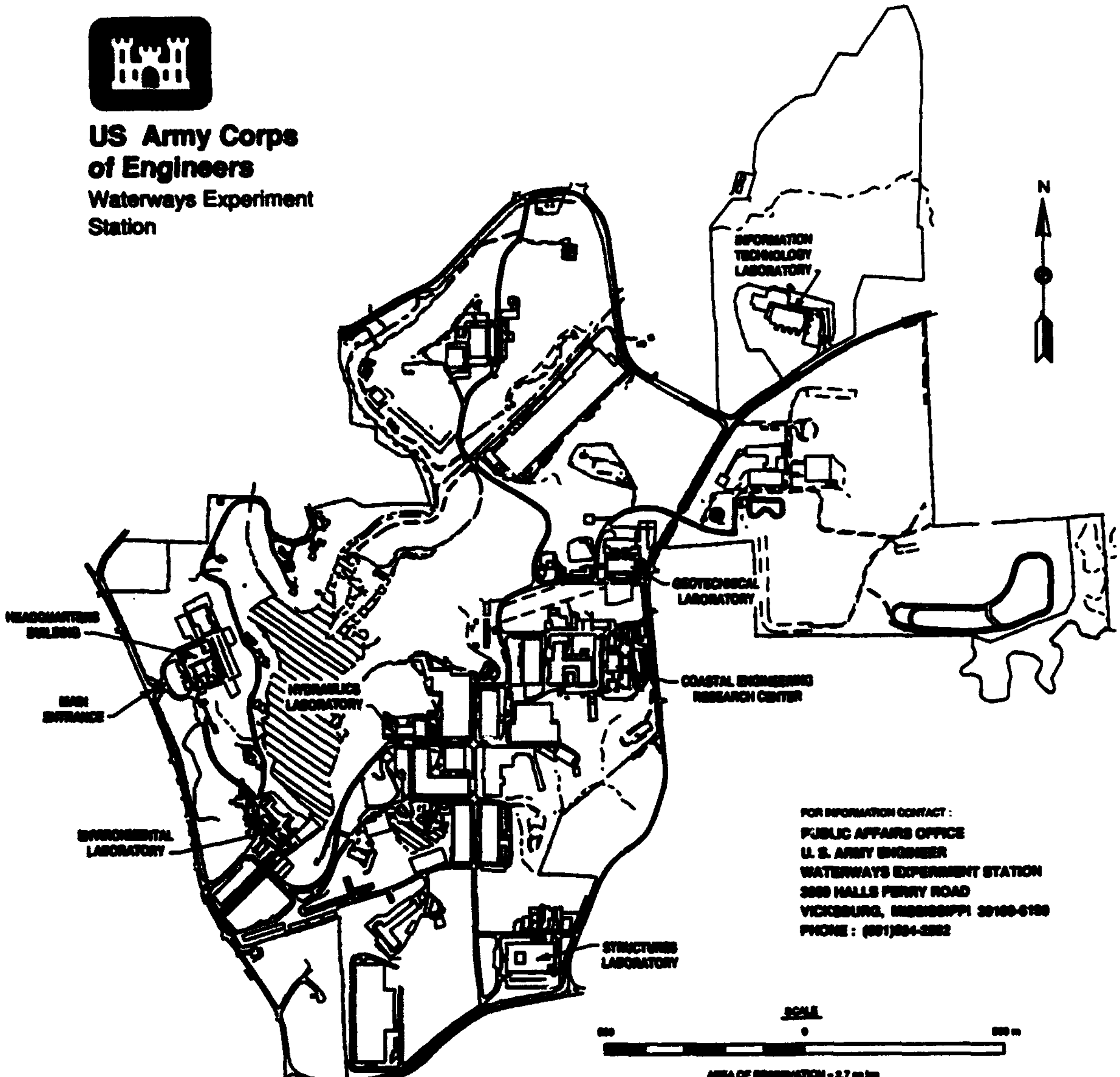
by José Llopis, Janet E. Simms

U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

Prepared for U.S. Army Environmental Center
Aberdeen Proving Ground, MD 21010-5401

US Army Corps of Engineers
Waterways Experiment Station



Waterways Experiment Station Cataloging-in-Publication Data

Llopis, José L.
Seismic refraction and electromagnetic surveys at Fort Detrick, Maryland / by José L. Llopis, Janet E. Simms ; prepared for US Army Environmental Center.
51 p. : ill. ; 28 cm. — (Miscellaneous paper ; GL-94-10)
Includes bibliographical references.
1. Soil surveys — Maryland — Fort Detrick (Frederick) — Geophysical methods. 2. Environmental monitoring — Maryland — Fort Detrick (Frederick) I. Simms, Janet E. II. U.S. Army Environmental Center III. U.S. Army Engineer Waterways Experiment Station. IV. Title. V. Series: Miscellaneous paper (U.S. Army Engineer Waterways Experiment Station) ; GL-94-10.
TA7 W34m no.GL-94-10

Contents

Preface

A geophysical investigation was conducted at Fort Detrick, Maryland, by personnel of the Geotechnical Laboratory (GL), U.S. Army Waterways Experiment Station (WES) during the period 21 through 28 June 1993. The investigation was performed for the U.S. Army Environmental Center (AEC), Aberdeen Proving Ground, Maryland. The AEC Project Engineer was Ms. Catherine Johnson and the AEC Project Geologist was Mr. Larry Nutter.

This report was prepared by Mr. José L. Llopis and Dr. Janet E. Simms, Earthquake Engineering and Geosciences Division (EEGD). The work was performed under the direct supervision of Mr. Joseph R. Curro, Jr., Chief, Engineering Geophysics Branch. The work was performed under the general supervision of Drs. A. G. Franklin, Chief, EEGD, and William F. Marcuson III, Director, GL. Field work and data analysis were performed by Mr. José L. Llopis and Dr. Janet E. Simms.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
acres	4,046.873	square meters
feet	0.3048	meters
miles (U.S. statute)	1.609347	kilometers
pounds (mass)	0.4535924	kilograms

1 Introduction

Background

Fort Detrick is located within the city of Frederick, MD approximately 47 miles west of Baltimore, MD and 45 miles north of Washington, D.C (Figure 1). From its activation in 1943 until 1969, Fort Detrick served as the nation's center for military offensive and defensive biological research. In 1969 President Nixon ordered the termination of US research in offensive biological warfare. In 1972 Fort Detrick was transferred under the command of the Office of the Surgeon General, Department of the Army. Today the major mission of the US Army Garrison at Fort Detrick is to provide centralized Base Operations Support Services, required locally or directed by higher authority, to support the facilities and operations of those tenant units assigned or attached to Fort Detrick, US Army Garrison.

Fort Detrick is divided into areas A and B (Figure 2). Area A (Main Post) is approximately 797 acres in area and contains most of the US Army Garrison facilities and all of the Post's major tenant activities. Area B is located about 0.5 miles west of the Main Post and contains approximately 399 acres. This area was used as a testing area until 1970 and a burial site from 1946 to at least 1977.

A Records Research (R/R) study was conducted at Fort Detrick in October 1976 to estimate possible contamination at the installation by chemical, biological, and radiological material, to assess the possibility of contaminant migration beyond the boundaries, and to evaluate the requirements for a preliminary survey. The R/R study reports that burial sites within Area B contain chemical, biological, radiological material and possibly unexploded ordnance (UXO's) (Department of the Army 1977).

Trichloroethylene (TCE), a suspected carcinogen, has recently been detected in water samples taken from several wells in Area B and in samples taken from water wells from private residences outside the boundaries of Area B. It is suspected that burial pits located within Area B are the source of the TCE. The main objective of an investigation, being managed by personnel of the US Army Environmental Center (AEC), is to determine whether burial pits located within Area B are the source of the TCE contamination and if so determine possible migration paths. Because of poor or no record keeping standards in the past, only the general locations of the burial pits are known.

Objectives

At the request of AEC, personnel of the US Army Engineer Waterways Experiment Station (WES) conducted a geophysical investigation at Fort Detrick during the period 21 through 28 June 1993. The objectives of the geophysical investigation were to determine the depth to bedrock and delineate the location of a geologic fault that is suspected of extending across Area B. Seismic refraction and electromagnetic (EM) methods were used to meet these objectives.

2 Area B Characteristics

Area Geology

Area B is located in the geologic subprovince called the Frederick Valley, an area about 6 miles wide and 23 miles long, which is within the Piedmont physiographic province. The ground surface is characterized by broad undulating knobs and ridges and stream valleys that are deep and narrow. Cambrian limestone and Triassic shales and conglomerates form the principal rock types underlying this area. Dip of the rock strata is usually steep and at Area B on the order of 30° to 50° (US Army Engineer District, Baltimore 1983).

Site Geology

The topography at the site is gentle and rather smooth, with elevations ranging between approximately 325 and 400 ft. MSL. In the central and northeast portions of the site are Triassic shales, mudstones, and limestone conglomerate, which are separated from Cambrian limestone by a large fault which runs from northwest to southeast and essentially through the center of the site. This fault is the subject of this geophysical investigation. The limestones are medium to massively bedded and have been solutioned to a moderate degree in which solution channels and cavities are present. These solutioned zones are often partially or nearly completely filled with a red, highly plastic, low permeability clay (US Army Engineer District, Baltimore 1983). A geologic map of the Area B is presented in Figure 3. Geologic cross sections through Area B are shown in Figure 4.

The Triassic red shale and mudstone are moderately hard and moderately jointed. The overburden is a low permeability red residual clay which ranges from about 5 to 20 ft in thickness. The Triassic conglomerate is a fanglomerate which has a consolidated coarse silty-clayey sandy matrix. The limestone conglomerate is soluble in mild acids, and is characterized by cavities and solution channels which are partially or completely clay filled. The Triassic shales are of the Newark group. The Upper Cambrian limestones are of the Frederick formation or the Rocky Springs Station member. The strike of the strata generally runs northeast to southwest and the dip is to the east-southeast about 30° to 50° (US Army Engineer District, Baltimore 1983).

Soils

Five major soil types are found in Area B and are identified as the Athol gravelly loam, Augusta gravelly loam, Hagerstown rocky loam, Lindside silt loam, and the Penn shaly loam. The Athol and Augusta gravelly loam occupy the major portion of the surface within Area B. The areal distribution of soils is shown in Figure 5. A description of the soils is presented in Table 1.

Table 1
Area B Soil Description

Soil Series	Description
Athol gravelly loam	Gravelly or rocky soils deep and well drained. Developed from weathered limestone, red shale and sandstone. Yellow-red to reddish brown, hard when dry, slightly plastic when wet. Some silt and clay occurring with depth.
Augusta gravelly loam	Gravelly or rocky soils, moderately well drained, moderately deep. Developed from colluvial and alluvial gravel and stony debris of quartzite and sandstone. Olive brown, hard when dry, sticky and plastic when wet. found on alluvial terraces and low deposits of colluvial material.
Hagerstown rocky loam	Deep, strongly developed well drained, derived from limestone. Brown to yellow red. Hard when dry, very sticky when wet. Contains many outcrops of limestone in form of ledges. Scattered rock fragments are present on the surface.
Lindside silt loam	Moderately well drained soil of floodplains and upland depressions. Developed from fine material washed from Duffield, Hagerstown, and Frankstown series. Dark gray to olive brown in color. Lower strata of clay is light to greenish blue.
Penn shaly loam	Well drained, moderately to very shallow, developed from purple to dark red shale and sandstone. Reddish brown silty to clayey loam with partly decomposed shale.

(Source: Department of the Army 1977)

3 Geophysical Test Principles and Field Procedures

Seismic Refraction Surveys

The seismic refraction method utilizes the fact that the compression-wave (P-wave) velocity of a material is dependent on its elastic properties. The method is based on the assumption that materials are locally homogeneous and isotropic and that the P-wave velocity of the subsurface materials increase monotonically. In the seismic refraction method, a seismic disturbance is usually produced by means of explosives or by striking a metal plate on the ground with a sledgehammer. The location of the seismic disturbance is considered to be a point source and the disturbance is transmitted through the ground as a series of waves. Geophones (velocity transducers) are implanted into the ground surface and laid along a straight line spaced at regular intervals. The length of the survey line depends on the required depth of investigation; a common rule of thumb is that the length of the line should be from three to four times the depth of interest. The function of the geophones is to detect the arrival of the P-wave. A geophone consists of a wire coil suspended on a spring and surrounded by a magnet. When a seismic disturbance sweeps by a geophone, the disturbance causes the magnet in the geophone to move relative to the wire coil thus generating an electrical signal. These signals are then transmitted via a cable to a seismograph where they are amplified and the time of arrival of the P-wave at each location determined.

The raw data obtained from the seismic test consists of time of arrival at each geophone location and corresponding geophone distances. The seismic refraction data is interpreted by plotting the P-wave arrival time versus geophone distance from the seismic source. Straight line segments are drawn through the plotted points. Points falling on or near the same straight line segment are interpreted to correspond to the same subsurface layer. The inverse slopes of the line segments drawn through the data points represent the P-wave velocities of the layer. The use of the delay-time data analysis method described by Redpath 1973 allows depths to interfaces beneath each shot point to be calculated.

An explosive called Kinepak was used as the seismic energy source for the refraction surveys. Kinepak is a two-component explosive consisting of ammonium nitrate (solid component) and nitromethane (liquid component). The solid component is packaged in rigid plastic tubes into which a pre-measured amount of the liquid component is poured on-site. After the liquid component has had time to mix with the solid component (approximately 15 min.) the mixture becomes a cap sensitive explosive.

Sticks of Kinepak were placed in the bottom of an augured 2-ft deep by 6-in. diameter shothole and backfilled with soil and tamped to minimize "blow-out" when detonated. The amount of Kinepak placed in a shothole varied between 1 and 4 sticks (approximately 0.3 to 1.3 lbs.) depending on site conditions. Reynolds Industries Model RP-83 exploding bridgewire (EBW) detonators were used to detonate the explosive charges. EBW's detonators differ from the standard blasting cap in that they contain only secondary explosives. The output is equivalent to the Mil Spec blasting cap but it is significantly safer to store, handle, and connect to the firing line because it does not contain any primary explosives.

The location of refraction lines R-1 and R-2 are shown in Figure 6. Lines R-1 and R-2 each consist of four separate end-to-end refraction lines or sections each 365 ft long. Figure 7 shows a typical seismic refraction line layout used for this investigation. Each section consisted of twenty-four geophones spaced 15 ft apart. Shothole locations were offset 15 and 90 ft from the end of each section. A shothole was also located in the center of each section. No 90-ft offset or center shots were used for Sections 3 and 4 of Line R-2.

EM Surveys

The EM technique is used to measure differences in terrain conductivity. Like electrical resistivity, conductivity is affected by differences in soil porosity, water content, chemical nature of the ground water and soil, and the physical nature of the soil. In fact, for a homogeneous earth, the true conductivity is the reciprocal of the true resistivity. Some advantages of using the EM over the electrical resistivity technique are (a) less sensitivity to localized resistivity inhomogeneities, (b) no direct contact with the ground required, thus no current injection problems, (c) smaller crew size required, and (d) rapid measurements (McNeil, 1980).

The EM equipment selected for this investigation was a Geonics model EM-34-3-DL conductivity meter. The EM-34 is a two-person portable system consisting of separate transmitter and receiver consoles and transmitter and receiver coils (loop antennae). The transmitter coil is energized with an alternating current at an audio frequency to produce a time-varying magnetic field which in turn induces small eddy currents in the ground. These currents then generate secondary magnetic fields which are sensed together with the primary field by the receiver coil. The units of conductivity are millimhos per meter (mmho/m) or, in the SI system, milliSiemens per meter (mS/m). The EM-34 is calibrated to read directly in mmho/m in areas where conductivities range between 1 and 100 mmho/m. The EM data are then presented in profile plots or as isoconductivity contours if data are obtained in a grid form. A more thorough discussion on EM theory and field procedures is given by Butler (1986), Telford et al. (1973) and Nabighian (1988).

The EM-34 transmitter operates at switch-selectable, controlled frequencies of 6.4, 1.6, and 0.4 Khz, and each frequency is keyed to transmitter-receiver (Tx-Rx) spacings of 10, 20, and 40 m, respectively. The EM-34 meter reading is a weighted average of the earth's conductivity as a function of depth. Referring to Figure 8, for the horizontal dipole case (Tx-Rx coils vertically and co-planar) 30 percent of the response at the surface is due to material deeper than 0.75 times the Tx-Rx coil separation. Therefore, for the horizontal dipole case a rule of thumb is that the depth of investigation is approximately equal to 0.75 times the Tx-Rx coil separation.

Horizontal EM profiling refers to the technique whereby the Tx-Rx coils are translated along a profile line keeping the frequency and coil spacing constant. A horizontal EM profile line will reflect variations of EM properties such as variations in soil or rock type and/or subsurface geometry such as variations in depths to interfaces within the depth of investigation, although strictly speaking, the depth of investigation itself will vary as the other parameters vary. Also, by expanding the Tx-Rx coil spacing about a point on the surface, the variation of EM properties as a function of depth can be obtained. Therefore, by conducting an EM horizontal profile line along a survey line using several coil separations a model of the thickness and conductivity of the subsurface layers can be obtained.

Figure 6 shows the location of the two EM profile lines, EM-1 and EM-2, that were conducted in Area B. EM line EM-1 was run coincident with refraction line R-1. The EM surveys were conducted using Tx-Rx coil separations of 20 and 40 m. The measurements were taken at 25-ft increments using the horizontal dipole survey mode.

4 Test Results and Interpretation

Seismic Refraction Surveys

The time-distance (TD) plots for refraction line R-1, Sections 1 through 4 are presented in Figures 9 through 12, respectively. Table 1 shows the symbols used to plot the TD data for a particular shotpoint offset.

Table 1
Key to symbols used in seismic refraction TD plots

Symbol	Shotpoint location
○	Offset 15 ft from SW end of line
●	Offset 90 ft from SW end of line
▲	Offset 15 ft from NE end of line
▴	Offset 90 ft from NE end of line
*	Center of line

The interpretation of the TD plots reveals three velocity layers for line R-1. P-wave velocity cross section plots for seismic Sections 1 through 4 are presented in Figures 13 through 16, respectively. Figure 17 shows the velocity sections for seismic Sections 1 through 4 placed end-to-end. The seismic refraction interpretation for line R-1 are summarized in Table 2.

Examination of the velocity cross section (Figure 17) indicates a very irregular bedrock surface. The TD plots (Figures 9-12) show significant scatter in the time of arrivals from the third layer. This indicates that the depth to the top of the bedrock is highly variable. It is noted that the calculated depths to the top of the bedrock and velocities, as shown in the cross section, are based on certain assumptions briefly mentioned above.

Table 2 Seismic refraction results, Line R-1			
Layer number	Approximate Velocity range, fps	Approximate depth to top of velocity layer, ft	Possible material type
1	1400 to 2100	Surface	Dry, loose overburden
2	2600 to 3500	4 to 6	Dry, overburden - highly weathered bedrock
3	13,500 to 14,800	9 to 39	Sound bedrock

The time-distance (TD) plots for refraction line R-2, Sections 1 through 4 are presented in Figures 18 through 21, respectively. The interpretation of the TD plots also reveals three velocity layers for Line R-2. P-wave velocity cross sections plot for seismic Sections 1 through 4 are presented in Figures 22 through 25, respectively. Figure 26 is a velocity cross section of seismic Sections 1 through 4 placed end-to-end. The interpreted results for line R-2 are summarized in Table 3.

Table 3 Seismic refraction results, Line R-2			
Layer number	Approximate Velocity range, fps	Approximate depth to top of velocity layer, ft	Possible material type
1	1475 to 1850	Surface	Dry, loose overburden
2	2900 to 3000	3 to 7*	Dry, overburden - highly weathered bedrock
3	13,050 to 16,100	10 to 49	Sound bedrock

* Layer 2 pinches-out towards the southern end of the line.

The results for lines R-1 and R-2 exhibit the same characteristics. Both lines indicate three velocity layers with corresponding velocities and depths to interfaces that agree very well. Both lines indicate that the depth to top of rock is highly variable indicating that the bedrock may be pinnacled because of weathering.

As indicated in Tables 2 and 3 there is a very large velocity contrast between layers 2 and 3. In cases where large velocity contrasts between successive layers exist a "blind zone" should be suspected. A blind zone refers to a layer that cannot be detected because of insufficient velocity contrast or thickness. The error that results from not knowing the existence of a blind zone is that the computed depth to the refracting layer is too shallow.

As an illustration of the magnitude of the error that can occur by having a blind zone consider the following example: Assume two velocities 3000 and 14,000 fps and it is suspected that there is a hidden layer between the low velocity (3000 fps) layer and the 14,000 fps bedrock refractor. Also assume that the thickness of the 3,000 fps velocity layer has a thickness of 20 ft. If it is also assumed that a suspected blind zone has a velocity of 5,000 fps (velocity of saturated sediments) how thick could it be and still not be detected? For this example it turns out that the maximum undetectable thickness of the hidden layer is approximately 13 ft. Therefore the depth to the bedrock refractor can range from a minimum of 20 ft (no hidden layer) up to a maximum depth of 33 ft; *i.e.*, 13 ft + 20 ft.

A fault with different geological materials on either side with little or no vertical displacement must have a sufficient seismic velocity contrast between the two rock types in order to be detectable with the refraction method. If there is a sufficient velocity contrast between materials on either side of the fault, the TD plot should indicate the velocity corresponding to the materials on each side of the fault. However, the ability to resolve a fault from the survey may be difficult if the site is geologically "noisy", i.e., irregular refractor surfaces, boulders, etc. When there is an irregular refractor surface the TD points tend to exhibit considerable scatter. This makes it very difficult to determine accurate velocities and thus reduces the ability to determine the existence of the fault.

The TD plot should be examined to ascertain if there is a time offset caused. A time offset from a refractor surface may be indicative of a vertical displacement in the refracting layer along the survey line. In this case there does not have to be a velocity contrast between the materials on either side of the fault in order to be detectable however, there must be adequate displacement of materials on either side of the fault. Again, if the data are noisy it is difficult to determine if the time offsets are caused by a fault displacement or by irregularities in the top of the refractor.

Examination of the TD plots for line R-1, particularly Sections 1 and 2, Figures 13 and 14, respectively, indicate anomalous data point scatter. The variability in the time of arrivals may be caused by variations in the depth to top of rock, voids, fractures, or horizontal velocity changes. These two sections indicate anomalous subsurface conditions which may be indicative of solutioning or variable depth of weathering.

Referring to the composite velocity profile for line R-2 (Figure 26), it can be seen that the average depth to bedrock is approximately 15 ft between distances of 15 and 360 ft at which point the depth to bedrock has an average of 25 ft to a distance of approximately 840 ft. Between distances of 840 and 1035 ft a large bedrock trough with a maximum depth of 50 ft has been interpreted. An alternative interpretation for the area between distances of 840 and 1035 ft is that there is a localized low-velocity zone possibly due to clay infilling or a shear/fracture zone.

The interpreted results are only as valid as the assumptions used. For example, lateral velocity changes are not handled very well by the delay-time interpretation method. The data interpretation should be evaluated in conjunction with other site information, such as logs from nearby wells, in order to improve upon the interpretation and to determine the validity of the interpreted model.

EM Surveys

The results for line EM-1 are presented in Figures 27 through 29. Figures 27 and 28 are plots of conductivity versus depth using 20 and 40 m coil spacings, respectively. The conductivity values for the 20 m data range between approximately 0.5 and 10 mS/m. The location of the extremely low values at distances of 167 and 1,542 ft correlate with the known locations of steel-wire fences located at distances of 181 and 1577 ft. The 20 m data show a high conductivity area between distances of approximately 217 and 392 ft. Between approximately 392 and 792 ft the conductivity values decrease from approximately 9.5 to 3 mS/m and remain relatively constant to a distance of 1592 ft at which point they begin to steadily increase to the northeastern end of the line. The 40 m data (Figure 28) is a little noisy however, the data show the same general trend as that of the 20 m data. The similarity in the trend between the 20 and 40 m spaced data is better illustrated when the data are plotted together as shown in Figure 29. In the 40 m data set, the high-valued conductivity data point located at a distance of 517 ft is considered to be a spurious data point and is disregarded. The 40 m data set, in general, seems to have a slightly higher or no difference in conductivity values than those of the 20 m data set. This would indicate that a. in the case where there is no change in conductivity values with respect to coil spacing that the EM survey detected only one layer along the survey line or b. in the case where there is a slight increase in conductivity with increasing coil spacing the conductivity of the material increases with depth thus indicating a possible increase in clay and/or water content with depth. In general, the variability in conductivity along the line is not significant with the exception of the area between 200 and 400 ft. The high conductivity values in this area may be caused by a localized increase in clay and/or water content which may or may not be associated with a fracture zone.

The results for line EM-2 are presented in Figures 30 through 32. Figures 30 and 31 are plots of conductivity versus depth using 20 and 40 m coil spacings, respectively. The conductivity values for the 20 m data range between approximately 3.5 and 8 mS/m. Conductivities between distances of -33 and 142 ft tend to have a decreasing trend towards the north. From a distance of 142 to the northern end of the line the data show a general increasing trend with minor fluctuations. The lower conductivity value at 742 ft is caused by a wire fence and a metal gate in the area. The 40 m data show a range of conductivities between approximately 1.5 and 5 mS/m with the same general trend as displayed by the 20 m conductivity data. The 40 m data has consistently lower conductivity values than the 20 m data as shown in Figure 32. The lower conductivity values for the 40 m data set implies that conductivity values decrease as a function of depth. This may suggest that a second deeper layer, possibly bedrock, with a lower clay and/or water content has been encountered. The lack of a significant shift in conductivity values along the survey line indicates that a fault contact was not crossed.

5 Summary and Conclusions

A geophysical investigation was conducted to determine the depth of bedrock and to delineate a suspected geologic fault with a northwest-southeast orientation that runs through the center of Area B. Cambrian limestones are mapped southwest of the fault whereas Triassic shales are mapped northwest of the fault. Two seismic refraction and two EM survey lines were run at Area B. The seismic refraction method was used to obtain velocity cross sections along each of the 1440-ft long survey lines. The velocity cross sections indicated three velocity zones. The two uppermost layers are interpreted as corresponding to dry unconsolidated materials. The third and deepest layer, ranging in depth between approximately 9 and 49 ft, and having velocities ranging between 13,050 and 16,100 fps is presumed to correspond to bedrock.

The results from Line R-1 show a highly variable depth to bedrock for the southern 700 ft of the survey line probably caused by a high degree of bedrock dissolution and weathering. An anomalously deep trough was interpreted for Line R-2 in an area spanned by distances 840 and 1035 ft. The anomalous seismic results for this section can also be alternatively interpreted as being a result of a low velocity zone possibly caused by fractures associated with a fault zone. No clear evidence of a fault was found along seismic refraction lines R-1 or R-2.

Two EM lines were run at the site to determine the location of the geologic fault. The maximum length of EM survey lines EM-1 and EM-2 were 1,865 ft and 925 ft, respectively. The maximum depth of investigation for these surveys was approximately 100 ft. In general, the range of conductivity values for the EM surveys was between 2 and 10 mS/m. The narrow range of conductivity values shown by both EM survey lines indicates that the survey lines did not cross a fault contact with materials having contrasting electrical properties such as would be expected when crossing from relatively low conductivity limestone to a relatively high conductivity shale material.

References

Butler, D. K. (1986). "Military Hydrology; Report 10: Assessment and field examples of continuous wave electromagnetic surveying for ground water," Miscellaneous Paper EL-79-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Department of the Army (1977). "Installation Assessment of Fort Detrick, Maryland," Record Evaluation Report No. 106, Vol. 1, Office of the Project Manager for Chemical Demilitarization and Installation Restoration, Aberdeen Proving Ground, MD.

McNeil, J. D. (1980). "Electromagnetic terrain conductivity measurements at low induction numbers," Technical Note TN-6, Geonics Limited, Mississauga, Ontario, Canada.

Nabighian, M. N. (1988). *Electromagnetic methods in applied geophysics*, Vol. 1, Society of Exploration Geophysicists, Tulsa, OK.

Palmer, D. (1980). *The generalized reciprocal method of seismic refraction interpretation*, Society of Exploration Geophysicists, Tulsa, OK.

Redpath, B. B. (1973). "Seismic refraction exploration for engineering site investigations," Technical Report E-73-4, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Telford, W. M., Geldhart, L. P., Sheriff, R. E., and Keys, D. A. (1973). *Applied Geophysics*, Cambridge University Press, NY.

US Army Engineer District, Baltimore (1983). "Study of proposed sanitary landfill Area B, Fort Detrick, Maryland," Baltimore, MD.

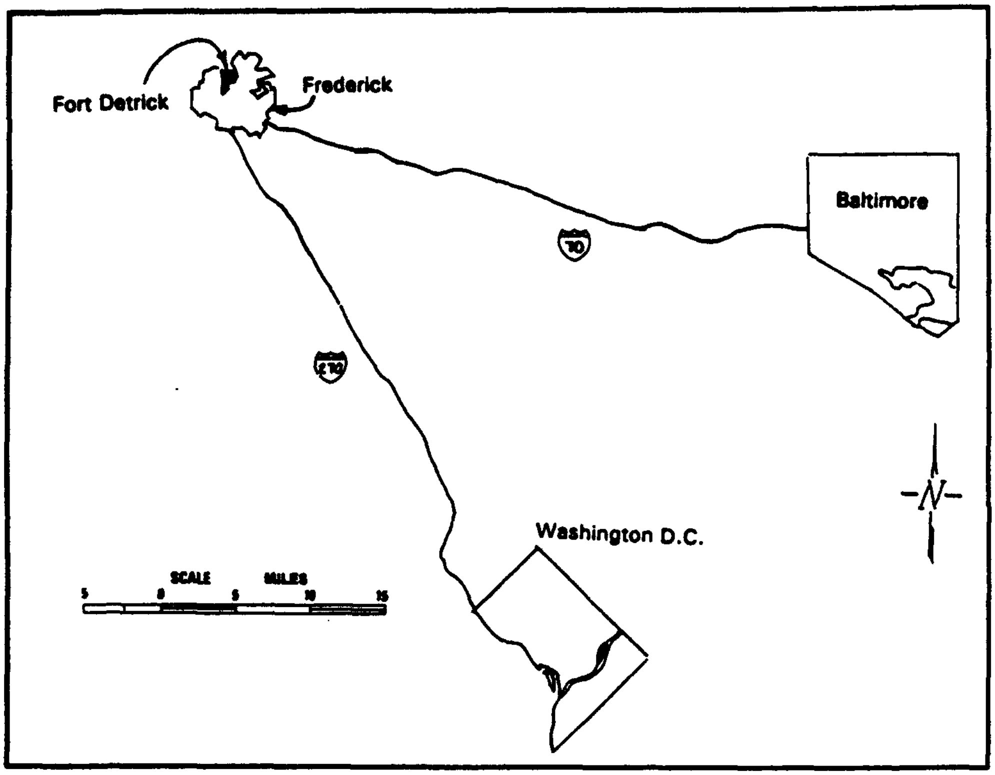


Figure 1. Vicinity map

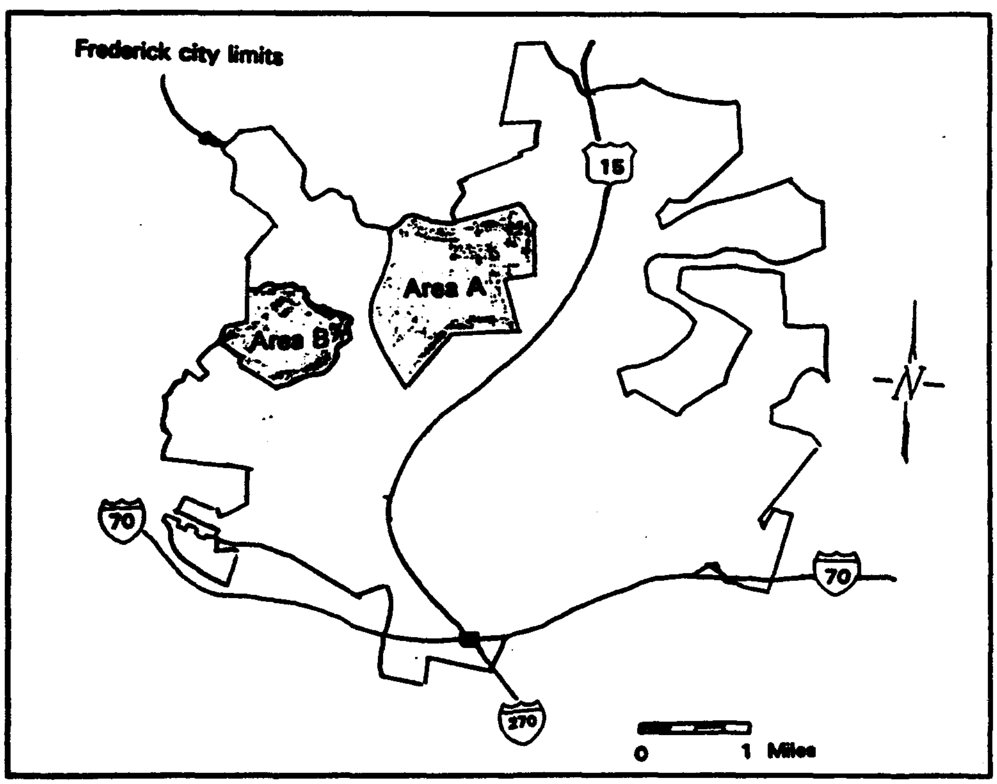


Figure 2. Location of Areas A and B, Fort Detrick

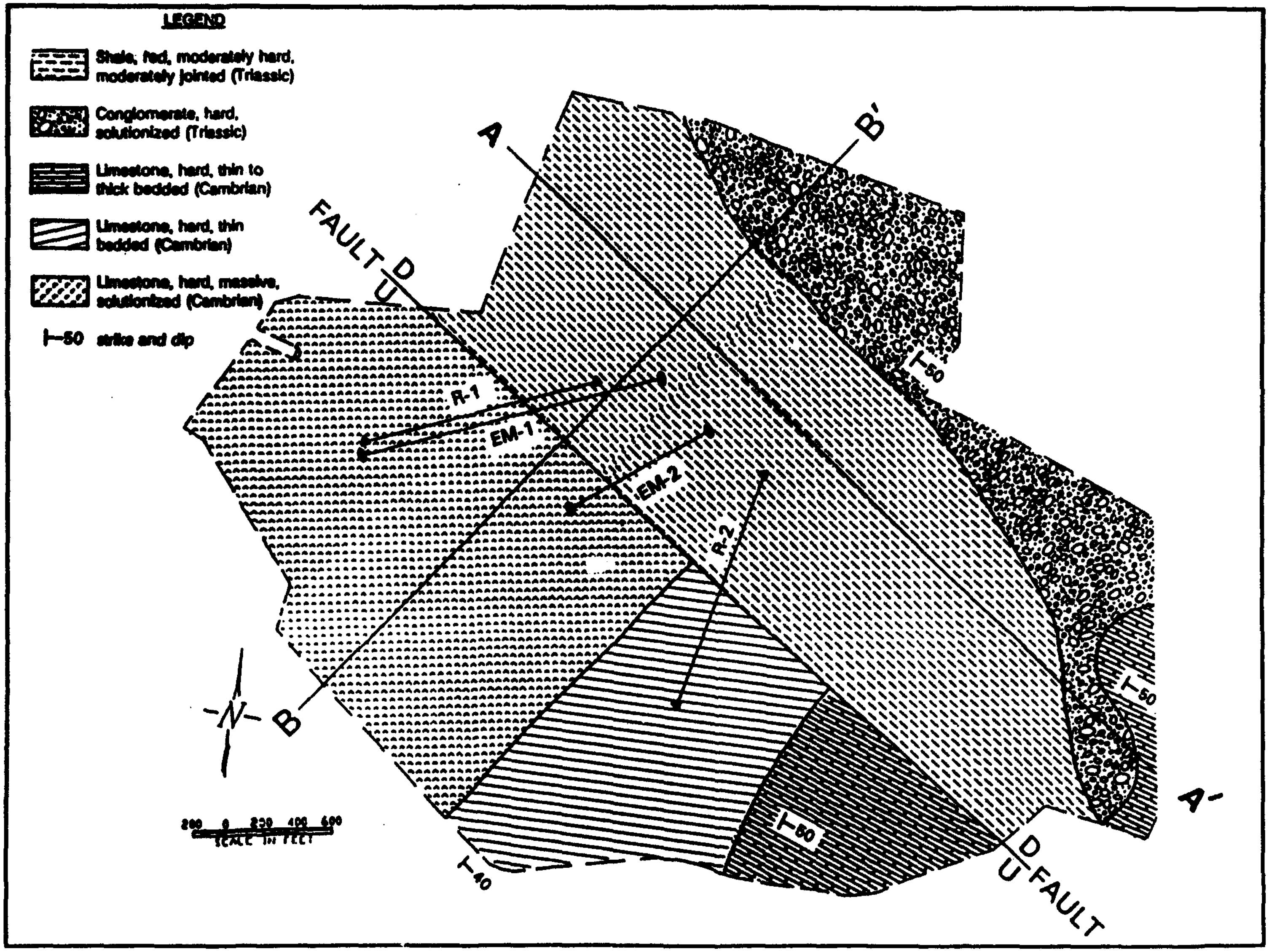


Figure 3. Geologic map of Area B

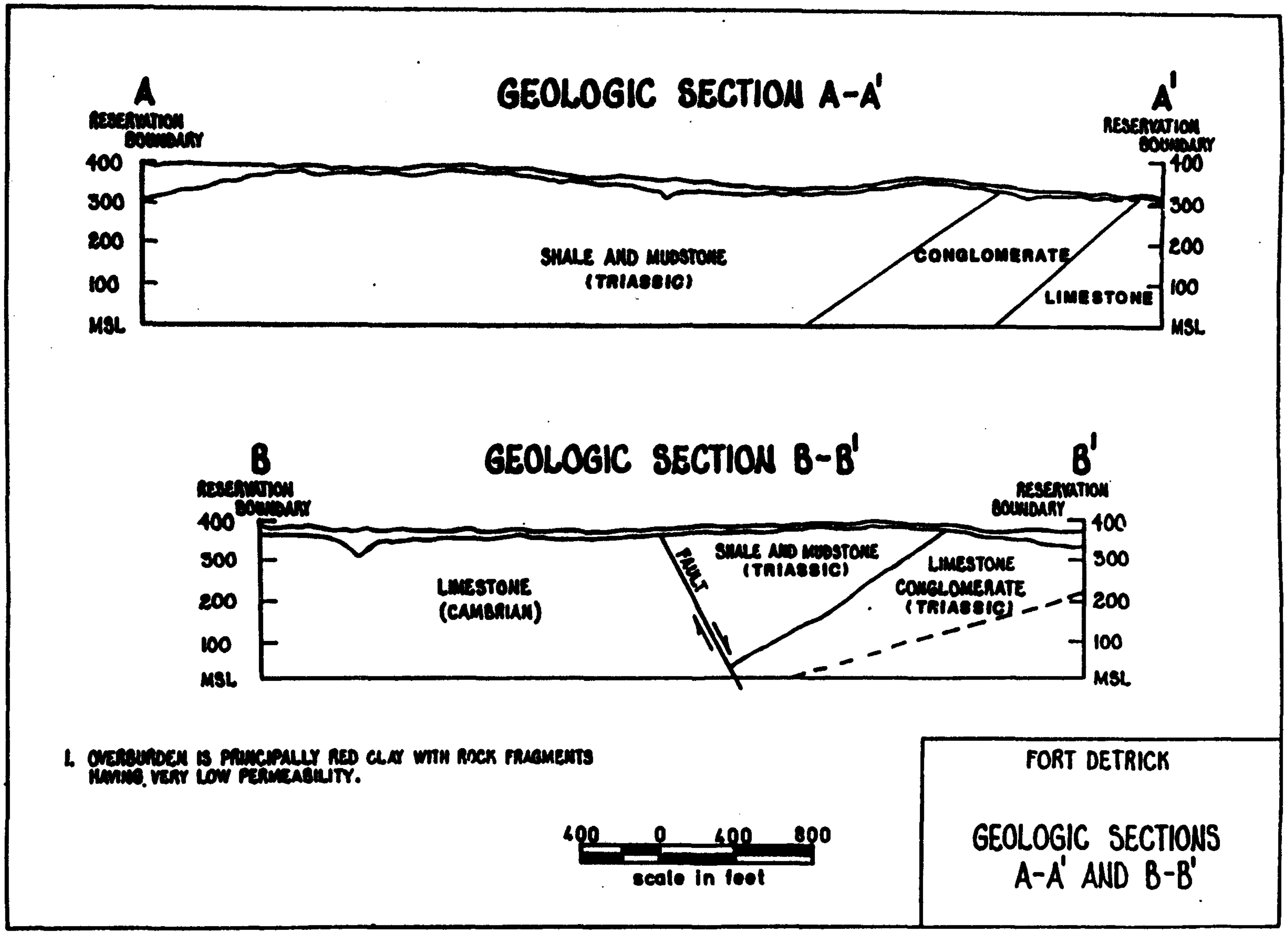


Figure 4. Geologic cross section, Area B

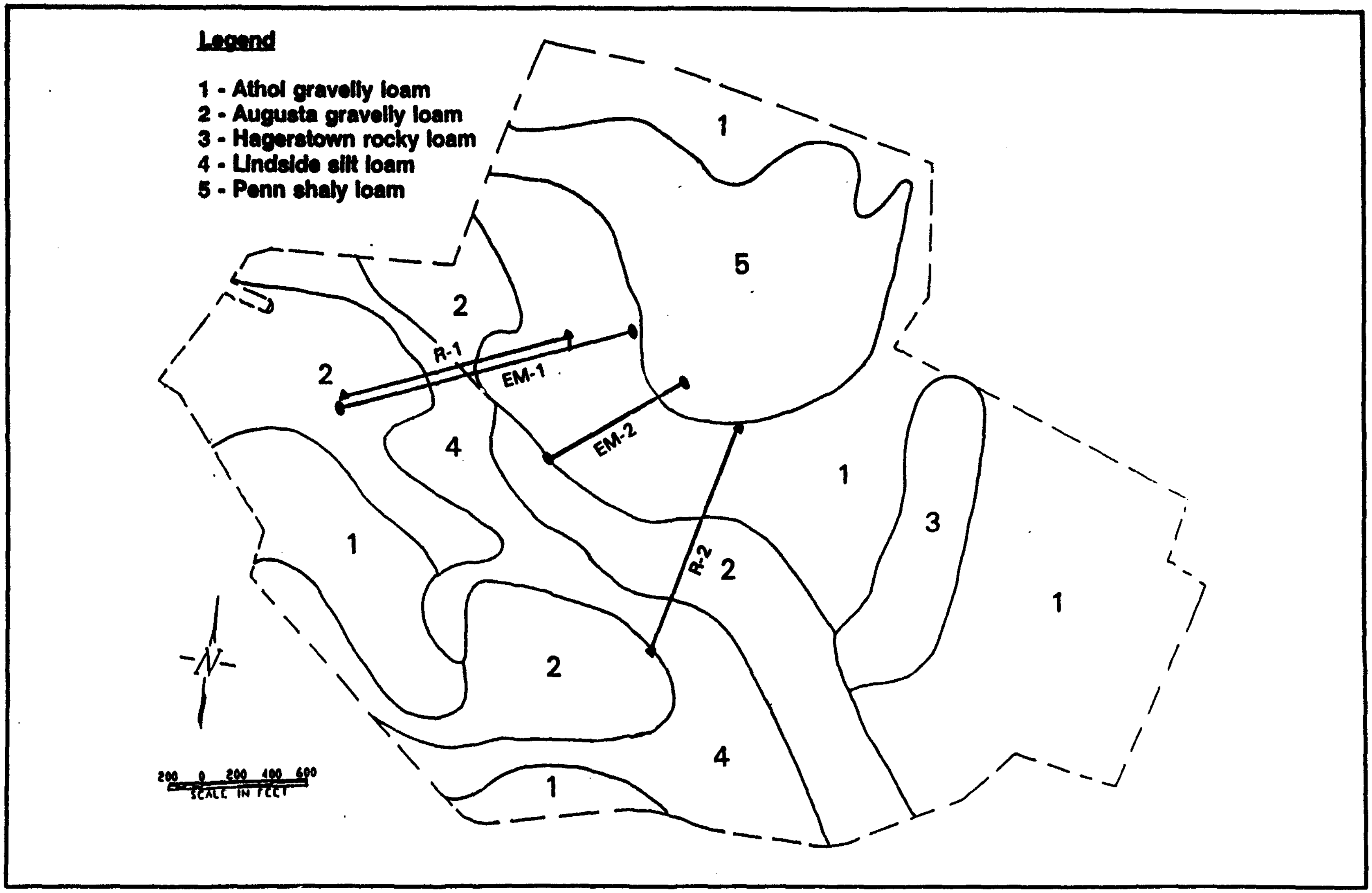


Figure 5. Areal soil distribution map, Area B

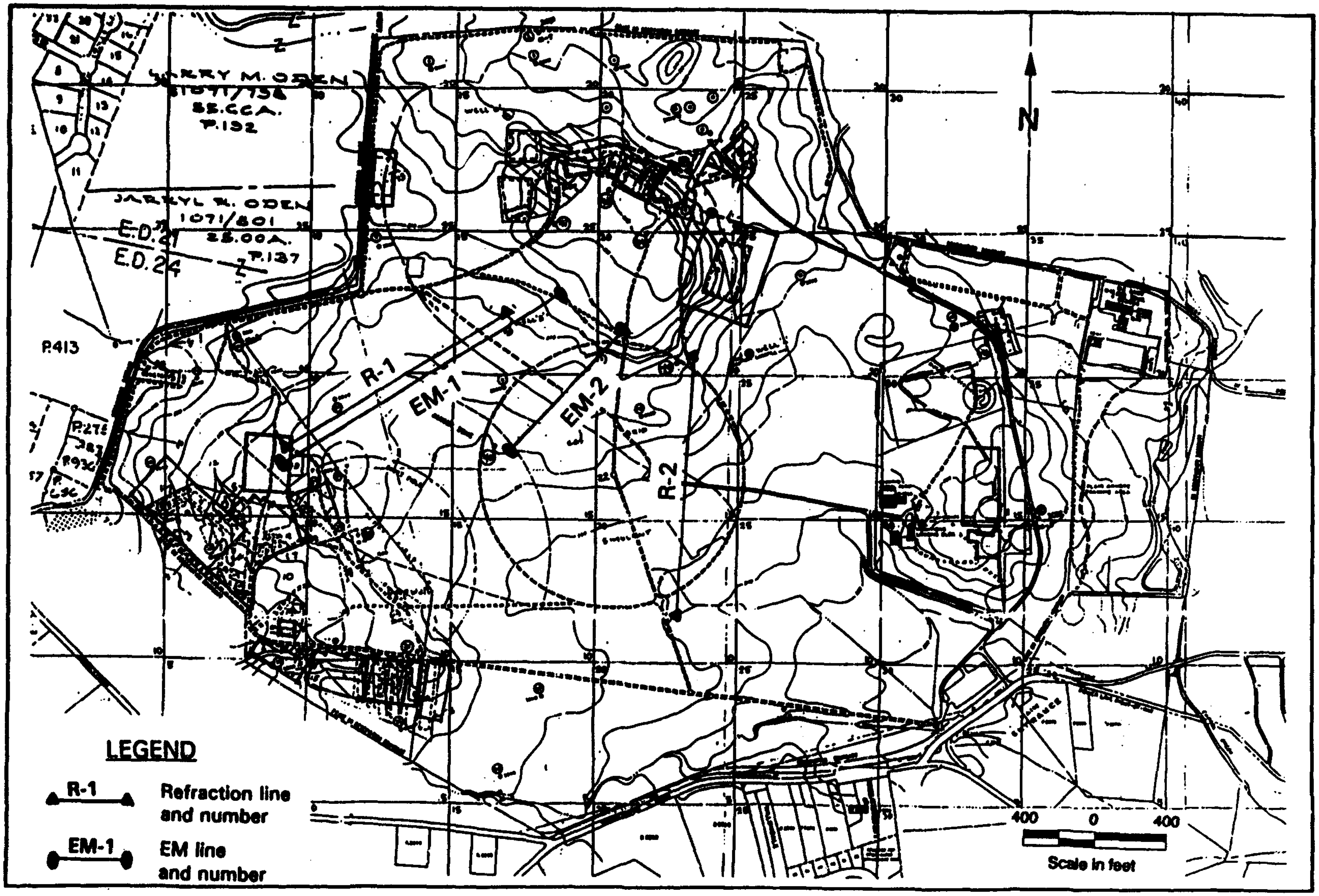


Figure 6. Geophysical test layout

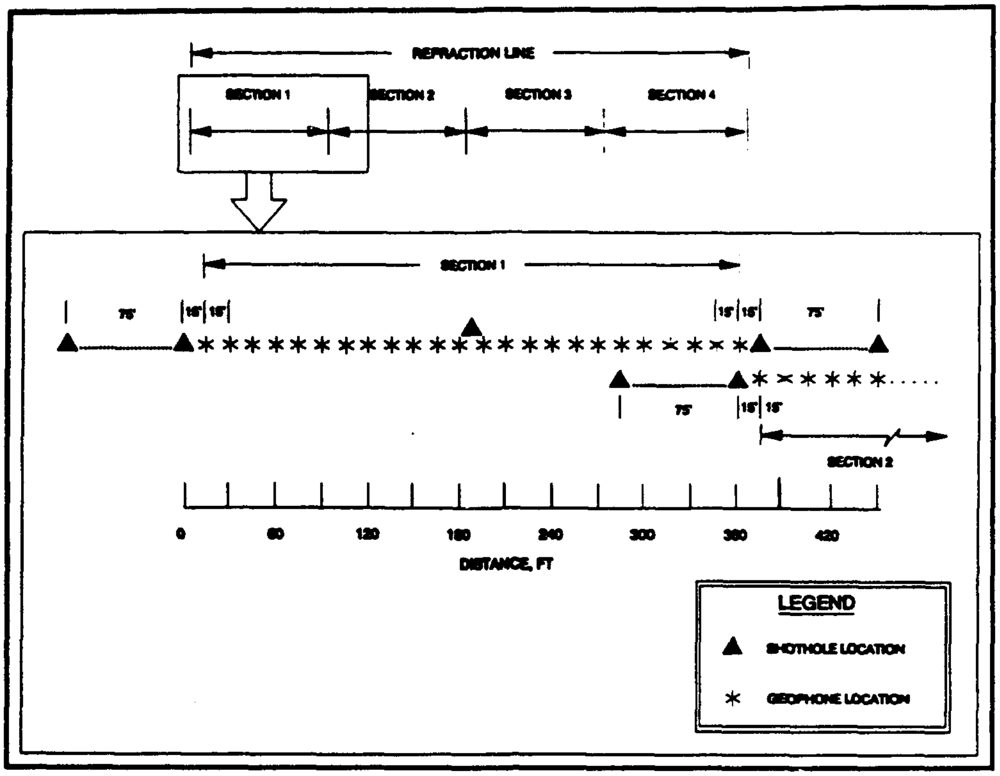


Figure 7. Refraction line layout

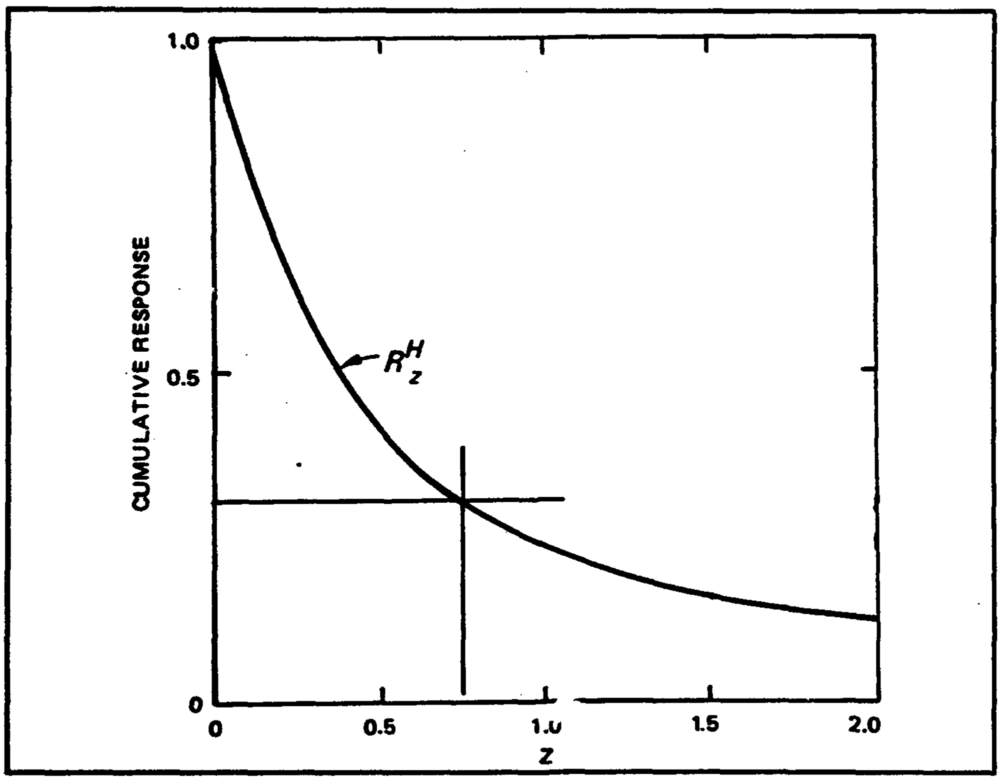


Figure 8. Cumulative response versus depth for horizontal dipoles

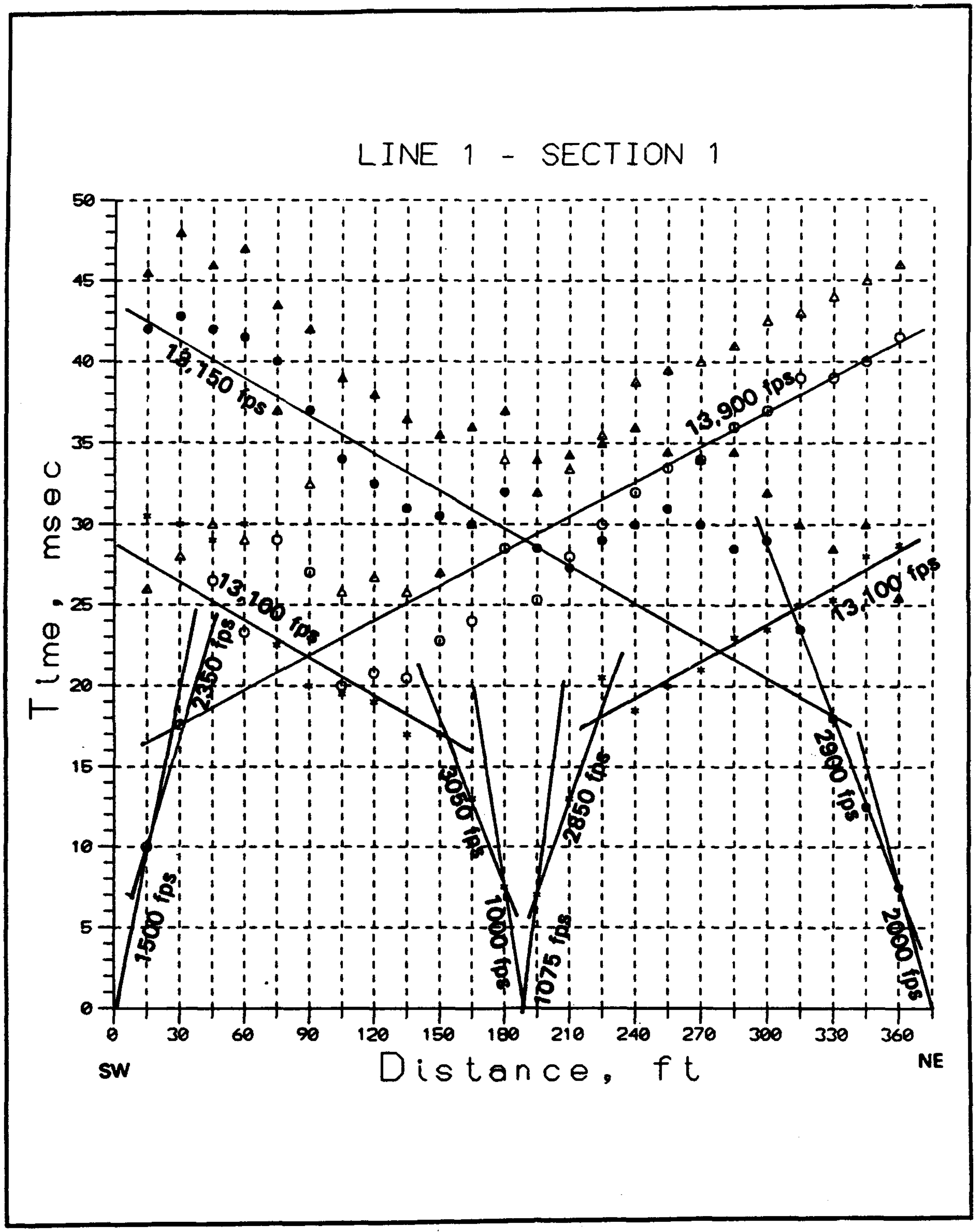


Figure 9. Time versus distance plot, line R-1, section 1

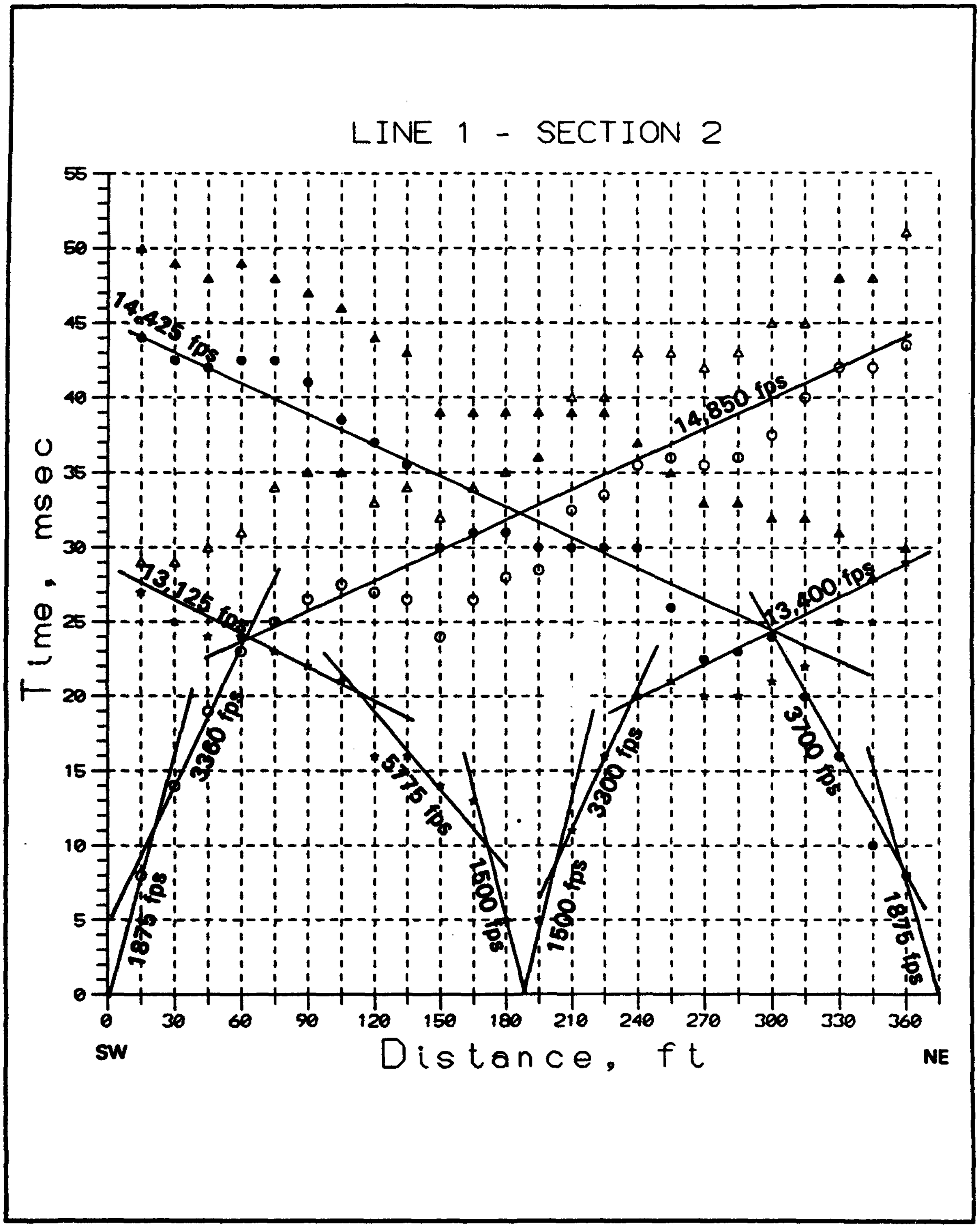


Figure 10. Time versus distance plot, line R-1, section 2

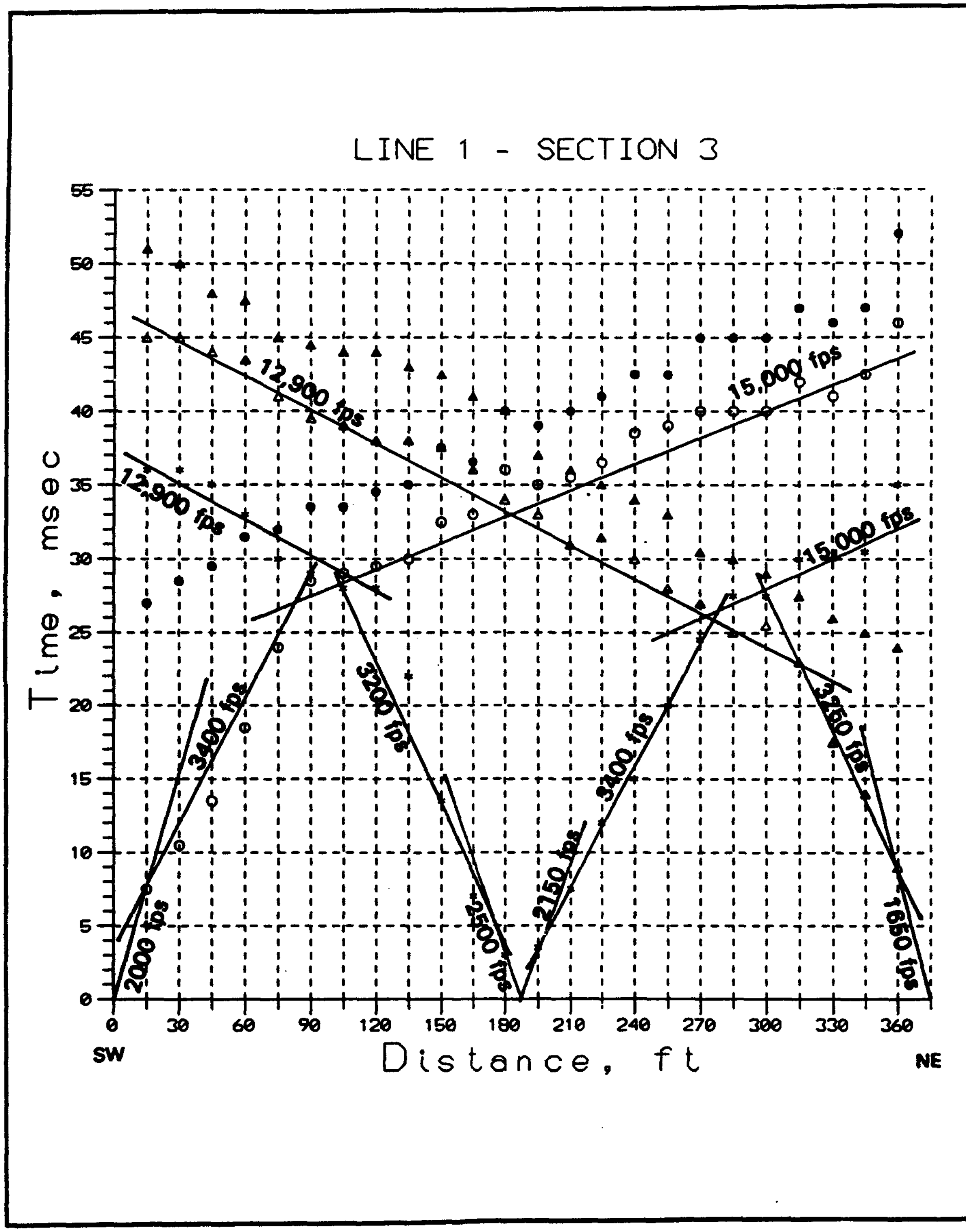


Figure 11. Time versus distance plot, line R-1, section 3

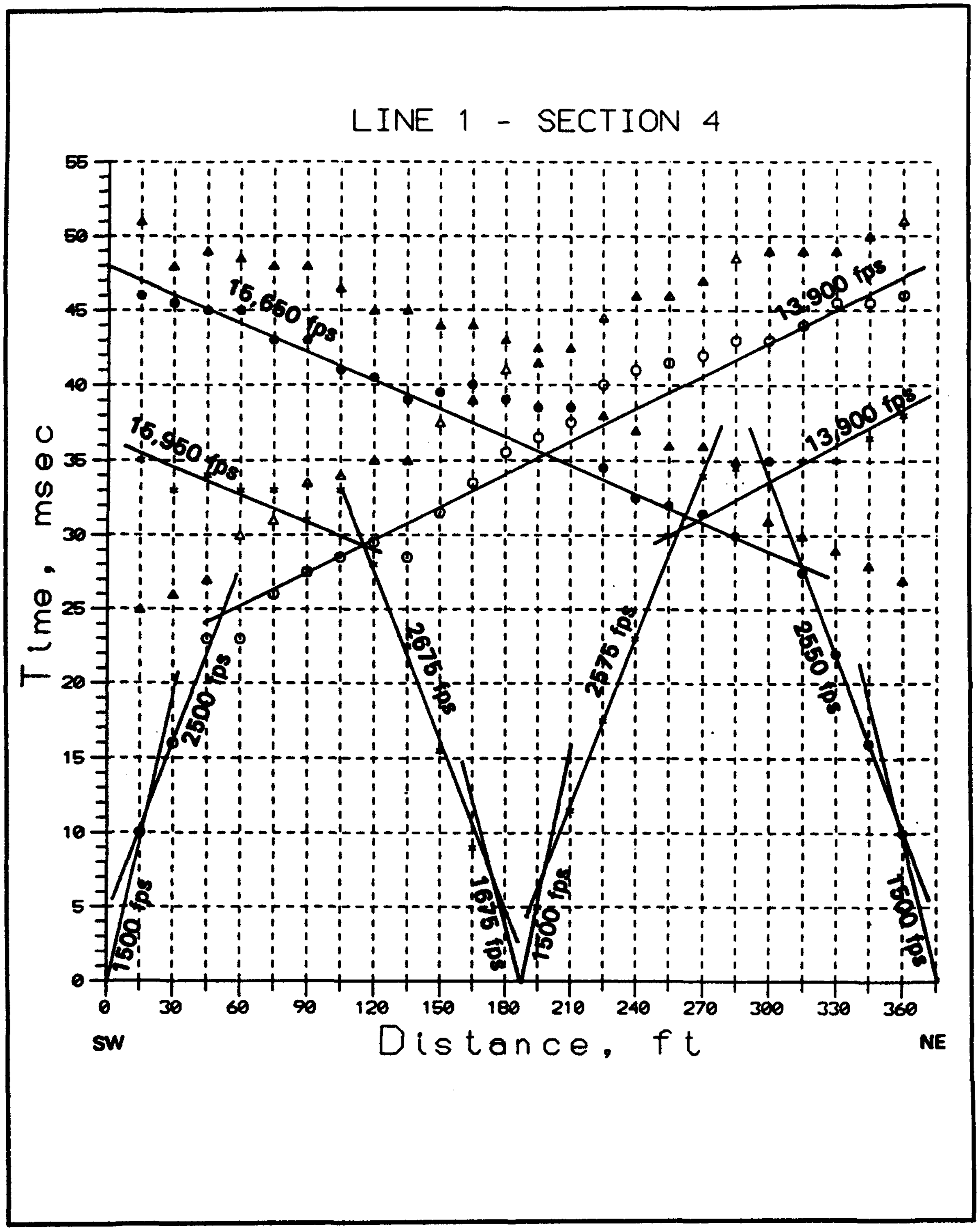


Figure 12. Time versus distance plot, line R-1, section 4

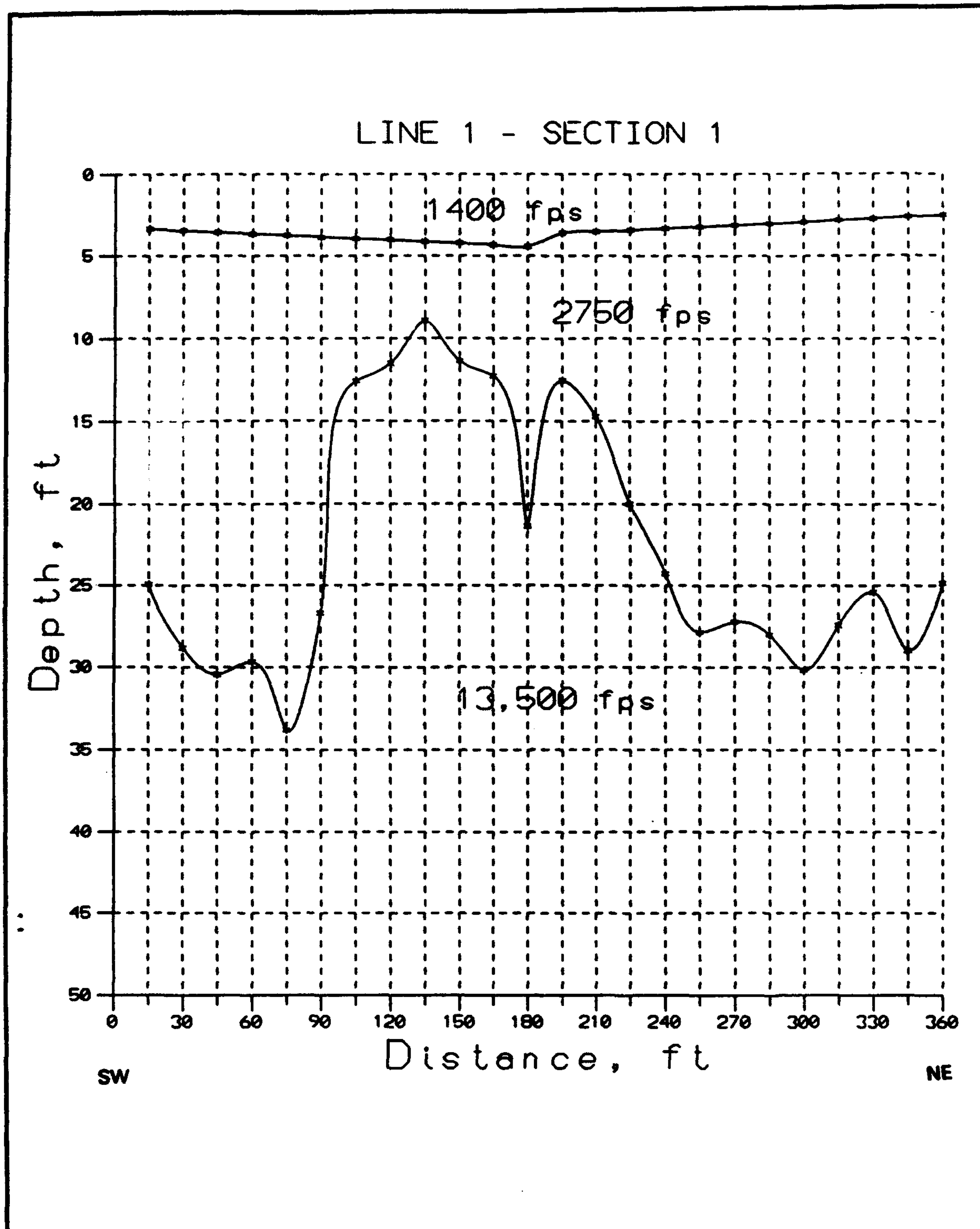


Figure 13. P-wave velocity cross section, line R-1, section 1

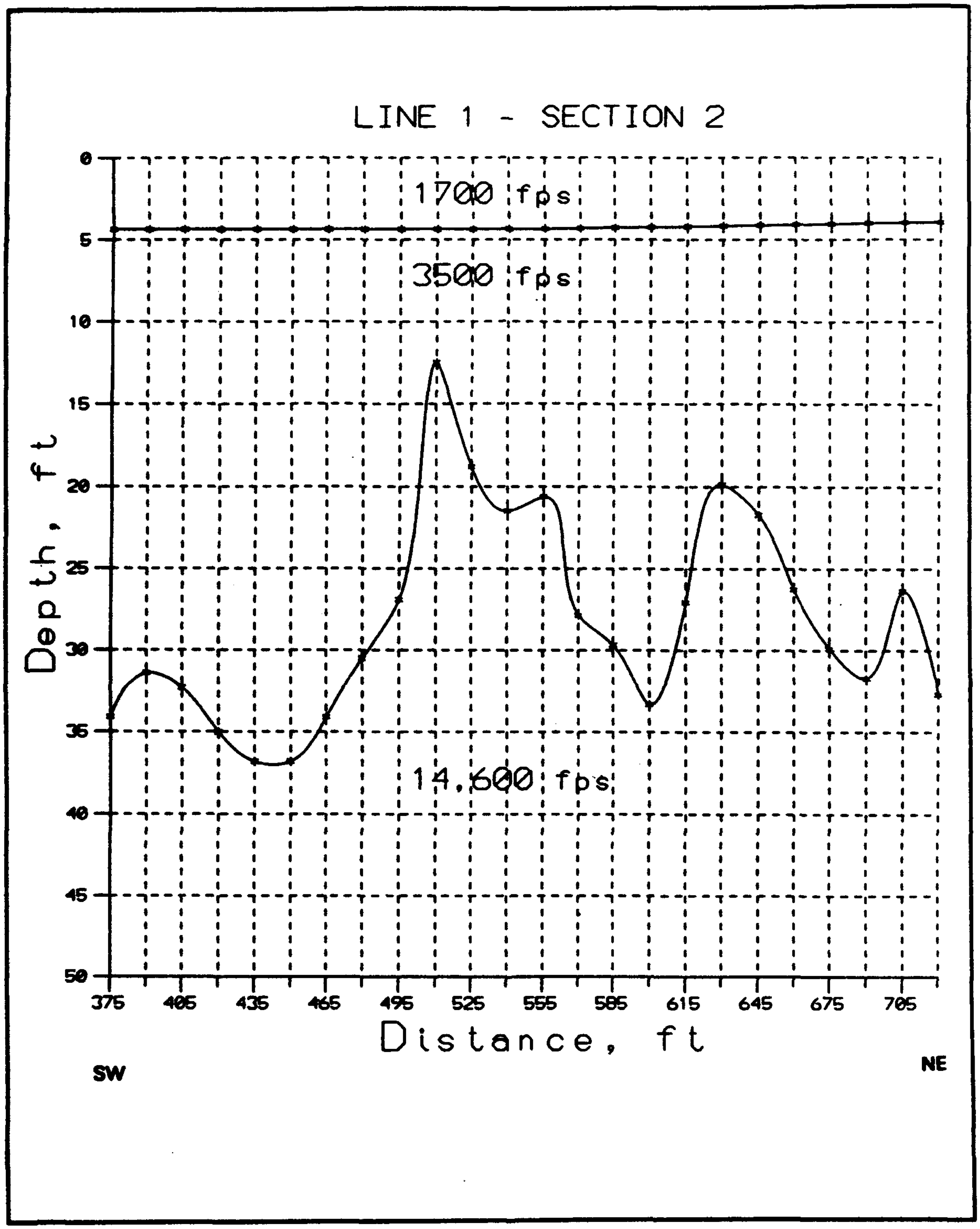


Figure 14. P-wave velocity cross section, line R-1, section 2

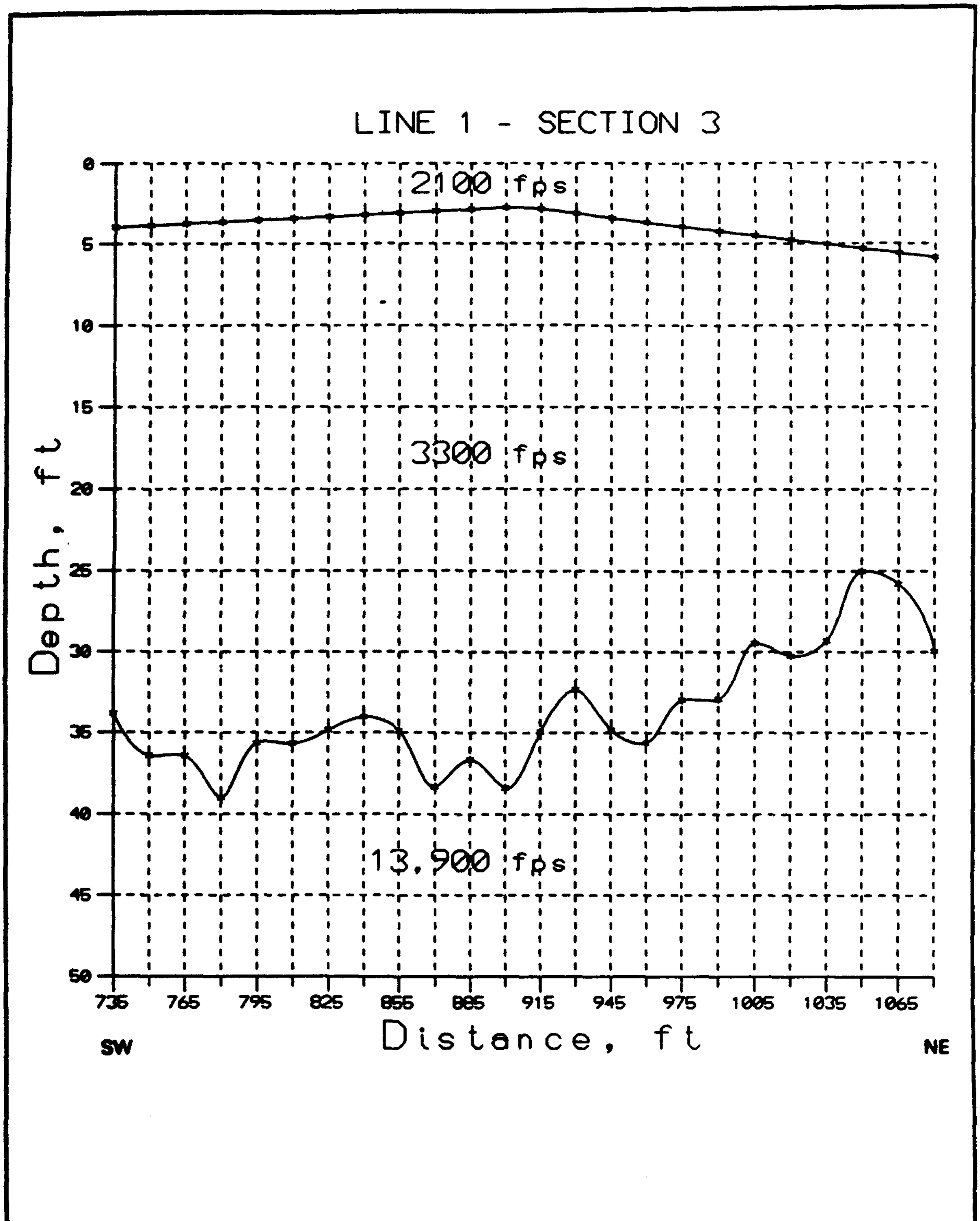


Figure 15. P-wave velocity cross section, line R-1, section 3

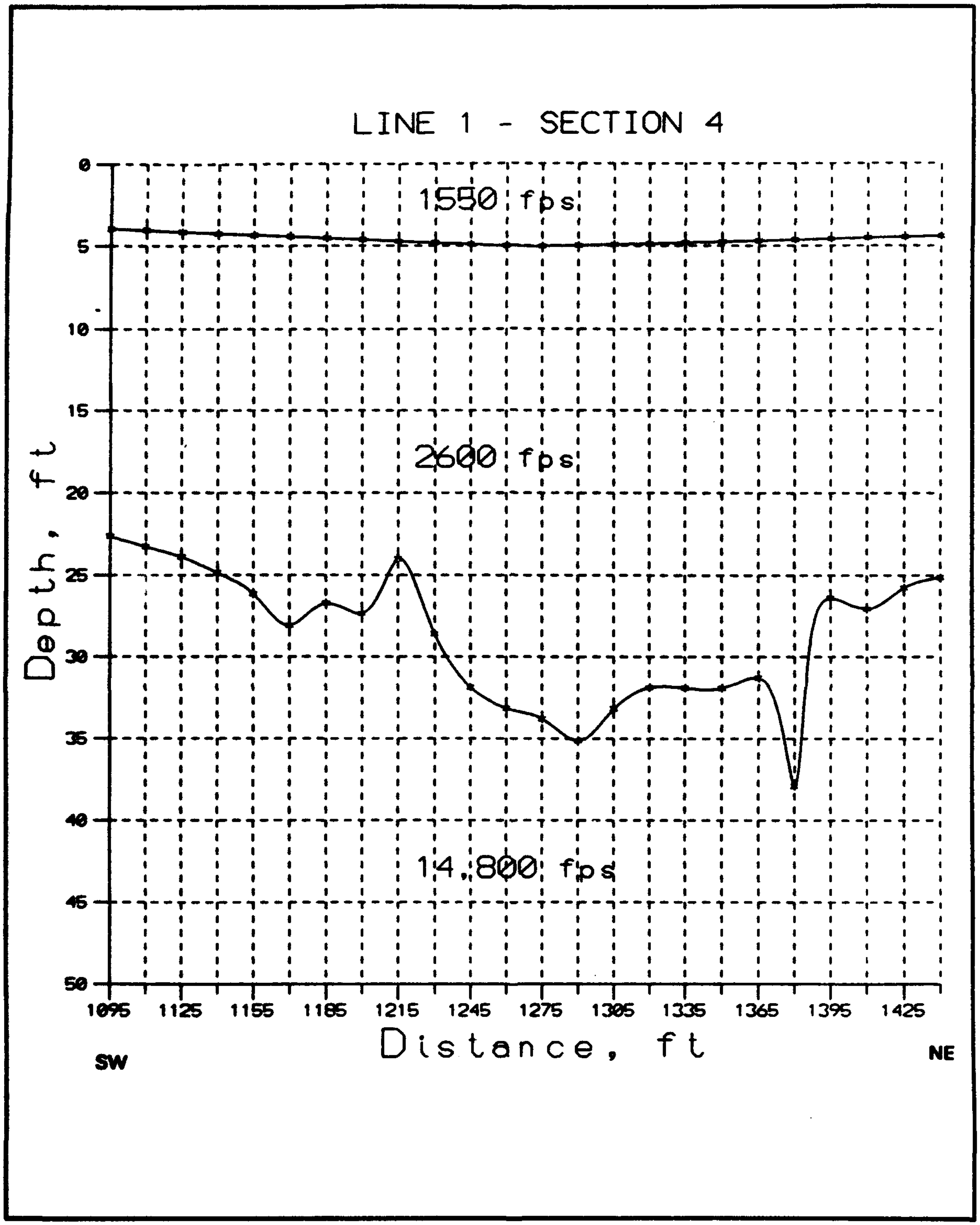


Figure 16. P-wave velocity cross section, line R-1, section 4

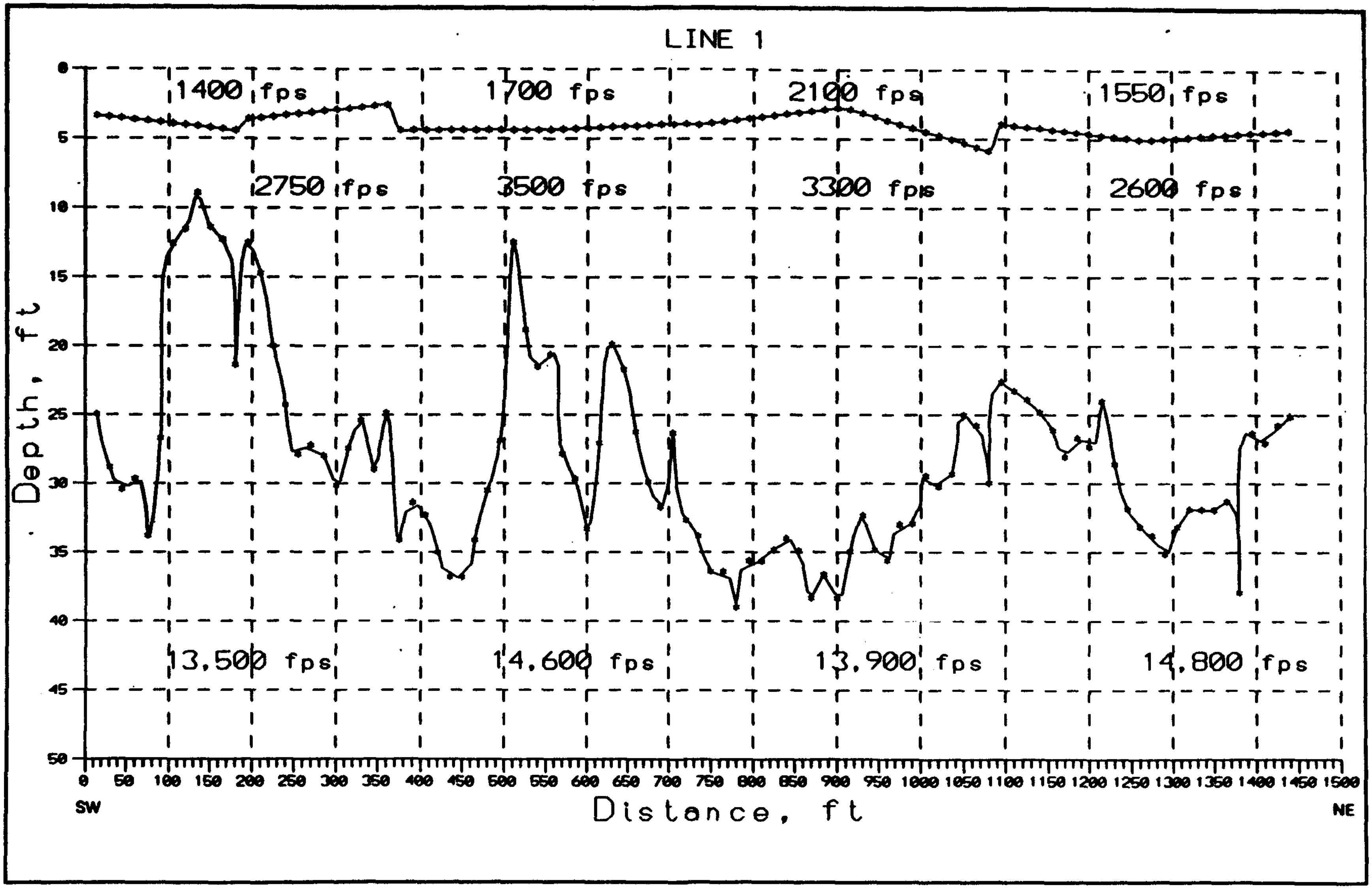


Figure 17. Composite P-wave velocity profile, line R-1

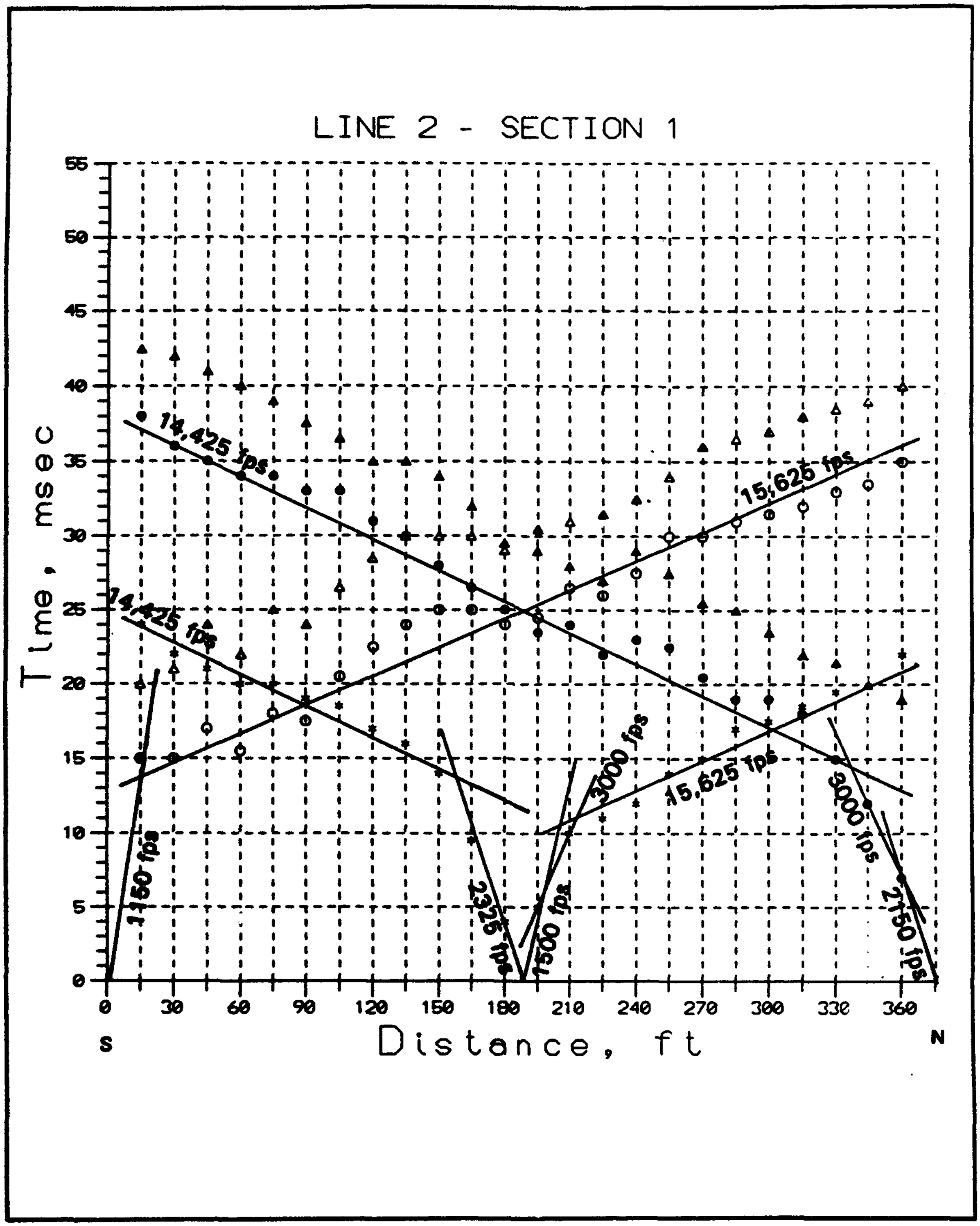


Figure 18. Time versus distance plot, line R-2, section 1

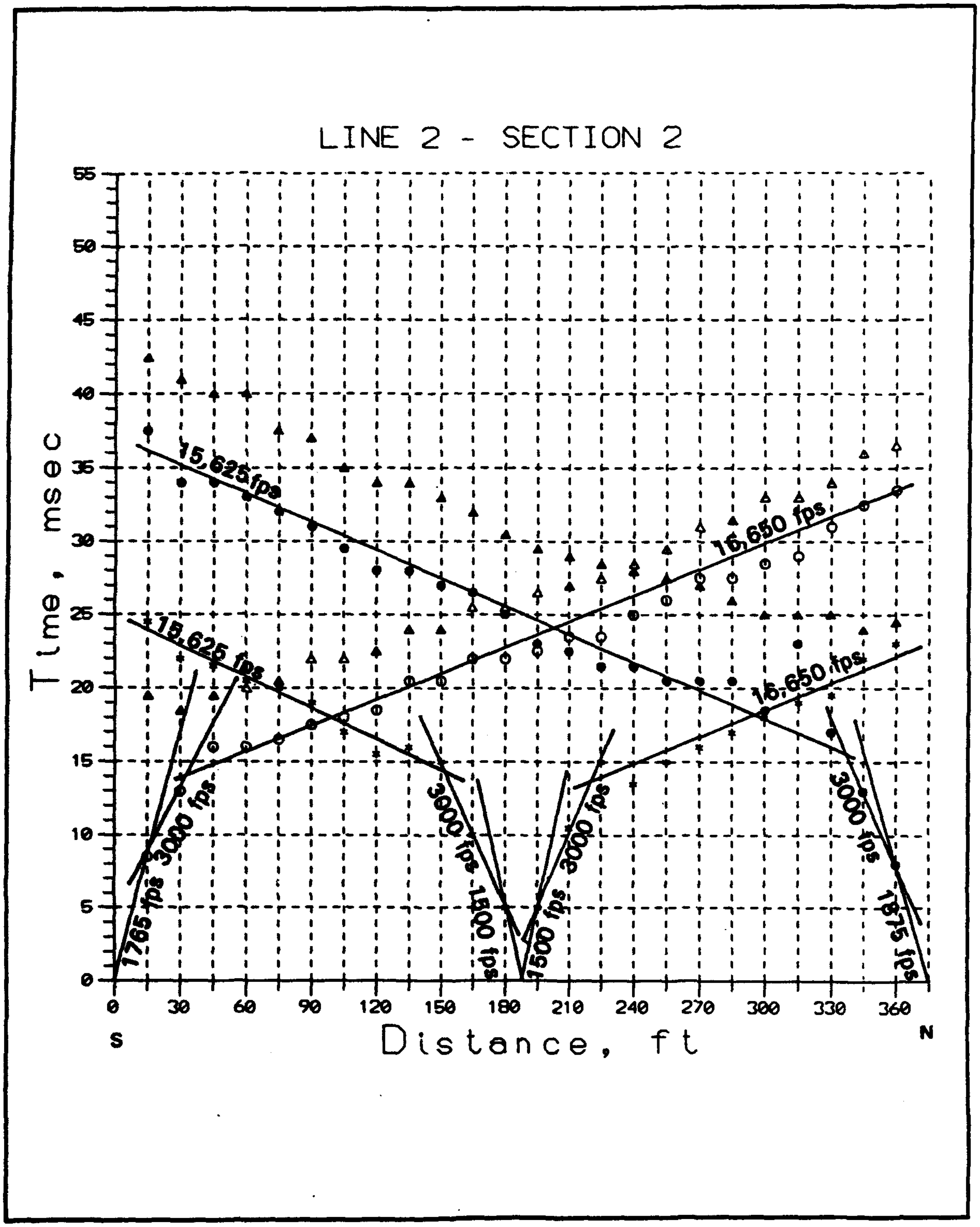


Figure 19. Time versus distance plot, line R-2, section 2

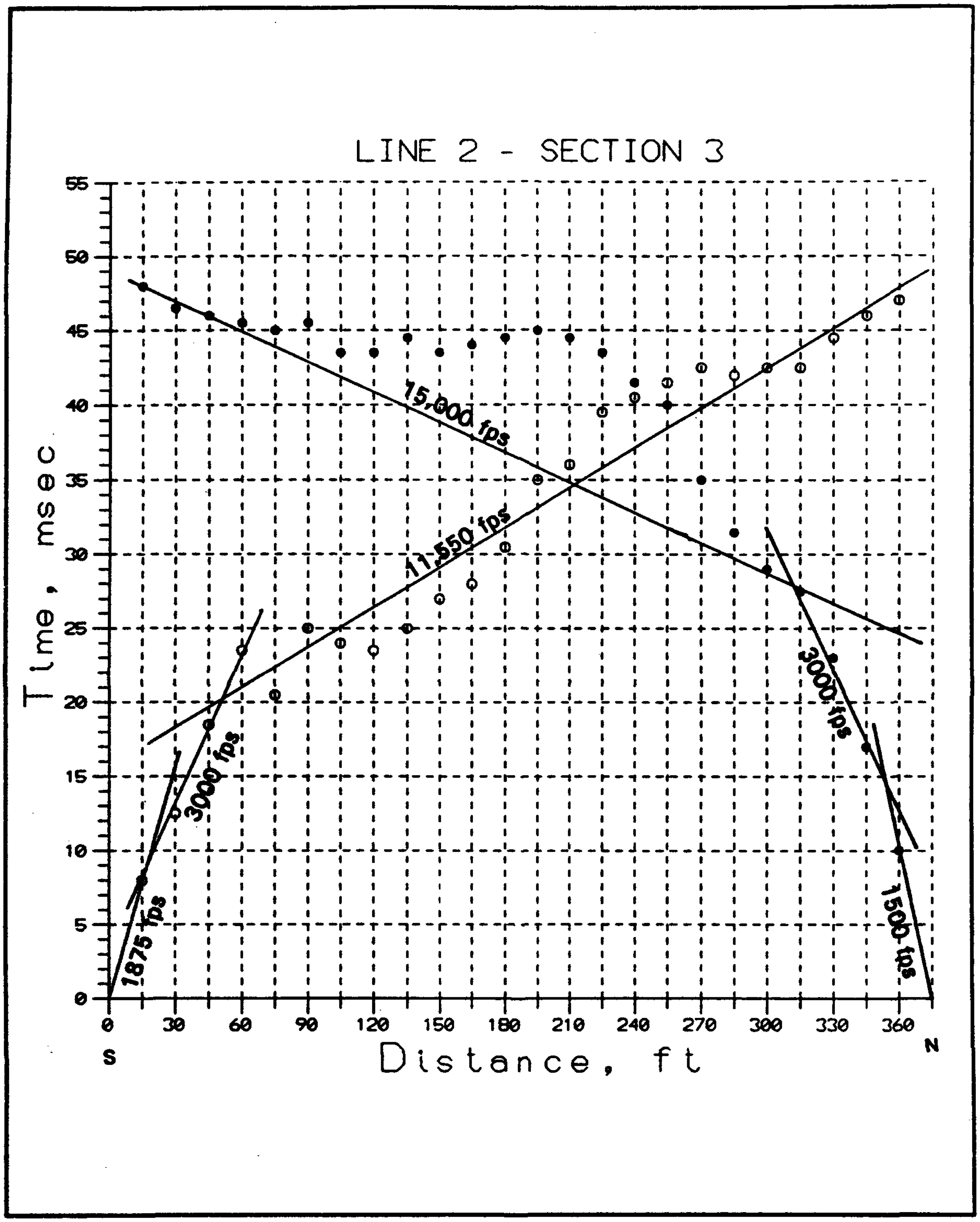


Figure 20. Time versus distance plot, line R-2, section 3

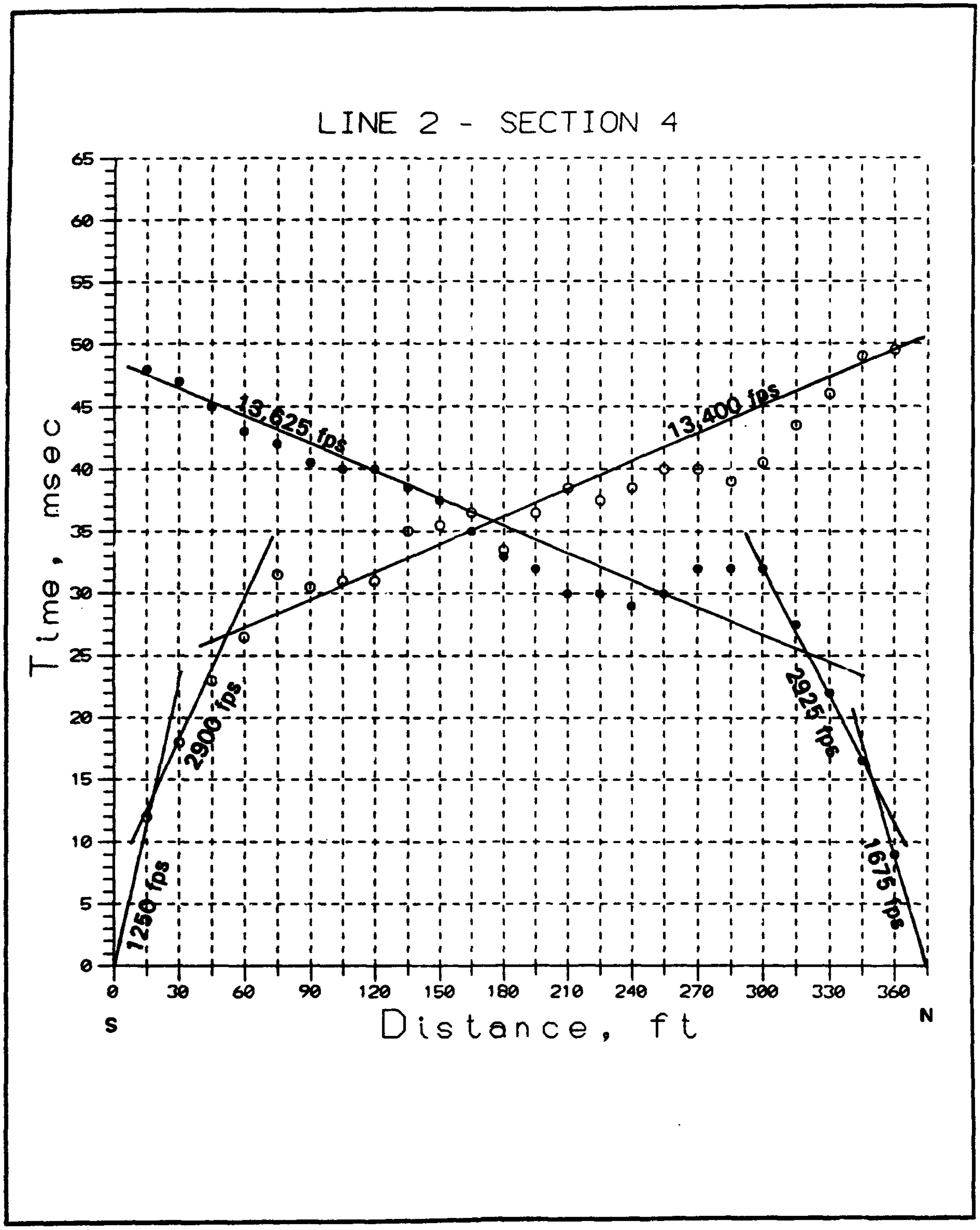


Figure 21. Time versus distance plot, line R-2, section 4

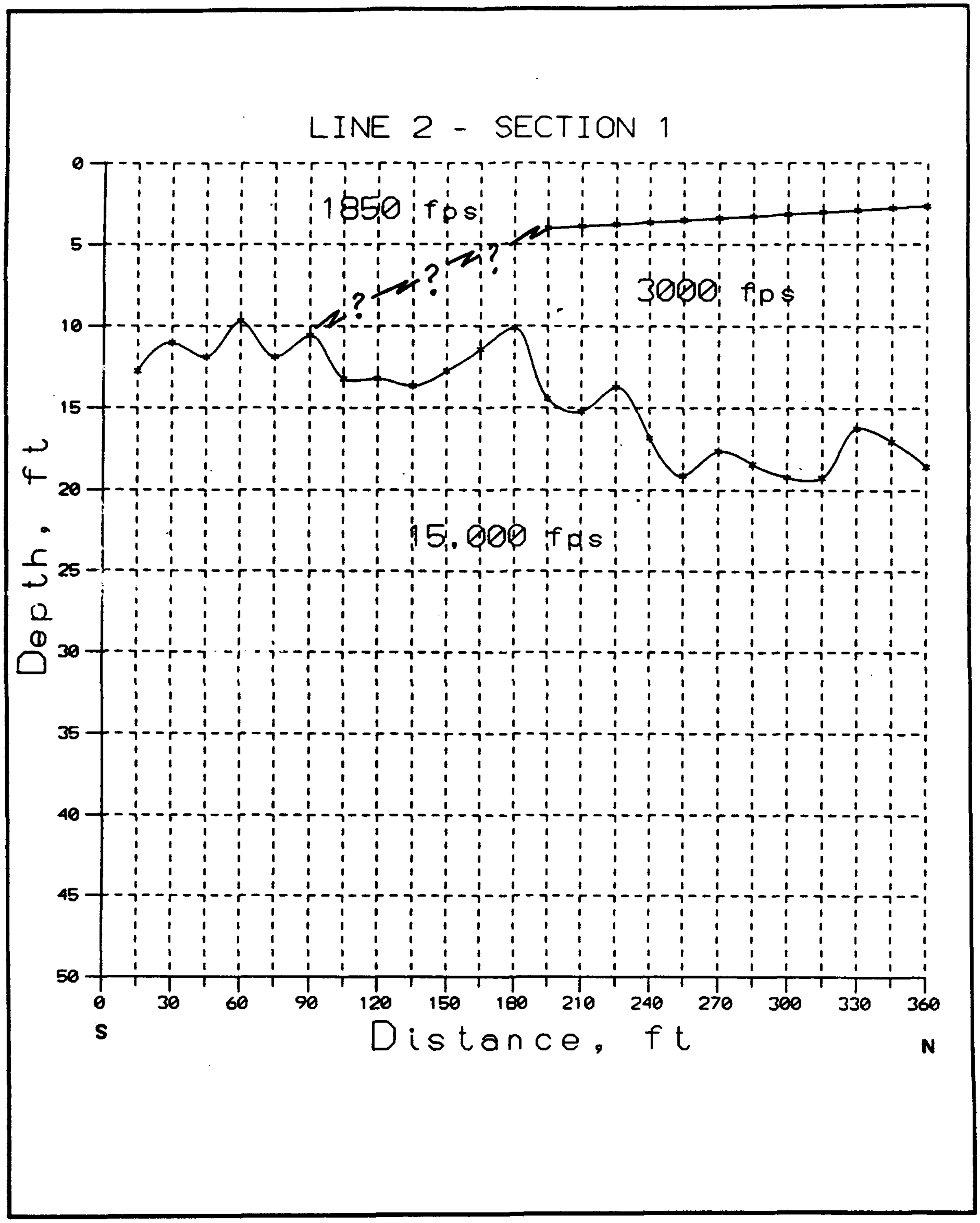


Figure 22. P-wave velocity cross section, line R-2, section 1

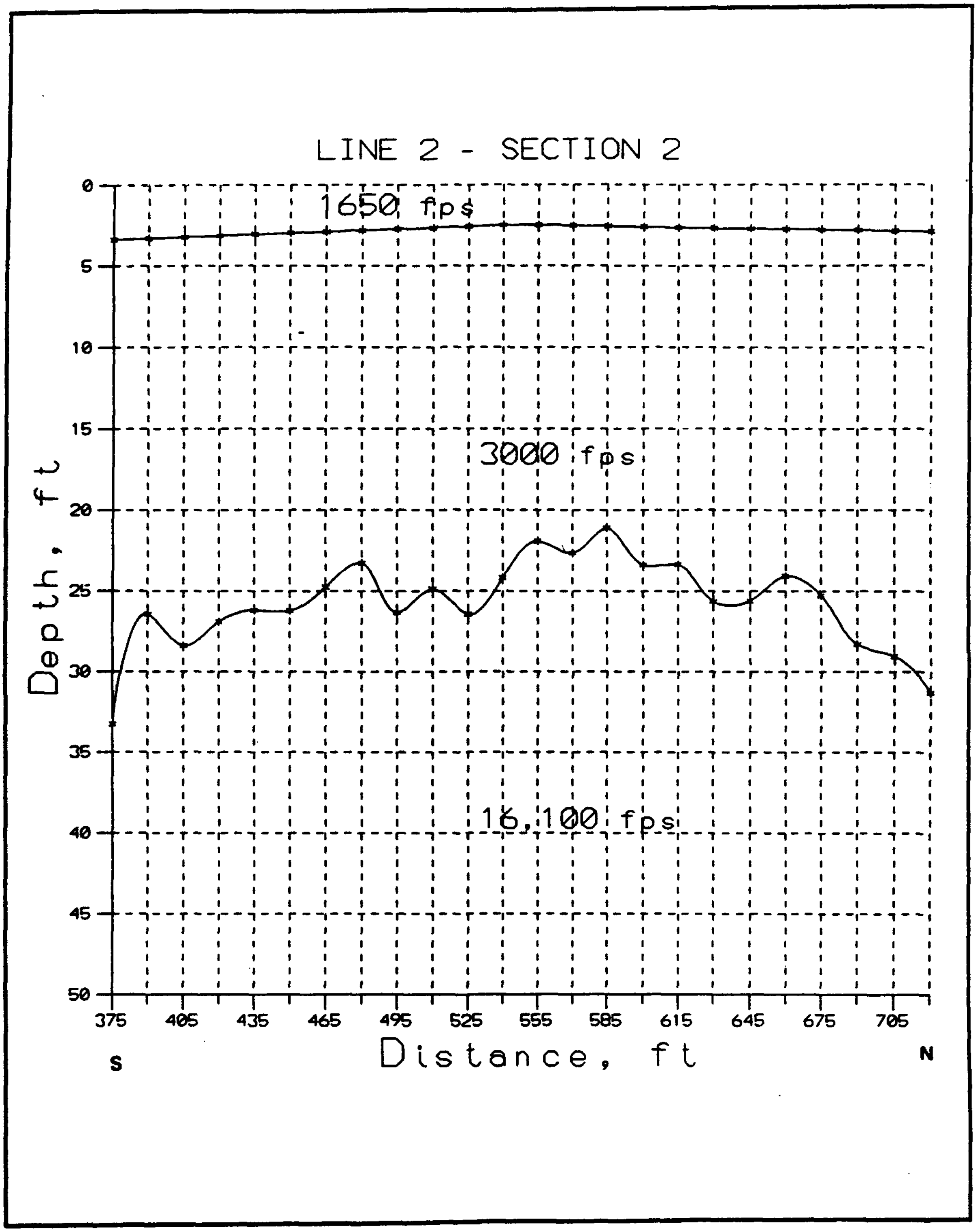


Figure 23. P-wave velocity cross section, line R-2, section 2

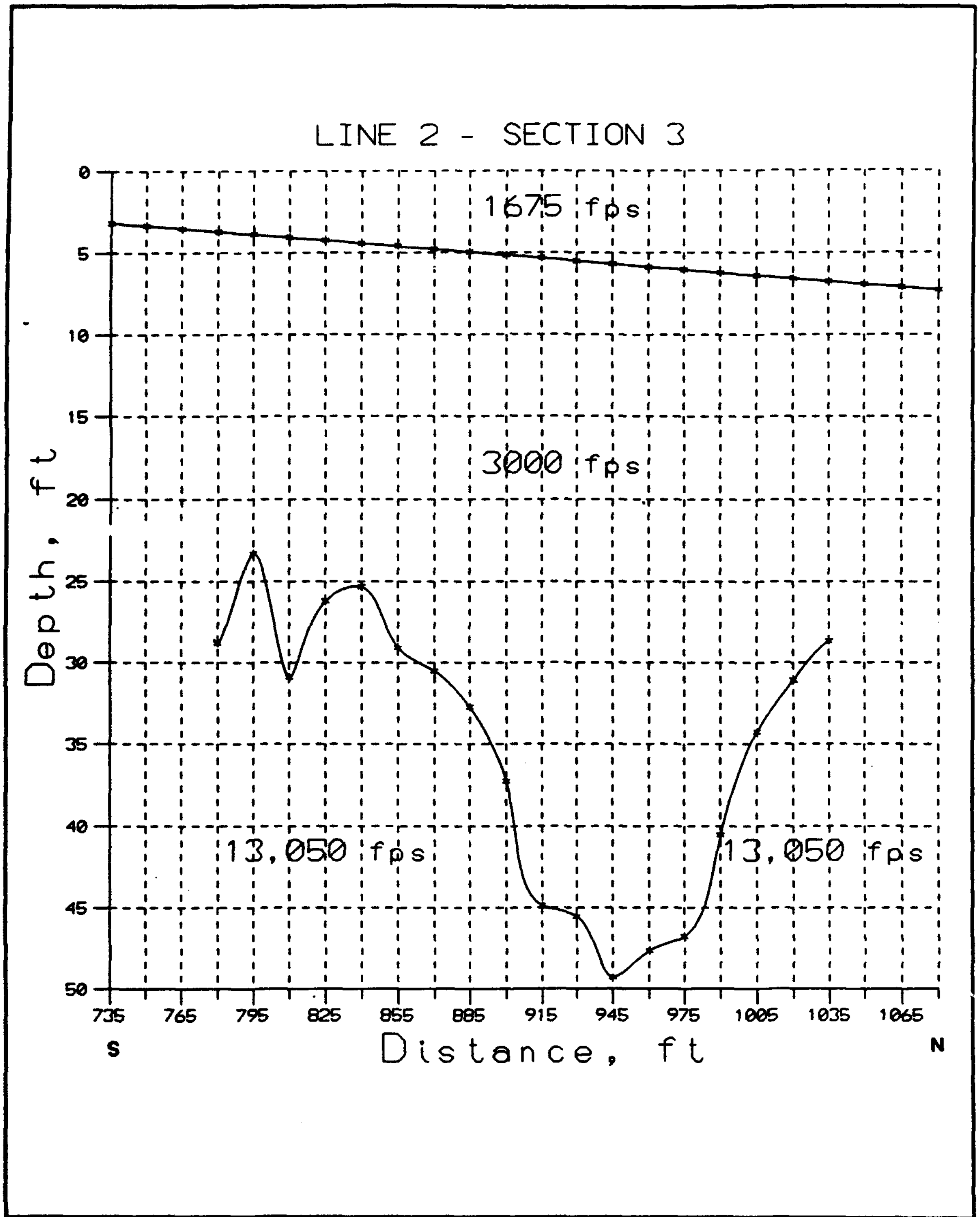


Figure 24. P-wave velocity cross section, line R-2, section 3

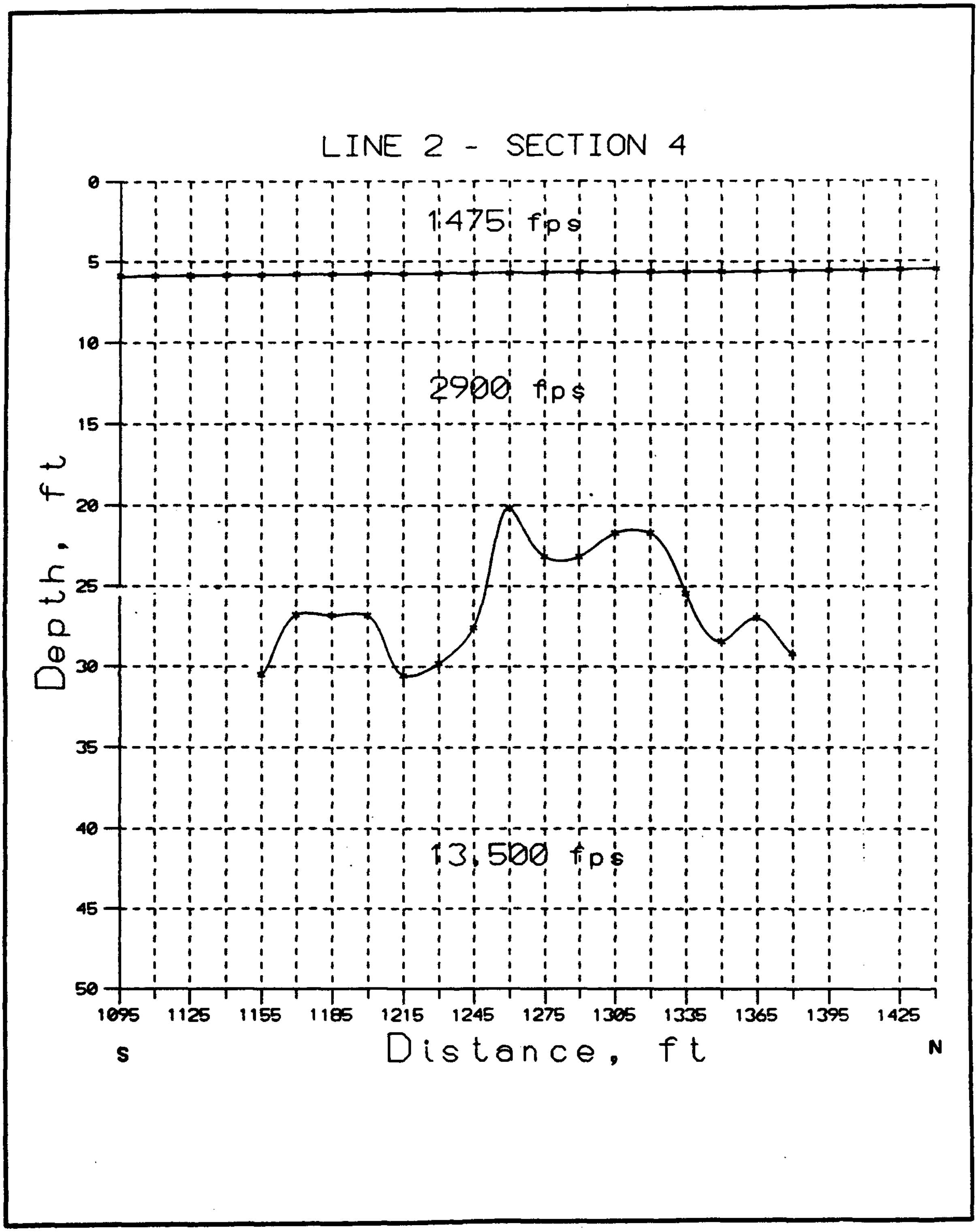


Figure 25. P-wave velocity cross section, line R-2, section 4

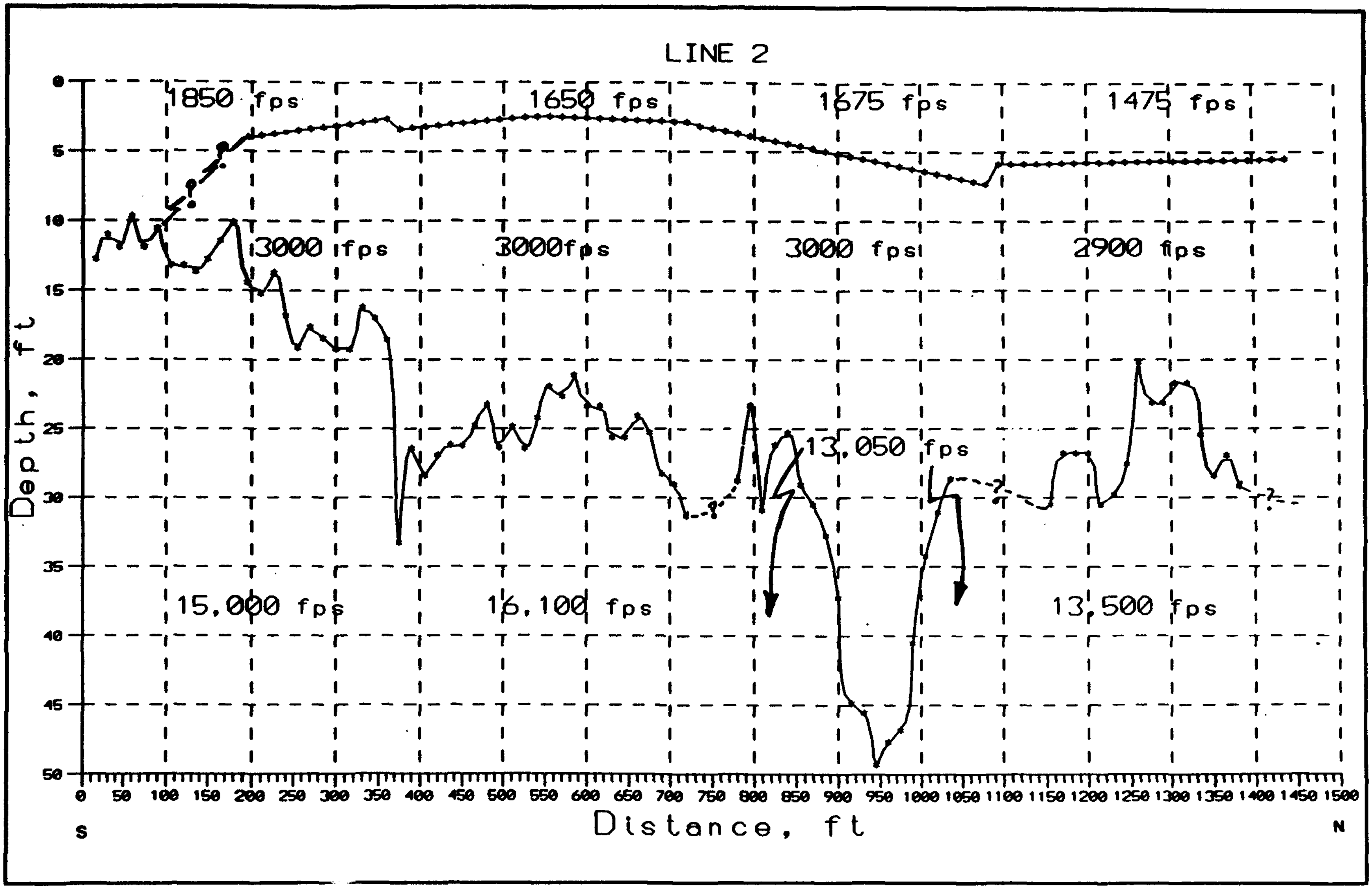


Figure 26. Composite P-wave velocity profile, line R-2

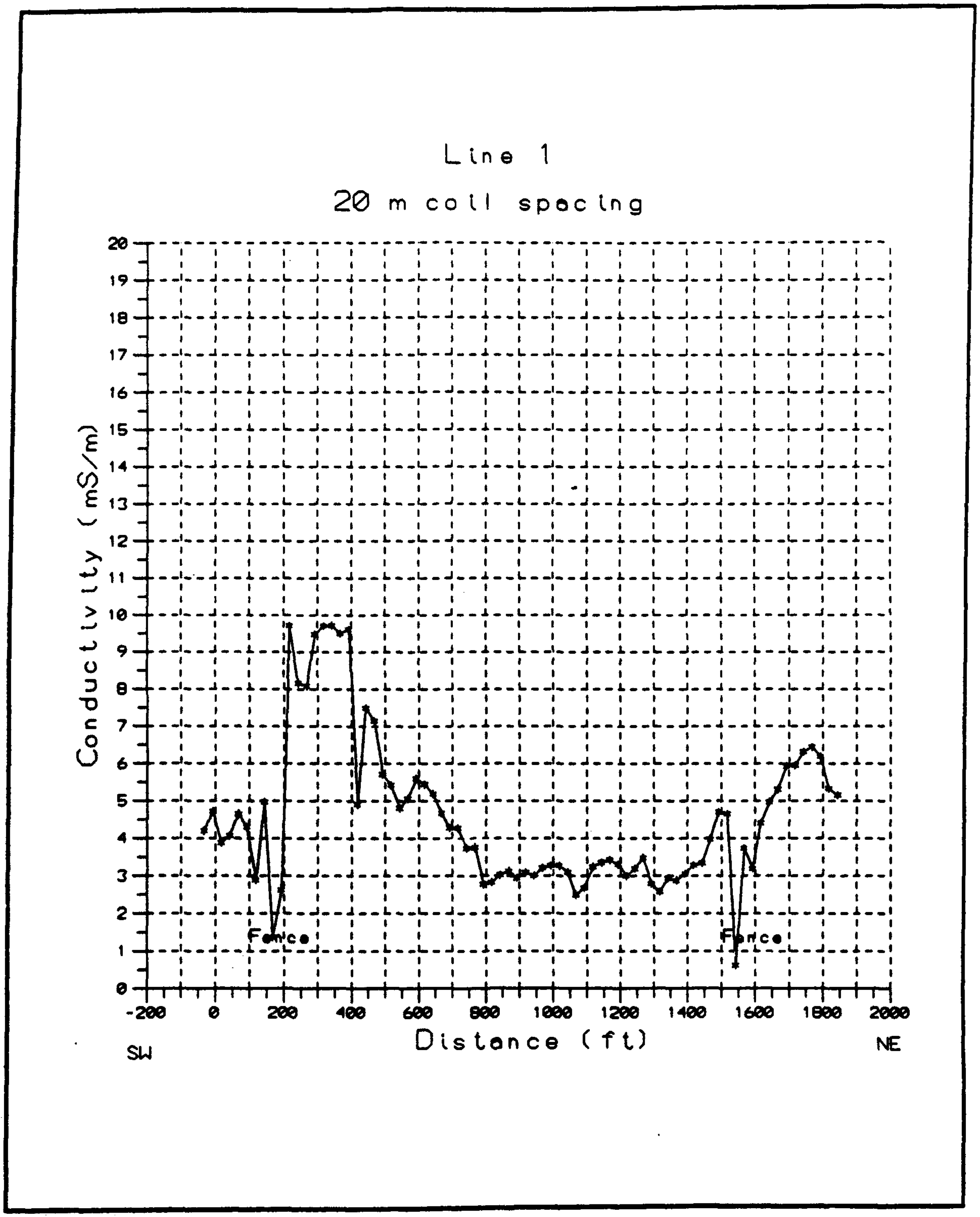


Figure 27. Line EM-1 survey results, 20 m coil spacing

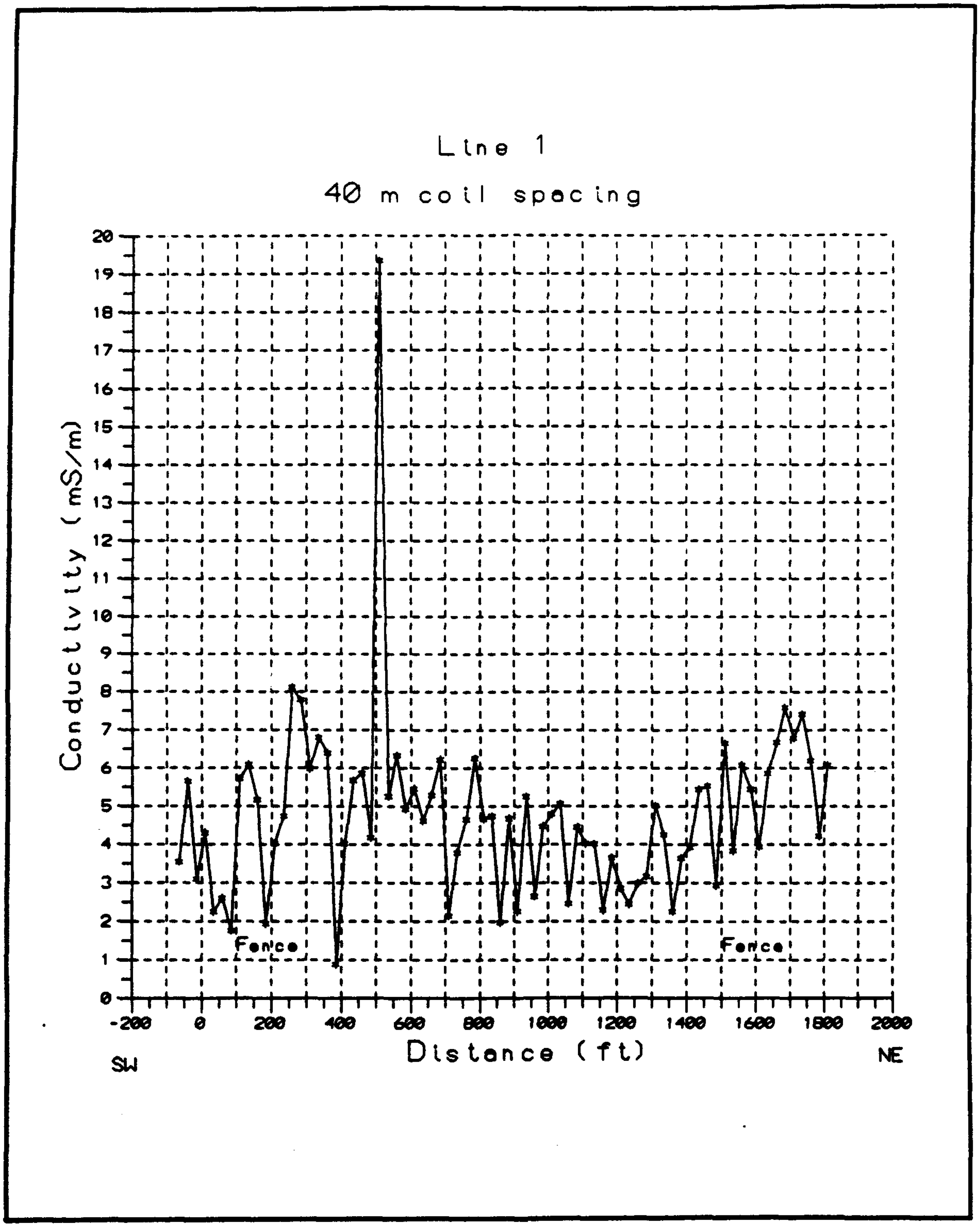


Figure 28. Line EM-1 survey results, 40 m coil spacing

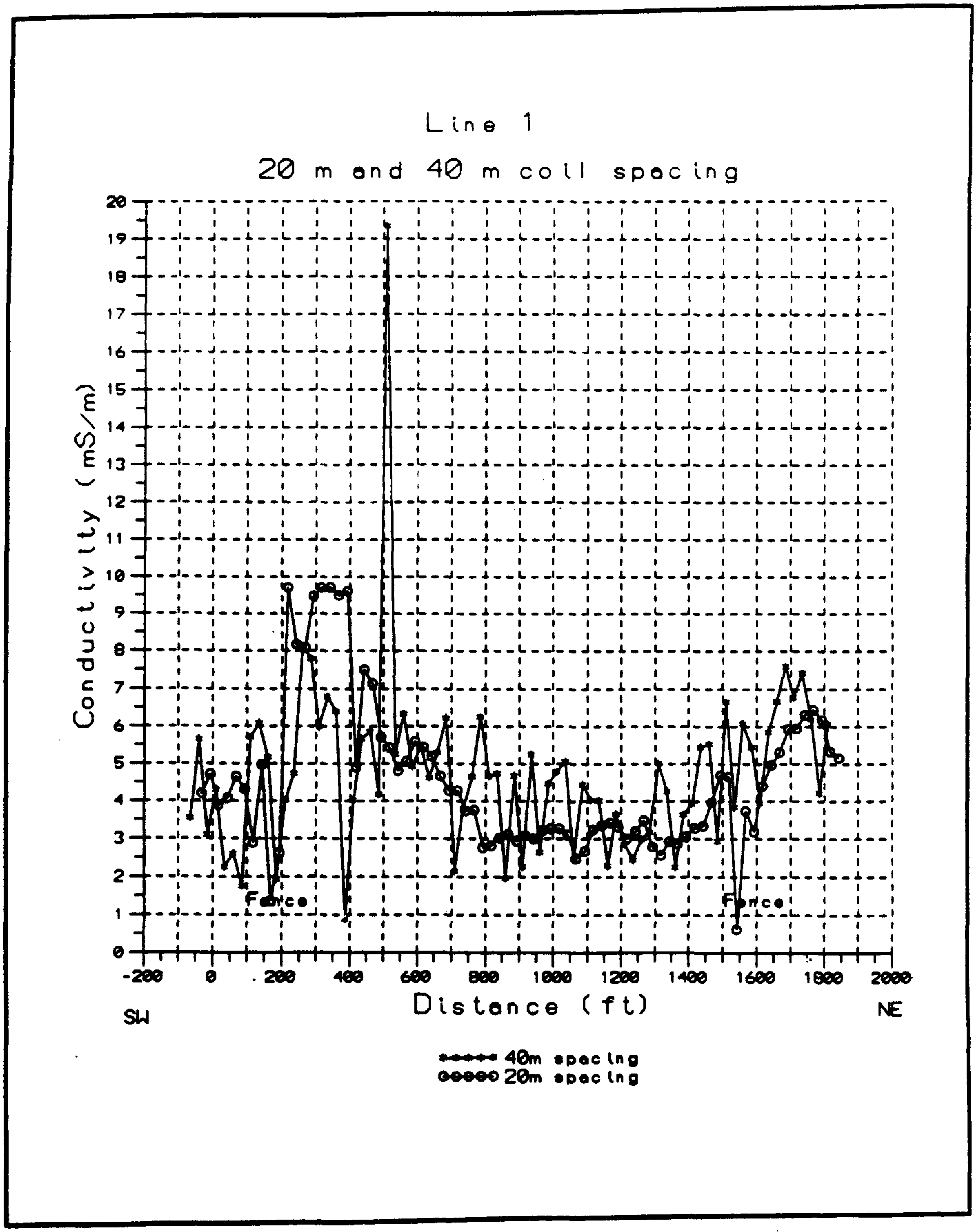


Figure 29. Line EM-1 survey results, 20 and 40 m coil spacings

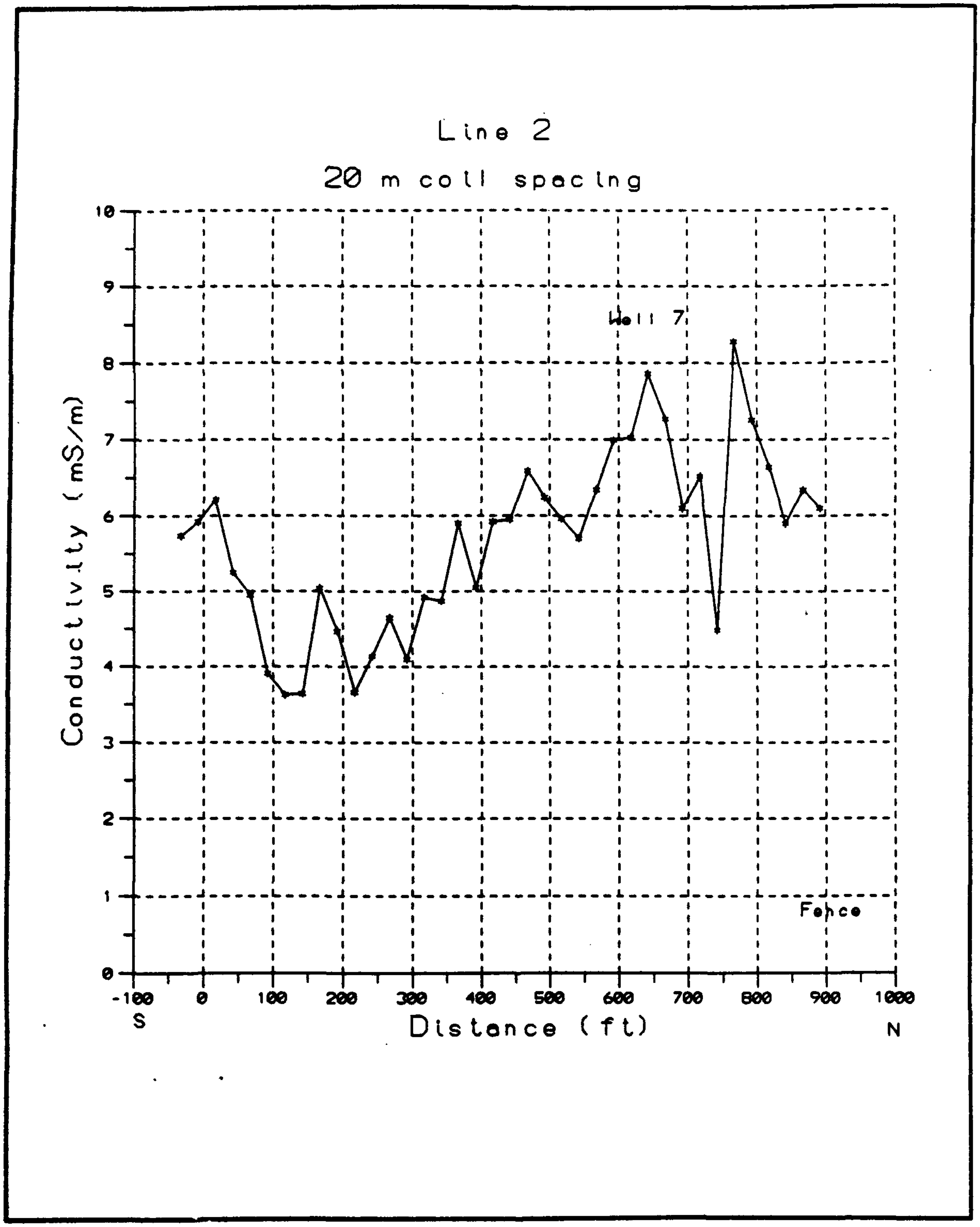


Figure 30. Line EM-2 survey results, 20 m coil spacing

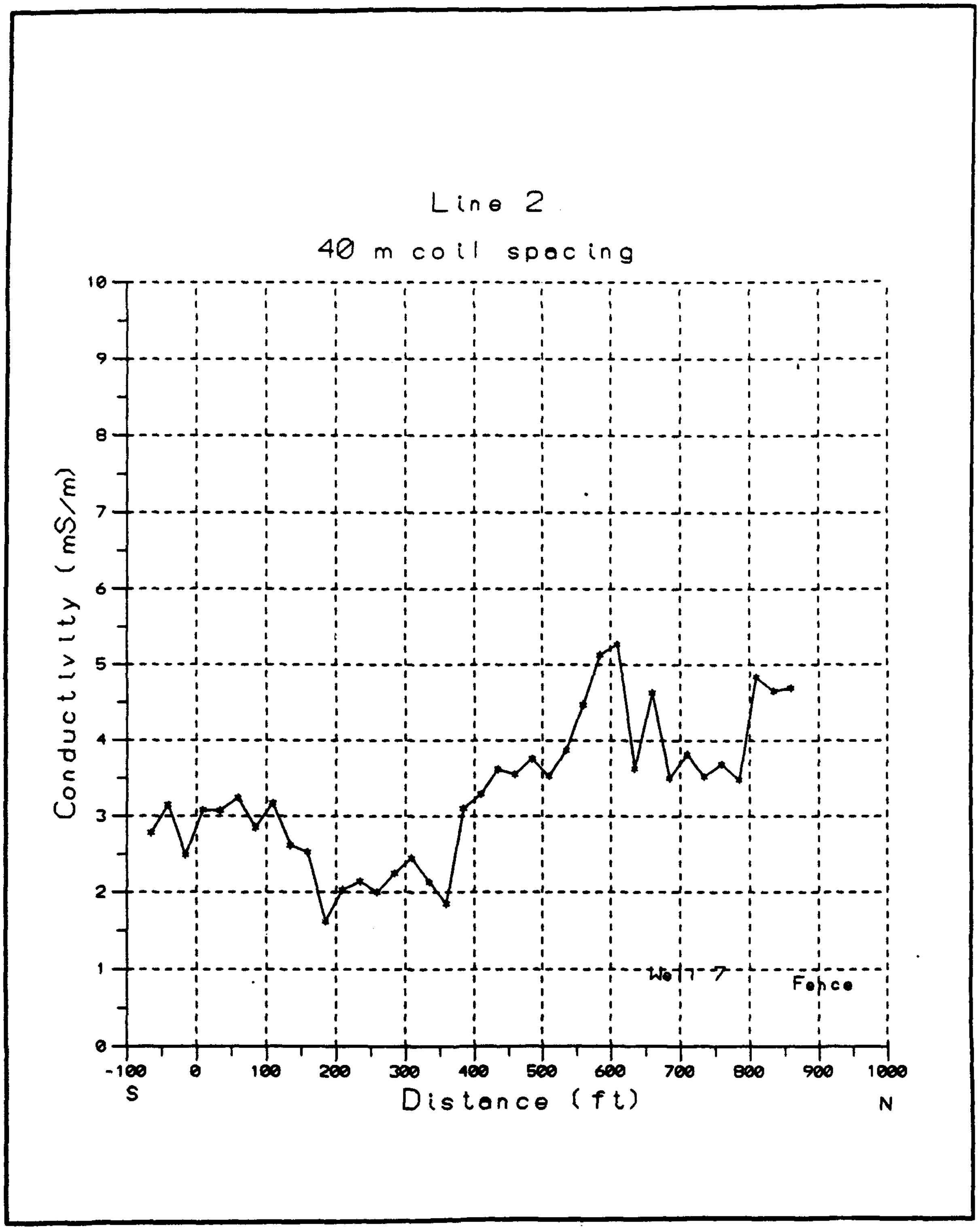


Figure 31. Line EM-2 survey results, 40 m coil spacing

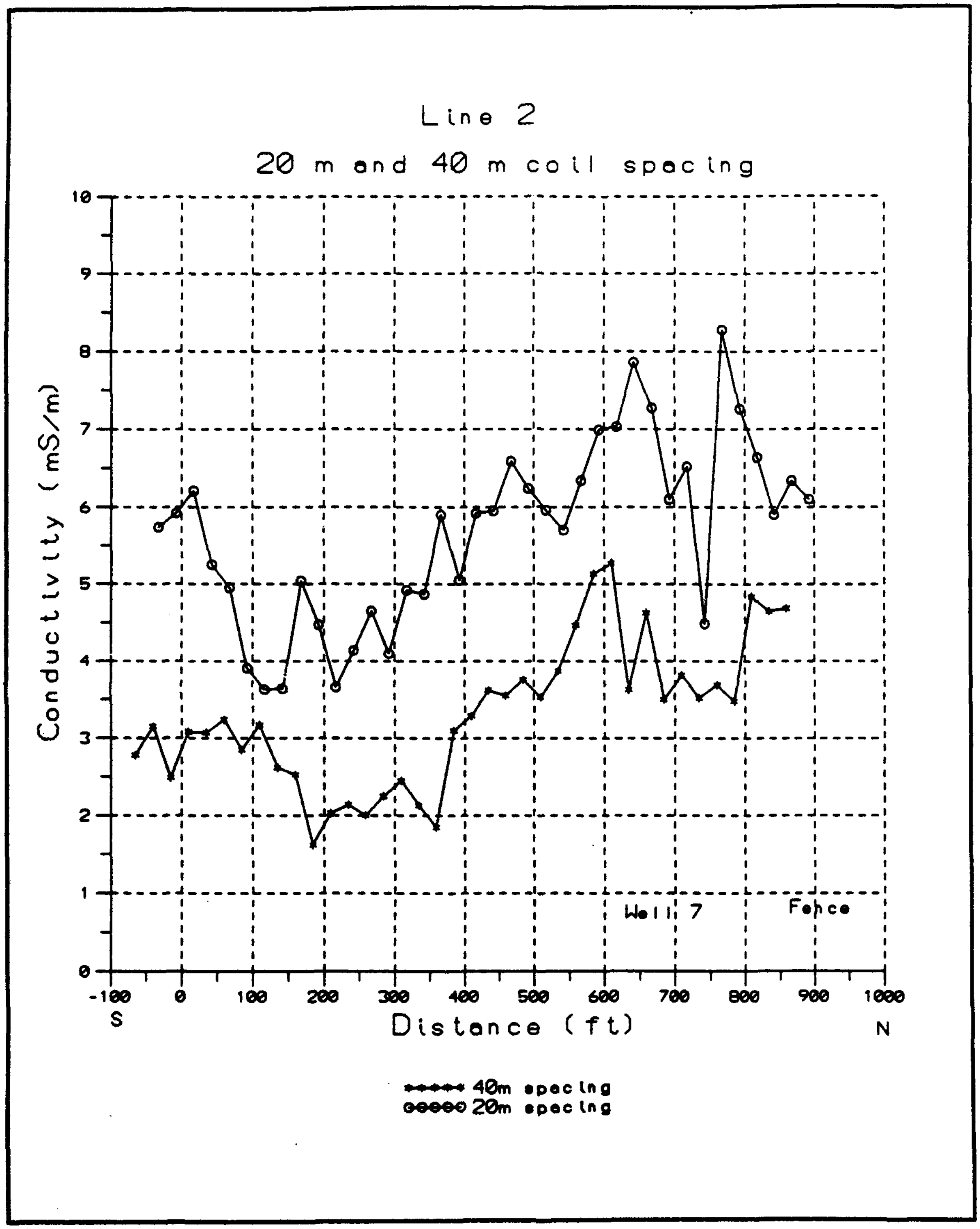


Figure 32. Line EM-2 survey results, 20 and 40 m coil spacings

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
March 1994

3. REPORT TYPE AND DATES COVERED
Final report

4. TITLE AND SUBTITLE
Seismic Refraction and Electromagnetic Surveys at Fort Detrick, Maryland

5. FUNDING NUMBERS
MIPR7082

6. AUTHOR(S)
José L. Llopis, Janet E. Simms

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
U.S. Army Engineer Waterways Experiment Station
Geotechnical Laboratory
3909 Halls Ferry Road, Vicksburg, MS 39180-6199

8. PERFORMING ORGANIZATION REPORT NUMBER
Miscellaneous Paper GL-94-10

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Environmental Center
Aberdeen Proving Ground, MD 21010-5401

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
This report is available from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A geophysical investigation was conducted to determine the depth of bedrock and to delineate a suspect geologic fault with a northwest-southeast orientation that runs through the center of Area B, Fort Detrick, Maryland. Previous geologic investigations indicate Cambrian limestones and Triassic shales southwest and northwest of the fault, respectively. Two seismic refraction and two EM survey lines were run at Area B to determine the depth to top of rock and to find evidence of the suspected fault. The seismic refraction method was used to obtain velocity cross sections along each of the 1440-ft long survey lines. The velocity cross sections indicated three velocity zones. The two uppermost layers are interpreted as corresponding to dry unconsolidated materials. The third and deepest layer, ranging in depth between approximately 9 and 49 ft, and having velocities ranging between 13,050 and 16,100 fps is presumed to correspond to bedrock. No clear evidence of a fault was interpreted from the seismic refraction surveys.

(continued)

14. SUBJECT TERMS
Electromagnetics
Geophysical surveys
Geophysics
Seismic refraction

15. NUMBER OF PAGES
51

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED		

13. **ABSTRACT (Continued)**

Two EM survey lines, with lengths of 925 and 1865 ft, were run at the site to determine the location of the geologic fault. The maximum depth of investigation for these surveys was approximately 100 ft. In general, the range of conductivity values for the EM surveys was between 2 and 10 mS/m. The narrow range of conductivity values shown by both EM survey lines indicates that the survey lines did not cross a fault contact with materials having contrasting electrical properties such as would be expected when crossing from relatively low conductivity limestone to a relatively high conductivity shale material.