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GEOPHYSICAL SITE INVESTIGATION, OHIO RIVER NAVIGATION PROJECT -- OLMSTEAD SITE

by

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This report documents the results of a geophysical investigation at the Olmsted site of the Ohio River Navigation Project. Surface and subsurface methods consisting of seismic refraction, crosshole, downhole, and uphole testing were performed. Testing was conducted on both sides (Kentucky and Illinois) of the Ohio River with compression and shear wave profiles developed along the center line of the proposed lock and dam and parallel to the river on each side. Data from borehole logs indicated the site consisted of four zones: alluvium, McNairy 1, McNairy 2, and Paleozoic. Stratigraphy and seismic velocities of these zones were determined. The shear wave velocities were obtained for future input to a dynamic analysis of the lock and dam.

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Preface

This report documents the geophysical site investigation conducted by the US Army Engineer Waterways Experiment Station (WES) at the Olmsted site of the Ohio River Navigation Project. The work was performed during the period 8-30 September 1987 for the Geotechnical Section of the US Army Engineer District, Louisville (ORL), under IAO No.ORL RM-B-87-463 dated 23 Feb 87, Appropriation No. 96x3121.

Mr. Loren Christman of the Geotechnical Section of the Engineering Division (ED-G), ORL was Project Monitor for this work. Also, Mr. Kenneth Parsons (ORLED-G) was the onsite monitor during the field work. Their assistance was instrumental in the successful completion of this work.

Mr. Donald E. Yule of the Field Investigations Group (FIG), Earthquake Engineering and Geophysics Division (EEGD), Geotechnical Laboratory (GL), WES, was the Project Engineer for this study. Mr Michael K. Sharp, FIG, EEGD, GL, was the coinvestigator and coauthor of this report. The field work was performed by Messrs. D. E. Yule, M. K. Sharp, and J. D. Meyers (FIG). The work was conducted under the direct supervision of Mr. J. R. Curro, Chief, FIG and Dr. A. G. Franklin, Chief, EEGD. The project was under the overall supervision of Dr. W. F. Marcuson III, Chief, GL.

COL Dwayne G. Lee, CE, was Commander and Director of WES during the investigation. Dr. Robert W. Whalin was Technical Director.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurements used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
feet per second	0.3048	metres per second

GEOPHYSICAL SITE INVESTIGATION

OHIO RIVER NAVIGATION PROJECT - OLMSTED SITE

Introduction

1. Background. Existing Lock and Dam 53 is a navigation control structure located on the Ohio River. This structure was built to maintain a channel deep enough for navigation during low water. Increased river traffic has created congestion at the lock during times of low water, with increasing problems evident for the future. To alleviate this problem, a new lock and dam has been proposed to replace the existing structure. This report presents the results of a geophysical site investigation conducted at the Olmsted site of the project. This information will be used as input to the design and construction of the new lock and dam.

2. Purpose. The purpose of the geophysical site investigation at the Olmsted site was to provide compression and shear wave velocities and stratigraphy of the McNairy Zone 1 and 2 materials. Also, the depths to the contact between McNairy Zone 2 and Paleozoic age materials was to be determined. The shear wave velocities of the materials are needed for future use in a dynamic analysis. For this study, a suite of seismic methods consisting of surface refraction, uphole, downhole and crosshole tests were conducted to meet these objectives.

Site Description

3. The site is located in the Ohio River valley at river mile 964.4 (see figure 1.). The geology of the site immediately along the river banks and under the river can be generalized from boring logs as alluvial deposits underlain by Cretaceous sediments subdivided into zone 1 and 2 of the McNairy formation which rests on a Paleozoic age rock. The alluvium exists between elevations 310 and 240 ft msl with the underlying Cretaceous sediments extending to estimated elevations of 50 to -30 ft msl. The boundary between zone 1 and 2 of the McNairy formation is approximately el 170 to 195 ft msl. The river level was at elevation 285 ft during testing. The alluvium consists of sands, silts, clays, and gravels. The McNairy zone 1 sediments consists of sands interbedded with silts and clays. Zone 2 consists of layers of indurated clays (siltstone), chert and shale. The Paleozoic age rock is assumed to be Mississippian limestone. For a more detailed discussion of the geology, refer to Geological-Seismological Evaluation of Earthquake Hazards at the Olmsted Project, Ohio River Lock and Dam 53 by E. L. Krinitzsky.

Test Program

4. Layout. The locations of tests performed during this investigation are shown in Figure 2. All phases of the geophysical test program, except the crosshole shear-wave test, were conducted according to guidelines found in EM 1110-1-1802, Geophysical Exploration, dated 31 May 1979. The test program consisted of one 1200 ft seismic refraction line (R1) on the river bank on the

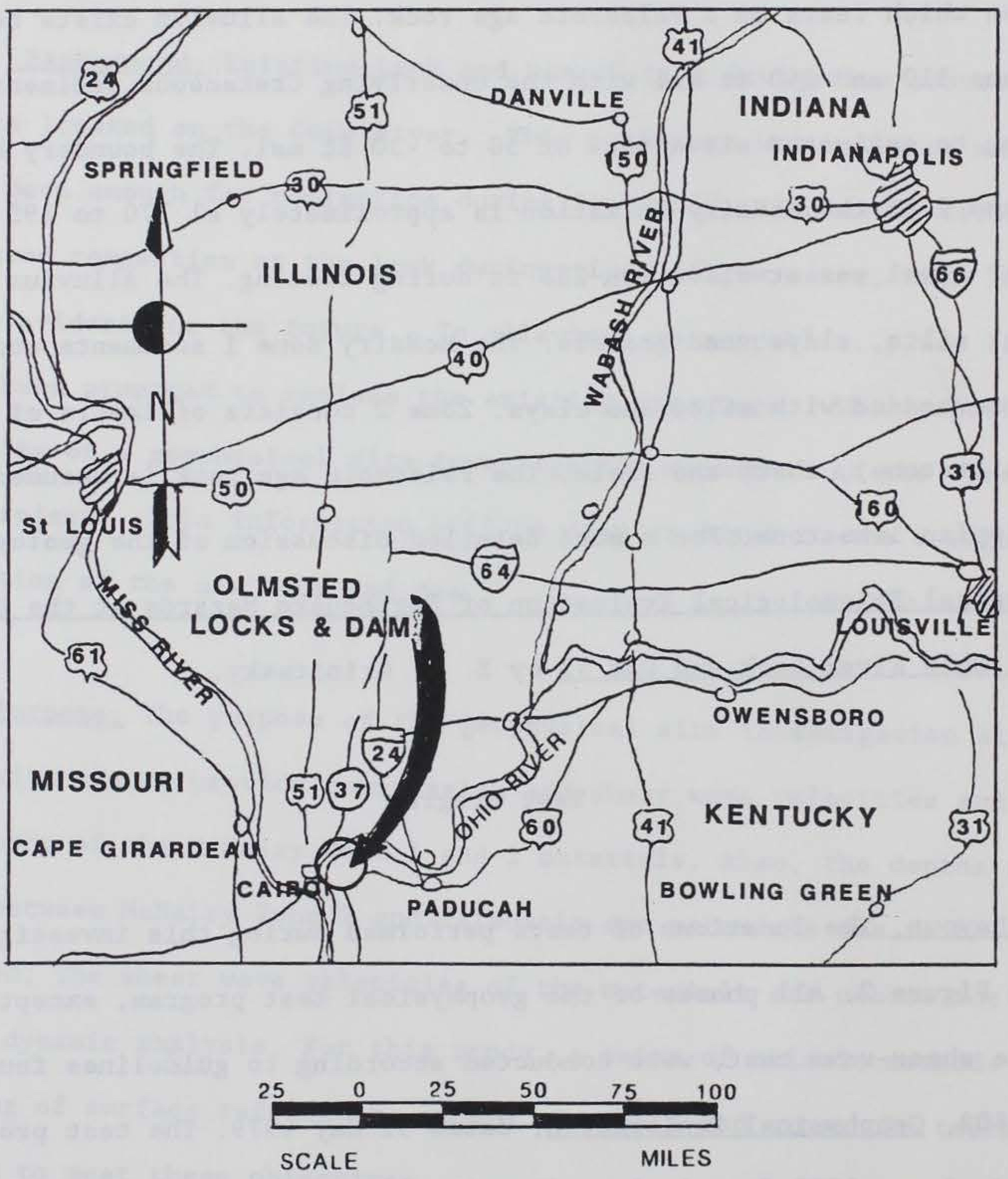


Figure 1 Location of Olmsted Locks and Dam project

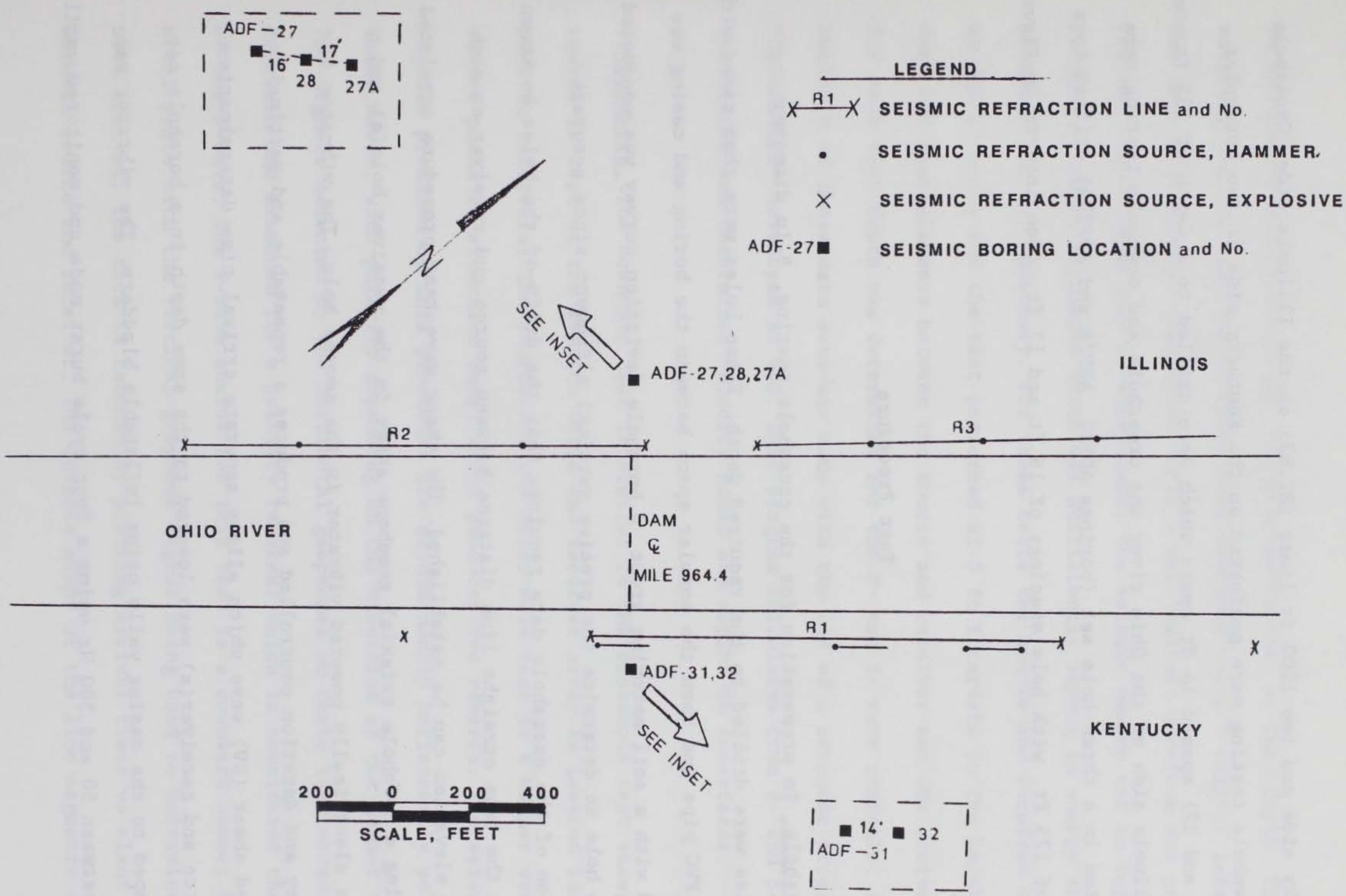


Figure 2. Test layout Olmsted Locks and Dam project.

Kentucky side and two 1200 ft lines (R2,R3) on the Illinois side. Crosshole and downhole testing were performed on the Kentucky side in two boreholes (ADF31 and 32) spaced 14 ft apart which were drilled to a depth of 155 ft. On the Illinois side of the Ohio river the crosshole and downhole testing were conducted in a three hole set (borings ADF27, ADF28 and ADF27A) drilled to a depth of 175 ft, with hole spacings of 16 ft and 17 ft, (See inserts in Figure 2).

Test Procedure

5. Crosshole. In preparation for the crosshole testing, 8 in diameter boreholes were drilled to the required depth. These holes were then cased with 4 inch PVC pipe and then the annular space between the boring and casing was grouted with a soil matching grout. A borehole deviation survey was conducted in each hole to determine the precise vertical alignment since accurate reduction of the crosshole data requires that the drift of the holes be known so that the true straight line distance between source and receiver at each testing elevation can be established. The shear wave test procedure consisted of placing a downhole triaxial geophone array in the receiver hole(s) and a downhole electrically powered vibrator in the source hole. The vibrator is frequency and duration controlled and produces a repeatable and vertically polarized shear (SV) wave which allows accurate arrival time determination. The source and receiver(s) were lowered to the same depth in a borehole set and clamped to the casing walls using inflatable bladders. The vibrator was varied between 50 and 500 Hz using a four cycle burst mode and monitored until

an optimal frequency was found that propagated well at that depth. The source waveform and the received waveform were recorded using a digital seismograph. The data were stacked (enhanced) until a well defined waveform was produced. For the compression wave (P-wave) test, the seismic source was an Exploding Bridgewire (EBW) detonator which was sufficiently strong in energy that data stacking was not necessary. For these tests the source and receiver were kept at equal depths and the test performed at 5 ft intervals in the boreholes. Once the true distance between the source and receiver and the arrival time for each test depth was determined for the P- and S- wave arrivals, an analysis of these data sets was made with the aid of a computer program "CROSSHOLE2" developed at WES. This program calculates true P- and S-wave velocities and determines velocity zones and depths to interfaces.

6. Downhole. The downhole test is similar to the crosshole test except the source is kept at the surface while the receiver array is lowered in a boring at 5 ft intervals. The source for the shear wave test is a hammer striking a wooden plank on alternate ends, which produces two records. The seismic signals produced by this procedure are predominantly horizontally polarized shear waves, with polarity depending on the direction of the hammer strike. The signals detected by the horizontal geophones on these two records are overlain and examined for a polarity reversal which is considered the arrival of the S-wave. The P-wave source for this test is a downward hammer blow to a steel plate with the vertical geophone signal being used to determine the P-wave arrival. The data is reduced by plotting arrival times vs slant distance between source and receiver. The inverse slope of the line segments drawn

through the data points gives the velocities and slope changes in the line segments indicates the approximate depths where the velocities change.

7. Uphole. The uphole test is performed similar to the downhole test, except that the source is placed at the bottom of the hole and moved upward at 5 ft depth intervals while the receiver remains at the surface. Only P-waves are obtained from this test with the source being an EBW detonator. The receiver is a triaxial geophone array placed at the ground surface. The data are reduced by plotting arrival times vs slant distance and interpreted the same as the downhole test. The advantage of performing both an uphole and downhole test is to verify the results of each. Also, the uphole utilizes an explosive source which in most instances produces a stronger first break arrival than the hammer source.

8. Surface seismic refraction. The procedure for the surface refraction tests was to place 48 vertical geophones spaced at 25 ft intervals and to detonate an explosive charge buried at a depth of 3 ft at each end of the line. This was done for all lines except for line R3 because site restrictions would not allow blasting at the east end of the line. In addition, along lines R2 and R3 intermediate source locations on the surface using a sledgehammer provided more information on the near surface layers. The data reduction consisted of plotting first arrival time of the P-wave at each geophone versus geophone distance from the source. From these time versus distance (TD) plots, P-wave velocities and depths to refracting interfaces were determined using the computer program "CARP" developed at WES.

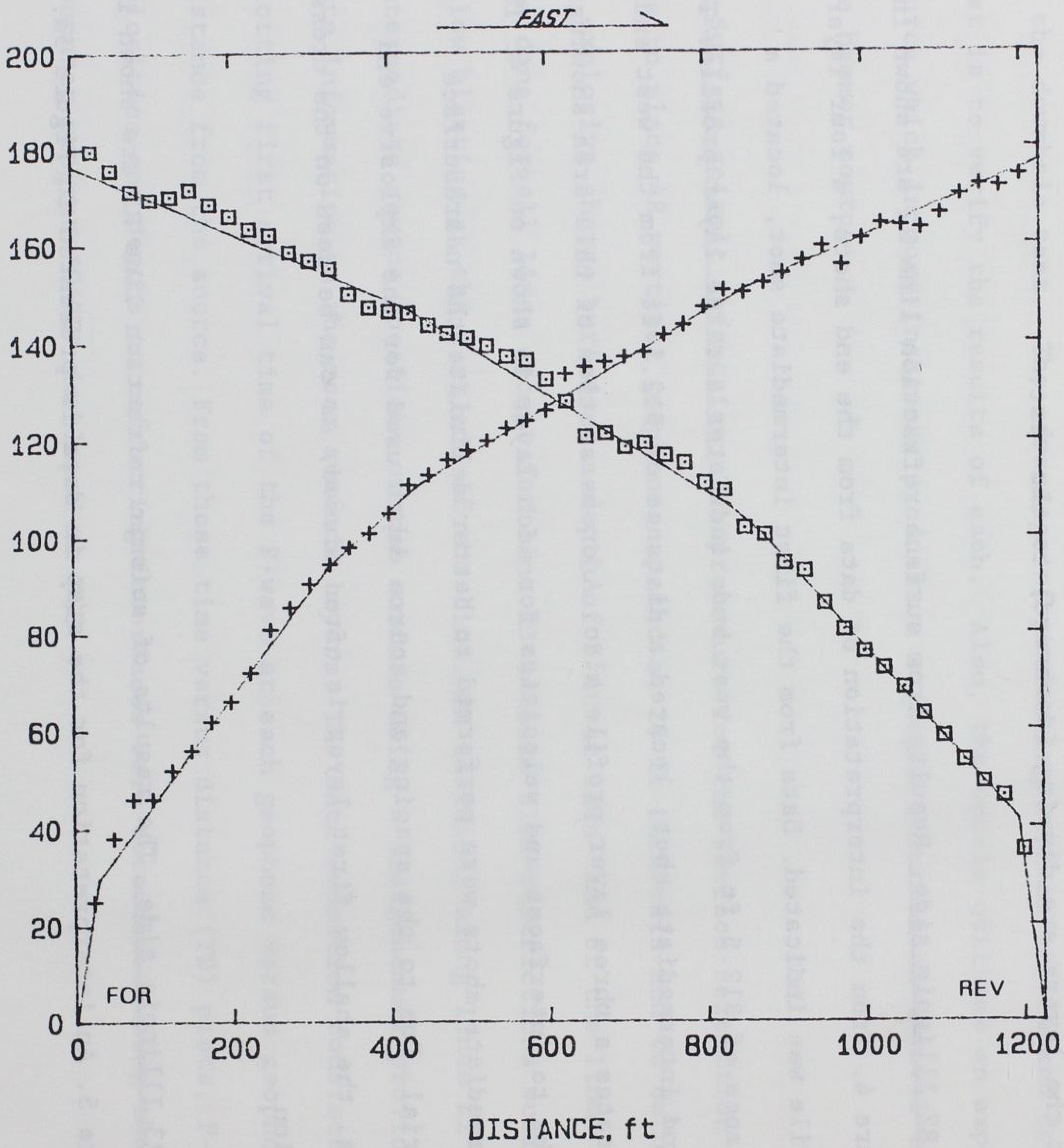
Test Results

Surface Seismic Refraction

9. R1 Kentucky side. The results from surface refraction line R1 are shown in Figure 3. From the TD plot a five layer seismic profile was indicated. A cross section is also shown on Figure 3 with the depths to interfaces and velocities presented. The depths to each interface on the west end of the line are deeper than the corresponding depths from the east end of the line. This indicates that the layers are dipping (downward) to the west.

10. R2 Illinois side. Results from surface refraction line R2 are shown in Figure 4. From the interpretation of data from the end shots, a four layer profile was indicated. Data from the first intermediate shot, located a distance of 312.5 ft from the west end, indicates a three layer profile. The second intermediate shot, located a distance of 912.5 ft from the west end, indicates a three layer profile also. A cross section of this area showing the depths to interfaces and velocities for each layer is shown on Figure 4. The intermediate shots were performed to better deliniate the near surface material. Due to the spacing and source depth used for the explosive end shots, the shallow first layer is often missed, as can be seen on the cross section.

11. R3 Illinois side. The results of seismic refraction line R3 are shown in Figure 5. An interpretation for the step in data is presented in Figure 5a.



** COMPUTED PROFILE END SHOT **

LAYER #	TRUE VEL. fps	DEPTH FOR. FT.	DEPTH REV. FT.
1	920		
2	4930	10.5	16.5
3	6840	90.0	71.0
4	10100	173.0	126.0
5	14230	294.5	272.0

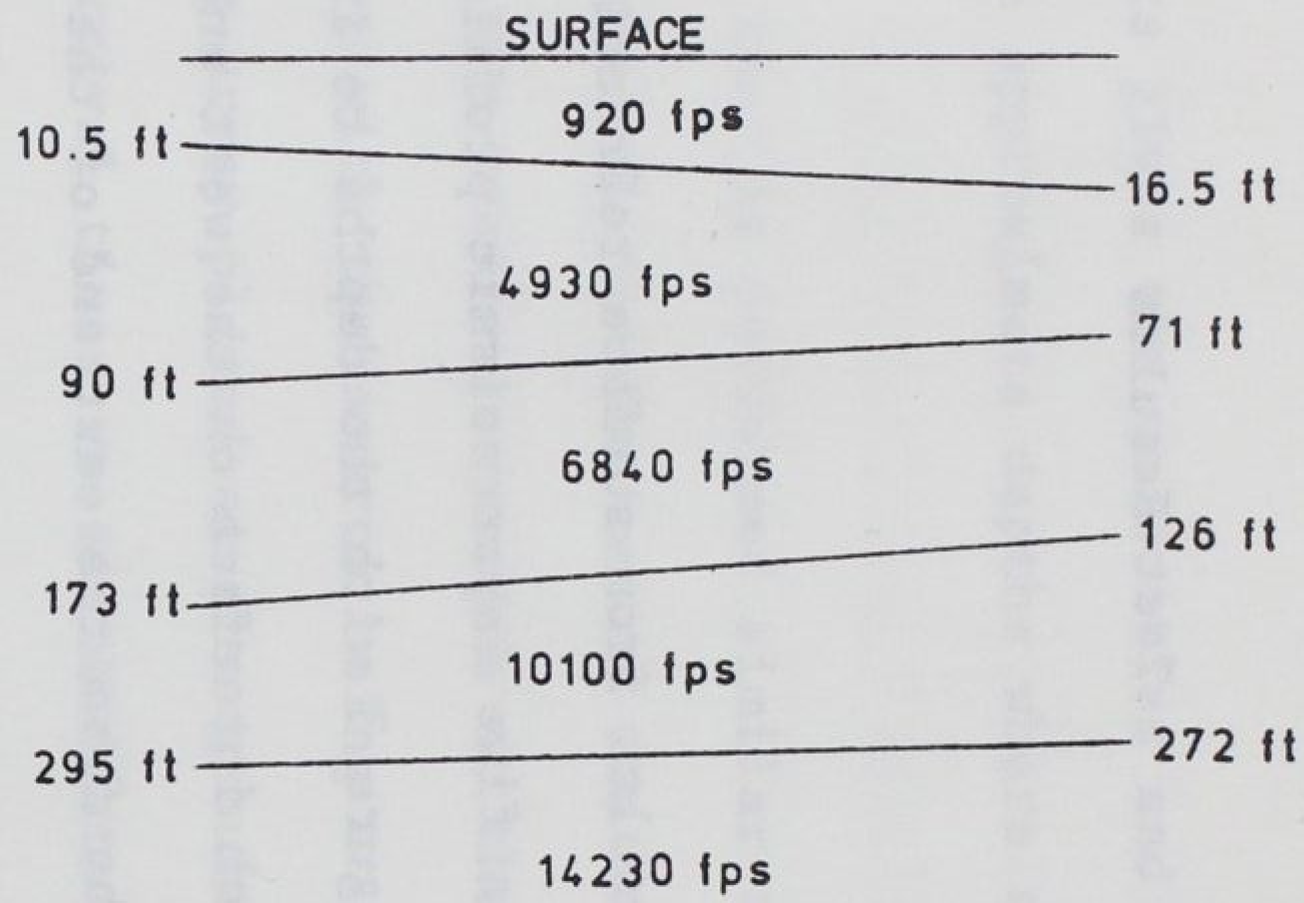
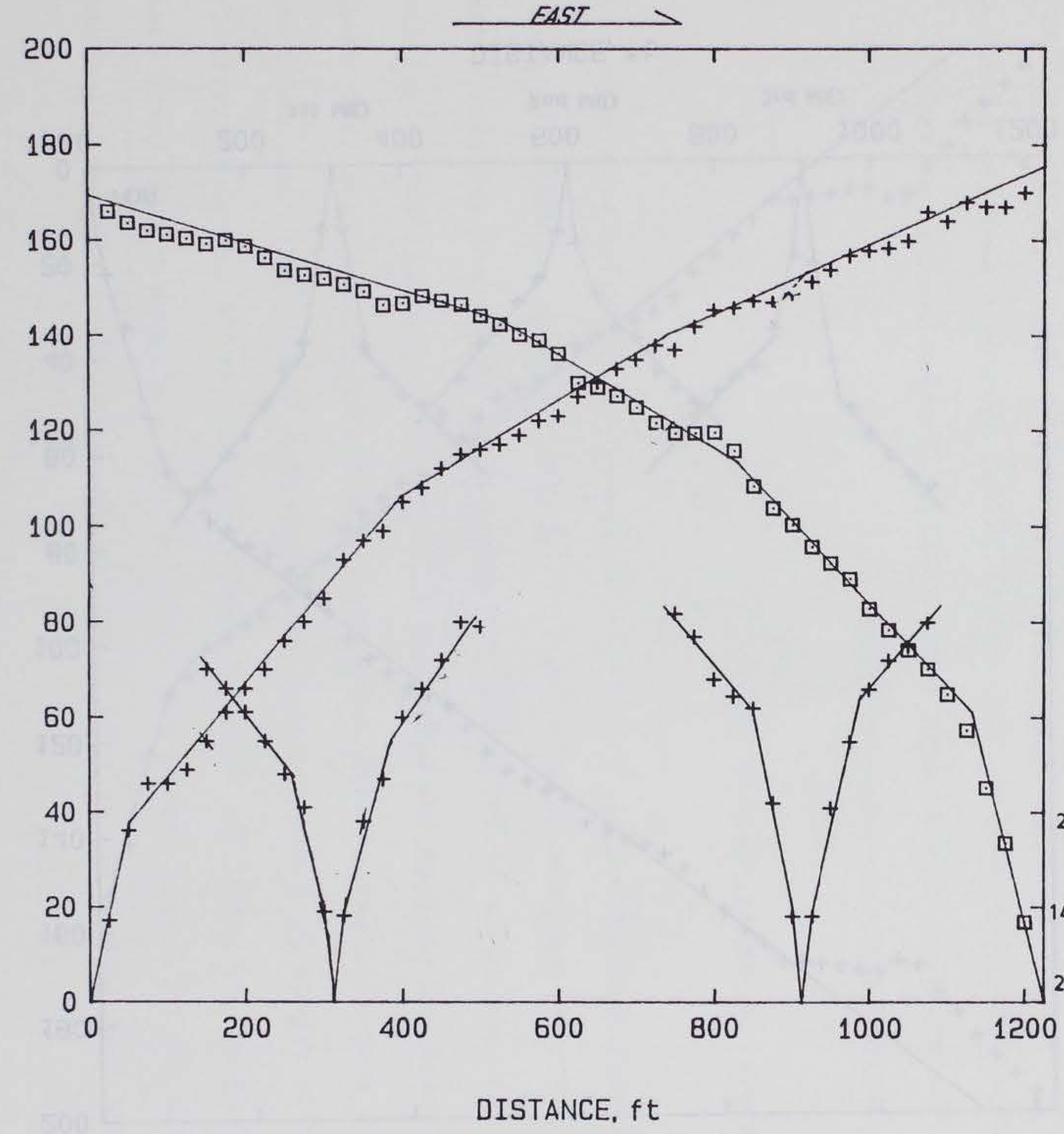


Figure 3. Surface seismic refraction line R1, Kentucky side.



** COMPUTED PROFILE END SHOT **

LAYER #	TRUE VEL. FT/S	DEPTH FOR. FT.	DEPTH REV. FT.
1	1430		
2	5400	20.5	33.5
3	10030	142.5	123.5
4	16170	240.0	320.5

** COMPUTED PROFILE 1ST MID **

LAYER #	VELFOR fps	DEPTH FOR FT.	VELREV fps	DEPTH REV FT.
1	730		600	
2	1330	4.0	1590	3.5
3	5380	24.0	4530	27.5

** COMPUTED PROFILE 2ND MID **

LAYER #	VELFOR fps	DEPTH FOR FT.	VELREV fps	DEPTH REV FT.
1	750		730	
2	1170	3.0	1230	3.5
3	5310	28.5	5560	30.5

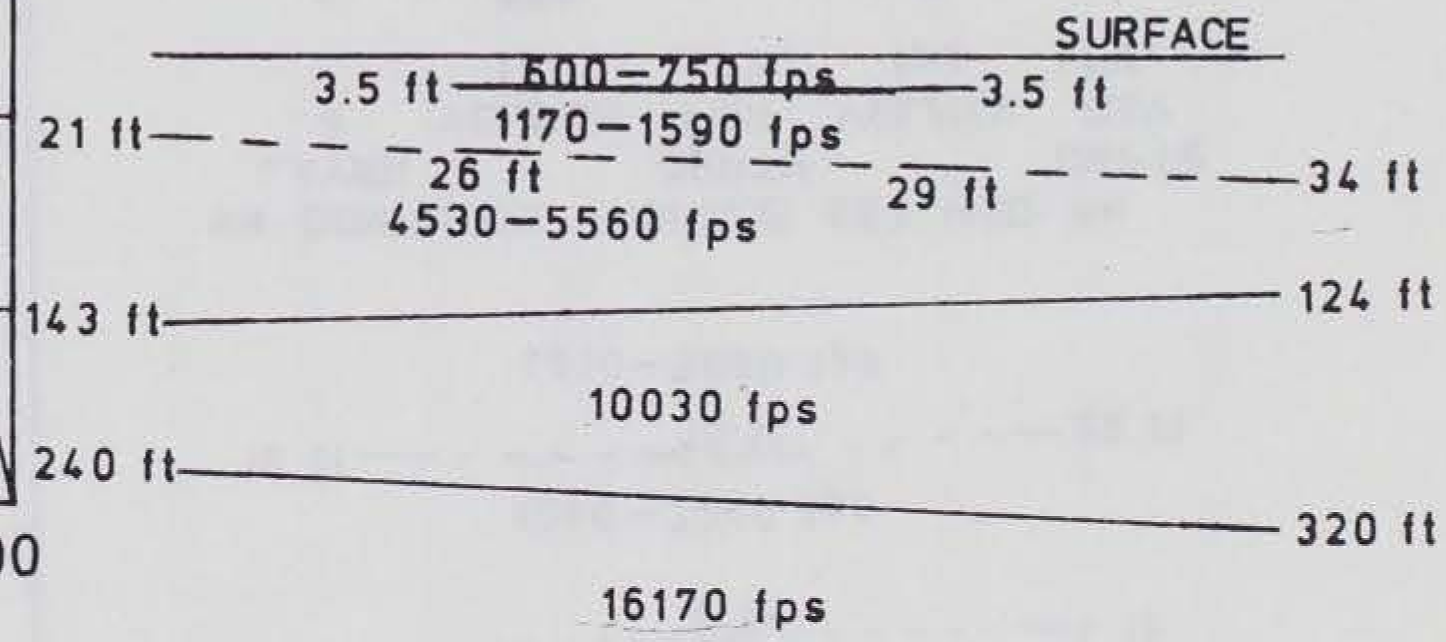
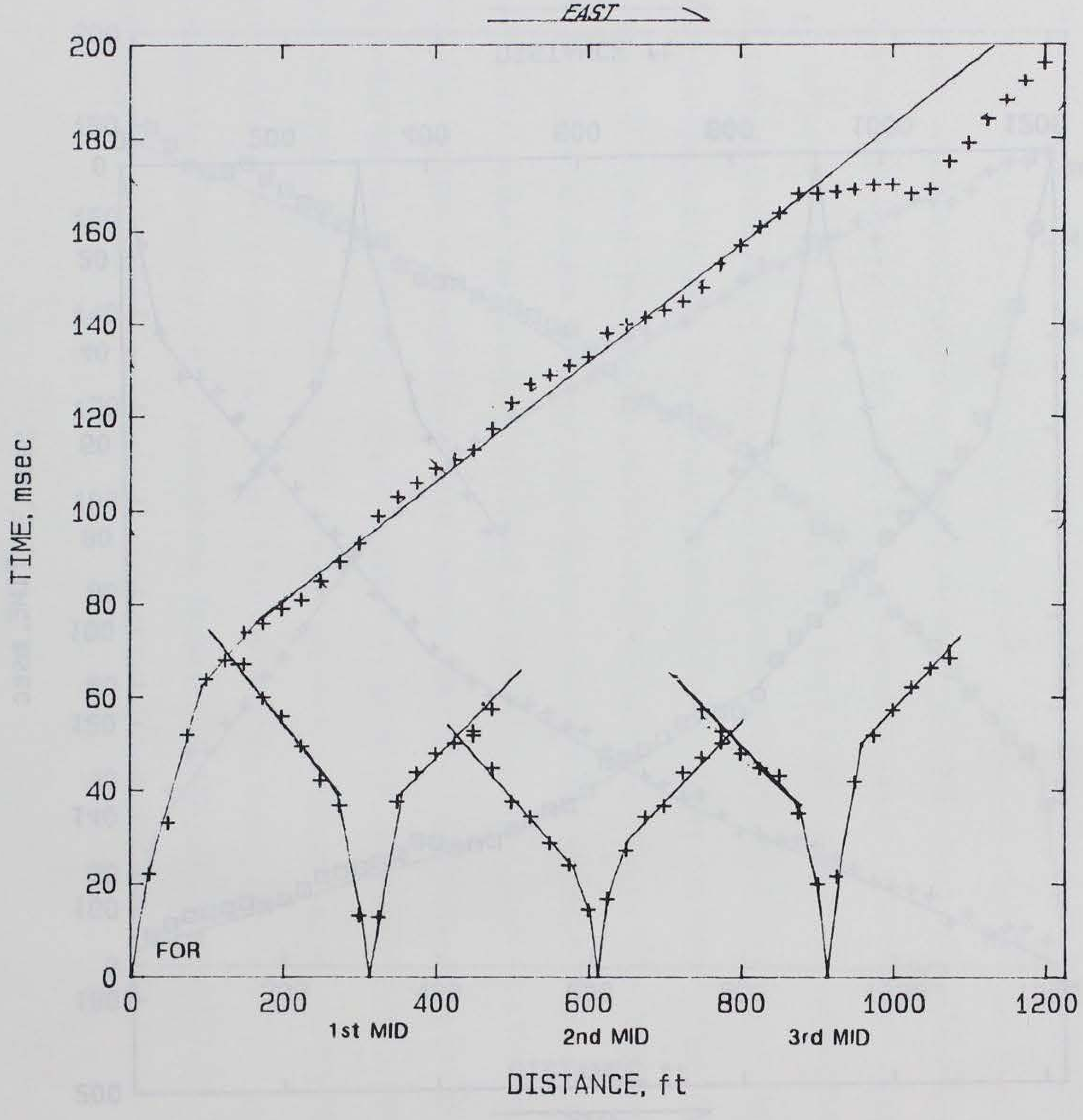
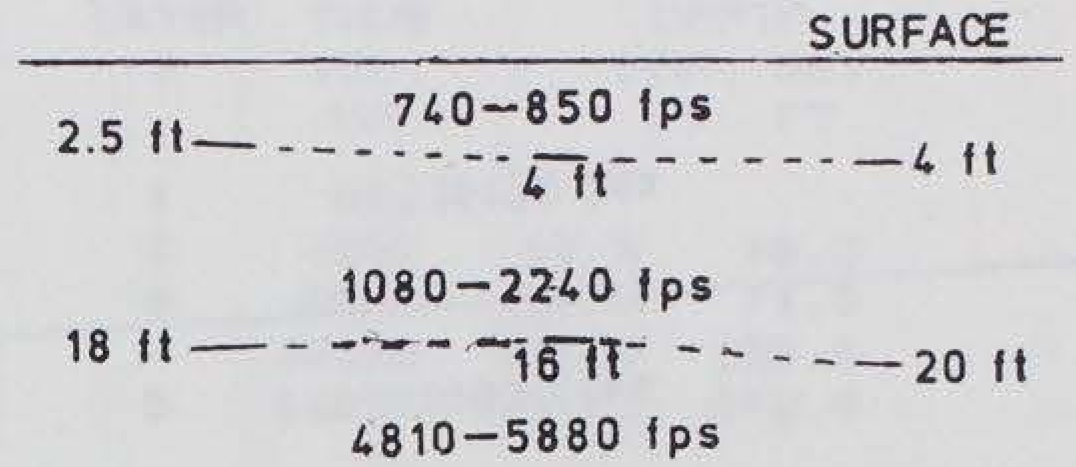


Figure 4. Surface seismic refraction line R2, Illinois side.





** COMPUTED PROFILE 1ST MID **

LAYER #	VELFOR fps	DEPTH FOR FT.	VELREV fps	DEPTH REV FT.
1	850		800	
2	1140	2.0	1130	2.5
3	4810	17.5	5880	18.5

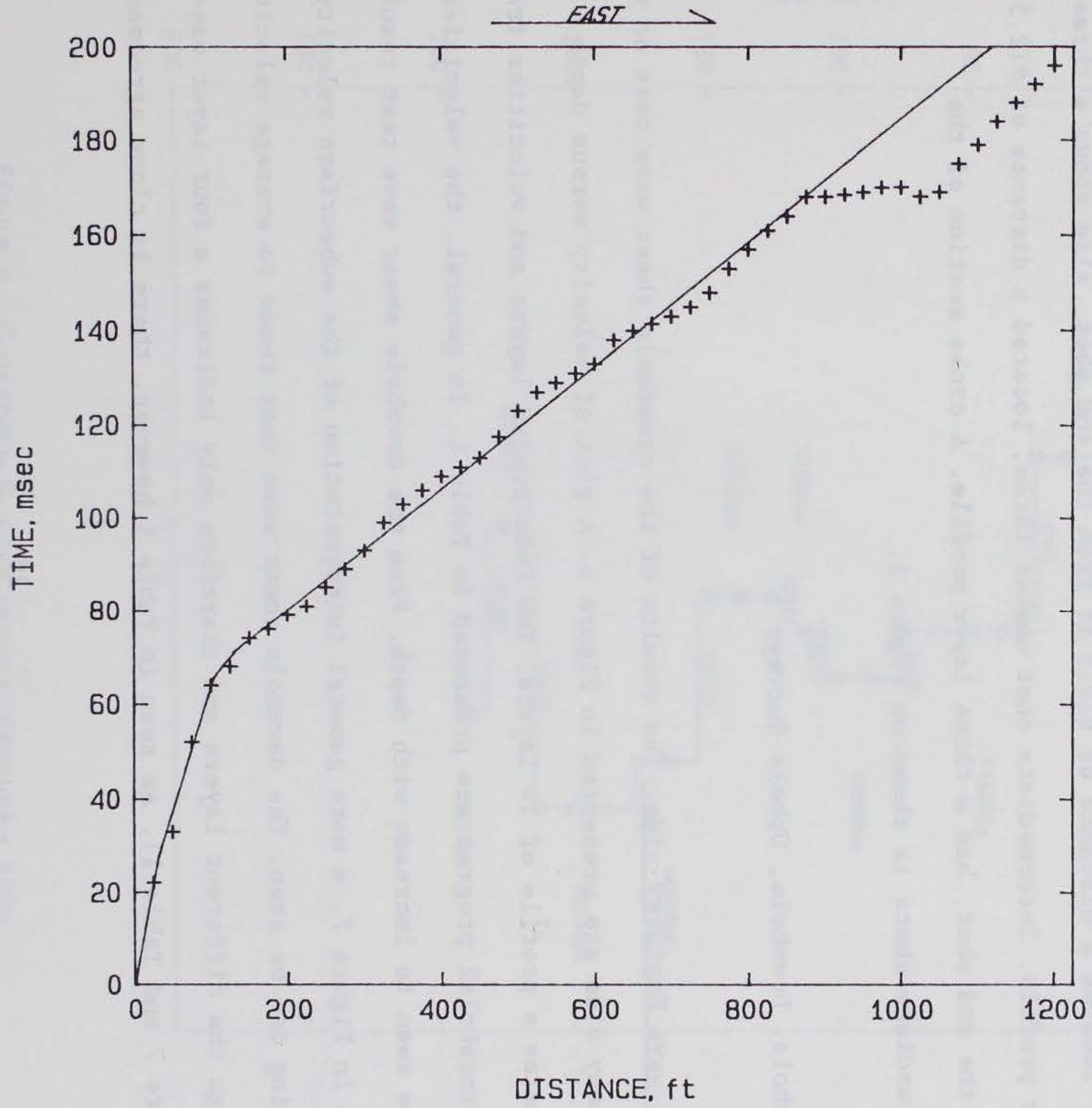
** COMPUTED PROFILE 2ND MID **

LAYER #	VELFOR fps	DEPTH FOR FT.	VELREV fps	DEPTH REV FT.
1	830		760	
2	2240	4.0	2120	4.5
3	5390	14.0	5760	17.0

** COMPUTED PROFILE 3RD MID **

LAYER #	VELFOR fps	DEPTH FOR FT.	VELREV fps	DEPTH REV FT.
1	740		740	
2	1370	4.0	1080	3.5
3	5700	18.5	5580	21.5

Figure 5. Surface seismic refraction line R3, Illinois side.



** COMPUTED PROFILE END SHOT **

LAYER #	VEL. FT/S	DEPTH FOR. FT.	DEPTH REV. FT.
1	1150		
2	1900	8.0	
3	4800	39.5	
4	7640	64.5	

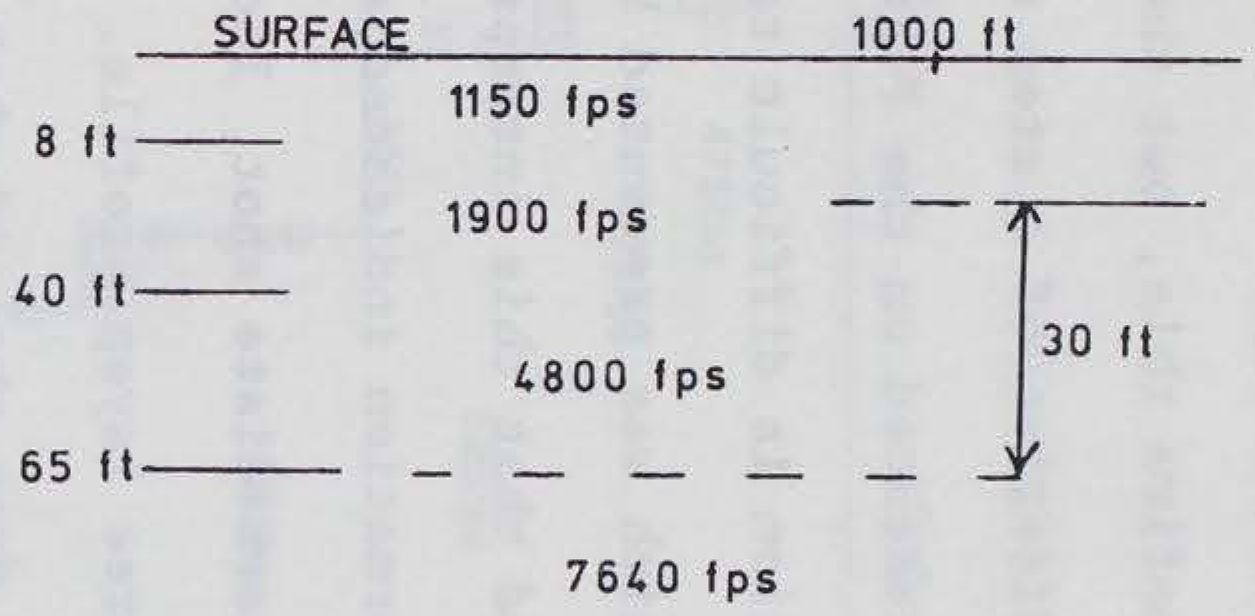


Figure 5a. Alternate interpretation of surface seismic refraction line R3, Illinois side.

More testing would be required to confirm this, but the step in the profile between 800 and 1200 ft could be indicative of a step up in the layering. A diagram of this interpretation is presented on the Figure, with the calculated step being 30 feet. This interpretation is difficult to confirm without the aid of a reverse shot on the line which was prevented by land access difficulties. However, it is believed that this interpretation is supported from drilling information. This information indicated a step up in zone 1 material in this area. The first intermediate shot, located a distance of 312.5 ft from the end shot, has a three layer profile. The second intermediate shot, located a distance of 612.5 ft from the end shot, also shows a three layer profile. Intermediate shot number three, located a distance of 912.5 ft from the end shot, has a three layer profile. A cross section of the intermediate shots is shown on Figure 5.

Crosshole, Downhole, Uphole Surveys

12. S-wave Kentucky side. The results of the crosshole shear wave test on the Kentucky side are presented in Figure 6. A plot of velocity versus depth indicates a profile of 14 layers. The interpreted layers and velocities from the Crosshole2 program are presented in Table 1. In general, the velocities can be seen to increase with depth. From the downhole shear wave test results shown in Figure 7, a more general interpretation of the subsurface velocity layering can be seen. The downhole shear wave test tends to average velocities through the different layers and therefore only indicates a four layer case (Figure 7 and Table 1). As seen in Table 1 however, there is close agreement

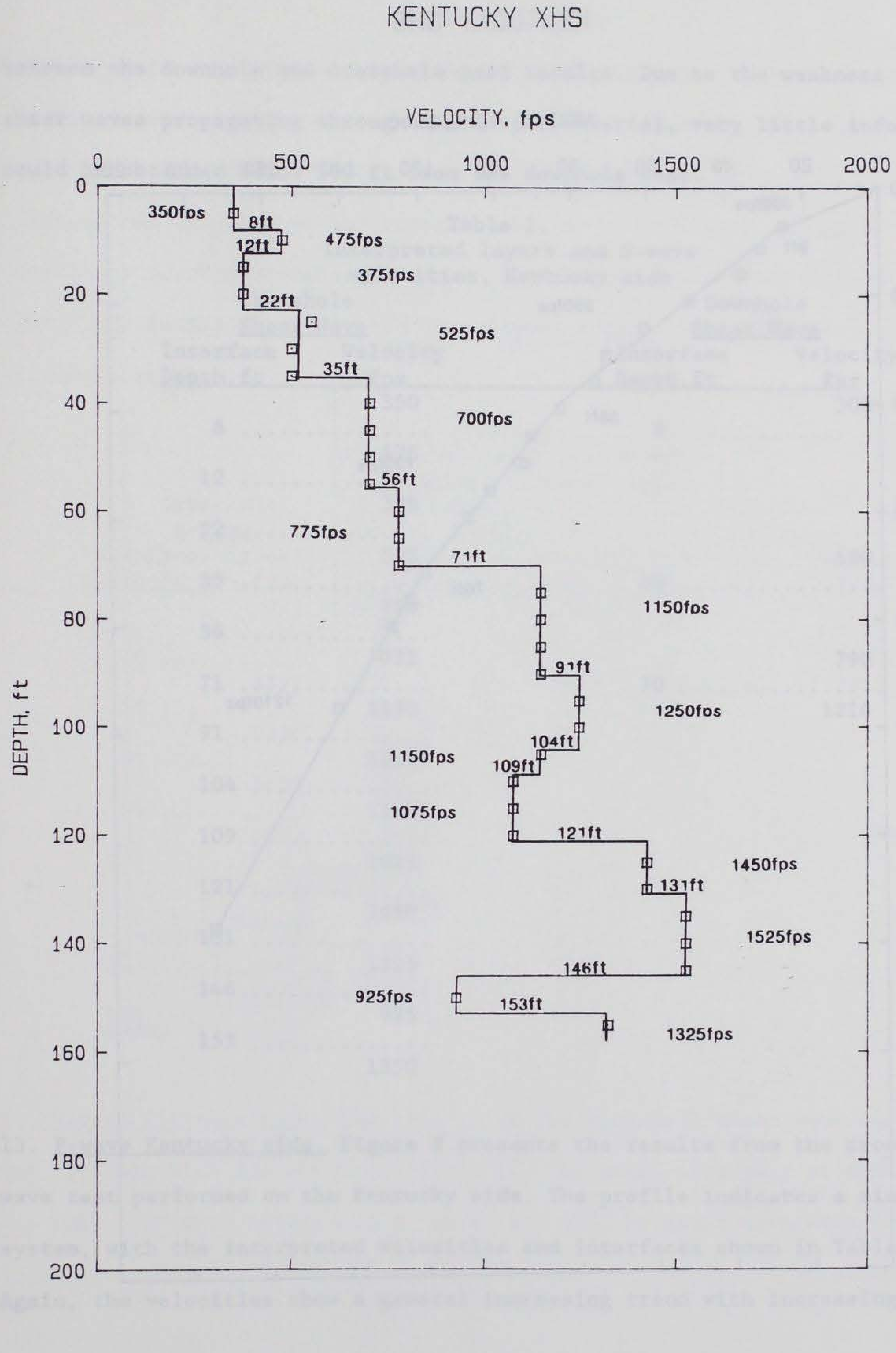


Figure 6. Crosshole S-wave results, Kentucky side.

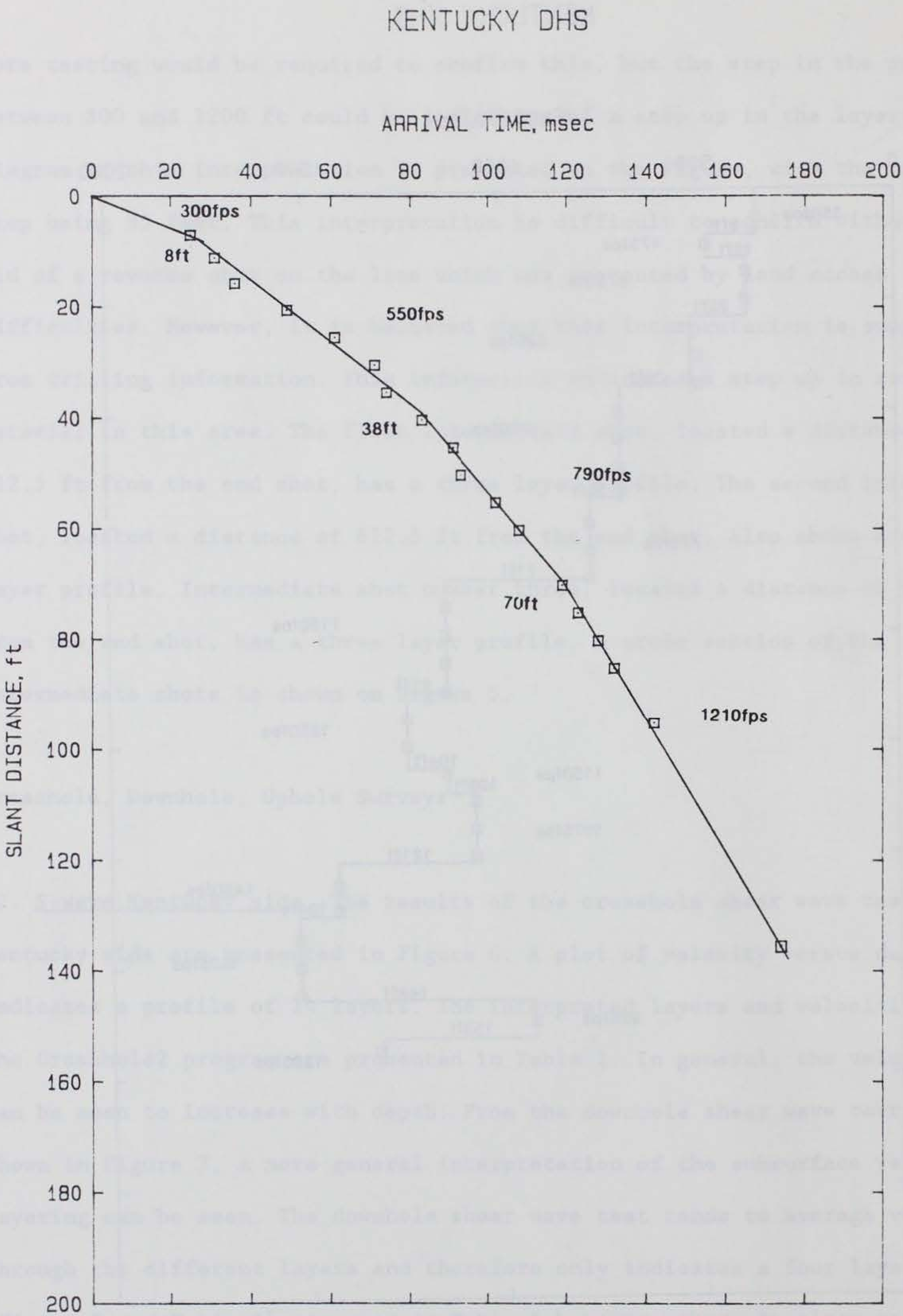


Figure 7. Downhole S-wave results, Kentucky side.

between the downhole and crosshole test results. Due to the weakness of the shear waves propagating through the deeper material, very little information could be obtained below 100 ft from the downhole test.

Table 1.
Interpreted layers and S-wave velocities, Kentucky side

Crosshole Shear Wave Interface Depth, ft	Crosshole Shear Wave Velocity fps	Downhole Shear Wave Interface Depth, ft	Downhole Shear Wave Velocity fps
	350		300
8		8	
	475		
12			
	375		
22			
	525		550
35		38	
	700		
56			
	775		790
71		70	
	1150		1210
91			
	1250		
104			
	1150		
109			
	1075		
121			
	1450		
131			
	1525		
146			
	925		
153			
	1350		

13. P-wave Kentucky side. Figure 8 presents the results from the crosshole P-wave test performed on the Kentucky side. The profile indicates a nine layer system, with the interpreted velocities and interfaces shown in Table 2. Again, the velocities show a general increasing trend with increasing depth.

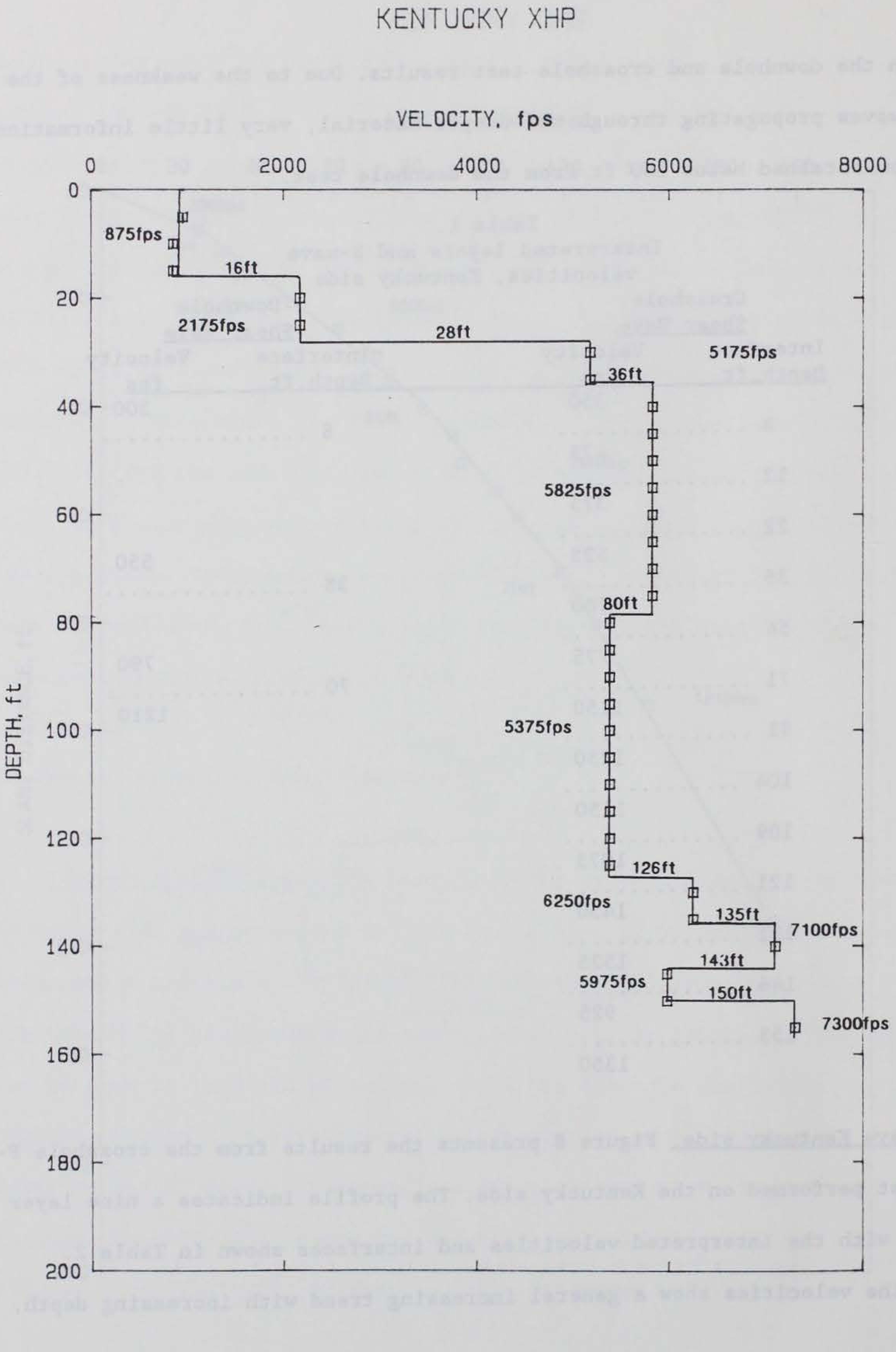


Figure 8. Crosshole P-wave results, Kentucky side.

Figure 9 shows the uphole P-wave results from this area. The signals from the near surface material were too weak to clearly define the upper 10 ft. The results of the downhole P-wave test are presented in Figure 10. Both the downhole and uphole show an increasing velocity with depth, and have their respective results presented in Table 2. Because of the averaging of the uphole and downhole tests, less layering is apparent compared with the crosshole tests.

Table 2.
Interpreted layers and P-wave velocities, Kentucky side

Crosshole P-Wave		Downhole P-Wave		Uphole P-Wave	
Interface Depth, ft	Velocity fps	Interface Depth, ft	Velocity fps	Interface Depth, ft	Velocity fps
	875		780		
		9			
16					
	2175		1522		1275
28		30		26	
	5175		5275		6100
36					
	5825				
80					
	5375				
126					
	6250				
135					
	7100				
143					
	5975				
150					
	7300				

14. S-wave Illinois side. The results of the crosshole shear wave test from the Illinois side are shown in Figure 11. The shear wave test at this location was only performed between hole set 28 and 27a. No shear wave test data were collected between hole set 27 and 28, because of equipment limitations. The

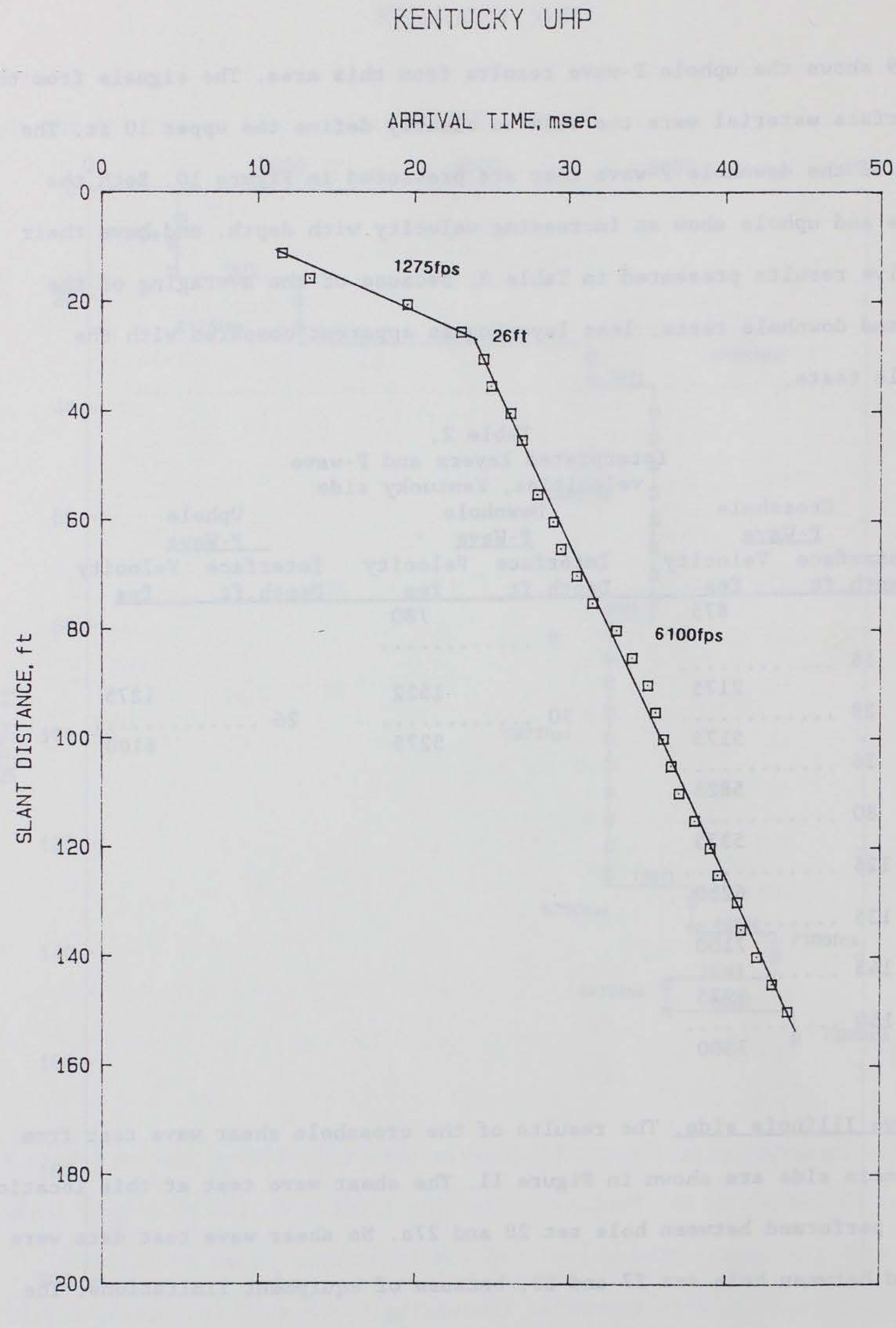


Figure 9. Uphole P-wave results, Kenucky side.

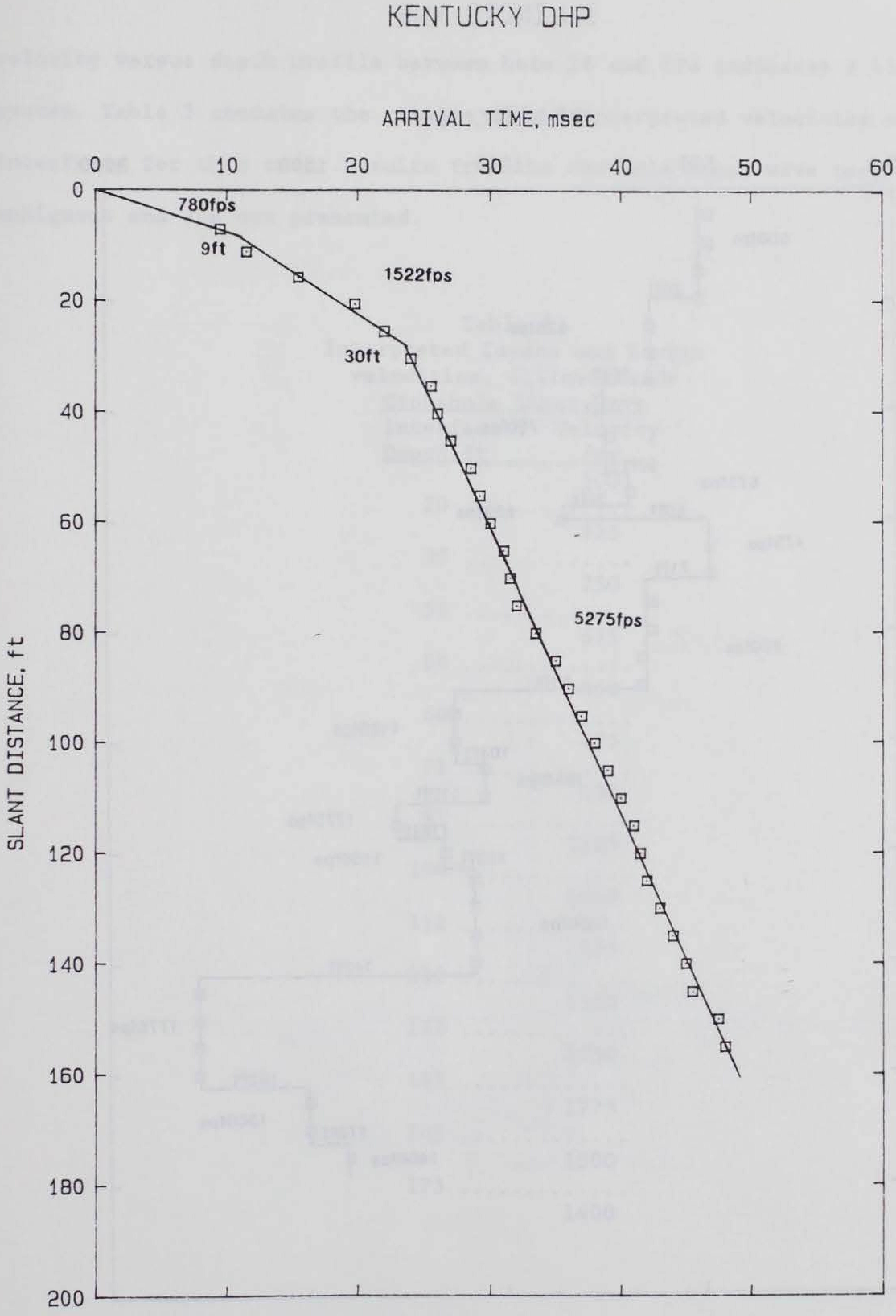


Figure 10. Downhole P-wave results. Kentucky side.

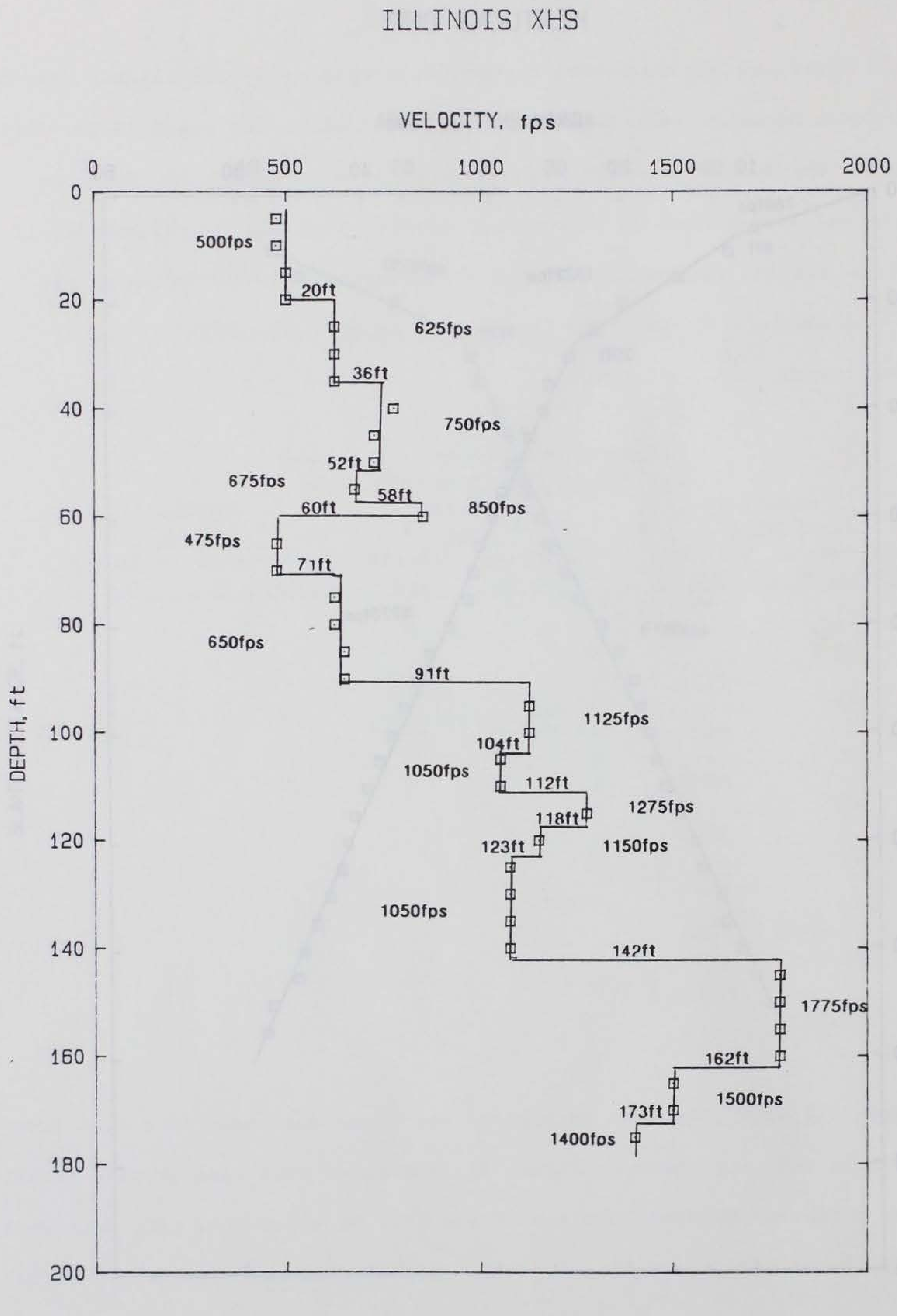


Figure 11. Crosshole S-wave results, Illinois side.

velocity versus depth profile between hole 28 and 27a indicates a 15 layer system. Table 3 contains the results of the interpreted velocities and interfaces for this test. Results from the downhole shear wave test were ambiguous and are not presented.

Table 3.
Interpreted layers and S-wave velocities, Illinois side
Crosshole Shear Wave

Interface Depth,ft	Velocity fps
	500
20	
	625
36	
	750
52	
	675
58	
	850
60	
	475
71	
	650
91	
	1125
104	
	1050
112	
	1275
118	
	1150
123	
	1050
142	
	1775
162	
	1500
173	
	1400

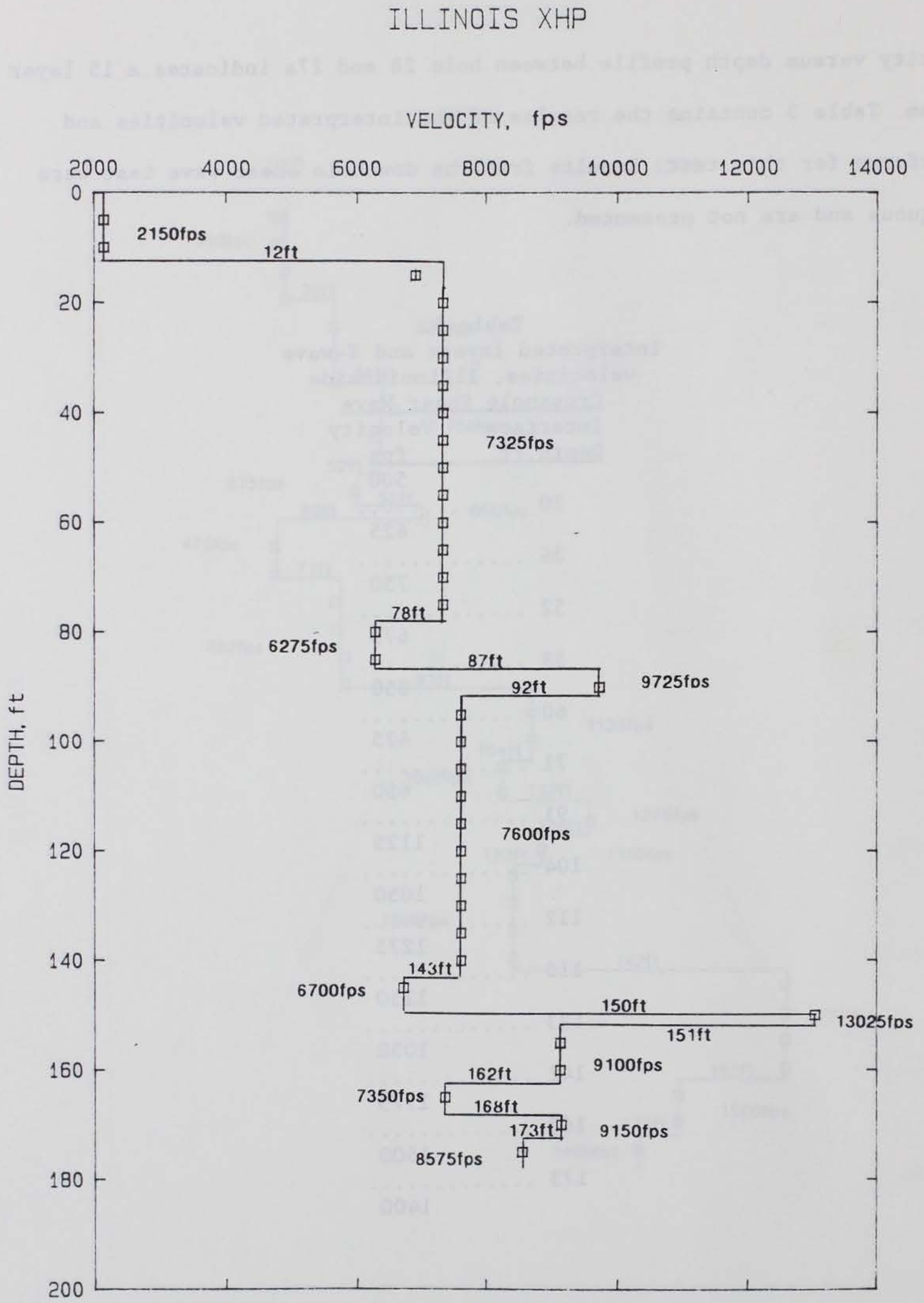


Figure 12. Crosshole P-wave results set 27-28, Illinois side.

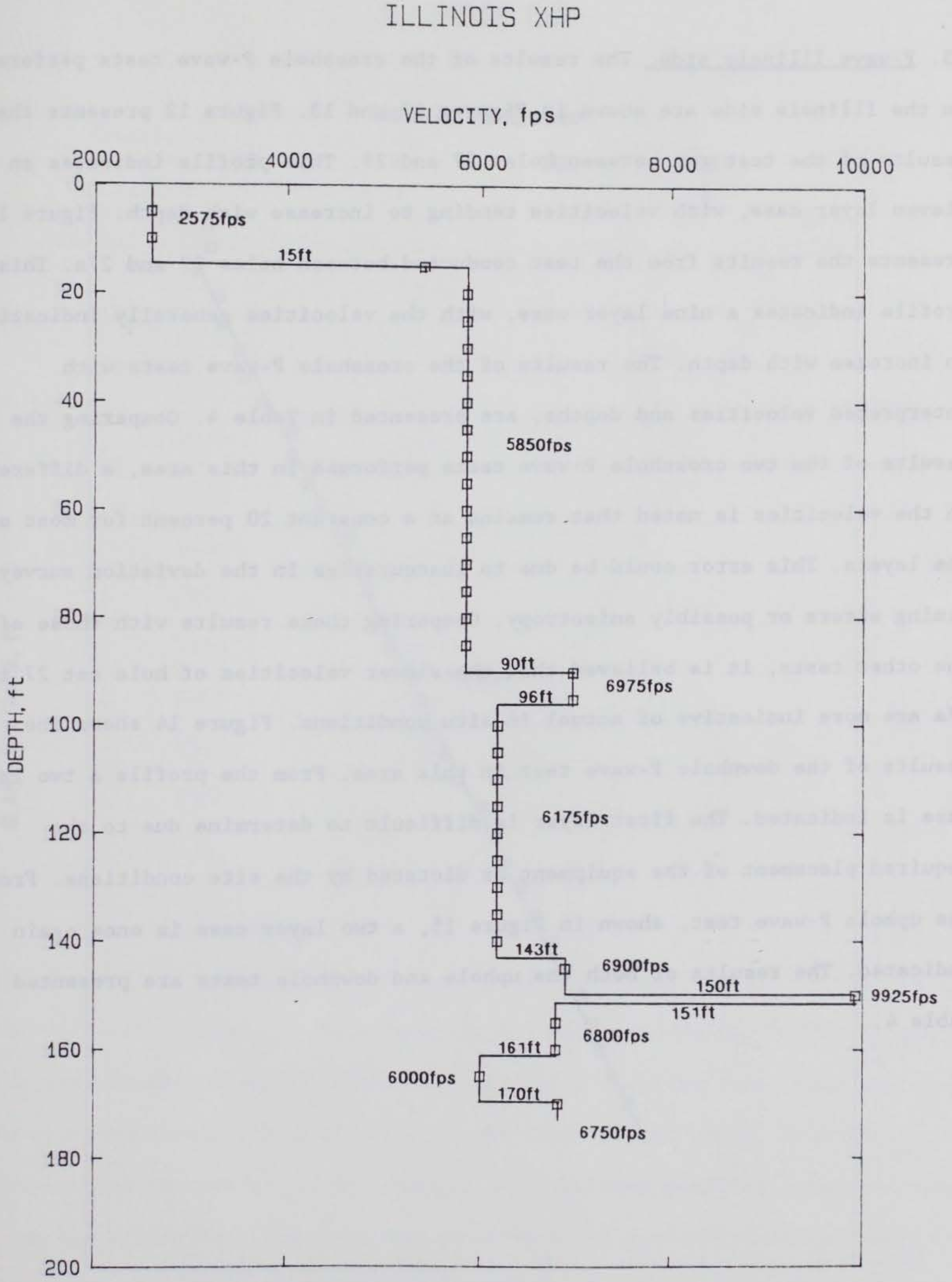


Figure 13. Crosshole P-wave results set 27-27a, Illinois side.

15. <u>P-wave Illinois side.</u> The results of the crosshole P-wave tests performed on the Illinois side are shown in Figures 12 and 13. Figure 12 presents the results of the test run between holes 27 and 28. This profile indicates an eleven layer case, with velocities tending to increase with depth. Figure 13 presents the results from the test conducted between holes 27 and 27a. This profile indicates a nine layer case, with the velocities generally indicating an increase with depth. The results of the crosshole P-wave tests with interpreted velocities and depths, are presented in Table 4. Comparing the results of the two crosshole P-wave tests performed in this area, a difference in the velocities is noted that remains at a constant 20 percent for most of the layers. This error could be due to inaccuracies in the deviation survey, timing errors or possibly anisotropy. Comparing these results with those of the other tests, it is believed that the slower velocities of hole set 27 to 27a are more indicative of actual in situ conditions. Figure 14 shows the results of the downhole P-wave test in this area. From the profile a two layer case is indicated. The first layer is difficult to determine due to the required placement of the equipment as dictated by the site conditions. From the uphole P-wave test, shown in Figure 15, a two layer case is once again indicated. The results of both the uphole and downhole tests are presented in Table 4.

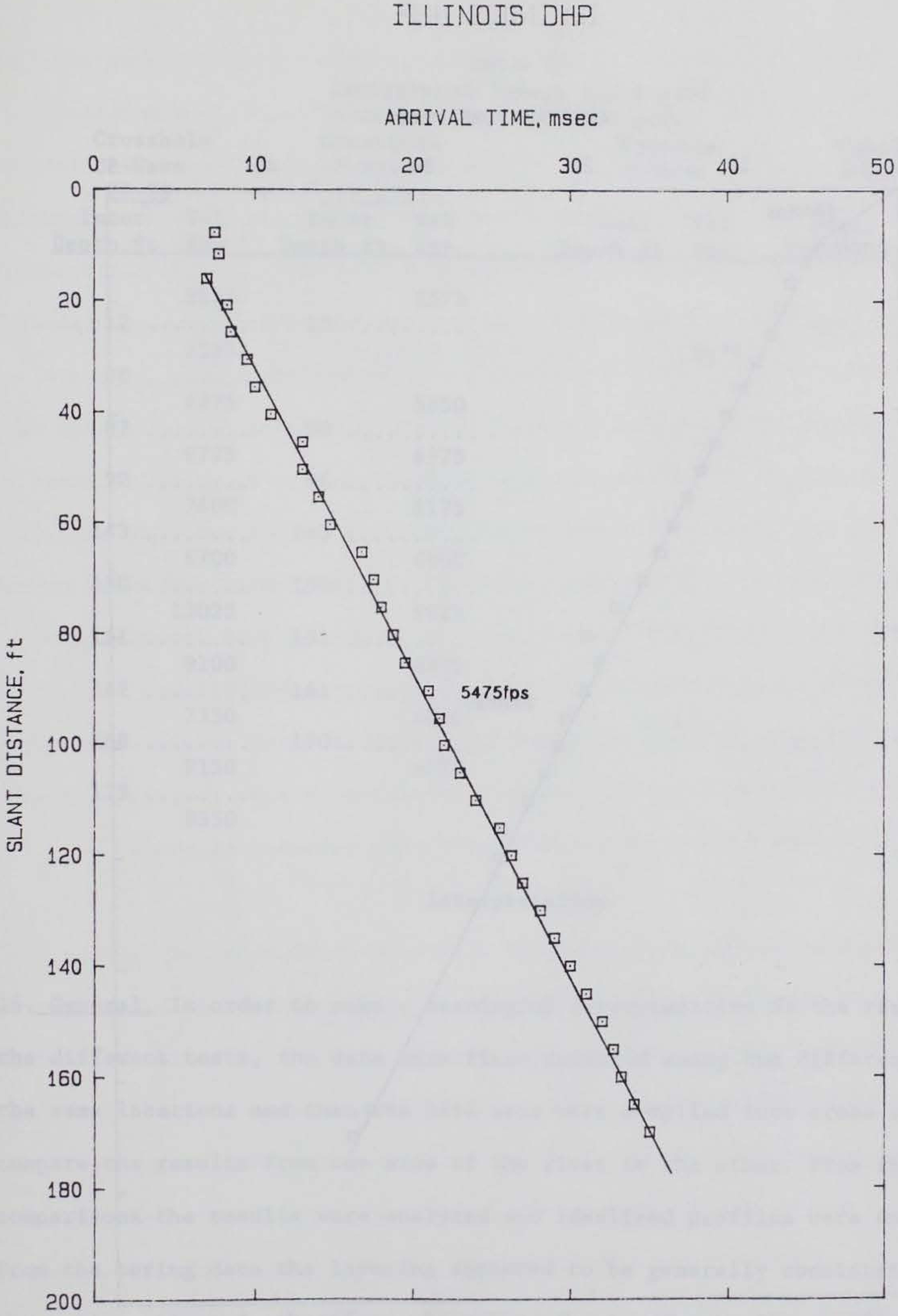


Figure 14. Downhole P-wave results, Illinois side.

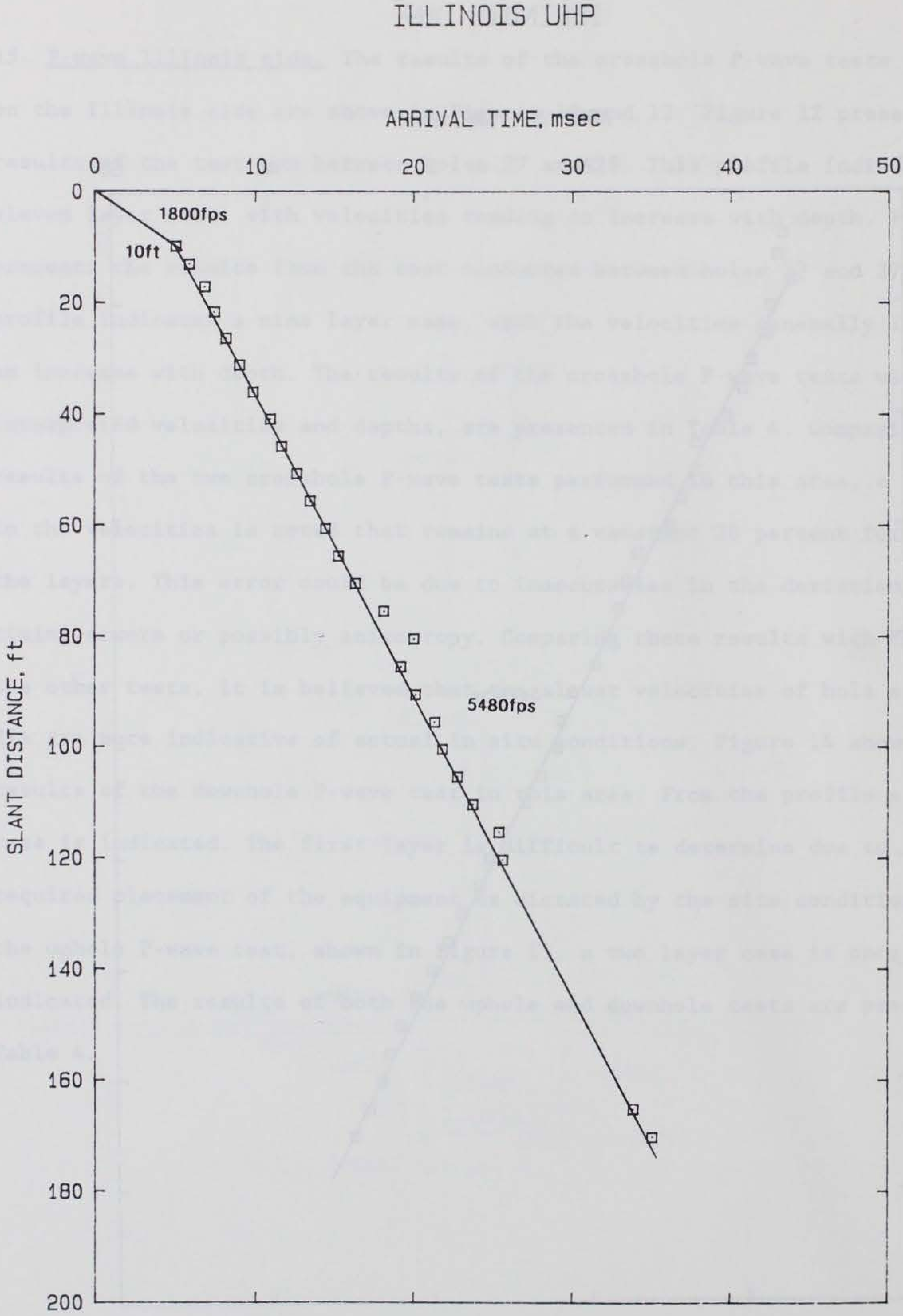


Figure 15. Uphole P-wave results, Illinois side.

Table 4.
Interpreted layers and P-wave velocities, Illinois side

Crosshole P-Wave 27-28		Crosshole P-Wave 27-27a		Downhole P-Wave		Uphole P-Wave	
Inter Depth, ft	Vel fps	Inter Depth, ft	Vel fps	Inter Depth, ft	Vel fps	Inter Depth, ft	Vel fps
	2150		2575				1800
12		15				10	
	7325				5475		5480
78							
	6275		5850				
87		90					
	9725		6975				
92		96					
	7600		6175				
143		143					
	6700		6900				
150		150					
	13025		9925				
151		151					
	9100		6800				
162		161					
	7350		6000				
168		170					
	9150		6750				
173							
	8550						

Interpretation

16. General. In order to make a meaningful interpretation of the results from the different tests, the data were first compared among the different tests at the same locations and then the data sets were compiled into cross-sections to compare the results from one side of the river to the other. From these comparisons the results were analyzed and idealized profiles were developed. From the boring data the layering appeared to be generally consistent beneath the entire site and, therefore, in making the interpretation an effort was

made to develop layering and velocities in a consistent manner when possible. Also using boring log data the velocities were correlated to material descriptions. From boring data the subsurface was divided into four distinct zones consisting of alluvium, McNairy zone 1, McNairy zone 2, and paleozoic materials. Within these zones the boring data show that the materials consist of many layers with varying properties. This is supported by the crosshole test results which also show the existence of inversion layers (layers with a slower velocity below a higher velocity layer). Inversion layers cannot be detected by surface refraction testing. Another case to consider is where a material, in the absence of water, would exhibit a P-wave velocity that is lower than or close to the velocity of water. In this case, the depth to the water table will be the controlling interface and will mask interfaces with such materials below the water table. These conditions complicate the interpretation and can mask the information that is being sought. However, the use of shear wave tests can help clarify the issue because the shear wave velocity of materials are not as affected by the presence of water.

17. <u>Crosshole tests Kentucky side.</u> The crosshole interpretation for the Kentucky side are shown in Figure 16. The P-wave velocity of the near surface alluvium (banded clay, silty) is approximately 875 fps and increases to 2175 fps at 16 ft where the material changes to a banded sand, silty clay. These sediments continue to a depth of 40 ft. At 28 ft the increase from 2175 to 5175 fps is due to the presence of the water table. The S-wave velocity of the banded clay, silty averages 400 fps with a range in values from 350 to 475 fps. The banded sand, silty clay has an average velocity of 475 fps with a

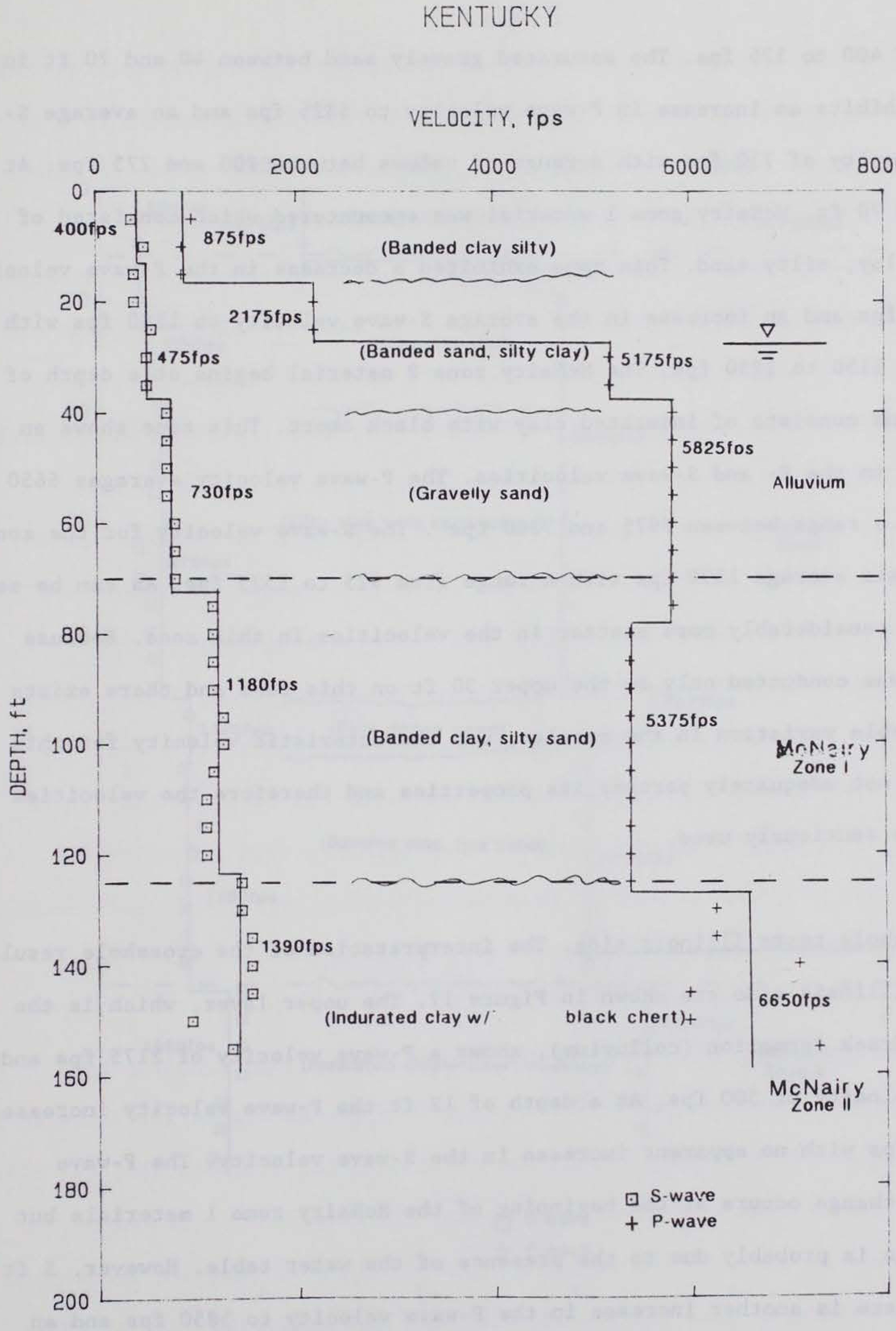


Figure 16. Composite crosshole S- and P-wave results, Kentucky side.

range of 400 to 525 fps. The saturated gravely sand between 40 and 70 ft in depth exhibits an increase in P-wave velocity to 5825 fps and an average S-wave velocity of 730 fps with a range of values between 700 and 775 fps. At a depth of 70 ft, McNairy zone 1 material was encountered which consisted of banded clay, silty sand. This zone exhibited a decrease in the P-wave velocity to 5375 fps and an increase in the average S-wave velocity to 1180 fps with a range of 1150 to 1250 fps. The McNairy zone 2 material begins at a depth of 125 ft and consists of indurated clay with black chert. This zone shows an increase in the P- and S-wave velocities. The P-wave velocity averages 6650 fps with a range between 5975 and 7300 fps . The S-wave velocity for the zone 2 materials average 1390 fps with a range from 925 to 1525 fps. As can be seen there is considerably more scatter in the velocities in this zone. Because testing was conducted only in the upper 30 ft on this zone and there exists considerable variation in the results, one characteristic velocity for this zone may not adequately portray its properties and therefore the velocities should be cautiously used.

18. Crosshole tests Illinois side. The interpretation of the crosshole results for the Illinois side are shown in Figure 17. The upper layer, which is the Porters Creek formation (colluvium), shows a P-wave velocity of 2175 fps and a S-wave velocity of 500 fps. At a depth of 12 ft the P-wave velocity increases to 5600 fps with no apparent increase in the S-wave velocity. The P-wave velocity change occurs at the beginning of the McNairy zone 1 materials but the change is probably due to the presence of the water table. However, 5 ft deeper there is another increase in the P-wave velocity to 5850 fps and an

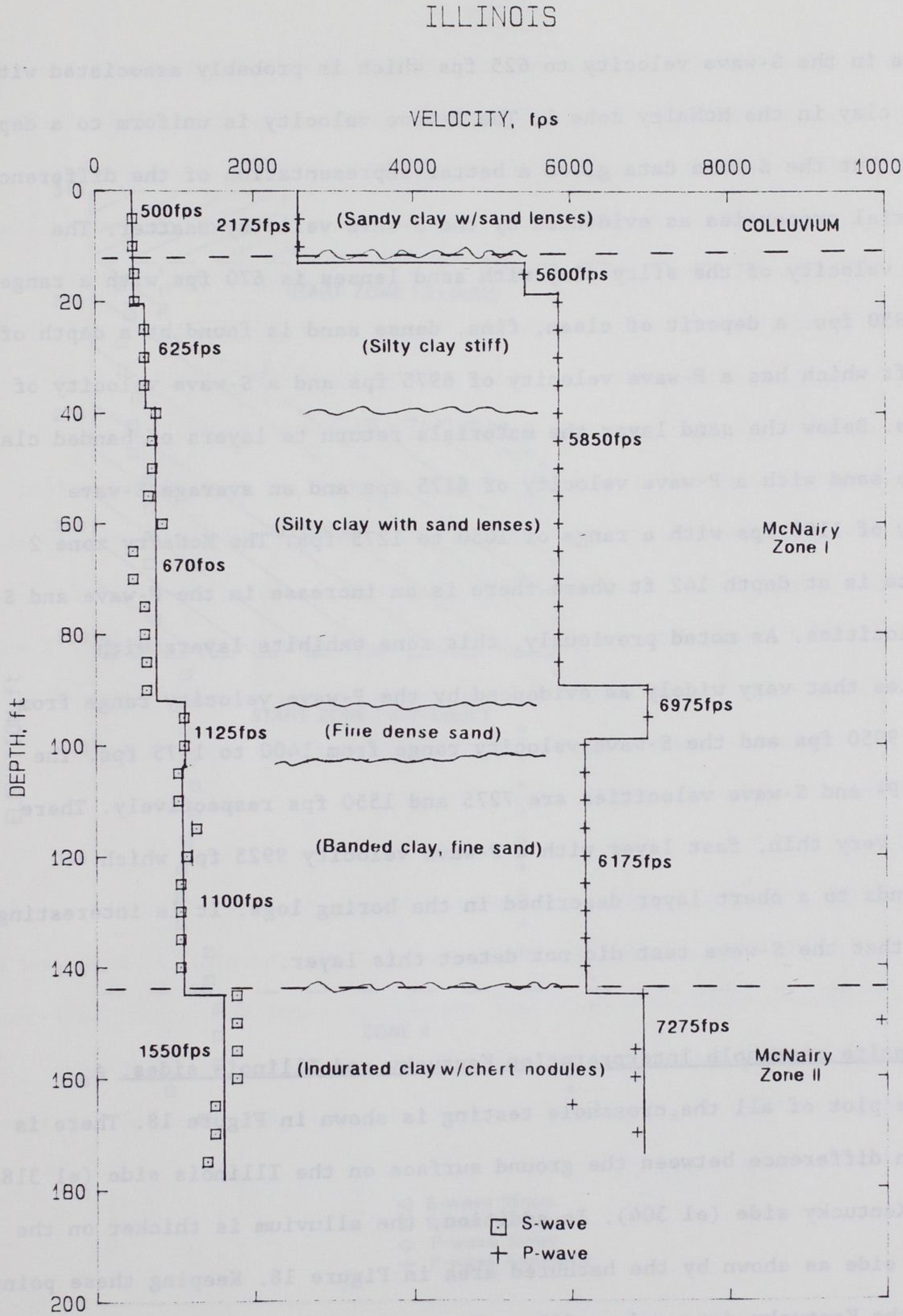


Figure 17. Composite crosshole S- and P-wave results, Illinois side.

increase in the S-wave velocity to 625 fps which is probably associated with stiffer clay in the McNairy zone 1. The P-wave velocity is uniform to a depth of 90 ft but the S-wave data gives a better representation of the differences in material properties as evidenced by the S-wave velocity scatter. The average velocity of the silty clay with sand lenses is 670 fps with a range of 475 to 850 fps. A deposit of clean, fine, dense sand is found at a depth of 90 to 100 ft which has a P-wave velocity of 6975 fps and a S-wave velocity of 1125 fps. Below the sand layer the materials return to layers of banded clay and fine sand with a P-wave velocity of 6175 fps and an average S-wave velocity of 1100 fps with a range of 1050 to 1275 fps. The McNairy zone 2 interface is at depth 142 ft where there is an increase in the P-wave and S-wave velocities. As noted previously, this zone exhibits layers with properties that vary widely as evidenced by the P-wave velocity range from 6000 to 9950 fps and the S-wave velocity range from 1400 to 1775 fps. The average P- and S-wave velocities are 7275 and 1550 fps respectively. There exists a very thin, fast layer with a P-wave velocity 9925 fps which corresponds to a chert layer described in the boring logs. It is interesting to note that the S-wave test did not detect this layer.

19. <u>Composite crosshole Interpretation Kentucky and Illinois sides.</u> A composite plot of all the crosshole testing is shown in Figure 18. There is an elevation difference between the ground surface on the Illinois side (el 318) and the Kentucky side (el 304). In addition, the alluvium is thicker on the Kentucky side as shown by the hachured area in Figure 18. Keeping these points in mind the Kentucky data and profile are superimposed on the Illinois data

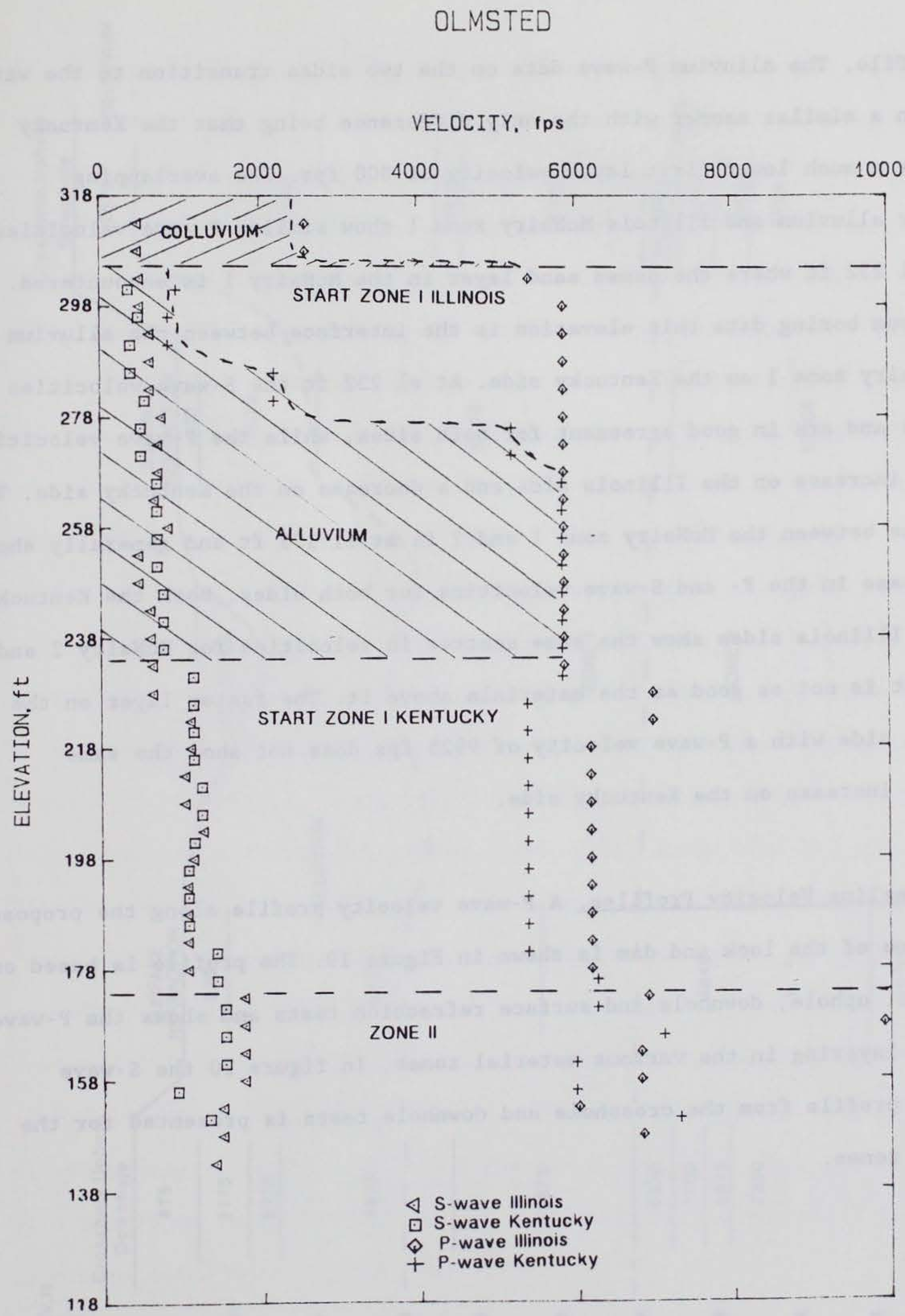


Figure 18. Composite crosshole S- and P-wave results, Olmsted site.

and profile. The alluvium P-wave data on the two sides transition to the water table in a similar manner with the only difference being that the Kentucky side has a much lower first layer velocity of 800 fps. The overlapping Kentucky alluvium and Illinois McNairy zone 1 show similar P-wave velocities until el 232 ft where the dense sand layer in the McNairy 1 is encountered. Also, from boring data this elevation is the interface between the alluvium and McNairy zone 1 on the Kentucky side. At el 232 ft the S-wave velocities increase and are in good agreement for both sides, while the P-wave velocities show an increase on the Illinois side and a decrease on the Kentucky side. The interface between the McNairy zone 1 and 2 is at el 173 ft and generally shows an increase in the P- and S-wave velocities for both sides. Both the Kentucky and the Illinois sides show the same scatter in velocities for McNairy 2 and agreement is not as good as the materials above it. The faster layer on the Illinois side with a P-wave velocity of 9925 fps does not show the same dramatic increase on the Kentucky side.

20. <u>Centerline Velocity Profiles.</u> A P-wave velocity profile along the proposed centerline of the lock and dam is shown in Figure 19. The profile is based on crosshole, uphole, downhole and surface refraction tests and shows the P-wave velocity layering in the various material zones. In figure 20 the S-wave velocity profile from the crosshole and downhole tests is presented for the material zones.

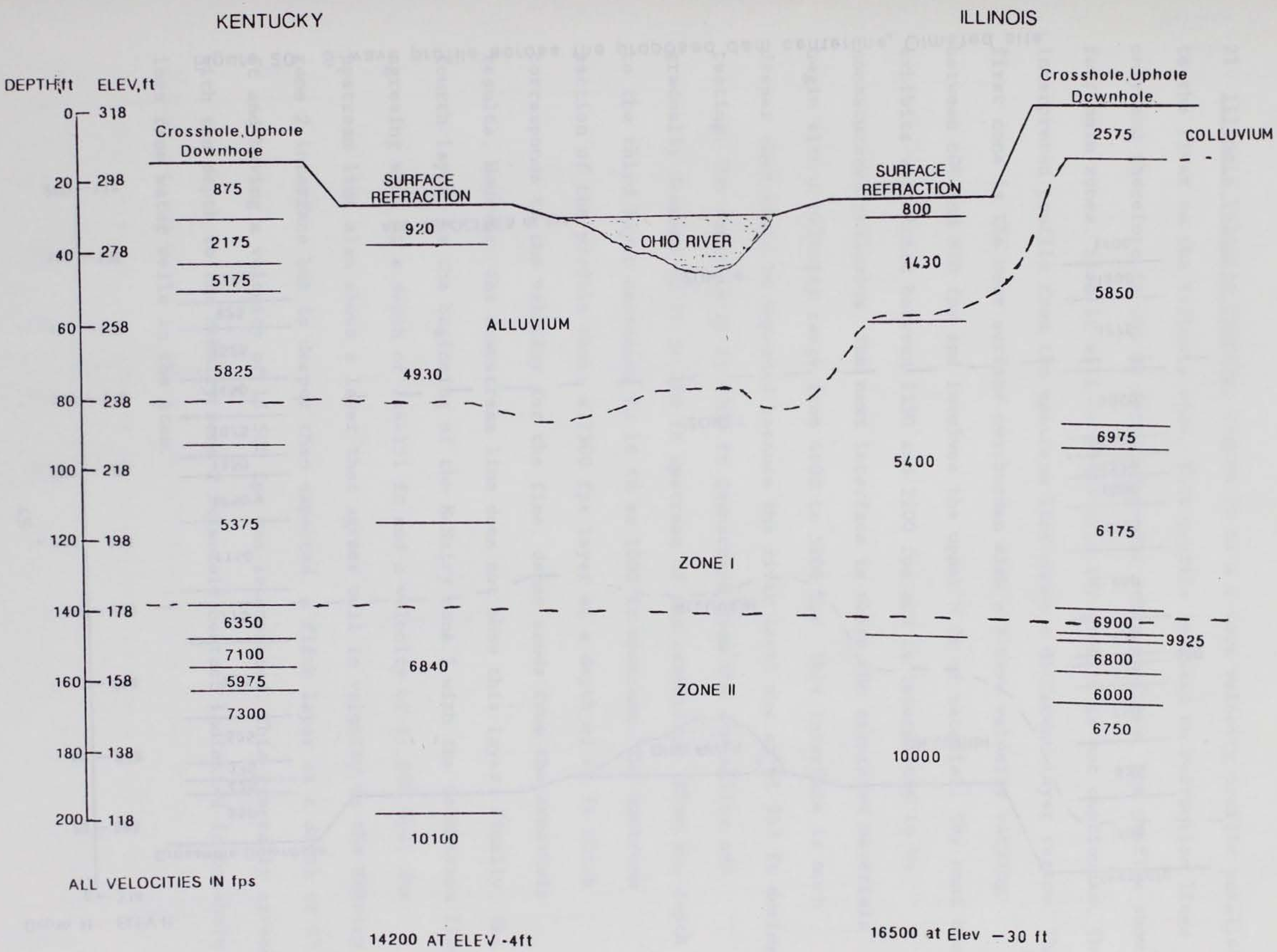


Figure 19. P-wave profile across the proposed dam centerline, Olmsted site.

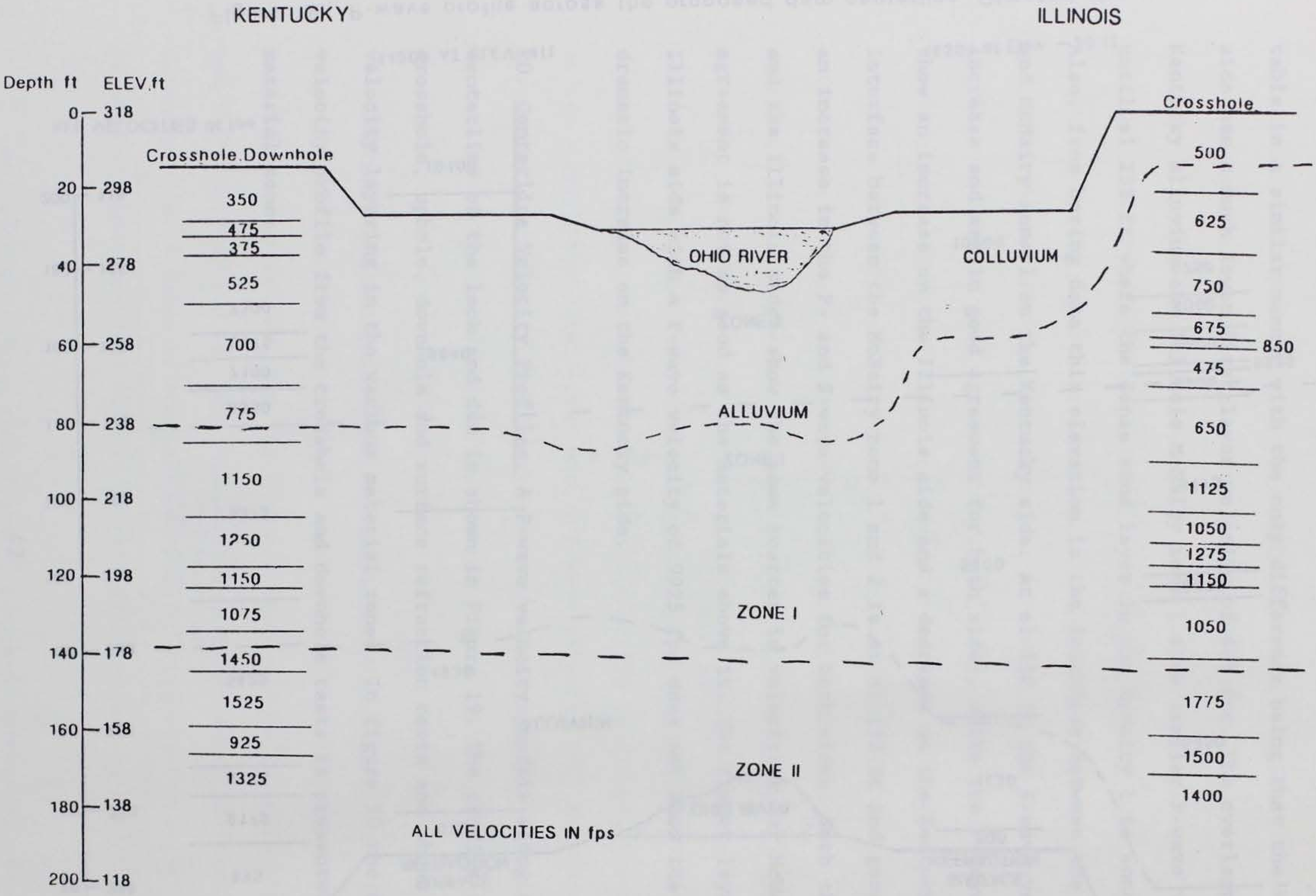


Figure 20. S-wave profile across the proposed dam centerline, Olmsted site.

21. <u>Illinois Velocity Profile.</u> Figure 21 is a P-wave velocity profile parallel to the river on the Illinois side. This profile is based on refraction lines only and therefore is not as detailed as the other profiles. The profile shows four main zones. Also it will be noted that the profile is not continuous. The interpreted profile from the upstream line shows a different layer regime. The first zone is the near surface overburden with a P-wave velocity varying between 600 and 850 fps and involves the upper 5 ft of material. The next zone exhibits velocities between 1150 and 2200 fps and is interpreted to be nonsaturated colluvium. The next interface is where the saturated materials begin with a velocity range from 4600 to 5800 fps. This interface is much deeper than would be expected because the river level was at el 285 ft during testing. The depth is 21 ft 1200 ft downstream from the centerline and gradually deepens to 37 ft 200 ft upstream of the centerline. Then the depth to the third layer decreases to 16 ft at 1000 ft upstream. The upstream section of the profile shows a 7300 fps layer at a depth of 67 ft which corresponds to the velocity for the fine, dense sands from the crosshole results. However, the downstream line does not show this layer. Finally, the fourth layer is the beginning of the McNairy zone 2 with the downstream line agreeing well at a depth of 144-151 ft and a velocity of 11,200 fps. The upstream line also shows a layer that agrees well in velocity to the McNairy zone 2 interface but is deeper than expected. A fifth layer at a depth of 277 ft and having a velocity of 16,500 fps was interpreted. This generally agrees with the depth to the McNairy zone 2 Paleozoic contact indicated in borehole logs from water wells in the area.

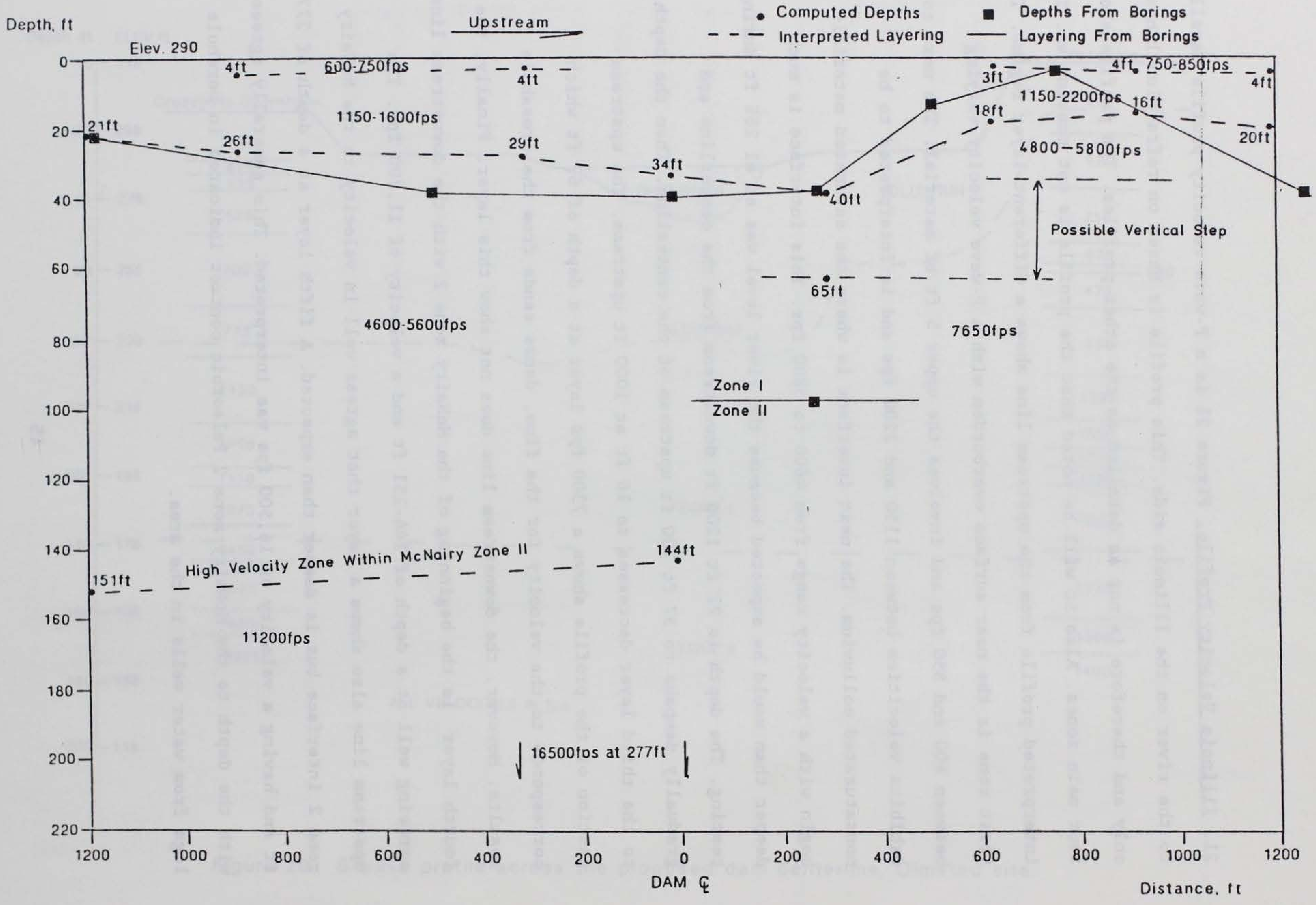


Figure 21. P-wave profile parallel to river, Illinois side.

22. Kentucky Velocity Profile. Figure 22 is a profile (parallel to the river) of the refraction data from the Kentucky side. The profile exhibits five layers and shows the computed depths to each. Layer one has a velocity of 920 fps and is indicative of the top 11-16.5 ft of material. The second layer extends to depths between 71 and 90 ft and has a velocity of 4930 fps. Layer three has a velocity of 6840 fps and extends to depths between 126 and 173 ft. The fourth layer has a velocity of 10,100 fps and extends to depths ranging from 272-294 ft. The final layer has a velocity of 14,230 fps and extends to an unknown depth. The results show that the layers are dipping downward at the dam centerline.

23. Conclusions. From the data that have been presented the following general conclusions are made.

a. The site can be divided into the following zones with characteristic P- and S-wave velocities as follows:

Material	P-wave	S-wave	
alluvium	900[1] - 5800[2]	400 - 700	
McNairy 1	5400 - 6200	600 - 1200	
McNairy 2	6200 - 7500	1400 - 1550	[1]unsaturated
Paleozoic	14,500 - 16,500	----	[2]saturated

b. These above zones are continuous and their velocities are fairly uniform except for the McNairy zone 2. The alluvium is much deeper on the Kentucky side but its velocities are similar to the McNairy zone 1 at the same

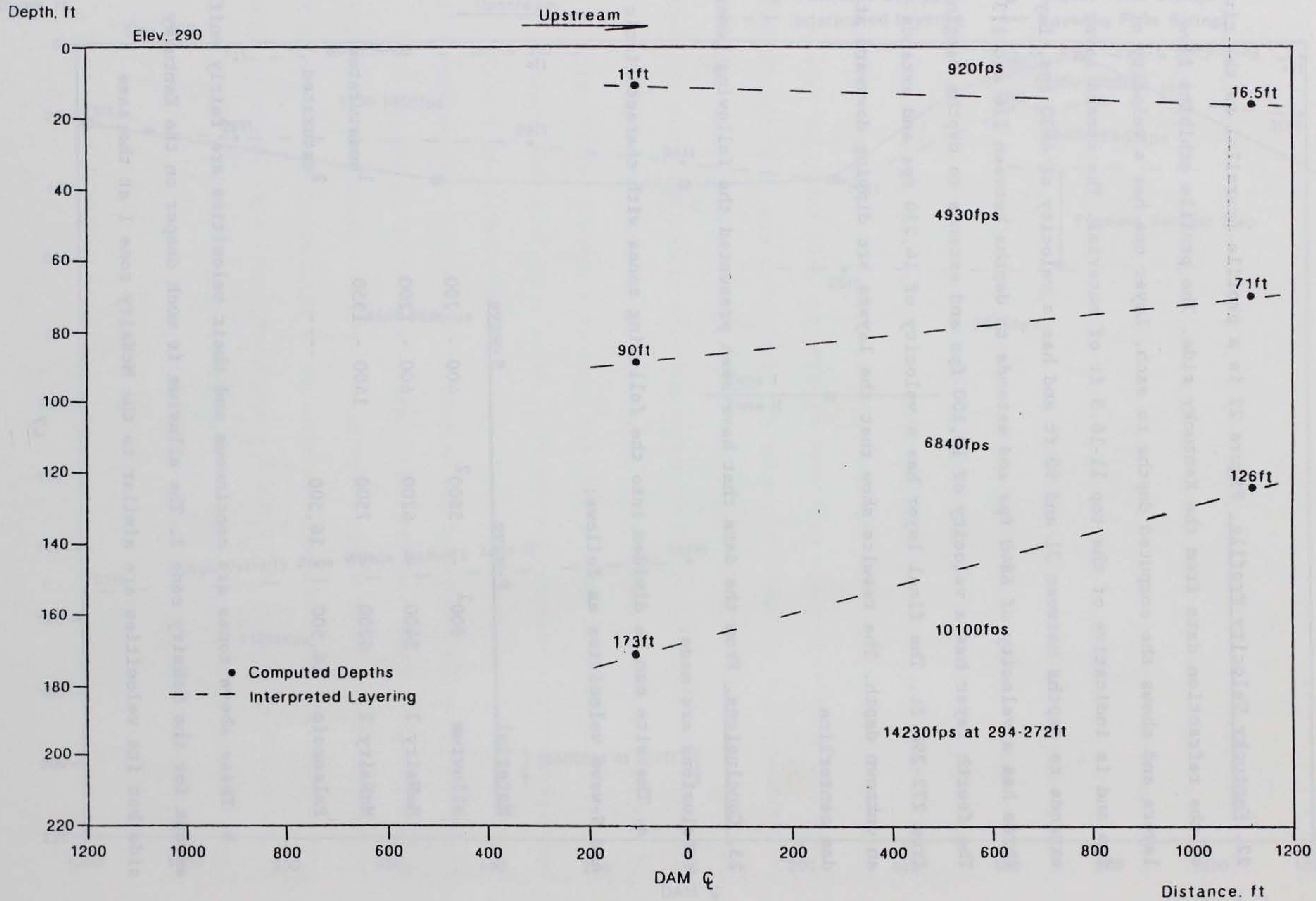


Figure 22. P-wave profile parallel to river, Kentucky side.

elevation. McNairy zone 2 appears to be much more complicated being composed of many thin, hard and soft layers.

c. The zone of 100% saturation is 16 to 37 ft in depth which is 11 to 32 ft below the level of the river. This is a surprising result but could be explained by a very low permeability layer preventing river water from saturating the sediments above.

d. The profile parallel to the Ohio River on the Illinois side shows a difference between the downstream and upstream seismic line in that a 7650 fps layer is evident on the upstream line only. Also the data from the upstream line can be interpreted as a 30 ft upward vertical discontinuity in that layer approximately 1000 ft upstream of the centerline. It will be noted that the upstream line was shot in one direction and therefore, no supporting results from a reverse traverse were available to help interpret that line. Also, there is no similar indication of a step in line R1, which sets constraints on the strike of the step if it exists. The velocity and depth of this layer corresponds to a fine dense sand layer detected in the crosshole tests on the Illinois side.

e. The results from the refraction lines show that the Paleozoic contact exists at approximate el 50 to -30 ft msl with the Mississippian limestone exhibiting a velocity of 14,500-16,500 fps. This generally agrees with water well boring data which shows limestone at el 32 on the Kentucky side dipping down to el -120 in Olmsted, Illinois.