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Engineering Geology
Engineering Geophysics

File 79149
February 7, 1980

SEISMIC REFRACTION INVESTIGATIONS
AND
SEISMIC CROSSHOLE INVESTIGATION

DICKEY-LINCOLN SCHOOL LAKES
SAINT JOHN RIVER BASIN, MAINE

Prepared For: U.S. Army Corps of Engineers
Waltham, Massachusetts

2344 Commonwealth Avenue Suite 1-2 Newton, Massachusetts 02166

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1.00 INTRODUCTION

This report presents the results of seismic refraction and crosshole investigations conducted for the U.S. Army Corps of Engineers in the Saint John River Basin of Maine. The investigations were performed by S.A. Alsup & Associates, Inc., of Newton, Massachusetts during the week of November 25, 1979. Locus of the investigations is shown in Figures 1 and 2.

The purpose of the investigations was to determine subsurface conditions and bedrock depth at the location shown in Figure 1, and to obtain subsurface velocities for compressional and shear waves at the location shown in Figure 2 to be used in calculation of engineering properties of subsurface materials beneath that locale. Some 1440 linear feet of refraction profiling and 19 crosshole elevation were accomplished during the effort.

Boring logs and other subsurface data were provided by the Corps of Engineers for several locales along the refraction lines and for the shothole used during the crosshole program. These data were correlated with the seismic results as appropriate, and should be considered incorporated in the result presented here. No conflicts between the data sets were noted.

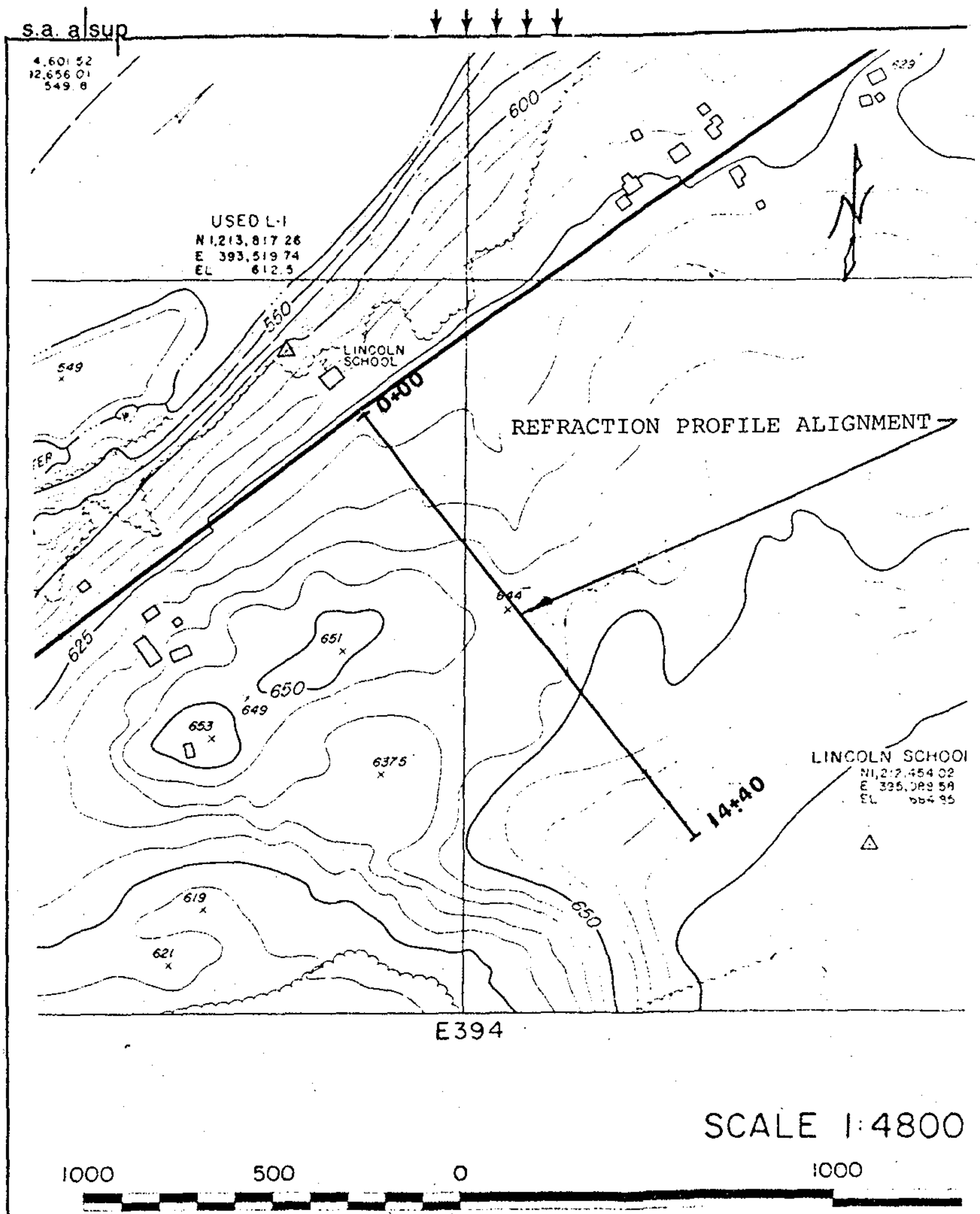


Figure 1. Locus of seismic refraction investigations, Dickey-Lincoln School Lakes, Saint John River Basin, Maine

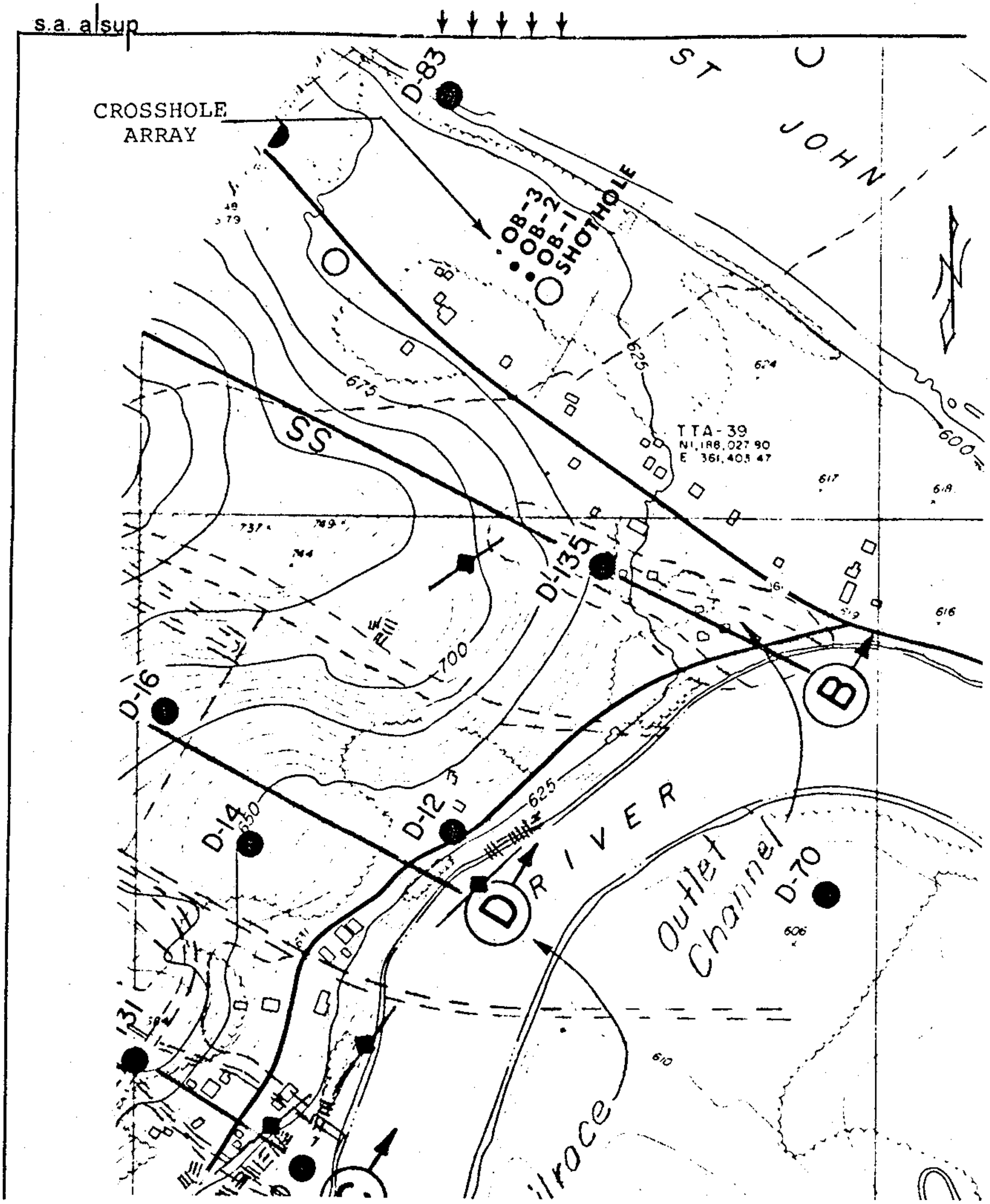


Figure 2. Locus of crosshole investigations, Dickey-Lincoln School Lakes, Saint John River Basin, Maine.

2.00 METHODS OF INVESTIGATION

The seismic refraction data were obtained using an SIE Model RS-4 Refraction Seismograph coupled to 12-element geophone spreads with geophone spacings of 20-feet. The RS-4 provides permanent self-developing dry-write chart recordings of the 12 data channels and one shot-initiation time channel coupled to crystal-controlled 10-millisecond timing lines. Seismograms obtained during the field investigations accompany the report. Small explosive charges initiated by "Instadet" electric blasting caps were used to generate the necessary shock waves for the refraction investigations. Typical charges were 1/8-lb 40% extra gel dynamite detonated in small tamped shotholes approximately 2-feet deep.

Six 240-foot geophone spreads were used for the refraction investigations, with end and quarter shots along each spread providing a complete refraction seismogram at 80-foot intervals along the profile examined. End shots were repeated as the spread was advanced along the profile to provide continuity and data redundancy.

The RS-4 seismograph was also used for the crosshole investigation, but coupled to three 3-component borehole seismometer sets in this instance. Each seismiometer set included one vertical and two horizontally sensitive geophones, with the horizontal geophone configured to have sensitive axis perpendicular to one-another. The seismometer sets each occupied a single observation borehole, with the necessary shock wave energy initiated by detonation of a single "Instadet" cap in a separate borehole in-line with the observation boreholes.

The crosshole investigations were performed by beginning the sequence with shot and all three seismometer sets in the bottom of the boreholes at an elevation -95 feet below ground surface at the shothole, then sequentially elevating seismometer sets and shotpoint at 5-foot intervals up the borehole array. Ground elevation and -5-foot elevation required use of a 1/16-lb dynamite charge to introduce the necessary shock wave energy, as is typical with such investigations when the shot point is above the water table in the shothole. At least two observations were made at each elevation for ease in analysis of the results, with the borehole seismometers rotated to a different position azimuthally for the separate observations.

Refraction data were analyzed according to the standard "cross-over distance" method, where the velocities are determined from the first-arriving compressional waves on the seismograms on a time-distance plot of arrivals. Distance from the shotpoint to velocity takeover points on the data plots are used in conjunction with the velocities determined from the plots to calculate depth to interfaces by this method. All data presented below assume that velocity changes determined by this method occur beneath the shotpoint generating the initial data, and all refractor velocities represent the average velocities determined from the "reversed" profile sections, excepth at the extremes of the profile investigated (where reversed data is not available).

Crosshole data were determined by calculating velocities from inter-borehole transit times divided into the inter-borehole distance, with supporting data from an initiating time determined by projection of average velocities to the shothole in the case of compressional wave. Shear wave initiation times were assumed identical to the compressional wave initiation time.

Poissons Ratio was calculated from the inter-borehole compressional and shear wave velocities according to the following relationship:

$$\text{Poissons Ratio} = \frac{(V_p/V_s)^2 - 2}{2(V_p/V_s)^2 - 1}$$

and Young's Modulus (E) from the relationship:

$$\text{Young's Modulus} = \frac{DV_s^2}{4636.8} = E$$

where V_p = compressional wave velocity in feet/second

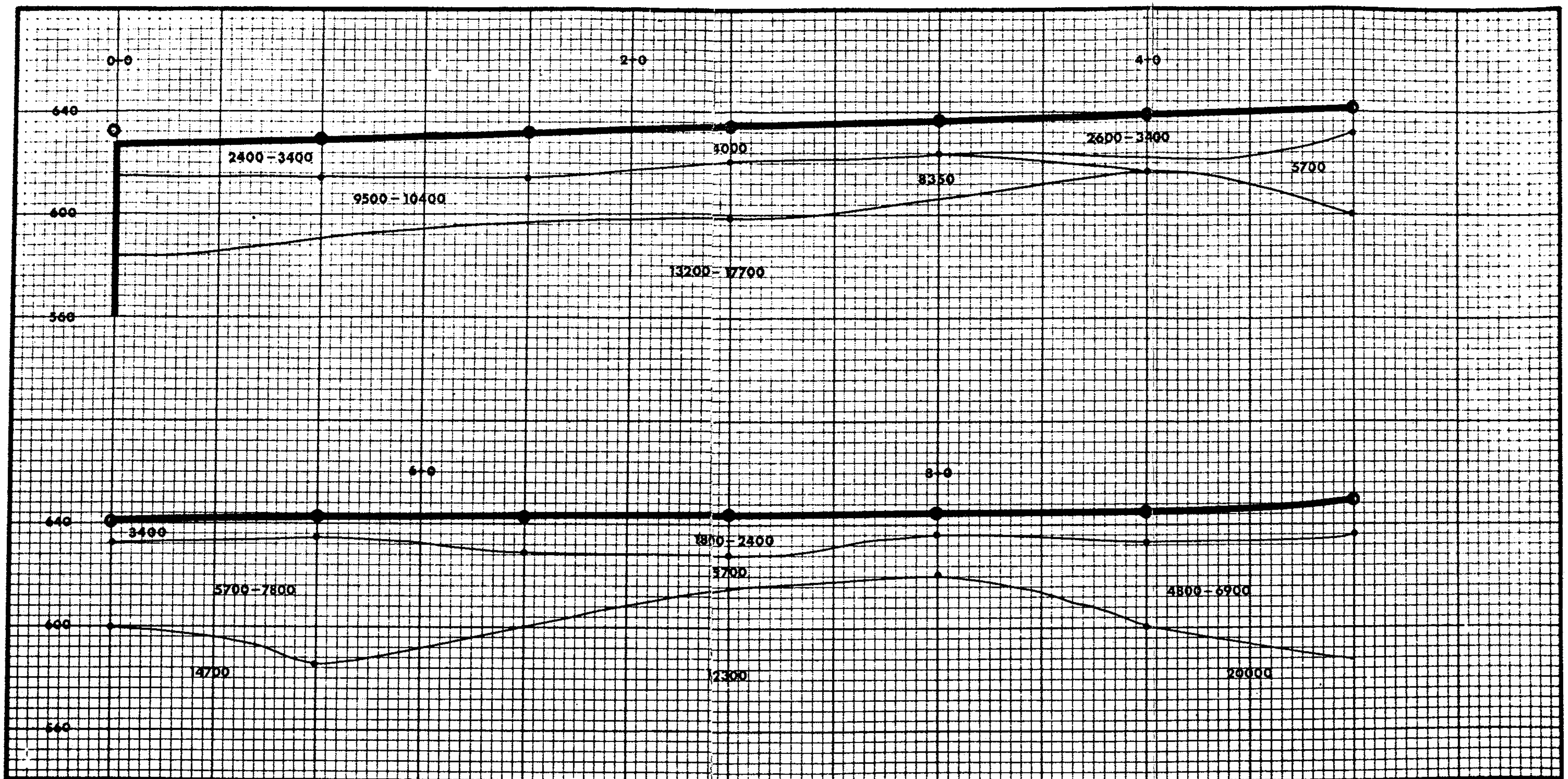
V_s = shear wave velocity in feet/second

D = bulk density in pounds/cubic foot (pcf)

4636.8 = 12 in X 12 in X 32.2 feet/second^2 for appropriate dimensional corrections

Since direct measurement of densities were not available for the crosshole positions, the following densities were assumed:

Depth (feet)	Density (pcf)	Depth (feet)	Density (pcf)
0	85	45	130
5	90	50	130
10	95	55	130
15	100	60	130
20	100	65	130
25	105	70	130
30	115	75	135
35	130	80	135
40	130	90	135
		95	135



INTERFACES OR INFERRED INTERFACES BETWEEN SEISMIC VELOCITY ZONES ON THE FIGURES ABOVE ARE BASED UPON THE RESULTS OF STANDARD GEOPHYSICAL INTERPRETATION TECHNIQUES. DEPTHS BELOW SURFACE, VELOCITY ZONE THICKNESS, AND VELOCITIES ARE INDICATIVE OF AVERAGE CONDITIONS BENEATH THE GEOPHONE SPREAD AND SHOULD BE USED FOR PLANNING PURPOSES ONLY. ESTIMATED ACCURACY OF THICKNESSES AND DEPTHS FOR THIS SURVEY IS ±10%. DEPTHS TO INFERRED SATURATED ZONES APPLY TO DEPTHS AT TIME OF SURVEY.

SCALE: VERTICAL 1" = 40'
HORIZONTAL

SHOT POINTS
GEOPHONE SPREAD — 1600
INFERRED SUBSURFACE VELOCITY BOUNDARIES — 4700
SEISMIC WAVE VELOCITIES IN FEET PER SECOND — 10200

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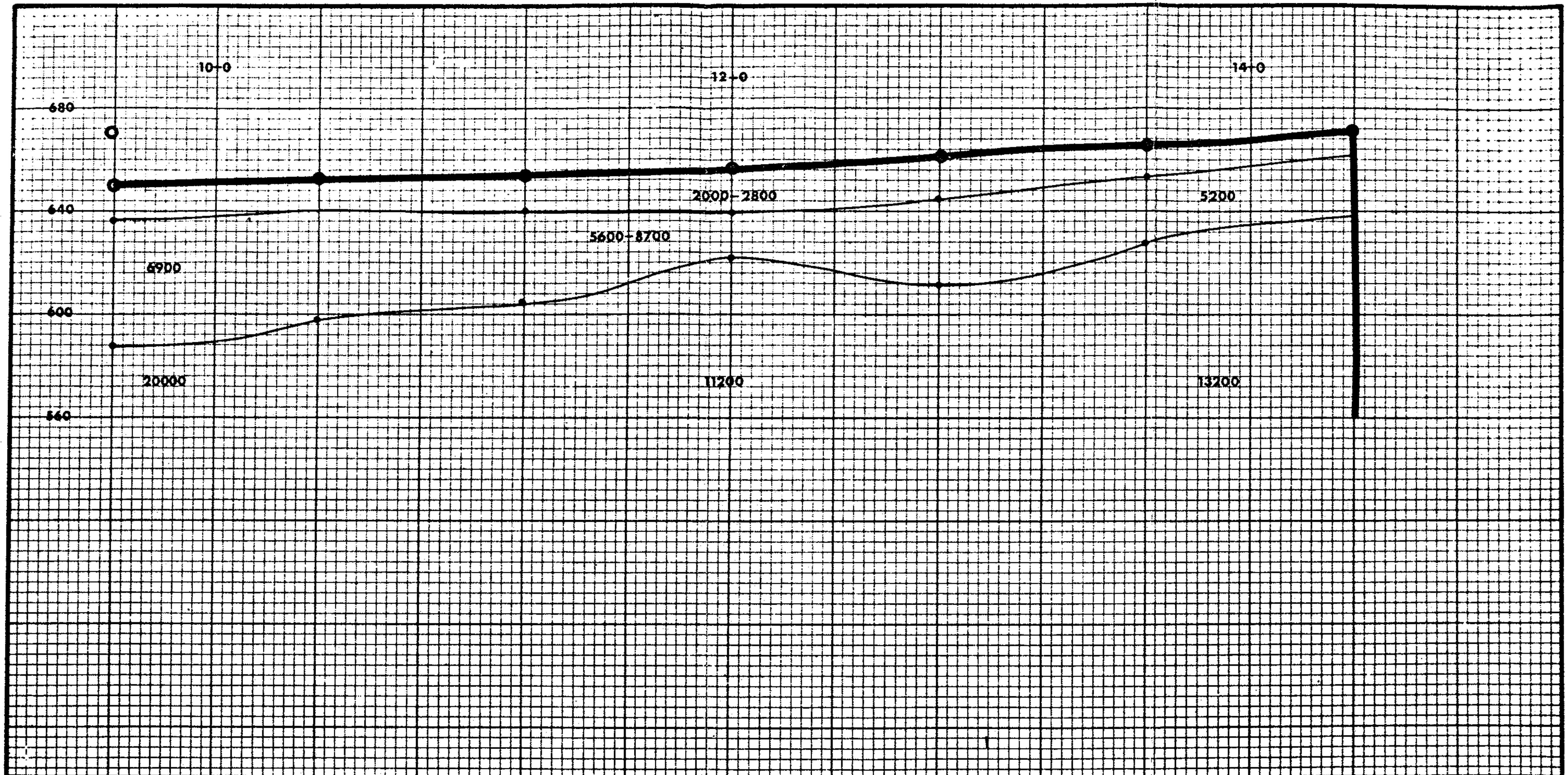
FIGURE 3



INTERFACES OR INFERRED INTERFACES BETWEEN SEISMIC VELOCITY ZONES ON THE FIGURES ABOVE ARE BASED UPON THE RESULTS OF STANDARD GEO-PHYSICAL INTERPRETATION TECHNIQUES. DEPTHS BELOW SURFACE, VELOCITY ZONE THICKNESS, AND VELOCITIES ARE INDICATIVE OF AVERAGE CONDITIONS BENEATH THE GEOPHONE SPREAD AND SHOULD BE USED FOR PLANNING PURPOSES ONLY. ESTIMATED ACCURACY OF THICKNESSES AND DEPTHS FOR THIS SURVEY IS ±10 %. DEPTHS TO INFERRED SATURATED ZONES APPLY TO DEPTHS AT TIME OF SURVEY.

SCALE: VERTICAL 1"= 40'
HORIZONTAL

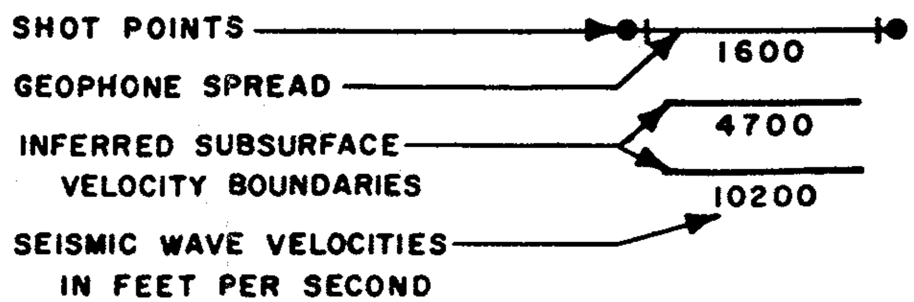


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FIGURE 4

The assumed values of bulk density may be either high or low, but are considered as representative for the materials present. If other values are deemed appropriate, the values of Young's Modulus presented in this report below may be corrected by increasing or decreasing the modulus proportionally with an increase or decrease of the density value assumed.

3.00 RESULTS/DISCUSSION

The results of the seismic refraction investigations are shown in Figures 3 and 4 as profiles or crossections of the subsurface in terms of velocity units. A thin (8 to 18-feet thickness) layer of low velocity deposits is typical beneath the entire profile, probably representing the surficial soils and low-density glacial till deposits. The surficial unit rests on partially weather bedrock (schist) from STA 0+00 to 3+20, and on moderate density glacial tills from STA 3+20 to 14+40. The bedrock in the initial part of the line is moderately dense or competent (probably rippable with heavy equipment), but is likely very hard and competent beneath the till beyond STA 3+20 (will require blasting). A deeper competent bedrock unit is indicated below the profile from STA 0+00 to 3+20 at depths ranging from 20 to 40 feet below ground surface. The compressional wave velocities in the glacial till unit above the bedrock beyond STA 3+20 are not particularly high, and in some cases are low for typical New England glacial tills. This velocity unit should be readily rippable with heavy duty excavation equipment, and it may include lithologies other than typical glacial till (including some water-saturated dense sands/silts, marine clays (?) or mixed till/alluvium). Test borings are recommended at STA 5+60 and 9+60 if heavy structures are anticipated on this material to determine the nature of the deposits.

The results of the crosshole investigations are shown in Figure 5 as a cross-section of the subsurface between boreholes, with velocity, density, Poissons Ratio, and Young's Modulus data plotted between each borehole at each depth investigated. Data in the figure are plotted with the compressional wave velocity in feet/second over the shear wave velocity in feet/second, followed by assumed density in pounds per cubic foot, calculated Poisson's Ratio, and Young's Modulus in 10^6 pounds per square inch.

Compressional wave velocities between the boreholes range from 7600 feet/second to 1900 feet/second, indicative of glacial tills in the higher velocities and loose unconsolidated dry to semi-dry soils in the lower velocities. Note that an effort was made to separate water-borne compressional waves from those transmitting through the soil structure, but this may not have been completely successful in the intermediate section of the borehole array because of the closeness of soils/water velocities in this section. Shear wave velocities are not affected by the water in this instance, so only the calculated values of Poissons Ratio might be questionable for data in this section. Shear wave velocities overall range from 4800 to 800 feet/second, and are not unusual for the type of materials present.

The bedrock unit at the base of the borehole array does not s.a. alsup

Depth (feet)	SHOTHOLE–OB-1 V_p	V_s	D	Poissons Ratio	Youngs Modulus (X 10^6 psi)	OB-1–OB-2 V_p	V_s	D	Poissons Ratio	Youngs Modulus (X 10^6 psi)	OB-2–OB-3 V_p	V_s	D	Poissons Ratio	Youngs Modulus (X 10^6 psi)
-0-	1900	700	85	.4215	.0090	1500	1000	85	.1000	.0183					
-5	2000	800	90	.4048	.0139	2800	1500	90	.2987	.0485	2500	1000	90	.4048	.0216
-10	2250	800	95	.4276	.0131	2500	900	95	.4256	.0166	3000	1200	95	.4047	.0295
-15	3450	1400	100	.4014	.0423	4000	1500	100	.4182	.0485	3500	1000	100	.4556	.0216
-20	4200	1600	100	.4151	.0552	4800	1400	100	.4535	.0423	5600	1500	100	.4614	.0485
-25	4100	1900	105	.3632	.0817	4600	1700	105	.4209	.0654	4200	2300	105	.2858	.1198
-30	5500	2000	115	.4238	.0992	4600	1800	115	.4096	.0804	4400	1800	115	.3995	.0804
-35	4600	2300	130	.3333	.1483	4600	1800	130	.4096	.0908	4600	2100	130	.3684	.1236
-40	4800	2400	130	.3333	.1615	4600	2100	130	.3684	.1236	4100	1800	130	.3806	.0908
-45	5400	1800	130	.4375	.0908	5400	2200	130	.4005	.1357	5400	1800	130	.4375	.0908
-50	5400	2150	130	.4058	.1296	5500	2600	130	.3561	.1895	6200	1900	130	.4482	.1012
-55	5200	2600	130	.3333	.1895	6600	2500	130	.4162	.1752	5600	2200	130	.4087	.1357
-60	6150	2250	130	.4227	.1419	6150	1900	130	.4472	.1012	6150	2500	130	.4010	.1752
-65	5300	2250	130	.3901	.1419	5300	2600	130	.3415	.1895	4300	1800	130	.3938	.0908
-70	5700	2800	130	.3491	.2198	5900	3400	130	.2514	.3241	7600	3200	130	.3422	.2871
-75	6300	2800	135	.3769	.2283	5300	2000	135	.4170	.1164	6600	3300	135	.3460	.3171
-80	6000	3100	135	.3179	.2798	6300	3200	135	.3261	.2981	5800	2800	135	.3481	.2203
-85	6700	3800	125	.2629	.4204	6700	3800	135	.2629	.4204	6500	4800	135	-.0997	.6708
-90	6400	3700	135	.2490	.3986	6500	3700	135	.2603	.3986	6800	4800	135	.0034	.6708

Figure 5. Results of crosshole investigations, Dickey-Lincoln School Lakes, Saint John River Basin, Maine.

exhibit very high velocities, and because of this observation, is expected to be somewhat weathered and/or fractured. Poissons Ratios in the unit are relative low, indicating significant rigidity, and two extremely low (and even negative) values are noted in the data between OB-2 and OB-3 at 90 and 95-foot depth. This result suggests that the shear waves measured have penetrated into competent rock while the compressional waves measured did not, and competent rock is likely present within 10 to 15-feet below the bottom of the boreholes.

Poisson's Ratio varies from 0.249 to 0.4556 with the exception of the two values noted above and one very questionable value at the surface between OB-1 and OB-2 where very low energy and complicated waveforms were present in the data. The range of values is typical, with one zone of higher values between 30 and 55-foot depth apparent.

Values of Young's Modulus range between 0.4204×10^6 psi and 0.0090×10^6psi and, in general, show a tendency to decrease systematically with decreasing depth. Such an observation is not unusual in crosshole results, and the tendency reflects both increasing compaction from overburden loading and increasing shear strength as the deposits become more compact. Note that the unusual values at borehole bottom between OB-2 and OB-3 are larger than those discussed immediately above. These have been deleted because of the uncertainty of the path of the shear waves.

(END)