RESULTS OF GEOPHYSICAL SURVEYS AT HOCOMONCO POND, WESTBOROUGH, MASSACHUSETTS

By Bruce P. Hansen

U.S. GEOLOGICAL SURVEY

Open-File Report 92-646

Prepared in cooperation with the

U.S. ENVIRONMENTAL PROTECTION AGENCY

WASTE MANAGEMENT DIVISION, REGION I

Marlborough, Massachusetts

1993

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CONVERSION FACTORS AND VERTICAL DATUM

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Velocity	
foot per second (ft/s)	0.3048	meter per second
foot per nanosecond (ft/ns)	0.3048	meter per nanosecond
	Area	
square foot (ft^2)	0.0929	square meter
square mile (mi^2)	2.590	square kilometer

Sea Level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929)--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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ABSTRACT

Seismic-refraction, continuous seismic-reflection profiling, and ground-penetrating radar surveys were done from May through July 1991 at the Hocomonco Pond Superfund site in Westborough, Mass., to delineate the configuration of a bedrock surface buried below glacial deposits. Analysis of seismic-refraction data from four locations near the pond indicate that the bedrock surface ranges in depth from 10 to 250 feet below land surface. Continuous seismic-reflection-profiling surveys on the pond detected the bedrock surface at several locations and consistently identified an irregular contact between shallow coarse-grained sediments and overlying fine-grained sediments. Ground-penetrating-radar surveys with 80- and 300-megahertz antennas penetrated to depths of 45 and 22 feet, respectively. The irregular coarse-grained surface covered by fine-grained and soft pond-bottom sediments that was identified by the continuous seismic-reflection surveys was delineated in more detail by the ground-penetrating radar surveys. The radar surveys also identified debris resting on the pond bottom. Best resolution was obtained by the 300-megahertz radar survey. Drilling or alternative geophysical surveys would help to delineate the bedrock surface in areas where the methods used did not give conclusive results.

INTRODUCTION

The Hocomonco Pond Superfund Site is in the town of Westborough, in south-central Massachusett (fig. 1). Soil and ground water at the site have been contaminated by creosote from a wood-treating facility that was located on the south side of the pond. Site investigations by consulting firms are providing hydrogeologic information needed to design remediation programs.

Creosote in the saturated zone has been detected in drill cuttings and ground-water samples collected from test wells. Creosote and related high-molecular-weight compounds dissolve slowly in ground water. They can remain as dense nonaqueous-phase liquids (DNAPL's), which can migrate downward to confining geologic units such as clay, dense till, or bedrock. If DNAPL's reach a confining layer, such as bedrock, they can migrate along the surface of that layer to areas of lower altitude. A bedrock-surface-altitude map (fig. 2) prepared from boring data and the results of a gravity survey (Keystone Environmental Resources, Inc., 1990) indicates that a closed depression is present in the bedrock surface on the southeast side of the pond. The bedrock depression could act as a sink for the DNAPL's that are present in the saturated un-

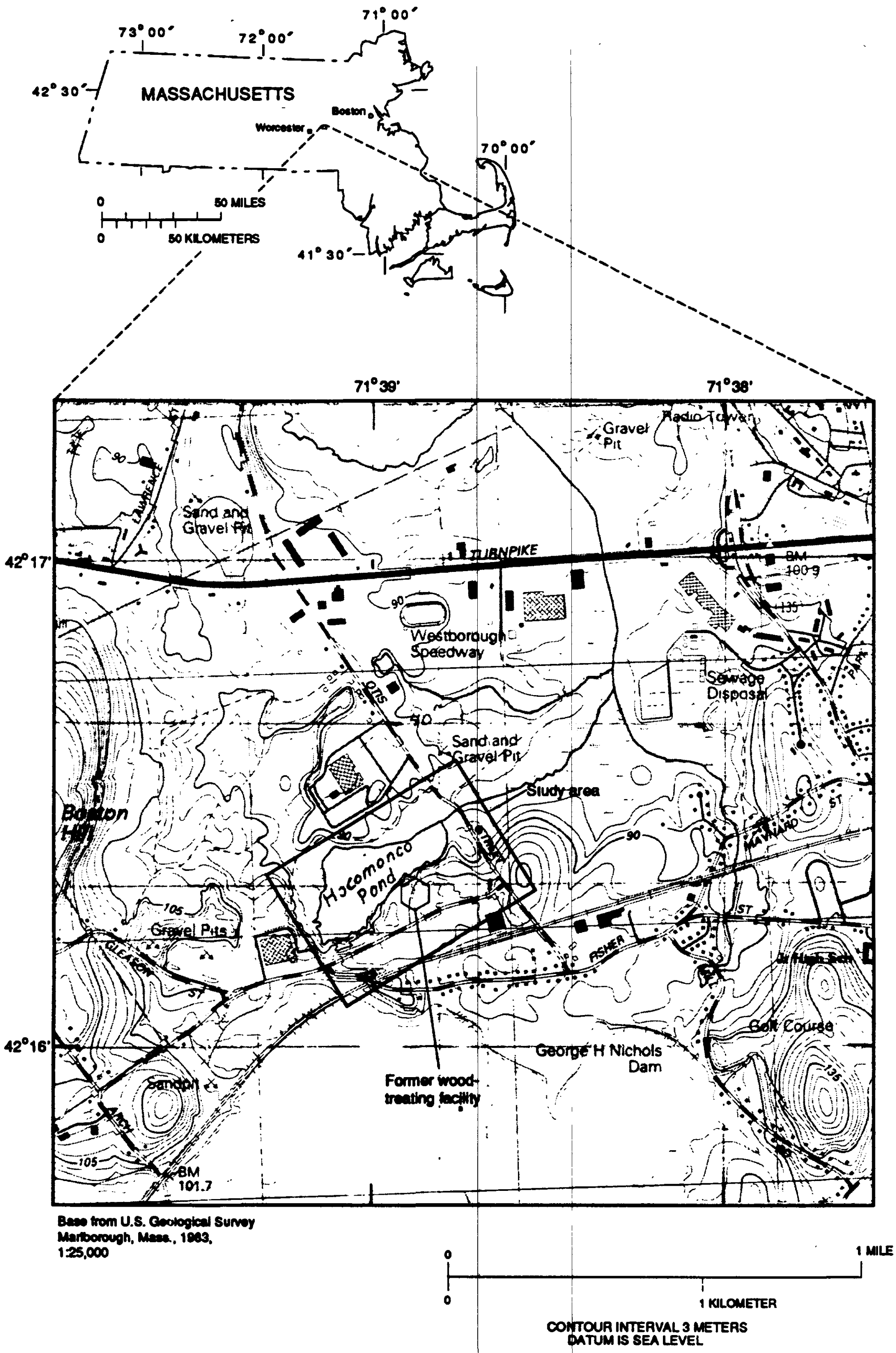


Figure 1.--Location of the Hocomonco Pond study site.

consolidated deposits under the site. No data are available to confirm the existence of the dashed closed contours on the northwest side of the bedrock depression. Supplemental bedrock-configuration data are needed to evaluate possible migration pathways. The U.S. Geological Survey (USGS), in cooperation with U.S. Environmental Protection Agency (USEPA), conducted geophysical surveys on Hocomonco Pond and adjacent land areas with the purpose of obtaining information on depth to bedrock and, if possible, on the structure and distribution of the unconsolidated deposits above bedrock. From May through July 1991, seismic-refraction surveys were done adjacent to Hocomonco Pond, and continuous seismic-reflection profiling (CSP) surveys and ground-penetrating radar (GPR) surveys were done on the pond. This work was done as part of a technical-assistance agreement between the USGS and USEPA.

Purpose and Scope

This report presents the results of the geophysical surveys that were done from May through July 1991 at the Hocomonco Pond Superfund site, Westborough, Mass. The report briefly describes the seismic-refraction, CSP, and GPR geophysical methods used, presents selected records of the data collected, and discusses the results.

Previous Investigations

Information on bedrock-surface altitude was available from test borings made during a number of investigations at the site (Burgess and others, 1985; Keystone Environmental Resources, Inc., 1990, 1991). Test-well logs for several locations on the north and west shore of the pond were available from several unpublished water-supply studies by the town of Westborough.

GEOPHYSICAL METHODS

All geophysical methods make use of the fact that different rock types have different physical properties. The physical properties of interest for this study are seismic velocity, acoustic impedance, and relative dielectric permittivity. Readers can find detailed descriptions of methods used in several references cited in the text.

Seismic Methods

Seismic methods make use of reflected and refracted waves of seismic energy, and they are based on the time that it takes energy generated at a point source to travel through the ground to receivers called geophones on land and hydrophones in water. By use of the seismic-refraction method, the velocity of sound through various layers can be calculated and, as a result, the structure and depth of various layers in the subsurface can be determined. The seismic-reflection method shows subsurface structure, but the depth of each subsurface layer can be determined only if the velocity of each layer is known.

Seismic Refraction

The use of the seismic-refraction method requires the assumption of a layered earth in which the velocity of seismic energy in each layer is greater than the velocity of seismic energy in the layer above it. When this condition is met, seismic energy originating from a sound source travels downward into the ground until it meets a refracting surface. The energy that is refracted along this surface continually generates seismic waves that travel upward to land surface, where they may be detected by a series of geophones. In some cases, thin, intermediate-velocity layers cannot be detected. Descriptions of seismic-refraction theory and interpretation methods are given in Dobrin (1976), Haeni (1988), Mooney (1981), and Redpath (1973).

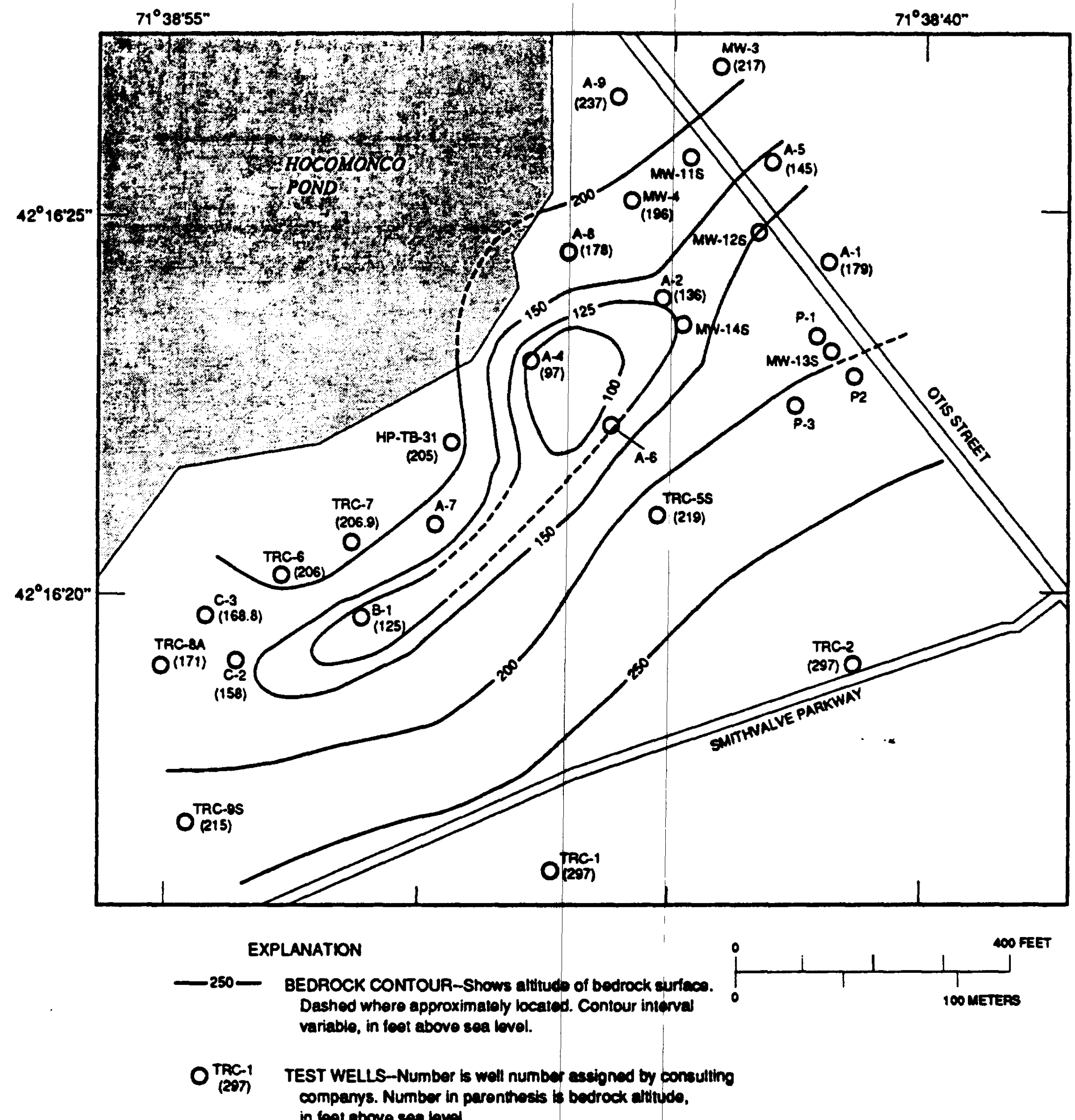


Figure 2.—Altitude of the bedrock surface on the southeast side of Hocomonco Pond. (Modified from Keystone Environmental Resources, Inc., 1990, fig. 5).

Seismic-refraction data at Hocomonco Pond were collected by means of a 12-channel signal-enhancement seismograph. Distance between the first and last geophone in each geophone spread--the arrangement of geophones in relation to the position of the energy source--was 550 ft and spacing between geophones was 50 ft. Small two-component explosive charges were used as a source of seismic energy. These explosive charges were buried 3 to 4 ft below land surface at a selected shotpoint. Altitudes and locations of all geophones and shotpoints were recorded. The seismic-refraction data were interpreted by computer-modeling techniques that incorporate delay-time and ray-tracing procedures (Scott and others, 1972; Scott, 1977).

Continuous Seismic Reflection

The seismic-reflection method detects seismic energy reflected from changes in the acoustic impedance in subsurface layers. Changes in acoustic impedance are common at geologic boundaries. Seismic-reflection surveying can be used on land or water, but the continuous seismic-reflection profiling (CSP) method can only be used on water. Because data are collected almost continuously, this method can be used to define the hydrogeologic units beneath a large water-covered area in a short time.

Further descriptions of the theory and adaptation of the method to shallow water surveying can be found in Ewing and Tirey (1961), Hersey (1963), Trabant (1984), Haeni (1971), EG&G Environmental Equipment Division (1977), and Sylwester (1983). The applications of this method to engineering, hydrology, and geology have been discussed by Moody and Van Reenan (1967), Haeni (1971), Haeni and Sanders (1974), Missimer and Gardner (1976), Freeman-Lynde and others (1982), Wolanssky and others (1983), Haeni and Melvin (1984), Morrissey and others (1985), Haeni (1986, 1989), Hansen (1986, 1989), Reynolds and Williams (1989), and Tucci and others (1991).

In the CSP method, an acoustic signal transmitted from a sound source near the water surface is reflected from interfaces between materials of different acoustic impedance. The acoustic impedance of any material is equal to the product of the velocity of sound in the material and the bulk density of the material.

The graphic recordings of CSP data represent a nearly continuous record of subsurface acoustic-property changes, which has the appearance of, and many times is a close representation of, the geologic section along the survey line. The lithology, structure, and contacts between geologic units can often be interpreted directly from the CSP records (Haeni, 1989). The depth to any contact shown on the record can be determined by dividing the two-way traveltime by 2 and multiplying the results by the velocity of sound through the subsurface deposits. For this study, a velocity of 5,000 ft/s for water and saturated unconsolidated deposits was used to compute depth to individual reflectors. In New England, the velocity of sound through saturated stratified glacial deposits generally ranges from 4,000 to 6,000 ft/s (Haeni, 1988, p. 41). Reflector depths determined from the records were not corrected for differences in the velocity of sound as it traveled through the water column. Corrections for the water column would have little effect because the velocity of sound in water (4,800 ft/s) is almost equal to the velocity of sound in stratified glacial deposits.

The CSP system that was used consisted of a graphic recorder, a high-voltage power supply, a high-resolution boomer sound source, a hydrophone streamer, a filter-amplifier, and two 110-watt generators. The acoustic signals generated by the sound source travel through the water column and into the subsurface. The sound reflected back to the surface is received by the hydrophone streamer and is amplified, filtered, and graphically recorded. In this study the unfiltered (raw) signal was also recorded on a digital audio-tape recorder. Such recorded data can be used to replay or postprocess the data.

A 17-ft outboard-powered boat was used to convey the CSP system and a two-man crew. The electronic equipment was powered by a small 800-watt generator. A second 2.5-kilowatt generator was used to power the high-voltage power supply. The sound source, mounted on a small catamaran, and the hydrophones were towed on opposite sides of the boat at about 0.5 ft under the water surface and with about a 10-ft separation. To minimize noise during surveying, The crew used a small electric fishing motor to propel the boat.

Ground-Penetrating Radar

Ground-penetrating radar (GPR) is the electromagnetic analogue of the CSP method; graphic displays of data from the two methods are similar in appearance. GPR systems transmit pulses of radio-frequency electromagnetic energy into the ground. This energy travels through the ground until it arrives at an interface between materials having different electrical properties. At this interface, some energy is reflected back toward the surface and the remaining energy continues deeper into the subsurface. Many of the materials found in geohydrologic settings exhibit different electrical properties, which are determined by water content, dissolved minerals in ground water, and expansive-clay and heavy-mineral content (Wright and others, 1984; Olhoeft 1984, 1986; Haeni and others, 1987). The reflected energy received by an antenna at the surface is amplified, converted to audio frequency range, recorded, processed, and displayed on a graphic recorder. The record shows the relative amplitude of the reflected signal and the total traveltime for the signal to pass down through the subsurface, reflect from electrical interfaces, and return to the surface. The two-way traveltime, which is measured in nanoseconds (1 nanosecond = 10^{-9} second), and a property called relative dielectric permittivity are used to compute depth to a reflector by means of equations presented by Beres and Haeni (1991). The dielectric permittivity is a measure of the capacity of a material to store a charge when an electric field is applied to it relative to the same capacity in a vacuum (Sheriff, 1984). Approximate values of relative dielectric permittivities and radar-wave velocities are listed for selected materials in table 1.

Transmission frequencies used in GPR surveys range from 80 to 1,000 MHz (megahertz). The frequency used for a given study is selected to provide an acceptable compromise between high resolution and deep penetration. High-frequency signals produce high-resolution records but have a limited depth of penetration. The principal factor limiting the depth of penetration of radar waves is the attenuation of the electromagnetic waves by earth materials. Radar-signal penetration depends on the electrical conductivity of the materials present and the frequency of the radar signal. Studies in areas of low electrical-conductivity materials, such as clay-free sand and gravel, show that low-frequency radar waves can penetrate to depths of 90 ft (Wright and others, 1984; Olhoeft, 1984, 1986). In highly conductive materials, such as clay-rich materials, the penetration depth of radar waves can be less than 3 ft (Wright and others, 1984; Olhoeft, 1984, 986). Approximate values of conductivity for selected materials are listed in table 1.

Table 1.--Approximate values of conductivity, relative dielectric permittivity, and radar-wave velocity for selected materials

[data from Ulriksen, 1982; Markt, 1988; ft/ns, foot per nanosecond; mho/m, mho per meter]

Material	Conductivity	Relative dielectric permittivity	Radar wave velocity (ft/ns)
Air	0	1	0.98
Pure water	10^{-4} to 3×10^{-2}	81	.11
Sea water	4	81	.11
Freshwater ice	10^{-3}	4	.49
Sand (dry)	10^{-7} to 10^{-3}	4 to 6	.49 to 40
Sand (saturated)	10^{-4} to 10^{-2}	30	.17
Silt (saturated)	10^{-3} to 10^{-2}	10	.31
Clay (saturated)	10^{-1} to 1	8 to 12	.35 to .28
Rich agricultural soil	10^{-2}	15	.25
Sandstone (wet)	4×10^{-2}	6	.40
Shale (wet)	10^{-2}	7	.37
Limestone (dry)	10^{-9}	7	.37
Limestone (wet)	2.5 x 10	8	.35
Basalt (wet)	10^{-2}	8	.35
Granite (dry)	10^{-8}	5	.44
Granite (wet)	10^{-3}	7	.37
Bedded salt	10^{-5} to 10^{-4}	3 to 6	.57 to .40

Selected radar records were interpreted on the basis of configuration, amplitude, continuity, and terminations of reflections. The electromagnetic velocities generally used for depth interpretation were 0.11 ft/ns in water and 0.20 ft/ns in saturated unconsolidated sediments. Lithologies of units were interpreted from the radar records by comparing the character of the reflected radar-wave configurations to a chart of radar-wave configurations from known unconsolidated deposits and depositional sequences in the glaciated Northeast (Beres and Hanei, 1991, p. 379).

The GPR equipment and a 1,000-watt power generator were mounted in a small inflatable rubber boat, which was propelled by a small outboard motor. The antennas, which were mounted in floating fiberglass enclosures, were towed next to the boat. Two radar surveys were done, one with dual 80-MHz center-frequency transmitting and receiving antennas and the other with 300-MHz antennas. The near-surface resolution of these surveys is 1 to 2 ft for the 80-MHz antennas and 0.3 to 0.5 ft using the 300-MHz antennas. The radar traverses were referenced to known landmarks, which were noted on the radar records. A constant course and constant speed were maintained between the landmarks.

RESULTS OF GEOPHYSICAL SURVEYS

The results of the seismic-refraction surveys and selected results of the CSP and GPR surveys that were conducted at Hocomonco Pond are presented in this section. All of the original data from these surveys are in the files of the U.S. Geological Survey Massachusetts-Rhode Island District Office in Marlborough, Mass.

Seismic Refraction

The locations of the four seismic-refraction lines are shown on figure 3, and geohydrologic sections interpreted from seismic-refraction data are shown on figure 4.

Line 1, on the northern side of Smithvalve Parkway, has a maximum bedrock-surface altitude of 305 ft on the eastern end of the line. This altitude decreases slightly to about 297 ft at point 1B in the middle of the line. From this point the bedrock-surface altitude declines to about 230 ft on the western end of the line. Bedrock altitudes determined from seismic refraction along the eastern half of the line are consistent with test-well data in this area (Burgess and others, 1985). The presence of a bedrock outcrop about 200 ft south of the eastern end of the line supports the interpretation of a shallow bedrock surface in this area.

Line 2 is northeast of Hocomonco Pond along Otis Street. The bedrock-surface altitude, 253 ft on the north end of the line, decreases to about 160 ft near the south end of the line. This line consisted of two geophone spreads. The data from the second spread indicate an intermediate-velocity layer (8,100 ft/s) between saturated stratified deposits (5,100 ft/s) and bedrock (16,000 ft/s). The intermediate layer was not indicated by the data from the first spread because the layer was either absent or too thin to be detected. The two spreads were interpreted separately, and the interpretations were combined into the geohydrologic section shown. The bedrock-surface altitudes on the south end of this line are in approximate agreement with data from two wells near the line (Keystone Environmental Resources, Inc., 1991). The center of a buried bedrock valley is defined by the bedrock-surface altitude of 150 ft at station 2B.

Line 3, along the south shore of the pond, has an irregular bedrock surface that decreases from an altitude of 195 ft on the western end to 178 ft on the eastern end. The time-distance data from this line did not indicate any material with a velocity between the typical velocities for saturated stratified deposits and bedrock. Data from a well near the eastern end of the line indicates a 34-ft layer of saprolite (Keystone Environmental Resources, Inc., 1991). The nondetection of an

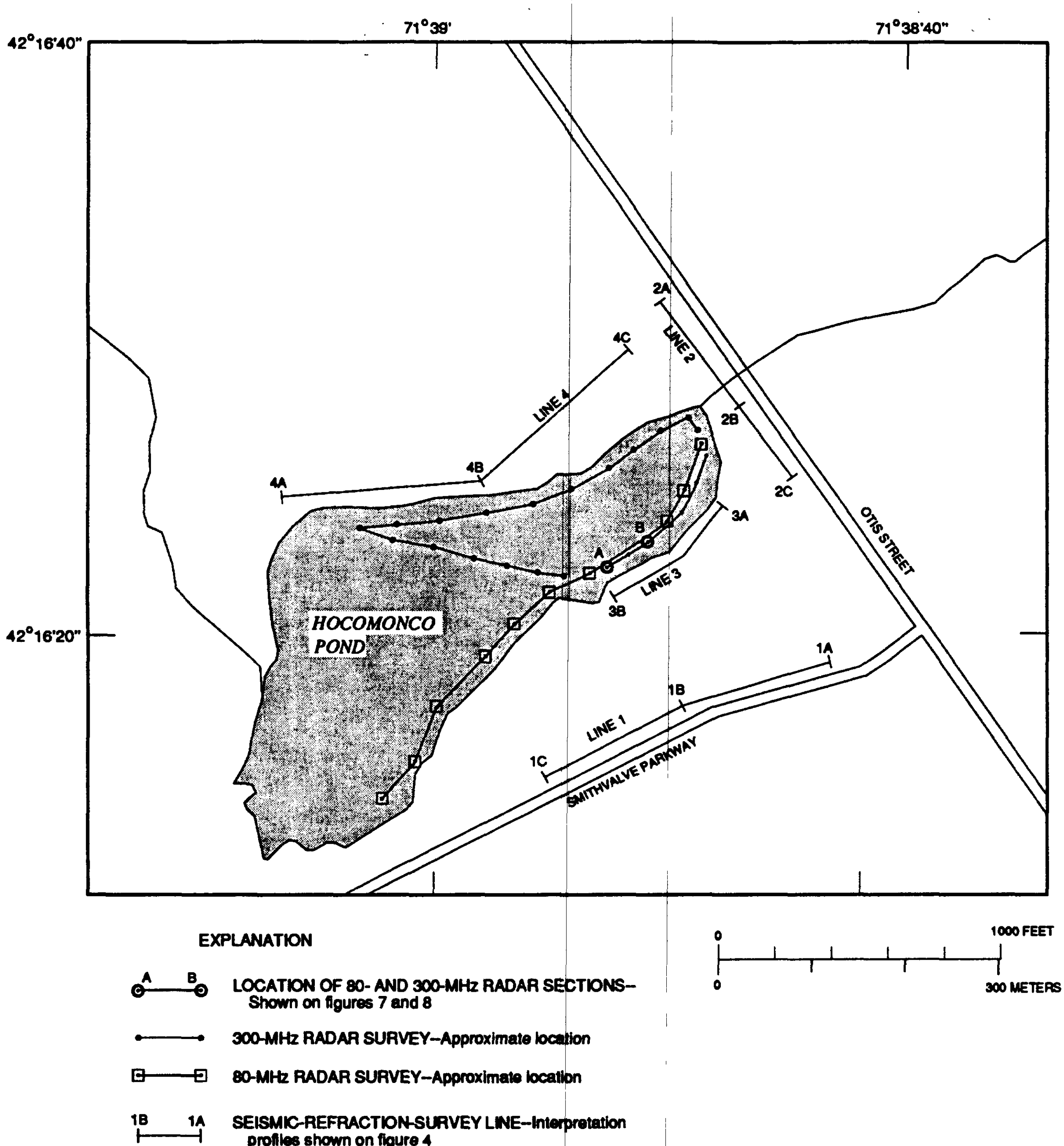


Figure 3.--Location of seismic-refraction lines and 80- and 300-megahertz ground-penetrating-radar surveys.

intermediate layer may be a result of too large a geophone spacing, or a "blind zone problem". The blind zone (Soske, 1959; Sander, 1978) occurs when a layer has an increase in seismic velocity with depth, but the velocity contrast or the layer thickness is too small to cause a return of first-arrival energy at land surface. This problem cannot be overcome by any change in the layout of the geophones or shotpoints. If this intermediate layer is present, then the computed depth to bedrock, for at least the east end of the line, will be in error, and the actual depth to bedrock will be greater than that shown. This error will probably be less than 50 percent (Redpath, 1973).

Line 4 on the north shore of the pond has a minimum indicated bedrock altitude of 30 ft. From this low point, the bedrock-surface rises toward the western and eastern ends of the line to 155 ft and 270 ft, respectively. The indicated

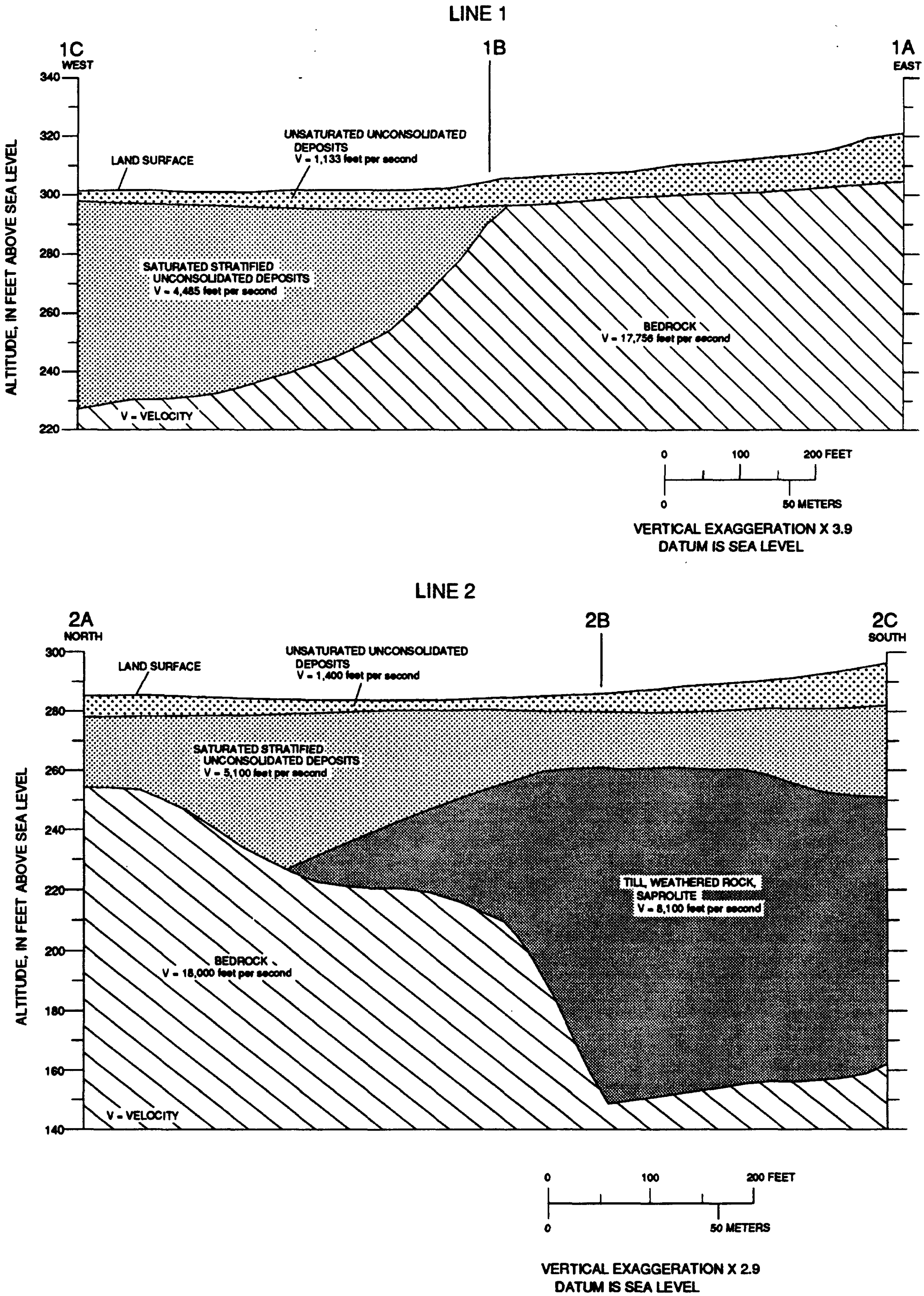
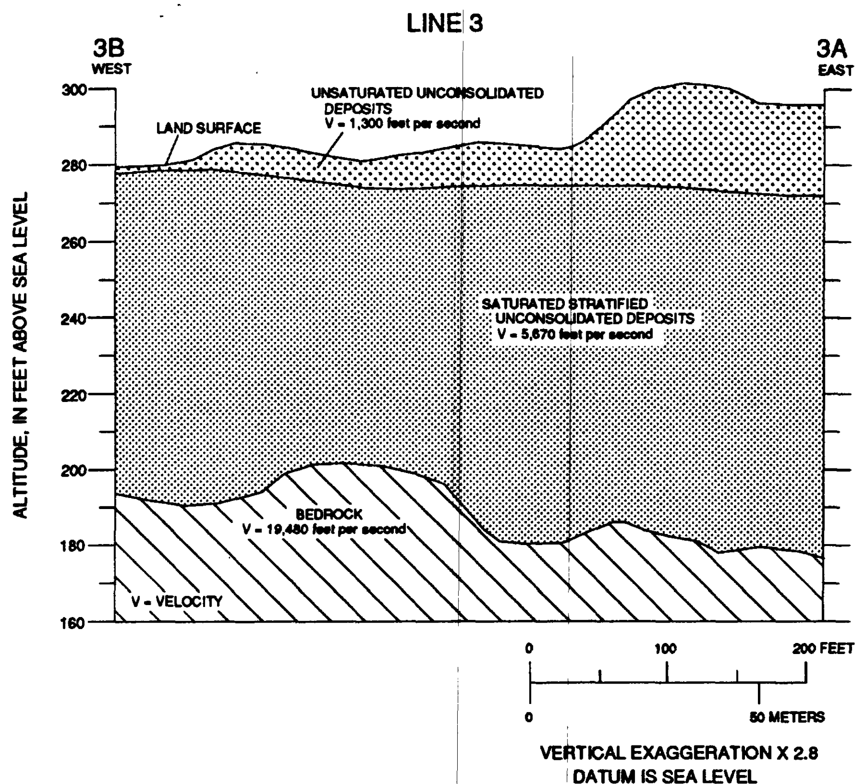


Figure 4.--Geohydrologic sections interpreted from seismic-refraction data for lines 1-4.



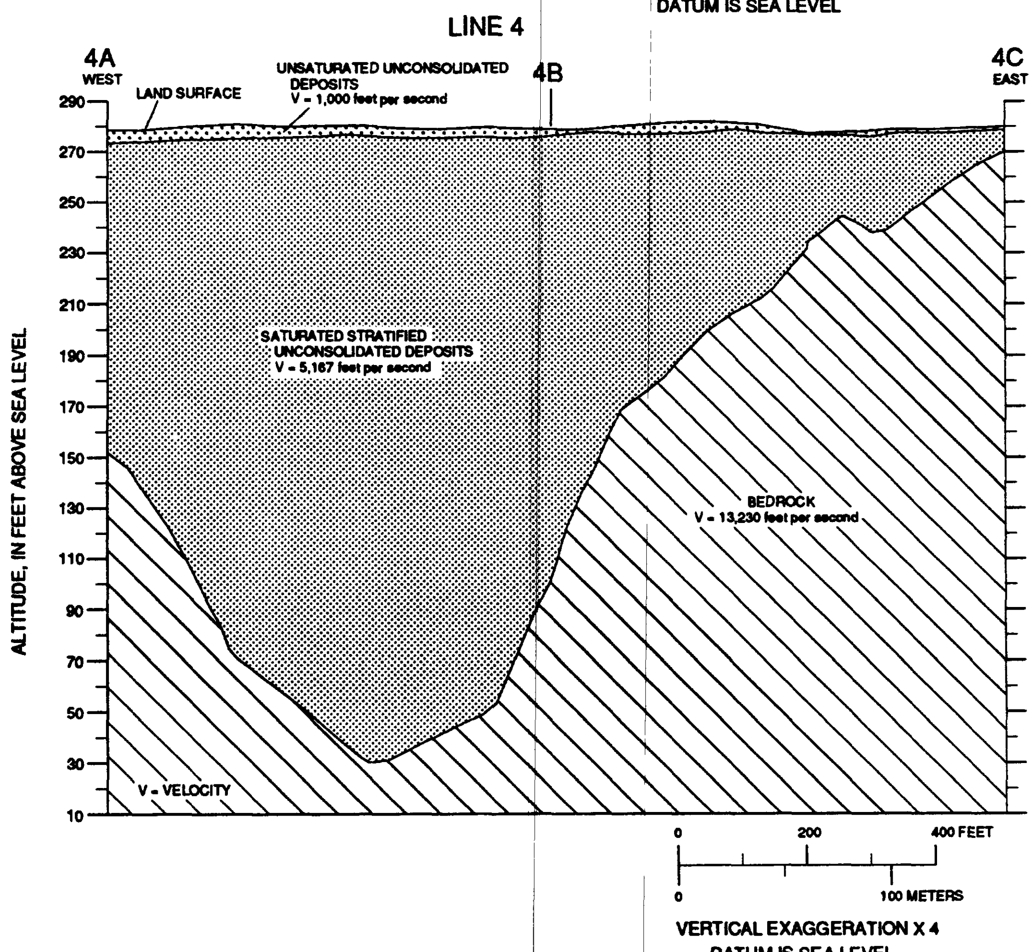


Figure 4.--Geohydrologic sections interpreted from seismic-refraction data for lines 1-4--Continued.

bedrock altitude in the middle of the line is in general agreement with a drilling "refusal" altitude for a water-supply test well drilled by the town of Westborough near that location.

Continuous Seismic Reflection

The location of the CSP survey lines are shown on figure 5. A section of record from stations 2 through 10 is shown on figure 6.

In general, analysis of the record shown on figure 6 and of other records from the pond identified a very irregular coarse-grained surface (hummocky and chaotic reflectors), which has been filled and covered by fine-grained deposits (flat, parallel reflectors). The thickness of the fine-grained deposits is variable. At station 4, fine-grained deposits are about 20 ft thick (water-bottom to coarse-grained contact). Between station 4 and 5, the thickness of the fine-grained deposits increases to at least 70 ft. At station 5, the coarse-grained contact is near the pond bottom. None of the continuous reflectors clearly indicates a till or bedrock surface at depth.

Sections of good record where deep structure is indicated (referred to in this report as "windows") are present at several locations. Because of the discontinuity of the sections where deep structure is indicated, the interpretation of these sections is subjective, and alternative interpretations are possible. One of these windows starts halfway between stations 7 and 8 and extends to station 8. The reflections (high amplitude) at 80 ft are interpreted to be the top of a coarse-grained unit possibly till. The darker reflections just below a depth of 105 ft at station 8 may represent the bedrock surface. In the section halfway between stations 8 and 9, the strong chaotic reflections, beginning about 115 ft below the pond surface and extending to a depth of at least 160 ft, indicate cross-bedded, coarse-grained deposits. Based on the seismic-reflection record, bedrock at this location may be at a depth of about 160 ft. Several deep, possibly continuous, reflections indicate a till or bedrock surface. One of these reflections starts at station 2 at a depth of 125 ft and trends across the record to a depth of about 100 ft at station 4. There is some evidence on the original record that this reflection is laterally more extensive, but the record is so weak that a conclusive determination is not possible.

The lack of a clearly defined bedrock or till surface at depth is probably due to attenuation and refraction of the acoustic energy by the thick sequence of coarse deposits or by methane gas in the shallow sediments. In addition, a small acoustic impedance contrast across the stratified coarse-grained sediments, till, weathered bedrock, and bedrock boundaries (contacts), may result in only weak reflected energy or no reflected energy, being returned to the surface from these contacts.

Ground-Penetrating Radar

Two GPR surveys were done on the Hocomonco Pond to test the utility of this method for detecting and delineating a bedrock surface at depth and to compare this method to the CSP method. The locations of the GPR surveys are shown on figures 3 and 5. The 80- and 300-MHz records were compared by running surveys lines at the same approximate location at both frequencies. The 300-MHz record (fig. 7) has a higher resolution than the 80-MHz record (fig. 8). Figures 7 and 8 are distorted because the radar-wave velocity in water is about one-half the radar-wave velocity in saturated unconsolidated sediments (table 1). Two depth scales, one for the depth of water and one for the depth of saturated sediment, are shown on the radar sections.

Interpretation of the 300-MHz record (fig. 7) shows a pond depth of about 5 ft near the left edge of the record (bottom of the area where no reflections follow direct arrivals), which decreases to about 2.4 ft at B. In the center,there appears to be about 2 ft of soft bottom sediment (low-amplitude parallel reflections), which thins to about 1 ft at B. Below the soft sediment, the parallel reflectors indicate a 7-ft-thick sequence of fine-

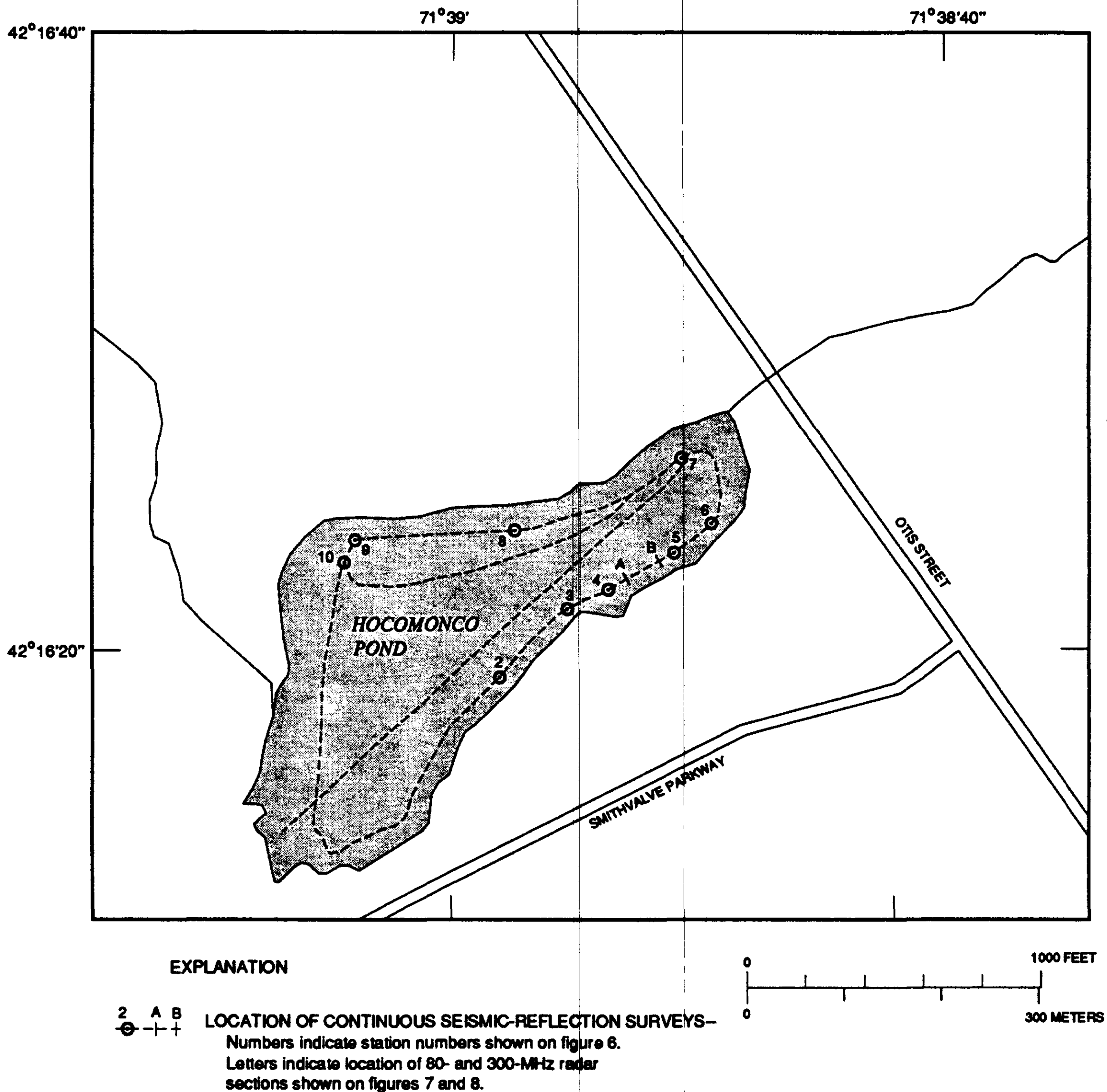


Figure 5.--Location of continuous seismic-reflection profiling surveys.

grained deposits that are probably glacial-lake deposits but also may be a continuation of the recent bottom deposits with thin imbedded reflecting beds. These fine-grained deposits appear to thin toward B as they lap onto coarser grained deposits (hummocky or chaotic reflections). The contact between the fine and coarse deposits becomes shallower toward B. The maximum depth of observed penetration on the 300-MHz record is about 22 ft below the pond surface.

On the 80-MHz record (fig. 8), the water depth is shown to be about 5 ft in the center of the record and about 4 ft at B. No soft bottom sediments can be seen. About a 30-ft thickness of fine-grained sediments (parallel reflectors) can be seen. The contact between the fine-grained deposits and coarse-grained deposits (hummocky or chaotic reflectors) is at a depth of about 35 ft in the center of the section and rises to about a depth of 5 ft at B. The maximum depth of radar-

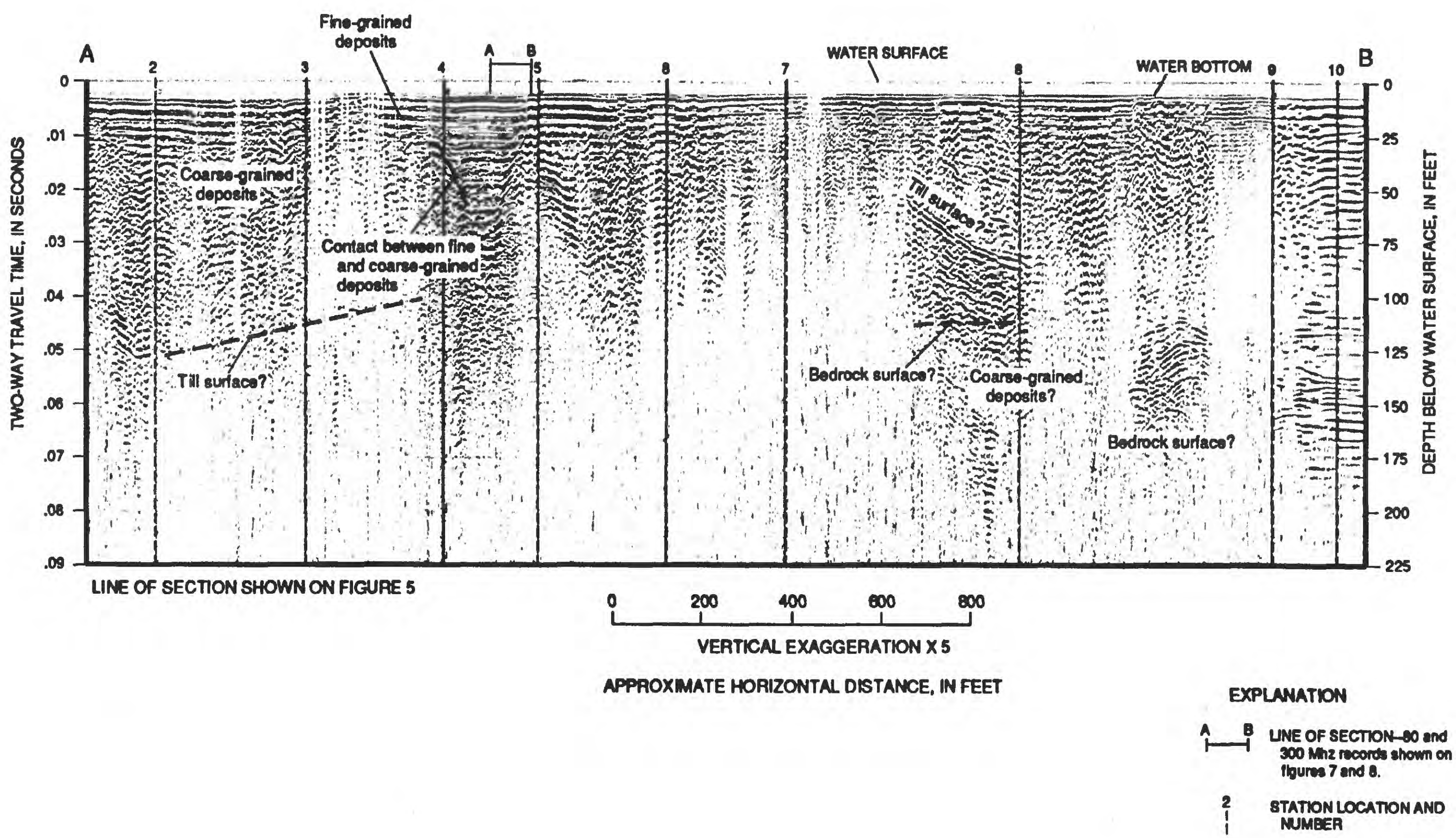


Figure 6.-- Interpretation of representative continuous seismic-reflection profiling record.

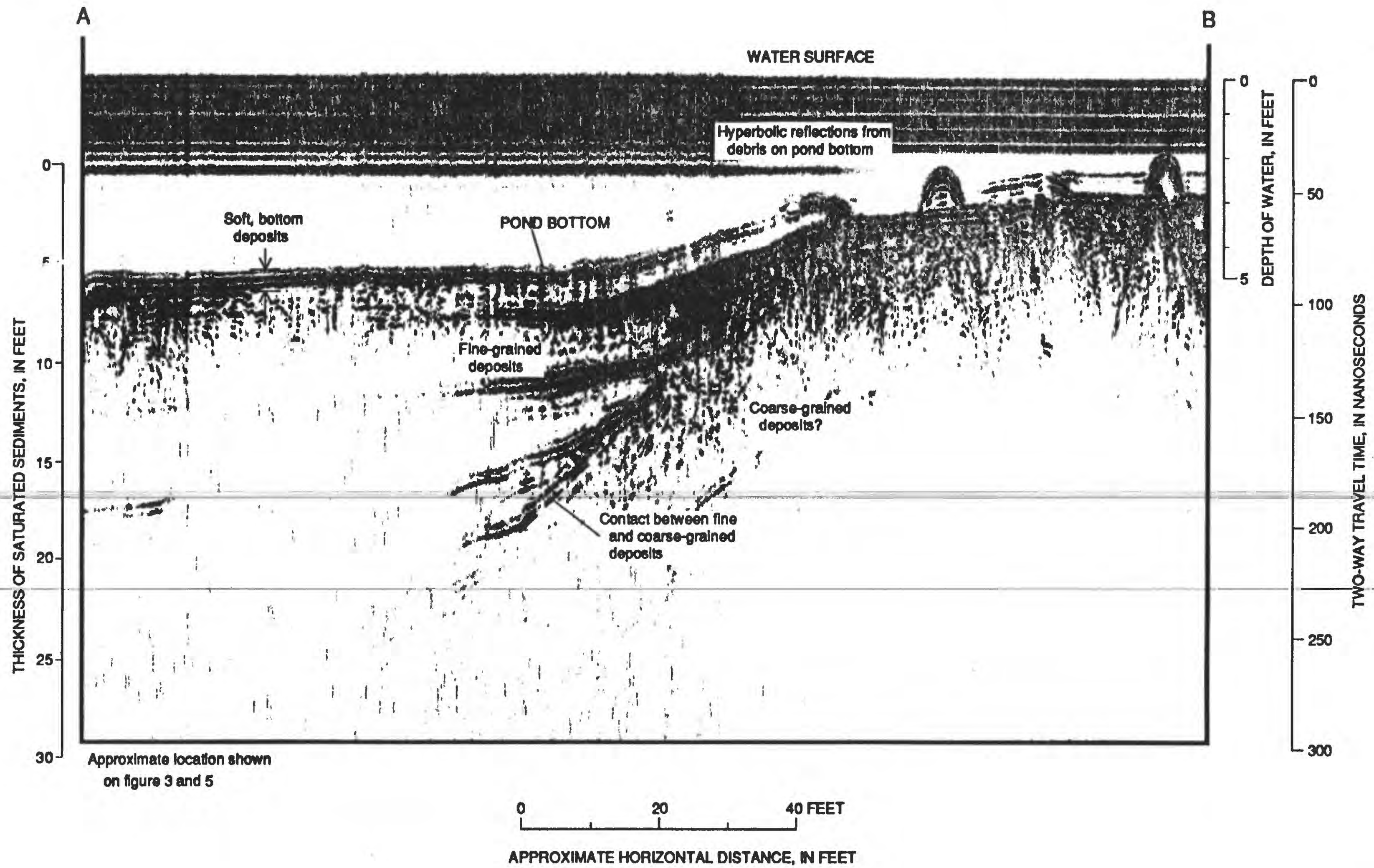


Figure 7.--Interpretation of 300-megahertz radar record of survey section A-B.

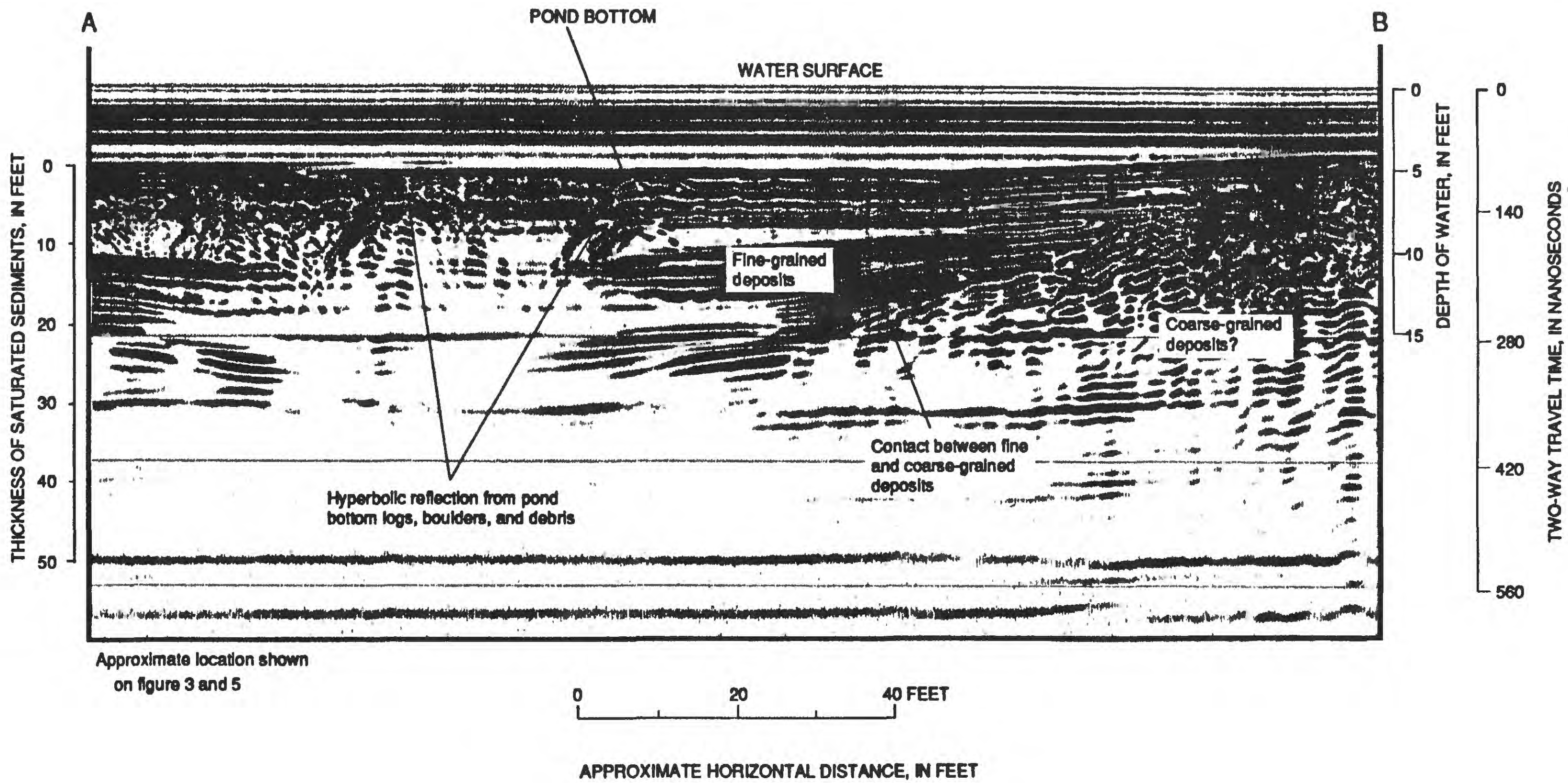


Figure 8.--Interpretation of 80-megahertz radar record of survey section A-B.

wave penetration shown in this section is about 45 ft below the pond surface.

The hyperbolic reflections that originate at or near the pond bottom are present on both radar records. These reflections are probably from point reflectors such as boulders, logs, and other debris that are resting on or are buried in the soft bottom deposits.

SUGGESTIONS FOR ADDITIONAL DATA COLLECTION

None of the geophysical methods used in this study or other data available conclusively delineate the bedrock surface along the southeast edge of Hocomonco Pond. Drilling might be required to obtain the necessary information; however, several geophysical methods may provide a cost-effective alternative to a drilling program along the poorly accessible southeast shore of the pond.

Rerunning a CSP survey along the edge of the pond using a sound source power level two or three times larger than that used in the original survey might provide a clearer definition of deep reflectors that were only weakly and inconclusively indicated by the original data. Two land-seismic techniques, the generalized reciprocal refraction method (Palmer, 1980; and Lankston, 1989) and multichannel land reflection (Dobrin, 1976; and Hajnal, 1978), also might provide the required information. Both of these methods require a close geophone spacing and have better resolution than the seismic-refraction method used in this study. A gravity survey on the pond surface (ice), or multi-channel land reflection and (or) refraction with hydrophones on the pond bottom might also provide the required information.

SUMMARY AND CONCLUSIONS

Geophysical surveys involving seismic refraction, continuous seismic-reflection profiling, and ground-penetrating radar methods were done to determine the depth to bedrock beneath and adjacent to Hocomonco Pond.

The bedrock-surface altitude under Line 1, south of the pond and along Smithvalve Parkway, ranges from 305 ft at the eastern end of the line to 230 ft under the western end of the line. The bedrock-surface altitude under Line 2, northeast of the pond and along Otis Street, is 253 ft on the northern end and decreases to about 158 ft near the southern end of the line. The bedrock-surface altitude under Line 3, along the southeast shore of the pond, is 178 ft on the eastern end and raises slightly to 195 ft on the western end of the line. The bedrock-surface altitude at the eastern end of this line may be lower than indicated because of the presence of a faster velocity layer indicated by data from a nearby well but not indicated by the seismic data. The bedrock-surface altitude under Line 4, on the north side of the pond, is 270 ft on the eastern end, decreases to 30 ft near the center, and then rises to 155 ft on the western end of the line.

Continuous seismic-reflection profiling on the pond identified a bedrock surface in only several locations. The bedrock was interpreted to be at 160 ft below the surface of the pond at one location. The CSP surveys indicated that the pond is underlain by an irregular, coarse-grained surface that is overlain by fine-grained sediments, which are probably glacial-lake deposits.

Two ground-penetrating radar surveys with 80- and 300-MHz antennas show maximum depths of penetration of 45 and 22 ft, respectively. Like the CSP results, analysis of the GPR data delineated an irregular coarse-grained surface covered by fine-grained sediment at most locations. The resolution of the 300-MHz records allows delineation of the presence and approximate thickness of a layer of soft pond-bottom sediment. The ground-penetrating radar surveys also identified the location of debris resting on or near the pond bottom.

None of the geophysical methods used, or the other data available, conclusively delineates the bedrock surface along the southeast edge of the pond. A conclusive determination of the bedrock-surface configuration in this area may require test drilling. Several geophysical methods, including a high power CSP survey, multichannel land seismic-reflection profiling, generalized reciprocal seismic refraction, and a gravity survey on the pond (ice) surface, could be a cost-effective alternatives to a test-drilling program along the poorly accessible shore of the pond.

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