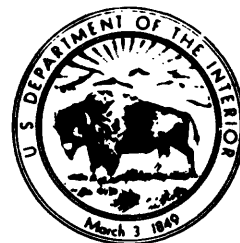GROUND-PENETRATING RADAR STUDY OF THE

THICKNESS AND EXTENT OF SEDIMENTS BENEATH

SILVER LAKE, BERLIN AND MERIDEN, CONNECTICUT

by F. P. Haeni, David K. McKeegan and Dennis R. Capron

U. S. Geological Survey

Water-Resources Investigations Report 85-4108

Prepared in cooperation with

CONNECTICUT DEPARTMENT OF ENVIRONMENTAL PROTECTION

HARTFORD, CONNECTICUT

1987

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ILLUSTRATIONS

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CONVERSION FACTORS AND ABBREVIATIONS

For the convenience of readers who may prefer to use metric (International System) units rather than the inch-pound units used in this report, values may be converted by using the following factors:

Multiply inch-pound unit	by	To obtain SI unit
inch (in)	25.40	millimeter (mm)
foot (ft)	0.3048	meter (m)
foot per nanosecond (ft/ns)	0.3048	meter per nanosecond (m/ns)

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 both the United States and Canada, formerly called "Mean Sea Level of 1929."

GROUND-PENETRATING RADAR STUDY OF THE THICKNESS AND EXTENT

OF SEDIMENTS BENEATH SILVER LAKE, BERLIN AND MERIDEN, CONNECTICUT

By F. Peter Haeni, David K. McKeegan, and Dennis R. Capron
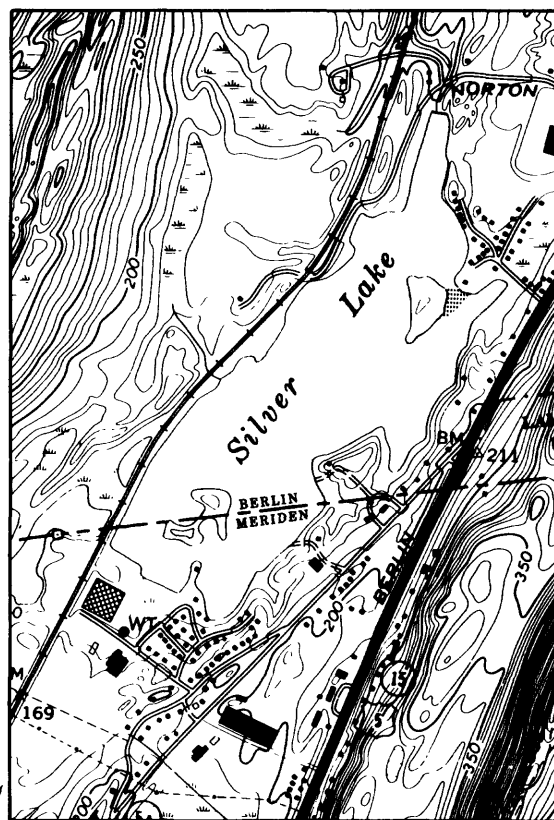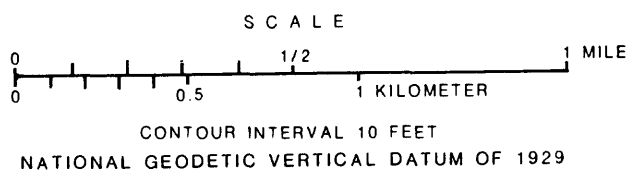
Abstract

A short-pulse ground-penetrating radar system was used to determine the extent and thickness of organic-rich lake-bottom sediments in Silver Lake in south-central Connecticut. Four miles of ground-penetrating radar profiles were obtained along traverses of the frozen lake during March 1984. The radar waves penetrated 6 inches of snow, 1 foot of ice, an average of 4 to 5 feet of water, and 5 feet of soft organic and inorganic deposits. A large area of the lake bottom is underlain by soft sediment that exceeds 5 feet in thickness. No radar reflections were obtained from the hard sub-bottom in these areas because the overlying sediment likely contains large proportions of silt and clay. Coring along two radar profile lines confirmed the depths of soft sediment calculated from the radar data.

Boring logs around the perimeter of the lake indicate that the eastern side may be underlain by till or poorly sorted sand and gravel, and that the rest of the lake is probably underlain by fine sand and silt, with some discontinuous layers of sand and gravel.

INTRODUCTION

Silver Lake is a shallow body of water located in the towns of Meriden and Berlin, Connecticut (fig. 1). The lake is highly eutrophic and, in the summer months, experiences profuse macrophyte growth and algal blooms. The lake bottom has been mined in the past for peat and several sources have reported a significant thickness of peat and other fine-grained sediments beneath the lake (J. C. Moulton, Connecticut Department of Environmental Protection, written commun., 1973; Charles Fredette, Connecticut Department of Environmental Protection, written commun., 1980; C. A. Selner, Central Connecticut State University, written commun., 1981)

The State of Connecticut has considered dredging to deepen all or part of the lake in order to help control weeds and restore the lake to a usable recreation area. However, the texture and thickness of lake-bottom deposits is not well known and this information is needed to plan the restoration work. This type of information is also needed in other lake studies where the interactions between lake and ground waters, and nutrient balance studies are being conducted (T. L. Winter, U.S. Geological Survey, written commun., 1983).

1

SCALE

0   1/2   1 MILE

0   0.5   1 KILOMETER

CONTOUR INTERVAL 10 FEET

NATIONAL GEODETIC VERTICAL DATUM OF 1929

Base from U.S. Geological Survey
Meriden Quadrangle 1:24,000 1967 photorevised 1972.

SCALE

0   10   20   30 MILES

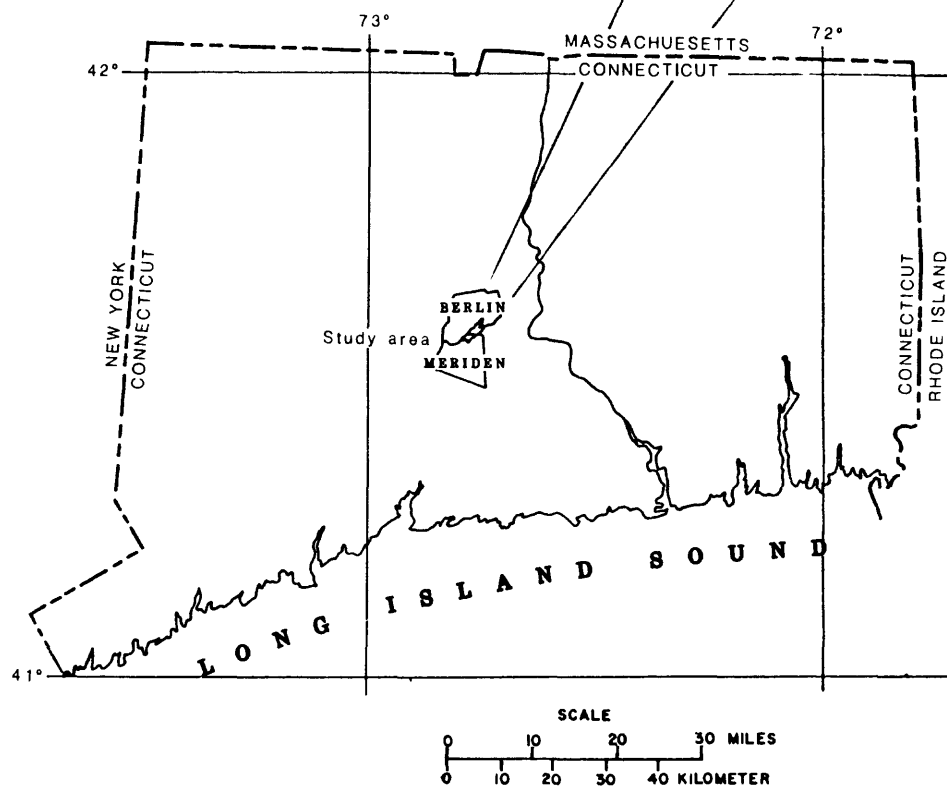0   10   20   30   40 KILOMETER

Figure 1.--Location of study area.

2

Purpose and Scope

This report presents the results of a study, done in cooperation with the Connecticut Department of Environmental Protection, to determine if ground-penetrating radar techniques could be used to delineate the thickness of soft organic and inorganic sediment in Silver Lake. Interpretations of radar profiles were verified by test borings.

Description of Study Area

Silver Lake occupies a glacial kettle hole and is surrounded by unconsolidated glacial deposits (fig. 2). The lake formed where a large block of ice, detached from a glacier, was buried by debris, and subsequently melted, leaving a depression in the local topography. Coarse-grained glacial sediments, then later fine-grained silt and clay mixed with organic material were deposited in this depression. Collapsed ice-contact stratified drift occurs on the eastern shore, and kame-terrace and ice-channel deposits are mapped on the western shore (Hanshaw, 1962). These deposits, in the Meriden quadrangle, generally range from fine sand to gravel. A bedrock contour map by Haeni (1976) based on drill-hole data from LaSala and Meikle (1964) and Mazzaferro (1973) and the bedrock geologic map (Hanshaw, 1968) indicates that the bedrock surface is over 100 feet deep in the southwest corner of the lake but it is close to the land surface near the northern part of the lake.

Three test borings were drilled on the edge of Silver Lake on January 5, 1984 to obtain data on the subsurface material surrounding the lake. The location of these sites is shown in figure 6 and the geologic logs of these holes are shown in table 1. Test hole ME 37TH penetrated 15 feet of till or very poorly-sorted sand and gravel, which is probably indicative of the material along the entire eastern shore of the lake and possibly underlying the eastern side of the lake. Split-spoon samples from test hole B 85TH, on the north side of the lake on the other hand, contained primarily very fine sand and silt, with a few layers of gravel.

Samples from test hole B 84TH, on the western side of the lake, were similar to those from B 85TH and consisted primarily of silt with some sand layers. Logs of other borings made at the south end of the lake (Dames and Moore 1981), also show that subsurface materials consist of sands and silts.

THEORY OF GROUND-PENETRATING RADAR

Ground-penetrating radar systems radiate short pulses of electromagnetic energy from a transmitting antenna. This energy enters the subsurface and, when electrical inhomogeneities are encountered, some energy is reflected back to the radar antenna and some transmitted downward to deeper layers. Electrical inhomogeneities are present in most hydrologic settings, especially at changes in degree of saturation, in clay content, or in composition of the subsurface materials.

3

EXPLANATION

Qs
Swamp deposits
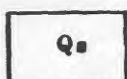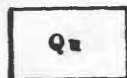
Qu
Stratified drift undifferentiated

Qal
Alluvium
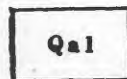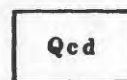
Qcd
Collapsed stratified drift

Qic
Ice-channel filling

Qk
Kame

Qkt
Kame terrace
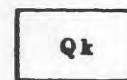
Qgd
Qgm
Ground moraine deposits, (Qgm)

———
Contact
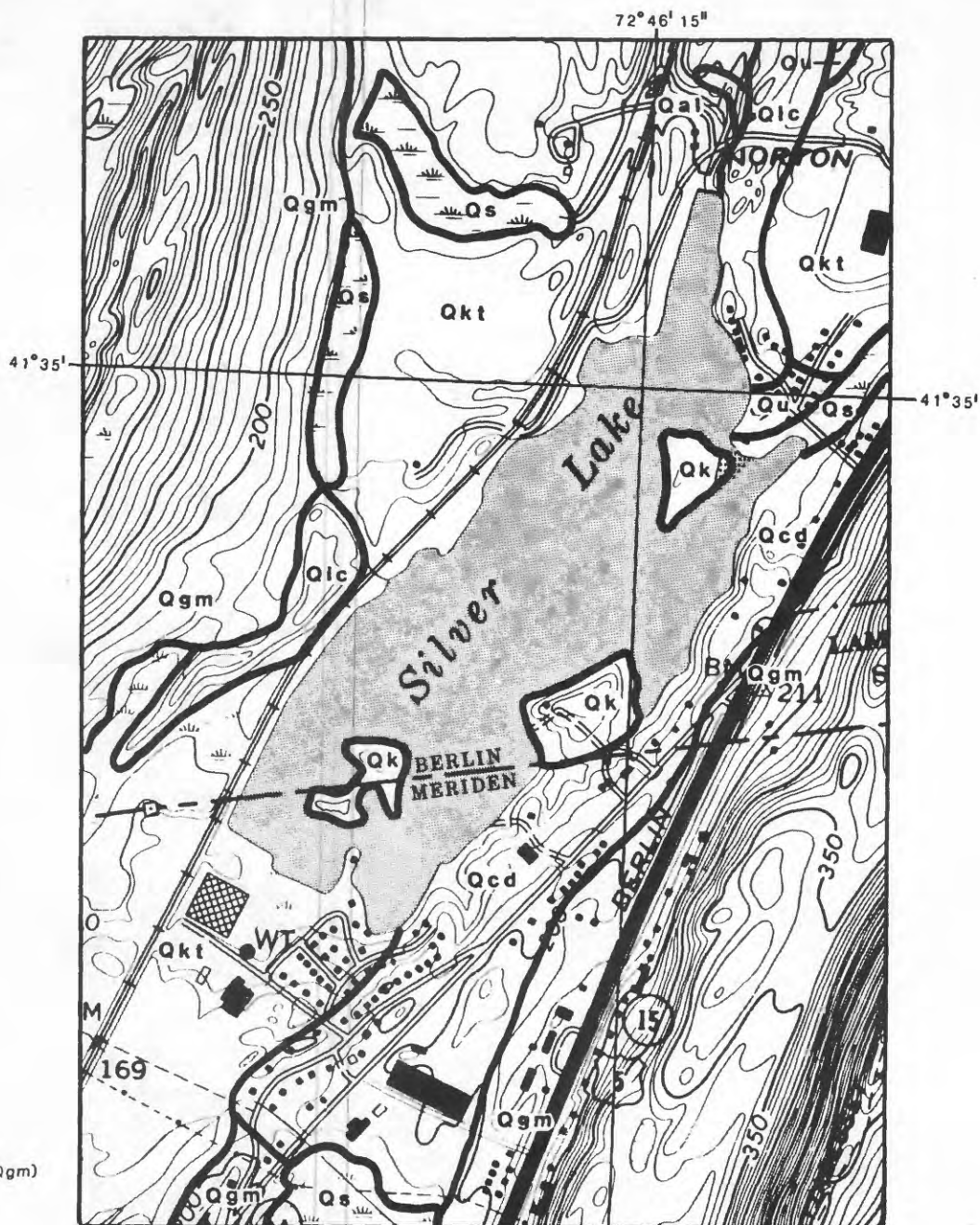
Base from U.S. Geological survey
Meriden Quadrangle 1:24,000 1967, photorevised 1972.

Modified from Hanshaw 1962.

SCALE

0   1/2   1 MILE
0   0.5   1 KILOMETER
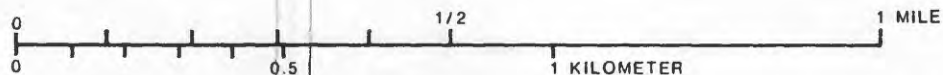
CONTOUR INTERVAL 10 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

Figure 2.--Surficial geology of study area.

4

TABLE 1--LOGS OF SELECTED TEST HOLES

Each entry lists U.S. Geological Survey test-hole number, location number, owner, year drilled, altitude of land surface, depth to water (if available), source of log, and description of earth materials penetrated.

Location number: Location number is the latitude and longitude of test hole site.

Altitude: Land surface at test-hole site, in feet above mean sea level, estimated from topographic map with 10-ft contour interval.

Depth to water: Measurement generally made shortly after completion of test hole and may not represent static conditions. Expressed in feet below land surface.

Source of log: All logs by U.S. Geological Survey.

Description of earth materials: Logs of test holes of the U.S. Geologiccal Survey are based on the Wentworth grain-size classification shown.

Terms used in logs of test holes of the U.S. Geological Survey.

Sand and gravel-Sorted stratified sediment varying in size from boulders to very fine sand.
"Poorly sorted" indicates approximately equal amounts, by weight, of all grain sizes.

Till--A predominantly nonsorted, nonstratified sediment deposited directly by a glacier and composed of boulders, gravel, sand, silt, and clay.

End of hole-Depth of bottom of test hole in which bedrock or refusal was not reached.

Refusal-Depth at which the drill equipment could not penetrate farther.

Percentage by weight of individual components in the sample.
Trace	0	10
Little	10 - 20	
Some	20 - 35	
..and..	35 - 50	

Town of Meriden
ME 37TH 413435N0724620. Carolyn Pomaricko. Drilled 1984
    Altitude 155 ft. Depth to water 6 ft.
    Log by U.S. Geological Survey

Materials	Depth (ft)	Thickness (ft)
Top soil.....................	0 - 1	1
Till, silty and clayey, red; some angular granules and pebbles;.....................	1 - 15	14
Refusal.................................	at 15	

Town of Berlin
B 84TH 413458N0724623. State of Connecticut. Drilled 1984
    Altitude 155 feet. Depth to water 7 ft.
    Log by U.S. Geological Survey

Materials	Depth (ft)	Thickness (ft)
Top soil.................................	0 - 1	1
Sand, red, poorly sorted..................	3 - 5	2
Gravel, red...............................	5 - 6	1
Sand, very fine to fine; some silt.......	6 - 8	2
Silt, red; and very fine to medium sand..	8 - 17	9
Silt, red; trace fine sand...............	17 - 19	2
Till or poorly sorted gravel.............	19 - 21	2
Silt and very fine to medium sand........	21 - 26	5
Till.....................................	at 26	

B 85TH 413457N0724607. Andy Fogler. Drilled 1984
    Altitude 151 ft. Depth to water 4 ft.
    Log by U.S. Geological Survey

Materials	Depth (ft)	Thickness (ft)
Top soil.................................	0 - 1	1
Sand, medium to coarse; some silt and clay; trace coarse gravel......................	1 - 5	4
Clay, organic, black......................	5 - 6	1
Sand, very fine to fine; and silt; trace medium to very coarse sand; trace red granules.................................	6 - 11	5
Silt, red.................................	11 - 17	6
Silt, red; trace very coarse sand..........	17 - 25	8
Gravel, pebble; very coarse, basalt........	25 - 26	1
Till, red.................................	26 - 27	1
Sandstone.................................	at 27	

The reflected signal is amplified, recorded, transformed to the audio frequency range, processed and displayed. The record displays the total traveltime for a signal to pass through the subsurface, reflect from an inhomogeneity, and return to the surface (fig. 3). This two-way traveltime, measured in nanoseconds (ns) (equal to 10^{-9} seconds) can be converted to thickness of materials if the relative dielectric permittivity of the subsurface material is known or if a control point is available from which it can be calculated. The relative dielectric permittivity is a measure of the capacity of a material to store a charge when an electric field is applied relative to the same capacity in a vacuum (Sheriff, 1984).

If the depth to a reflector is known, the relative dielectric permittivity at a given point can be calculated using:

$$E_r = (t/2)^2 \times (c/d)^2 \quad (1)$$

where:

E_r = relative dielectric permittivity (a dimensionless ratio);

t = two-way travel time, in seconds;

c = speed of light in free space, in feet per second (9.835712×10^8) and;

d = depth to the reflector, in feet.

If the relative dielectric permittivity is calculated from equation 1 or can be estimated from published data, the depth to a reflector can be calculated by rearranging the above equation to:

$$d = V_m \, t/2 \quad (2)$$

The radar wave velocity (V_m) is equal to :

$$V_m = c/\sqrt{E_r} \quad (3)$$

The penetration depth of a ground-penetrating radar system depends primarily on the conductivity of the earth materials, and also on the frequency of the electromagnetic waves (Geophysical Survey Systems, Inc., 1974; Olhoeft, 1984). In general, the radar system will penetrate resistive or low-conductivity earth materials and will not penetrate conductive or low-resistivity units. Penetration depths of 90 feet in clay-free sand and gravel have been reported (Wright and others, 1984) and less than 3 feet in clay-rich soil (Olhoeft, 1984).

Radar has been used to determine the thickness of organic material such as peat in many studies (Geophysical Survey Systems, Inc., 1974; Bjelm, 1980; Ulriksen, 1980, 1982), and the results have been shown to agree closely with test-hole data (Ulriksen, 1982).

RADAR FIELD METHODS

A commercial ground-penetrating radar system with a 80 megahertz (MHz) center frequency antenna was used to profile the soft organic and inorganic sediments beneath Silver Lake. The profiling was done in March 1984, when the lake was frozen and covered by 1 foot of ice and 6 inches of snow. The electronic equipment was mounted on a sled (fig. 4) that was pulled by a small tractor
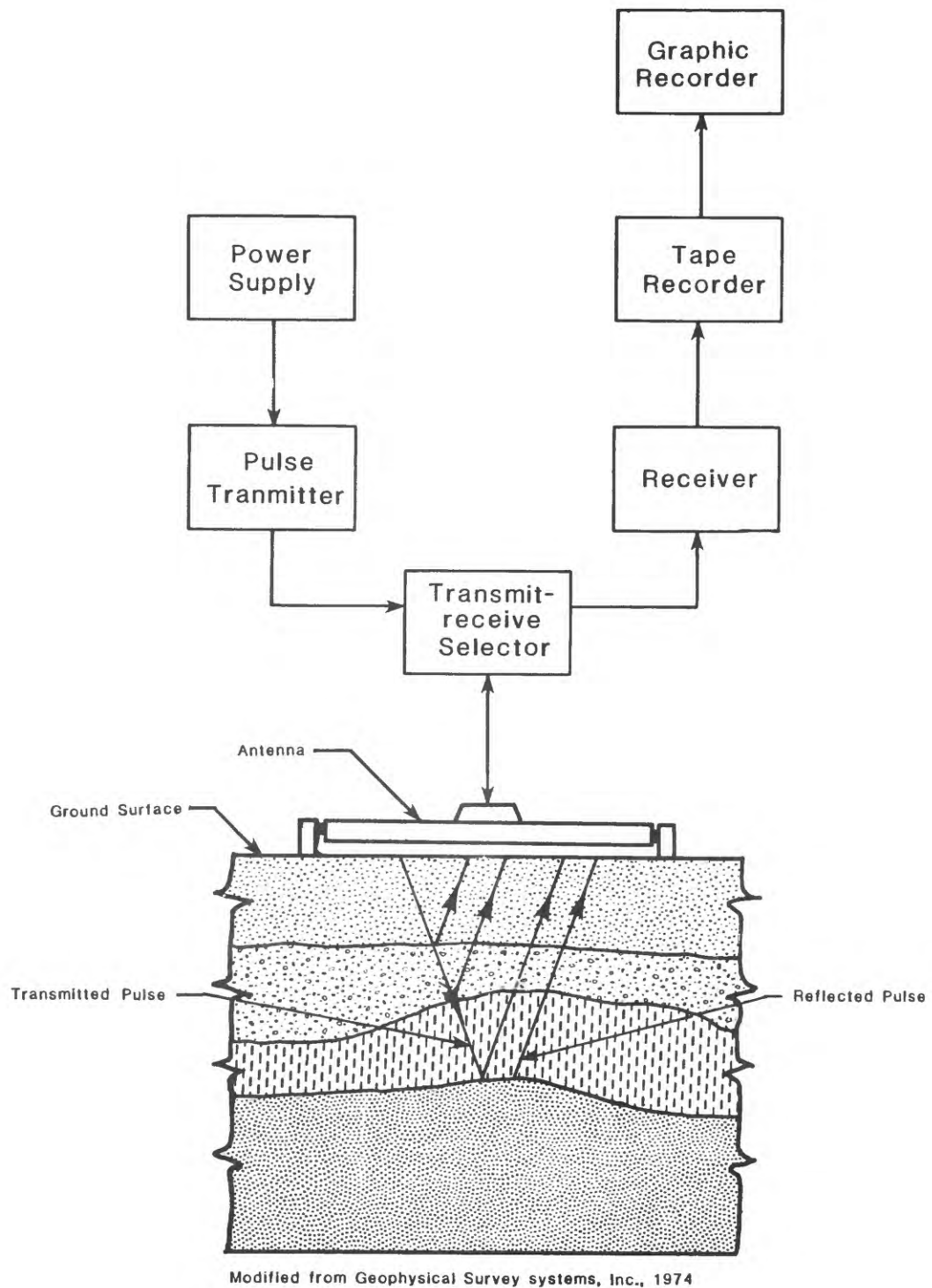
6

Figure 3.--Simplified block diagram and functional operation
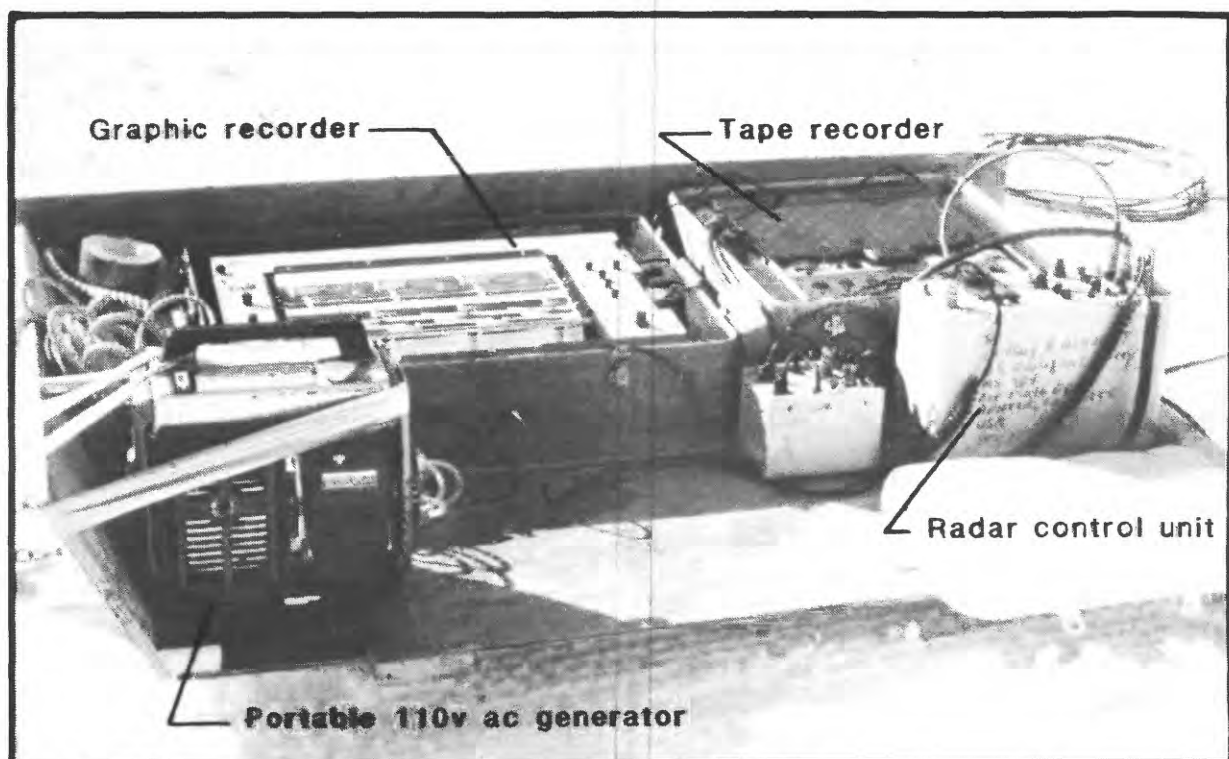of a ground-penetrating radar system.

Figure 4.--Ground-penetrating-radar electronic equipment
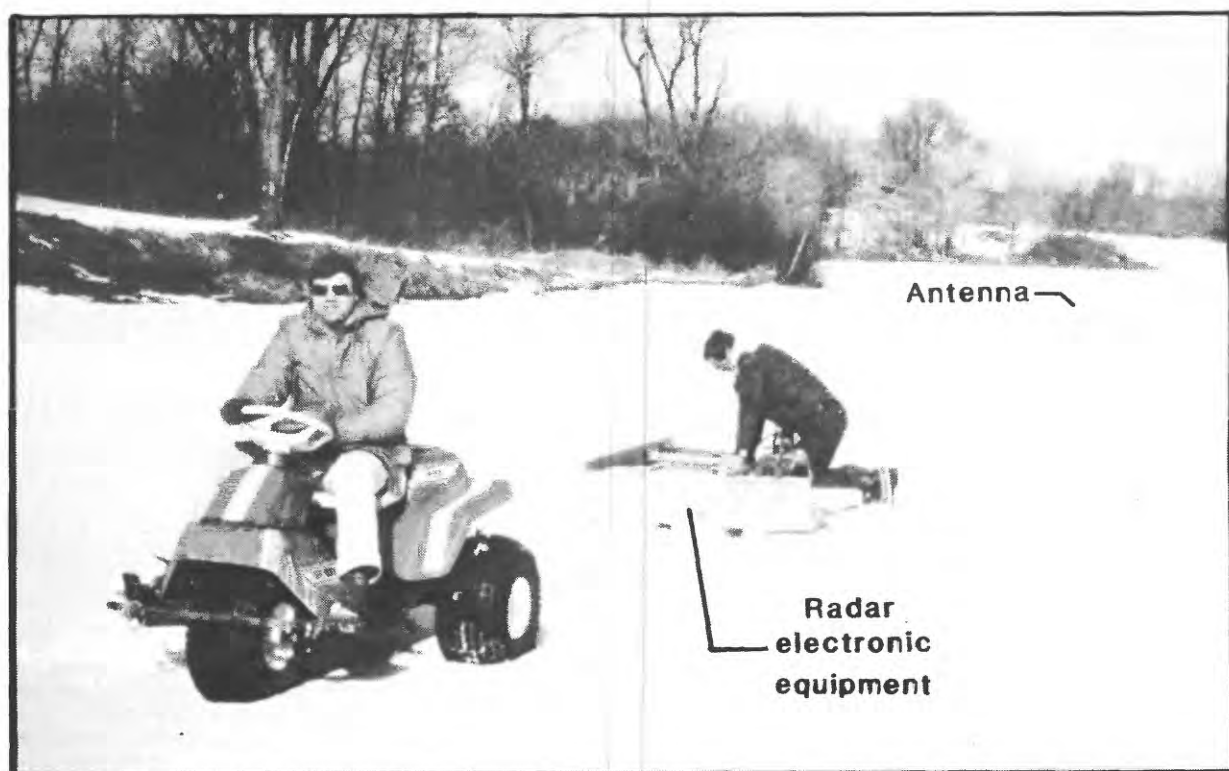mounted on wooden sled.

Figure 5.--Field operation of ground-penetrating radar system.

with the antenna trailing 90 feet behind the sled (fig. 5). Approximately 4 miles of profile line were run in one field day (fig. 6). Geographic positioning was accomplished by maintaining a constant speed between two known points on the lake shore.

RESULTS OF RADAR PROFILING

Interpretation of Radar Profiles

The field radar records were interpreted using velocity data calculated from previously published relative dielectric permittivities for ice, freshwater, and peat. Relative dielectric permittivities for peat ranging from 43 to 74 have been published (Geophysical Survey Systems, Inc., 1974; Ulriksen, 1982) and a value of 56 was used for this study. This value was determined by comparing the calculated thickness of sediment at two locations with preliminary coring data. Commonly used relative dielectric permittivities of 4 for ice and 81 for freshwater also were used (Geophysical Survey Systems, Inc., 1974; and Ulriksen, 1982).

The radar velocities determined for each material, using equation (3) and the assumed relative dielectric permittivities were: ice, 0.5 ft/ns; water, 0.11 ft/ns; and peat, 0.13 ft/ns. These velocities were used to calculate depths using equation (2) and to map the thickness of the sediments in Silver Lake. The assumption was made that the soft sediments have a radar velocity that is similar to peat and that these materials are uniform and have a constant radar velocity throughout the lake.

On most profiles, the thickness of the snow and ice was not observed and the radar was not able to penetrate the entire thickness of the soft sediments on the lake bottom. The lack of penetration probably is due to the presence of silt and clay mixed with the organic material. Using the previously listed velocities, approximately 1 foot of ice, 4 to 5 feet of water, and about 5 feet of soft sediment could be penetrated by the radar signal. More than 5 feet of soft sediment exists in a large part of the lake, but total thickness could not be determined using this geophysical method. The ice-water interface was not observed due to its limited thickness and multiple radar echoes. Typical radar profiles and geologic interpretations are shown in figures 7 through 10. The locations of these profiles are shown in figure 6. Because the radar unit measures the time between the outgoing radar pulse and the return of the reflected signal, the depth to individual reflectors must be calculated. This can be done using the following formula:

$$T_t = \frac{d_1}{V_1} + \frac{d_2}{V_2} + \frac{d_3}{V_3} \ldots + \frac{d_n}{V_n} \qquad (4)$$

where T_t = One-way total travel time, in nanoseconds;
d_1 = thickness of layer 1, in feet;
d_2 = thickness of layer 2, in feet, (and so on):
V_1 = radar velocity in layer 1, in nanoseconds per foot;
V_2 = radar velocity in layer 2, in nanoseconds per foot (and so on)

9

EXPLANATION

A _____ B   Radar profile line

•⁵   Coring locations

84
-⦷-   Test hole
      Number is town number used
      in U.S. Geological Survey
      publications.

72°46' 15"

NORTON

41° 35'   41° 35'

84

85

BERLIN
MERIDEN

BM
211

WT

M

169

15

BERLIN

250

200

200

200

350

350

SCALE

0   1/2   1 MILE

0   0.5   1 KILOMETER

CONTOUR INTERVAL 10 FEET
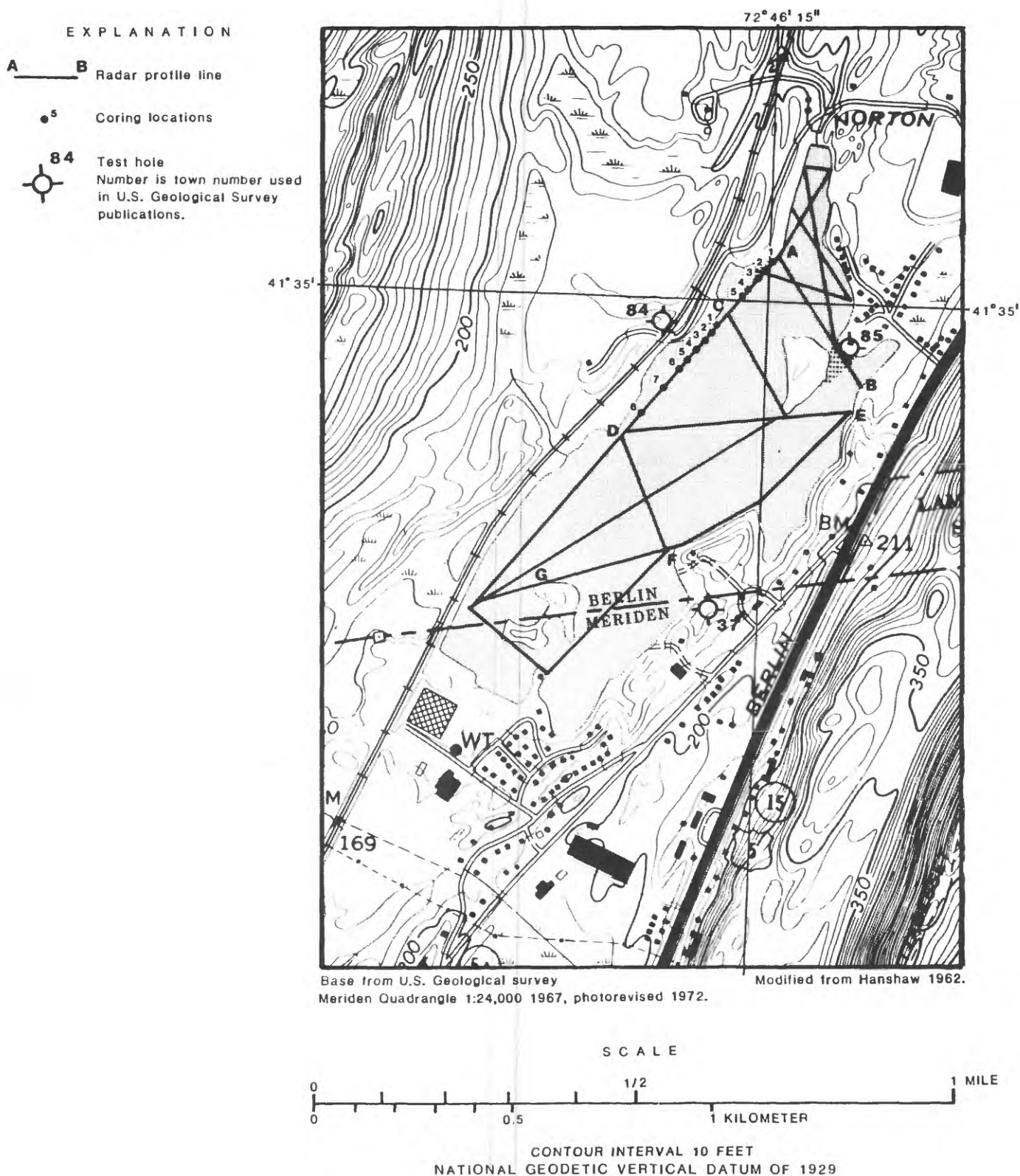NATIONAL GEODETIC VERTICAL DATUM OF 1929

Figure 6.--Location of radar profile lines core sites,
           and test holes.

10

In the interpreted profiles shown in figures 7-10, an approximate depth scale has been added. This scale is only for purposes of illustration and assumes a constant thickness of ice and water above the soft material.

Figure 11 shows the thickness of soft organic and inorganic material beneath Silver Lake. The large area in the center of the lake where no radar reflections were obtained from the subsurface is interpreted as having greater than 5 feet of soft organic and inorganic material below the lake bottom.

Verification of Radar-Profiling Interpretations

To confirm the radar results, 13 sites were cored along radar profiles A-C and C-D. The location of these sites is shown in figure 6. The core data were also used to verify the assumed radar velocities used to interpret the radar records. The material penetrated in the cores was predominantly black organic ooze, fibrous peat, and inorganic silt and clay. This was underlain by a hard substrate that was not recovered in the cores. This hard bottom layer is believed to have been sand and gravel or sand and silt deposits.

Table 2 compares the thicknesses of organic material and the water column calculated from the radar data to thicknesses measured in the cores. The thickness of ice is not included because it was not detected by the radar and was determined to be 1 foot thick over the entire lake. The differences are small and are attributible to errors in correlating the locations on the radar profiles with the cored sites and to variations in the composition of the soft lake-bottom sediments.

CONCLUSIONS

Ground-penetrating radar is a geophysical technique that can be used to economically map the thickness and extent of soft organic and inorganic sediment deposited in lakes. Penetration depths may be limited by the presence of conductive material, primarily silt and clay.

Ground-penetrating radar was able to penetrate 6 inches of snow, 1 foot of ice, 4-5 feet of water, and up to 5 feet of soft organic and inorganic sediments in Silver Lake located in the towns of Meriden and Berlin, Connecticut. Most of Silver Lake is underlain by more than 5 feet of soft organic-rich sediment, but deeper radar penetration was probably prevented by the presence of significant quantities of silt and clay in the subsurface material.

Boring logs around the perimeter of the lake indicate that the soft materials in the eastern part of Silver Lake may be underlain by till or poorly-sorted sand and gravel, and that the rest of the lake is probably underlain by fine sands and silts with some discontinuous areas of sand and gravel.
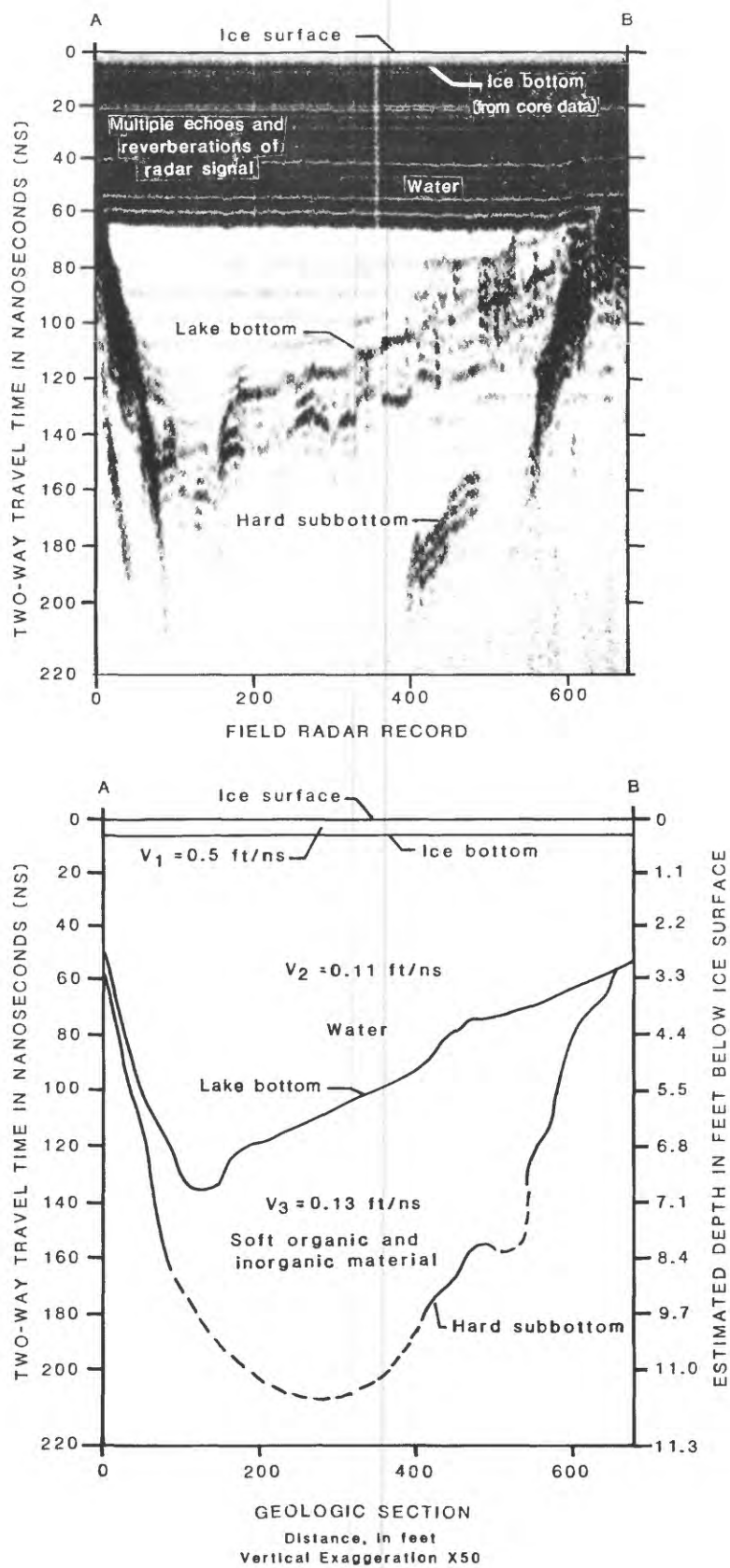
Figure 7 --Field radar record of line A-B and interpreted geologic
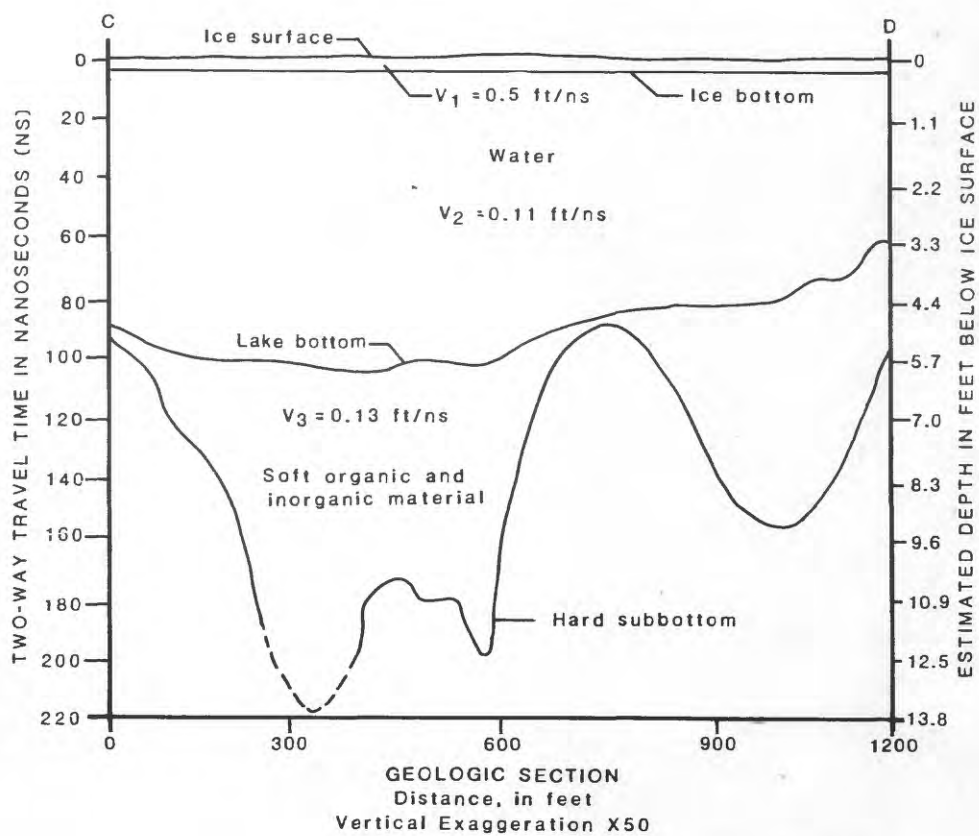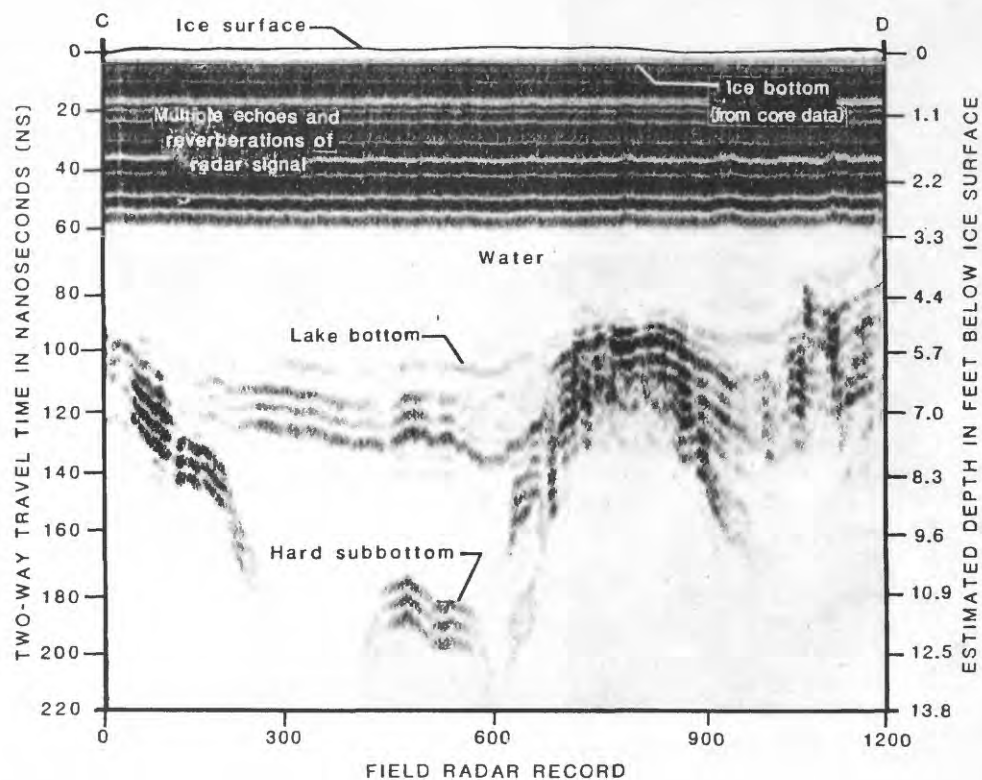section.

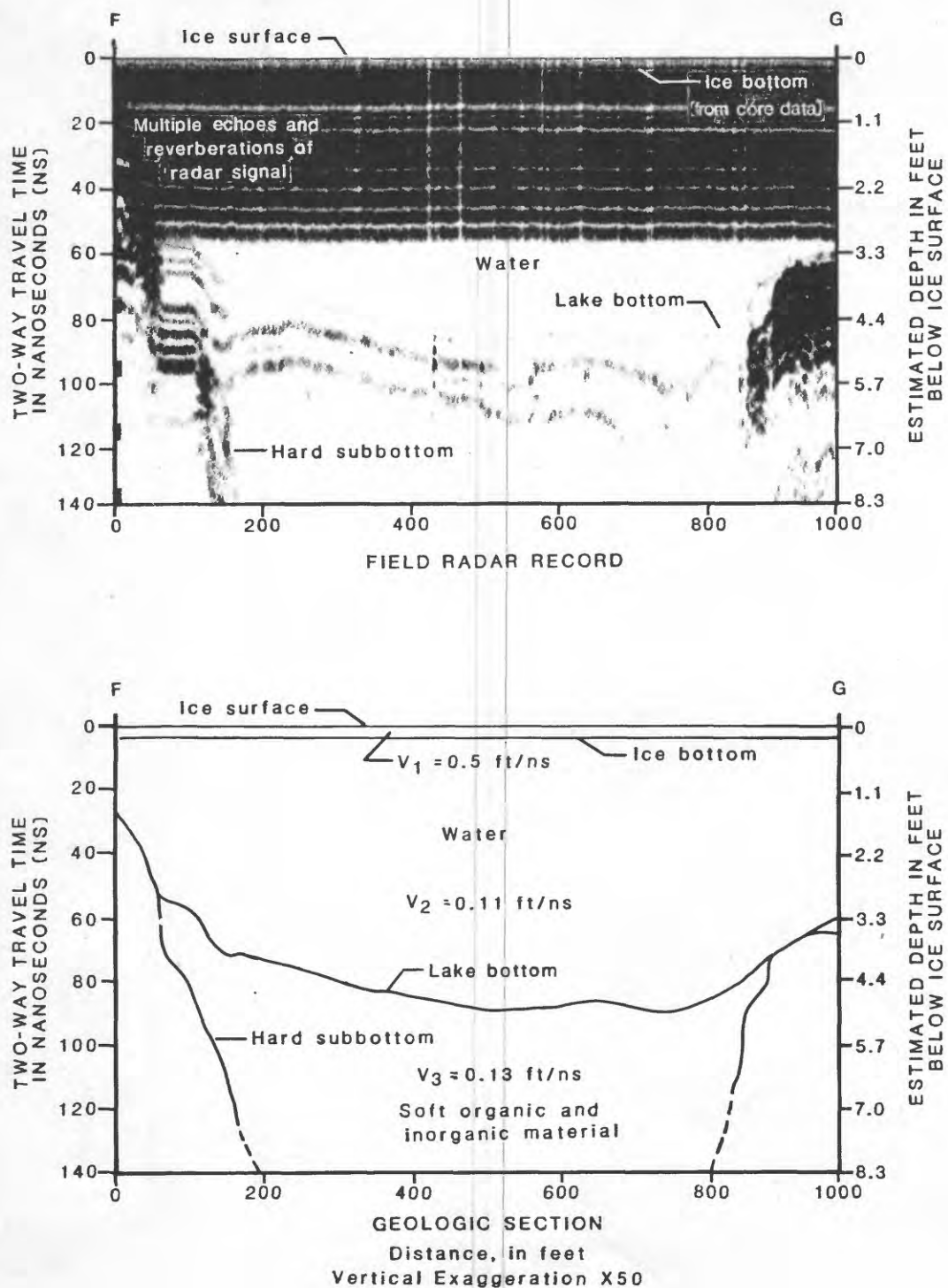Figure 8.--Field radar record of line C-D and interpreted geologic section.

Figure 9.--Field radar record of line F-G and interpreted geologic section.

14
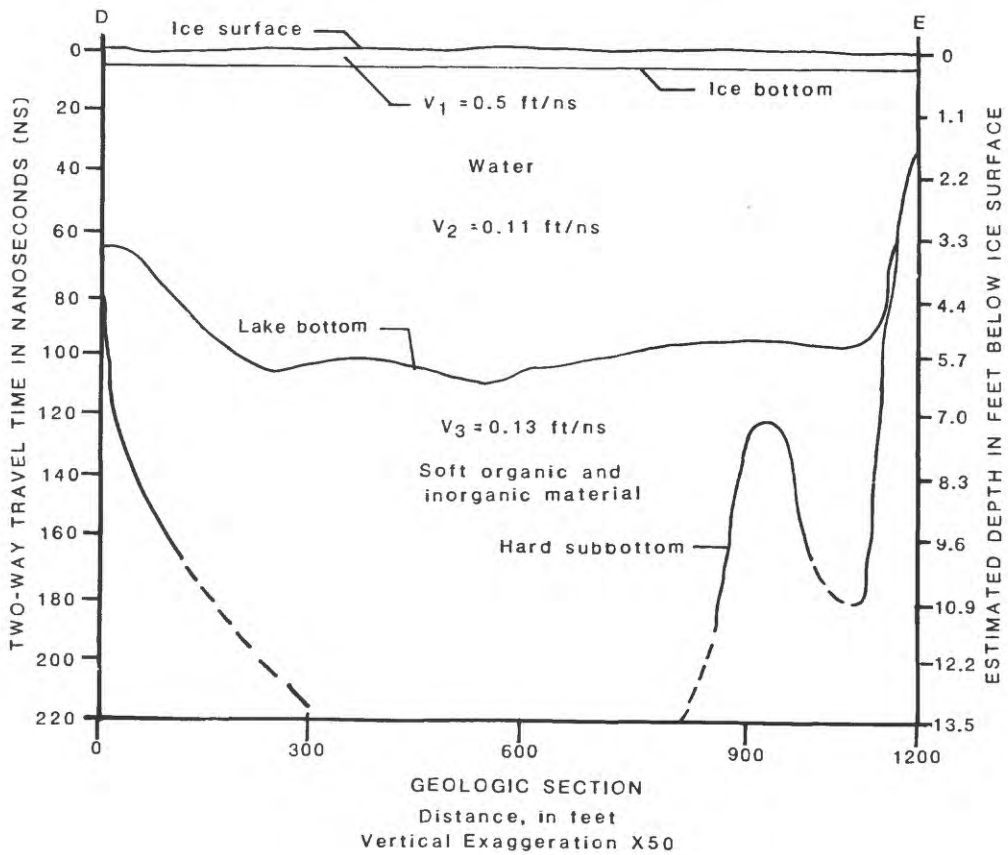
Figure 10 --Field radar record of line D-E and interpreted
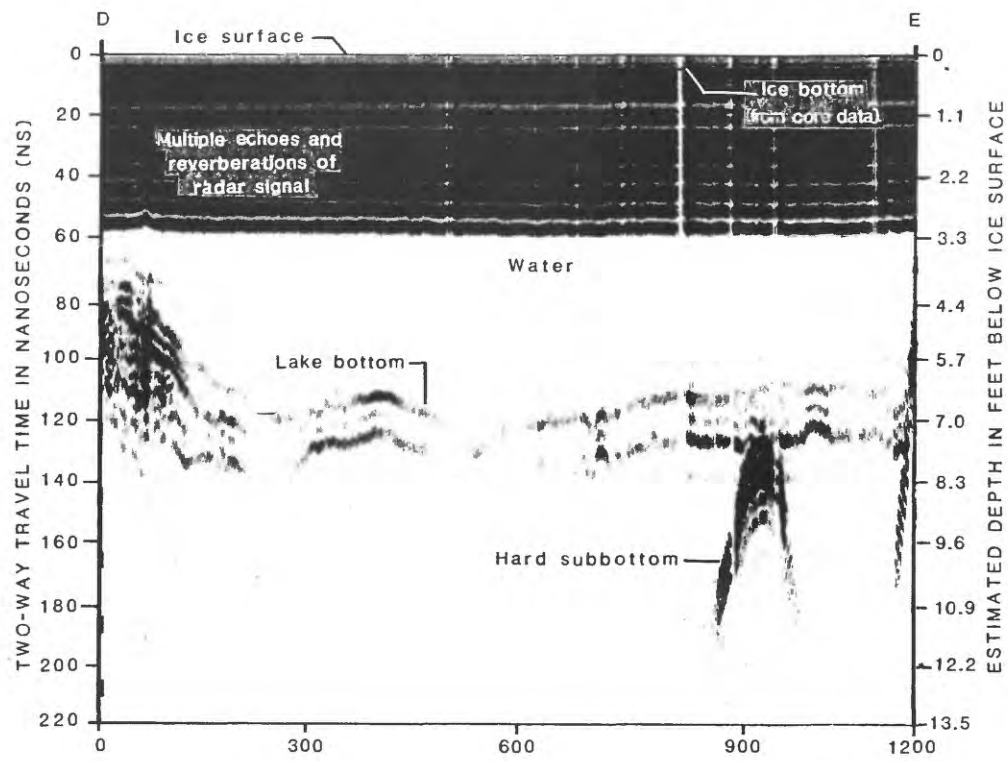geologic section.

15

72°46' 15"

41°35'   41°35'

BERLIN
MERIDEN

72°46' 15"

SCALE

0   1/2   MILE

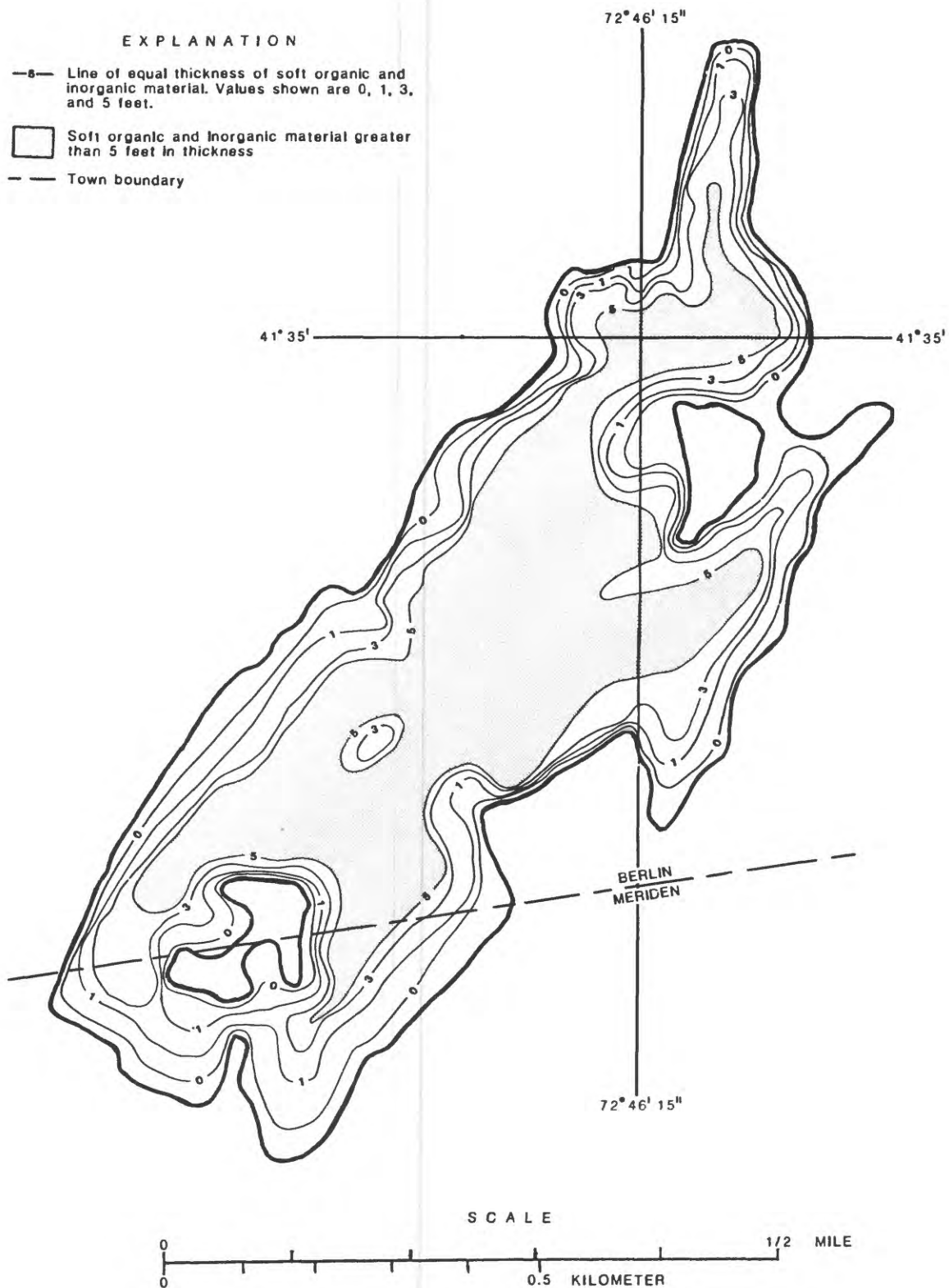0   0.5   KILOMETER

Figure 11.--Thickness of soft organic and inorganic material.

16

Table 2 - Thickness of organic, lake-bottom sediment and overlying water
column computed from radar data and from measurements at core
sites

[Profile and station locations shown in figure 6, > = greater than]

	Water depth (feet)		Sediment thickness (feet)	
	Radar	Measured	Radar	Core
Profile A-C				
Station 1	4.4	4.8	0	0.5
2	5.8	5.7	1.2	1.3
3	5.7	5.6	>4	5.3
4	5.2	5.1	>4	7.2
5	4.9	4.4	2.0	2.7
Profile C-D				
Station 1	4.9	4.8	1.5	1.0
2	5.0	4.8	2.5	2.8
3	5.2	5.1	4.6	4.1
4	5.4	5.1	>5.5	5.0
5	5.4	5.1	4.5	3.9
6	5.4	4.7	5.5	5.9
7	4.8	4.0	1.3	1.0
8	4.4	4.1	3.0	4.2

REFERENCES CITED

Bjelm L , 1980 Geological interpretation with subsurface interface radar in
    peat lands: Proceedings of the 6th International Peat Congress,
    August 17-23, 1980 Duluth Minnesota, p. 7-8.

Dames and Moore, 1981, Groundwater investigations for the Westvaco Corporation,
    Container Division Meriden, Connecticut: Dames and Moore,
    Cranford New Jersey 75 p.

Geophysical Survey Systems, Inc., 1974, Continuous subsurface profiling by
    impulse radar: Hudson, New Hampshire, Geophysical Survey Systems, Inc.,
    20 p.

Haeni, F. P., 1976, Contour map of the bedrock surface, Meriden Quadrangle,
    Connecticut: U.S. Geological Survey Miscellaneous Field Studies
    Map MF-661 A scale 1:24,000.

Hanshaw, Penelope, 1962, Surficial geology of the Meriden quadrangle
    Connecticut: U.S. Geological Survey Geologic Quadrangle Map
    GQ-150.

_____ , 1968, Bedrock geologic map of the Meriden quadrangle,
    Connecticut: U.S. Geological Survey Geologic Quadrangle Map
    GQ-738.

LaSala A. M., Jr., and Meikle, R. L., 1964, Records and logs of selected wells and
    test borings and chemical analysis of water in the
    Bristol-Plainville-Southington area, Connecticut: Connecticut
    Water Resources Bulletin 5, 18 p.

Mazzaferro, D. L. 1973, Hydrogeologic data for the Quinnipiac River basin,
    Connecticut: Connecticut Water Resources Bulletin 26, 54 p.

Olhoeft, G. R., 1984, Applications and limitations of ground-penetrating radar
    [abs.]: Society of Exploration Geophysicists, Fifty-fourth Annual
    International Meeting, Atlanta, Georgia p. 147-148.

Sheriff, R. E., compiler, 1984, Encyclopedic dictionary of exploration geophysics
    (second edition): Tulsa, Oklahoma, Society of Exploration
    Geophysicists, 323 p.

Ulriksen P., 1980 Investigation of peat thickness with radar, Proceedings of
    the 6th International Peat Congress, Duluth, Minnesota, August 17-23,
    1980, p. 126-129.

_____ 1982, Application of impulse radar to civil engineering: Lund,
    Sweden Lund University of Technology p. 179.

Wright, D. C. Olhoeft, G. R. and Watts, R. D. 1984, Ground-penetrating radar
    studies on Cape Cod: Proceedings of National Water Well Association
    Conference on Surface and Borehole Geophysical Methods, February 7-9, 1984,
    San Antonio, Texas, p. 666-680.