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GEOLOGICAL SURVEY OF CANADA
OPEN FILE 8733

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N.A. Morgan, B.J. Todd, and C.F.M. Lewis

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Canada

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Publications in this series have not been edited; they are released as submitted by the author.

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Abstract

In 1964, interpreted seismic reflection profiles, a sediment isopach map, and a map of depth to bedrock in Lake Erie were included in the unpublished Ph.D. thesis of Dr. Nabil Assad Morgan of the Department of Physics at the University of Toronto. These interpretations and compilations have never been published in the scientific literature. Ongoing research in the Great Lakes by geoscientists within the Geological Survey of Canada, and their colleagues in Canada and the Unites States, means that it is now essential to revive Dr. Morgan's work and release it in an Open File for general access.

Introduction

Dr. Nabil Assad Morgan obtained his Ph.D. from the Department of Physics at the University of Toronto in 1964. His thesis was entitled "Geophysical studies in Lake Erie by shallow marine seismic methods" (Morgan, 1964). Lake Erie, the shallowest of the Laurentian Great Lakes, is bounded by Ontario to the north, Michigan to the west, Ohio and Pennsylvania to the south, and New York to the southeast and east (Fig. 1)

The first part of his thesis concerned the sampling of Lake Erie sediments and the correlation of their measured seismic wave velocity with their other physical properties. Porosity is the key parameter on which wave velocity depends most. Other properties measured included grain density, bulk density and grain size distribution. These results were published by Morgan (1969).

The second part of the thesis concerned the use of a sparker seismic reflection system in Lake Erie. At the time of Morgan's work, the sparker was a new marine seismic instrument designed by Dr. G.F. West (University of Toronto) in 1961 and fabricated by Huntec Ltd. in Toronto. Eleven hundred miles (1770 km) of Lake Erie sediments were surveyed and interpreted. Contour maps of Lake Erie showing total sediment thickness and bedrock topography were prepared but were *never published in the scientific literature*. The purpose of this Open File is to publish this work so that it can be on record as the first maps of their type for all of Lake Erie. Other published surveys for parts of Lake Erie include Wall (1968) in the central basin, Hobson *et al*. (1969) for the western basin, and Williams *et al*. (1980) for the southern part of the lake.

Lake Erie seismic profiling

The bedrock horizon interpreted by Morgan compared well with the depth to bedrock recorded in a borehole at the tip of Long Point and at several gas wells in the northern part of the eastern basin (Appendix 1, Table 1). Two sheets of interpreted seismic profiles were prepared as well. In addition to the lake bottom and bedrock horizons the sparker records revealed an intermediate horizon which produced multiple reflections indicating the elastic properties of the sediments differed above and below the horizon. The geological identity of this horizon was not determined by Morgan (1964). Here, the intermediate reflector is interpreted to record the buried surface of desiccated (and strengthened) sediments exposed to subaerial conditions during the lowstand in Lake Erie during the early Holocene Epoch (Lewis *et al.*, 2012, and references therein).

The seismic survey of Lake Erie was conducted from CNAV *Porte Dauphine*, a research vessel programmed by the Great Lakes Institute of the University of Toronto. Surveys were conducted at 5 knots (9.3 km/hr). The source and receiver were separated by about 5 to 10 feet (1.5 to 3.1 m), and were towed 150 feet (45.7 m) astern at a depth of about 7 feet (2.1 m). The estimated accuracy of ship positioning was ±0.25 mile (402.3 m) nearshore, ±0.50 mile (804.7 m) at maximum radar range from shore landmarks (~24 miles, 38.6 km), and ±1.50 miles (2.4 km) in the central part of the lake when the ship was beyond radar range of shore. Many multiple reflections were observed. Seismic wave velocity used to estimate depth to reflectors was determined to be 5000 feet per second (1524 m/s). The unidentified intermediate horizon was clear on profiles 23S and 24N, partially clear on 25S. The horizon disappeared in the central region, then was clear on 8N and 7S, except near Long Point (i.e. clear on N and S flanks of eastern basin, but not in central region). Bedrock was difficult to identify west of 83°35´W.

Five sheets from the thesis were recreated from scans obtained at the University of Toronto. Sheet 1 is a trackplot of the seismic survey lines in Lake Erie. Sheet 2 is a set of interpreted seismic profiles from eastern Lake Erie. Sheet 3 is a set of interpreted seismic profiles from western Lake Erie. Sheet 4 is an isopach map of sediment thickness in Lake Erie. Sheet 5 is a map of the bedrock topography in Lake Erie and adjacent Ontario based on seismic profile interpretations and well data. Sheets 1, 4 and 5 are presented on a bathymetric compilation of Lake Erie compiled by the National Geophysical Data Center (1999).

These five sheets were patched together from a number of hand-held scanned pages, each of which was distorted in the scanning process. (The original sheets had been tightly folded in the thesis pocket for 56 years and the paper along the folds could not be flattened by hand). The maps (Sheets 1, 4 and 5) were rectified using Geographical Information System software. The distortions in the scans could not be completed eliminated in the process of sheet rectification, so the sheets presented here are not *exact* duplicates of the originals held by the University of Toronto. Copying the original sheets using a flatbed scanner would have reduced the distortions in the scans to a minimum. The use of a flatbed scanner is the standard operating procedure at the Geological Survey of Canada when scanning and digitizing paper maps.

Acknowledgements

We thank the University of Toronto for facilitating scans of portions of the Ph.D. thesis text of Dr. Nabil A. Morgan and allowing its included sheets to be scanned. Dr. Morgan passed away in 2014 (Appendix 2). Ms. Barbara Edwards (Reference Specialist, University of Toronto Archives and Records Management Services, UTARMS) assisted in accessing Dr. Morgan's thesis and copied Chapter 6 gratis. Mr. Tys Klumpenhouwer (University Archivist, UTARMS) assisted with

clarification of the Morgan thesis references. Gordon Cameron (Geological Survey of Canada) reviewed the manuscript.

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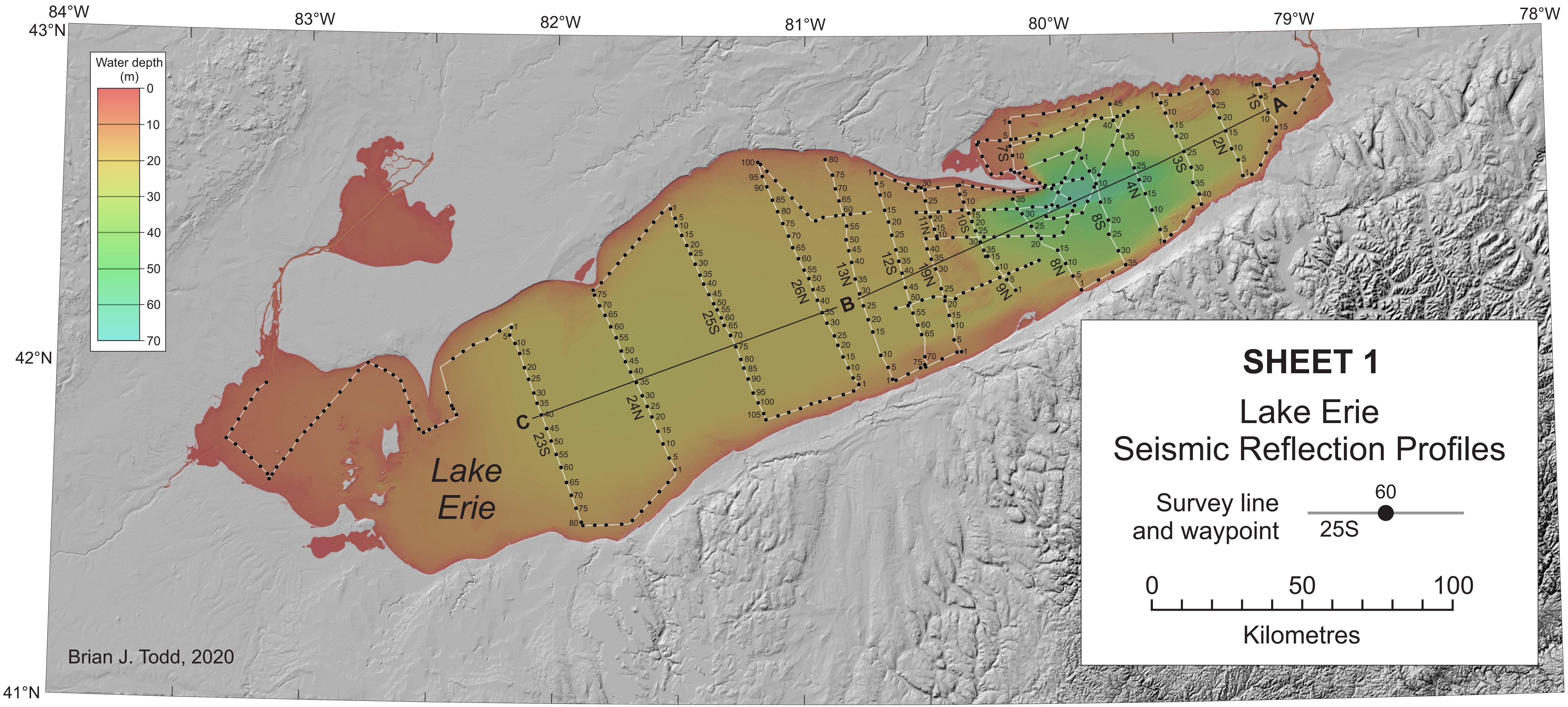
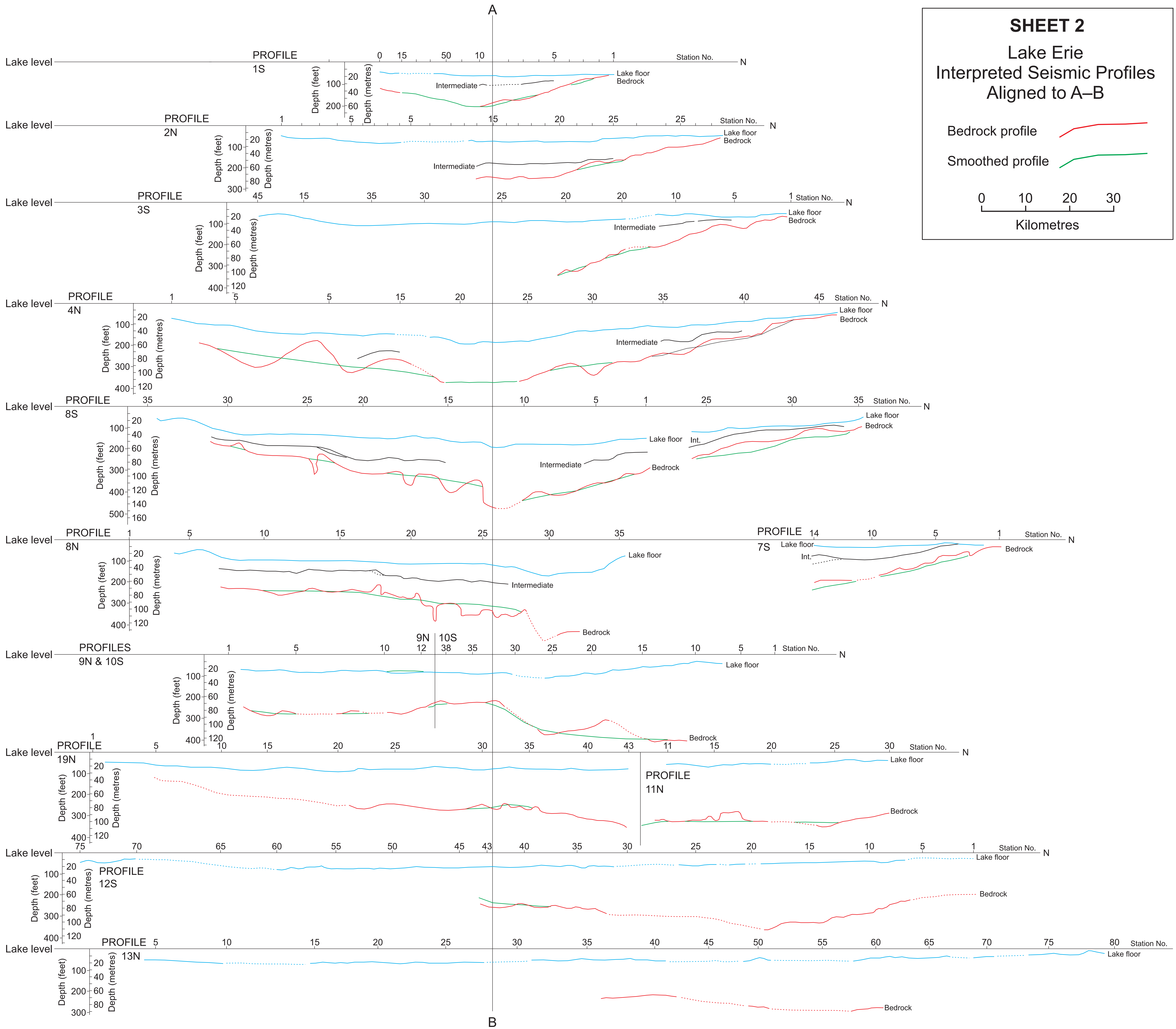
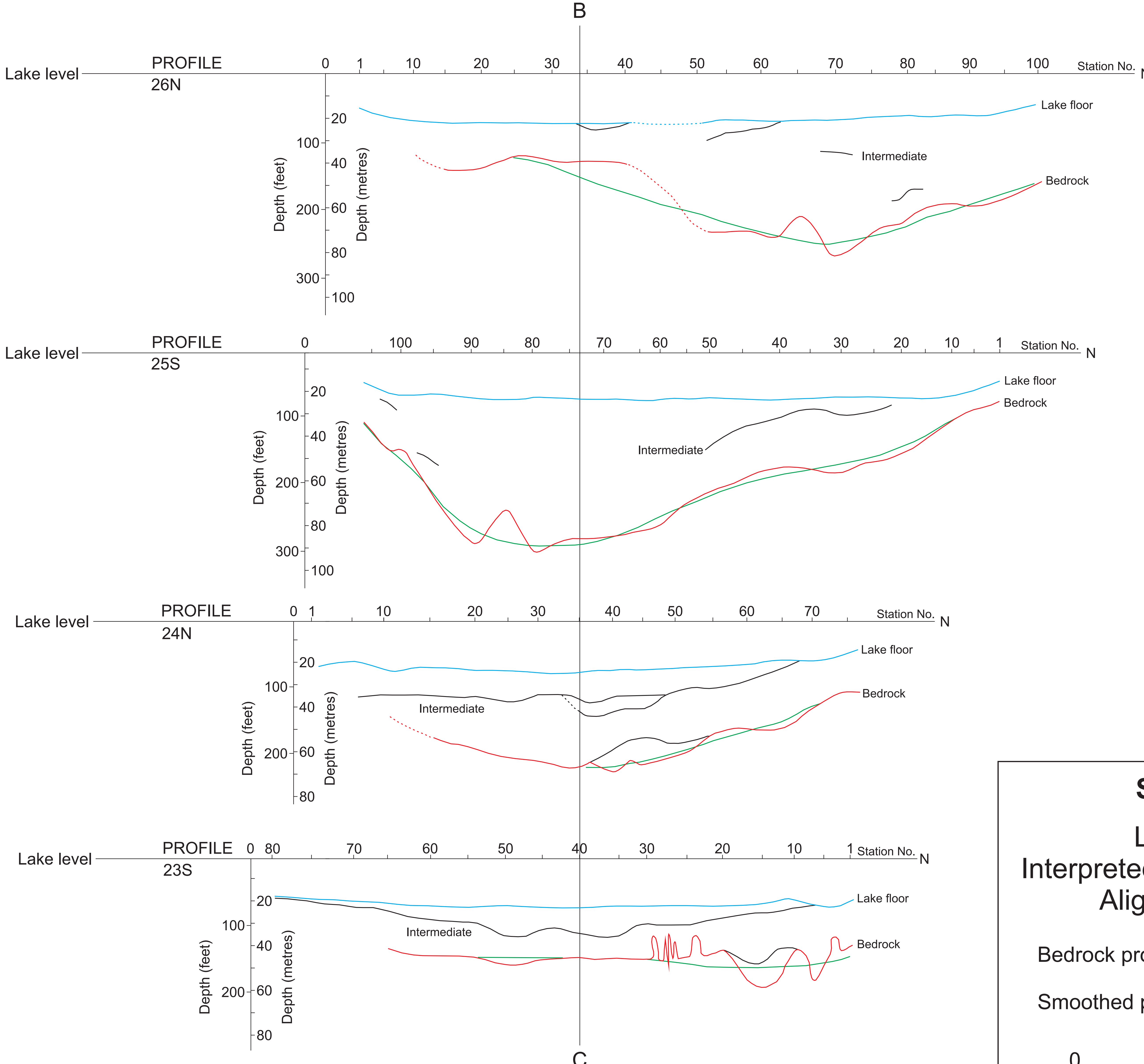
Figure 1. Location map of Lake Erie. Long Point is indicated on the north shore of the lake.

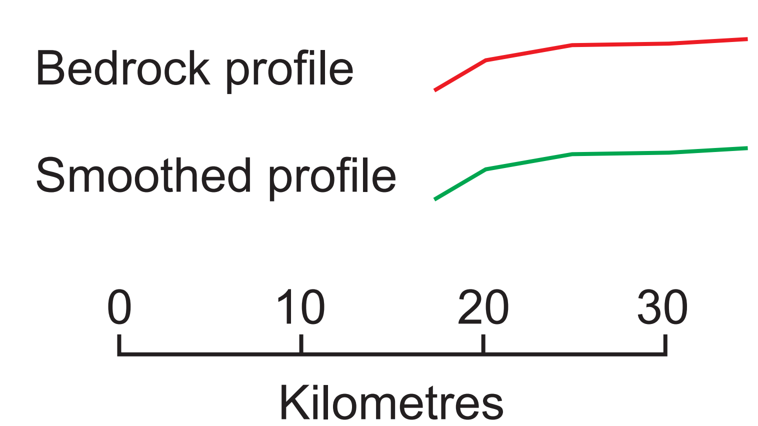

84°W
83°W
82°W
81°W
80°W
79°W
78°W
43°N
42°N
41°N
Water depth (m)
0
10
20
30
40
50
60
70
Lake Erie
A
B
C
1S
2N
3S
4N
7S
8S
8N
9N
10S
11N
12S
13N
19N
23S
24N
25S
26N
SHEET 1
Lake Erie
Seismic Reflection Profiles
Survey line and waypoint
60
25S
0
50
100
Kilometres
Brian J. Todd, 2020

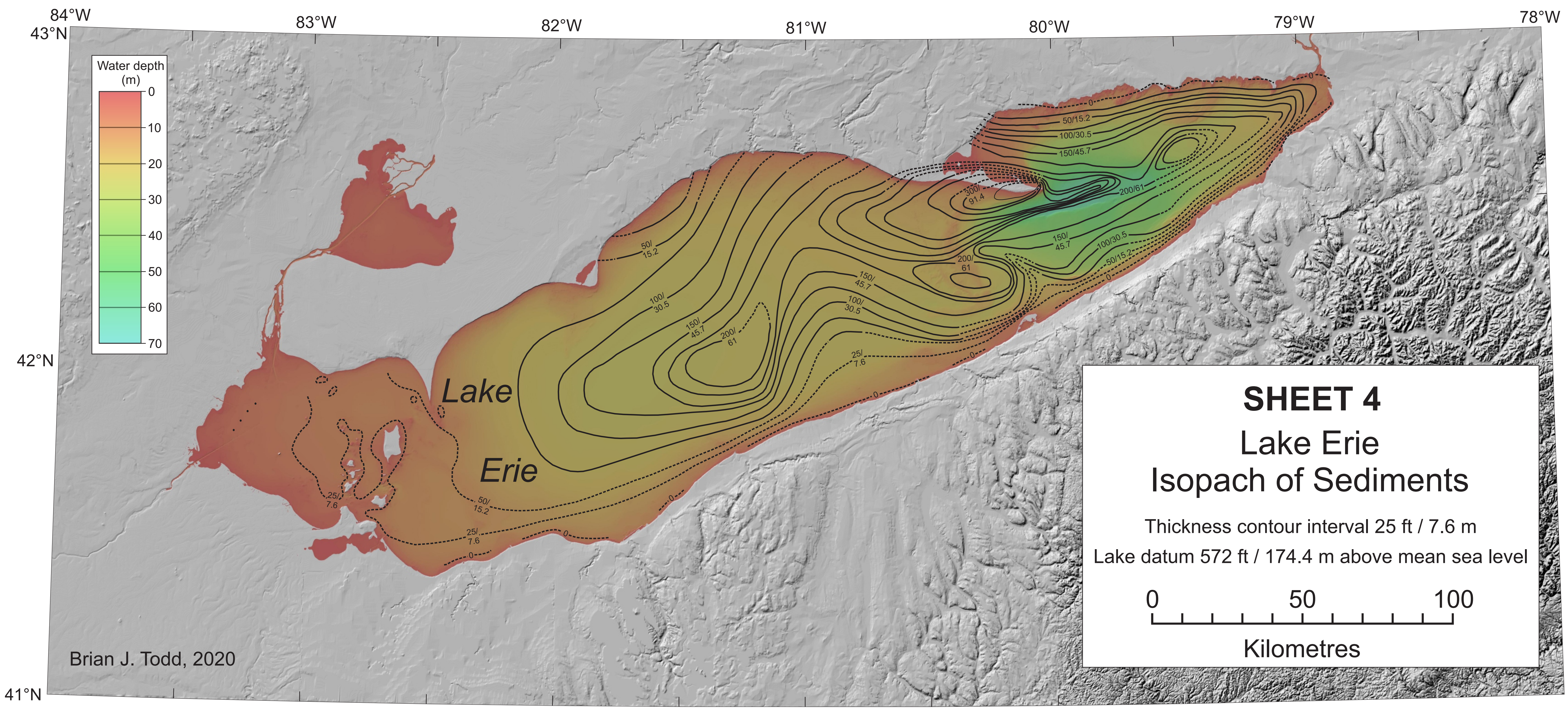

SHEET 2
Lake Erie
Interpreted Seismic Profiles
Aligned to A–B
Bedrock profile
Smoothed profile
0 10 20 30
Kilometres
A
B
Lake level
PROFILE 1S
PROFILE 2N
PROFILE 3S
PROFILE 4N
PROFILE 8S
PROFILE 8N
PROFILE 7S
PROFILES 9N & 10S
PROFILE 19N
PROFILE 11N
PROFILE 12S
PROFILE 13N
Station No.
N
Lake floor
Bedrock
Intermediate
Int.
Depth (feet)
Depth (metres)

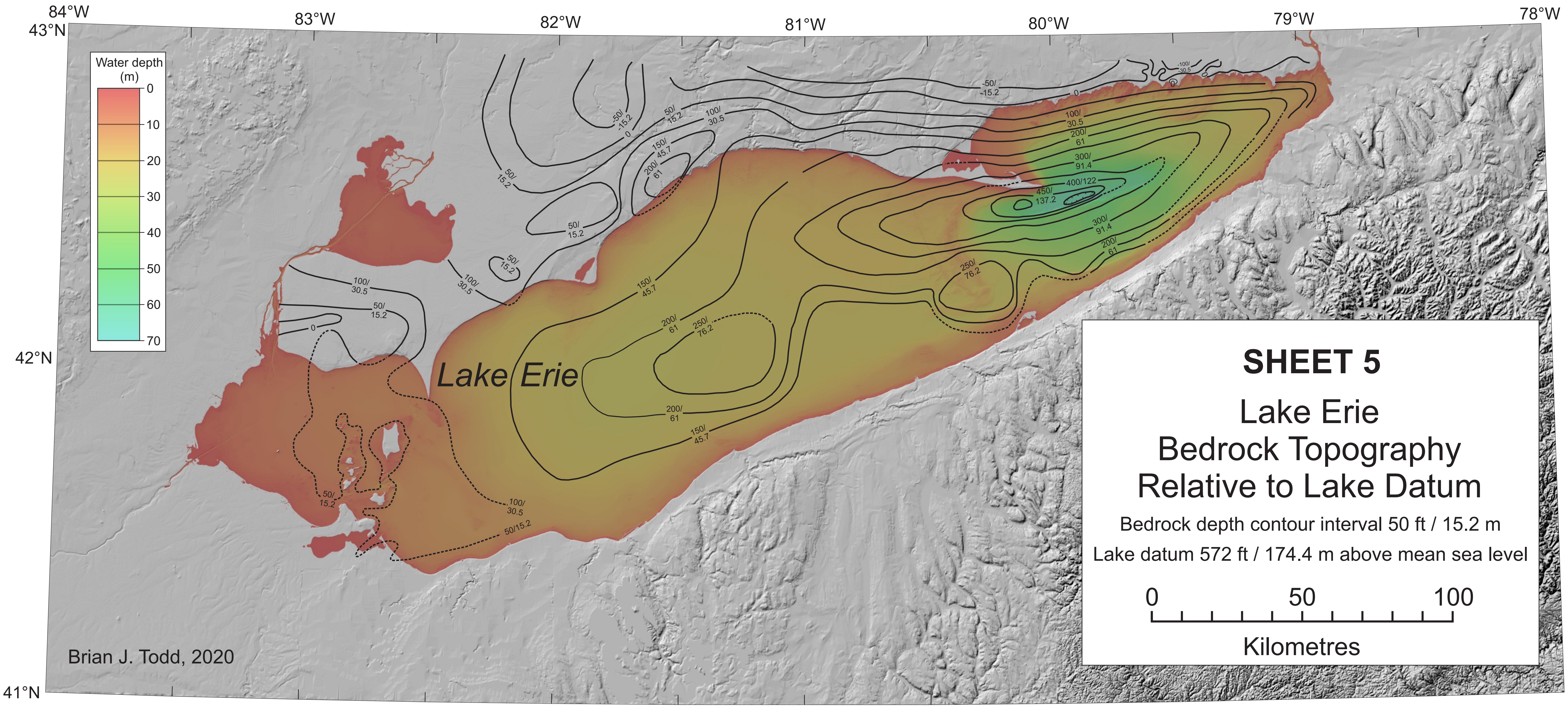


SHEET 3

Lake Erie
Interpreted Seismic Profiles
Aligned to B–C




84°W
83°W
82°W
81°W
80°W
79°W
78°W
43°N
42°N
41°N
Water depth (m)
0
10
20
30
40
50
60
70
Lake
Erie
SHEET 4
Lake Erie
Isopach of Sediments
Thickness contour interval 25 ft / 7.6 m
Lake datum 572 ft / 174.4 m above mean sea level
0
50
100
Kilometres
Brian J. Todd, 2020


84°W
83°W
82°W
81°W
80°W
79°W
78°W
43°N
42°N
41°N
Water depth (m)
0
10
20
30
40
50
60
70
Lake Erie
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Relative to Lake Datum
Bedrock depth contour interval 50 ft / 15.2 m
Lake datum 572 ft / 174.4 m above mean sea level
0
50
100
Kilometres
Brian J. Todd, 2020

Appendix 1: Chapter 6

from

Geophysical studies in Lake Erie by shallow seismic methods

by

Nabil A. Morgan

1964

University of Toronto

Chapter 6: Results of seismic work on Lake Erie

INTRODUCTION

The second part of this thesis describes the use of the sparker in mapping the shallow geological contacts beneath Lake Erie. The purpose of these investigations has been to determine the distribution and thicknesses of the bottom sediments in situ. One thousand one hundred line miles were surveyed covering all the lake. The first section of this chapter will show how the sparker records may be interpreted while in the second section the results are presented. Cross sections of some of the profiles will be given and elevation contour maps of the lake bottom and of the bedrock surface will be shown.

6.1 INTERPRETATION OF SPARKER RECORD

Typical sparker records which were taken on Lake Erie shown on Figures 1 and 2.

To provide locations on the sparker records, station marks were assigned at five minute intervals and given serial numbers on each profile. As the bridge's and the operator's watches are synchronized, each of these stations may be located on the navigational charts.

The first step in the interpretation is to identify the reflectors. Before going into this, it is preferable to mention beforehand how the arrival times are measured from the sparker records. As was mentioned in Chapter 3, the flying spot of the recorder sweeps the width of the record in a known time (on Lake Erie it was either 200 milliseconds or 250 milliseconds) and with constant speed. Hence the arrival times of signals may be measured from the time-break marker with a linear scale. Since the source and receiver were kept very close together (5 or 10 feet), the reflections were considered to be vertical. Hence the one-way time to a reflector is measured as half the time taken by the flying spot to make the sweep from the time-break recorded event. In taking velocity surveys, however, the whole travel time is used. Now let us consider the problems in identifying reflections. The most important, among others, are in properly identifying multiple reflections and secondary pulses.

Multiple reflections

Multiple reflections sometimes become very misleading unless the interpreter knows how to distinguish them from the real reflection. The most frequent cause of multiples is the reflection at the water–air interface on account of the large velocity contrast between water and air (approximately 5:1). If the reflecting surfaces are horizontal, multiples may be identified by adding the travel times between different horizons to the first arrival time and comparing these times with the events that are suspected to be multiple reflections. Since the multiples generally follow the topography of the reflector, this may help in identifying them. Sometimes it is also helpful to compare their intensities on the record. The higher the order of the multiple, the fainter will be the signal (if we assume that the amplifier unit has no automatic gain control). If it happens that the reflection from a deep horizon should become confused with multiple reflections from a shallow zone, then the identification of reflections becomes more difficult. Examples of different kinds of multiples are shown on Figures 3, 4 and 5, which are taken from Lake Erie profiles.

If the reflector is dipping, multiples may be recognized from their apparent increase of dip with increasing order. An illustrating example is shown on Figure 6.

Secondary source

A second event nearly always appears about 2–5 milliseconds behind each arrival on the sparker records. This second event is attributed to a secondary source following the initial spark. The creation of this secondary source may be explained as follows: A bubble of water vapour (and probably also containing some hydrogen and oxygen gases) is created as a result of the sparks. The bubble will increase in volume until the pressure of the gases falls well below the pressure of the surrounding water, at which point it will begin to collapse. The collapse will continue until the work done becomes equal to strain energy, and the pressure is again much larger than the surrounding pressure, causing it to “explode” a second time. Several oscillations of diminishing amplitude may occur before the vapour becomes fully condensed.

It was found that the interval between the spark and the secondary source is reduced if the source is brought closer to the water surface. However, if the source is too close, it is liable to bounce in the swells and the record becomes blurred. A depth of about ten feet was found to be generally satisfactory. This gives an interval of two milliseconds, between the spark and the “bubble pulse”.

Secondary source events may be recognized by the fact that they follow the spark arrival times very closely. Though it may be troublesome if reflections from a geological interface coincide with this event. In this case, it is advisable to follow the trace over a long distance on the record before making any decision. Traces due to secondary source are shown on Figures 1 and 2.

Sometimes reflections from fish shoals are shown on the records. There is no way of identifying the source of these reflections except that these events do not persist for very long. Undulation of reflections due to the rolling of the ship may show the records, and is reduced by using higher writing speed. Ambiguities sometimes arise from reflections arriving from a passing ship. Again this is a transient event and does not persist on the records.

Overcoming the difficulties of separating true from fictitious reflections depends on the judgement of the interpreter, and on his experience.

After the real reflectors have been identified and their arrival times measured, the next operation is the conversion of these times into depths. A knowledge of the variation of velocity in the water and in the sediments is essential to carry out this operation.

A few velocity profiles were taken using the procedure explained in Chapter 5. An example of a velocity survey record is shown on Figure 7. The seismic velocity in water (taken from the direct time–distance curve), was found to be 5000 feet per second. From laboratory seismic velocity measurements (Figure 1, Chapter 3), it was found that the seismic velocity in water is 5018 feet per (1.53 km/sec). A velocity value of 5000 feet sec per second was used to convert the one-way bottom reflection times into depths. The variation of seismic velocity in marine sediments was discussed in Chapter 5, and characteristic curves were considered as a means of finding the velocity gradient (a) in the velocity function

$$v = v_0 + a z$$

where v_0 is the seismic velocity at the top of the sediments. The average seismic velocity in cores was found to be 5150 feet per second. It was also found (Chapter 3) that 48% of cores taken from the Lake Erie bottom have seismic velocities less than 5018 feet per second. A value for (v_0) was taken to be 5000 feet per second.

Computation of velocity gradient (a) using the procedure described in Chapter 5 for the velocity surveys are given in Table A-2 and range from 0.06 sec^{-1} to 0.13 sec^{-1}. From these values of (a) it is evident that vertical gradients are negligible in the Lake Erie sediments, especially since the depths that are involved are not large. Accordingly, the velocity in sediments may be considered to be constant, at

$$v = v_0 = 5000 \text{ feet per second.}$$

This value has been used to convert one-way reflection times into depths. Depth computations for the bottom and for the bedrock surface were compared with information given by offshore wells and they agree fairly well.

After the one-way reflected times are converted into depths, the subsequent step in interpretation is to construct cross sections for all the profiles, putting in all the information obtained from the sparker records.

The last stage is to draw a contour map for each reflector in the area. This is done from the cross sections.

6.2 REPRESENTATION OF RESULTS

In this section we will present the results obtained from the interpretation of the sparker records taken on Lake Erie.

During July and November of 1961 preliminary surveys were conducted on the eastern half of the lake (east of longitude 81°W). Thirteen profiles were taken in a NNW–SSE direction, which is approximately perpendicular to the strike of the bedrock. Interpretation of the records revealed two important features. First, a very deep trough of sediments was discovered southeast of Long Point peninsula although its boundary was not completely determined. Second, an intermediate horizon in the sediments appeared as a reflector on some of the records. In October 1962, seven more profiles were surveyed in order to gain more information about these two features and in September 1963, an extension of the survey into the western half of the lake was undertaken. Another eight profiles were added totaling 1100 line miles of survey of the lake.

The ship track is shown on sheet 2 in the attached envelope at the end of the thesis. Some of the profiles are shown on sheet 3 and sheet 4; their positions are given by line AB and BC (sheet 2).

The sparker records show two distinct reflectors throughout most of the lake. These have been investigated as the bottom (i.e., the top of the sediments) and the bedrock (i.e., the bottom of the sediments) from the information given by hydrographic maps and offshore wells. In addition to these two interfaces, another reflector between the bottom and the bedrock sometimes shows up on the records and is identified only as an intermediate reflecting horizon.

The intermediate horizon

The intermediate layer which sometimes appears as a reflector on the sparker records lies roughly midway between the bottom and the bedrock (see sheets 3 and 4.) From a comparison of travel times (Fig. 3) it was shown that it is capable of producing multiple reflections, indicating that this horizon separates two different zones in the sediments having distinctly different elastic properties. It may represent an interface between unconsolidated and semiconsolidated sediments in those areas in which it appears. There is no further evidence that might indicate whether or not the intermediate horizons appearing on different records are the same. The margin of this reflector was traced carefully on all the records. Starting from the west and moving east it shows very clearly on profiles 23S and 24N, partially on profile 25S (in the northern part), and disappears completely in the central region of the lake. On profiles 8N and 7S it appears very clearly except in the vicinity of Long Point peninsula. This general picture, in which this reflector appears on the north and south flanks of the profiles but not in the central region, continues until we move east of profile 8S and 6N, where it appears only partially near the Canadian side.

The bedrock

All the bedrock cross-sections were regionally smoothed and a contour map of the bedrock, using the lake level as datum, was made. This is shown on sheet 5 in the attached envelope. The depths given by the sparker agree very well with the off-shore gas wells (Department of Energy Resources) confirming that the velocity value used to convert times into depths is satisfactory. The wells that were used as checks are listed on Table A-1. An attempt to join the depth contours given by the sparker to contours given by wells on shore was made from information given in the literature for Southern Ontario (Caley and Sanford, 1952a, b; Sanford, 1953, 1954a, b). These contours are also shown on sheet 5. The two sets of contours appear to join quite well.

In the eastern half of the lake the bedrock on the American side did not show up on the sparker records. Probably this is because the sediments in the region absorbed the seismic energy and prevented it from penetrating to the bedrock. The dip of the bedrock [surface] in the eastern half of the lake is generally towards the central NE–SW line. The dip to the south is roughly twice the dip to the north (16 ft./mile compared to 8ft./mile). The deepest part of the bedrock encountered in Lake Erie was found to lie south east of Long Point peninsula, where it was found to lie 500 feet below the lake level. In April 1963 the Great Lakes Institute of the University of Toronto drilled a hole at the tip of Long Point very close to the interpreted position of the 400 foot contour line. The bedrock was encountered at 391 feet below water level, confirming the interpretation of the sparker records. In the vicinity of this point it was found that the dip to the north is considerably larger than the dip to the south (200 ft./mile compared to 30 ft./mile). Another feature of the bedrock topography in the eastern half of the lake is the plane at 250 foot depth off Erie, Pennsylvania. Between the longitudes 80°30´W and 8l°W and south of latitude 42°10´N, the contours show a relatively large area, close to the American side, with shallow bedrock of less than 150 feet below lake level. The deepest bedrock contour in the central region of the lake was found to be 250 feet below lake level.

In the far west region of the lake (west of longitude 83°35´W) the sparker records were not of much use as far as the bedrock is concerned. The bedrock was difficult to identify and seems to be obscured by the bottom or by multiple reflections. The two depth, contours of 100 feet and 50 feet were extended from the land into the lake from information given by gas wells, from hydrographic maps, from data given by Lewis (1963) and by Hartley (1961).

The sediment thickness

From the seismic interpretations, an isopach map showing the thickness of sediment was constructed and is shown on sheet 6 in the attached envelope. The sediment thickness in Lake Erie ranged from a minimum of zero (where the bedrock outcrops at the bottom) to a maximum of 375 feet. There appear to be four distinct sedimentary basins. Starting from the east, the first lies east of Longitude 79°40´W and has a maximum thickness of about 250 feet. The second lies between Longitude 79°40´W and 8l°W and it appears to have two pockets. The more northerly of these contains the greatest thickness of sediment found anywhere in the lake (> 375 feet), which was encountered at the tip of Long Point peninsula. A thick sediment filled channel (>300 feet) branches from this basin about 4 miles to the south of Long Point and extends east-northeast for about 12 miles. The south pocket has a maximum sediment thickness of 225 feet. An observed feature of the second basin complex is the relatively thin sediment (<175 feet) which lies between the north and south pockets east of Longitude 80°20´W. The third basin lies between the longitudes 8l°W and 82°30´W. It appears to be asymmetrical, with its axis displaced toward the American side. The sediments attain a maximum thickness of about 200 feet and disappears only on the American side. The fourth and final basin occurs west of 82°30´W. As mentioned earlier, the sparker records were not of much use in mapping the bedrock topography in this region, and the sediment thickness had to be inferred from hydrographic maps, offshore gas wells (Department of Energy Resources) and from data given by Lewis (1963) and Hartley (1961). The bedrock crops out on all of the islands in this area, implying a zero sediment thickness. It was found that the sediment thickness in this area did not exceed 50 feet.

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Table A-1. Depths of bottom and bedrock wells in Lake Erie.

Well No.	Well name	Location (latitude, longitude)	Bottom depth (feet)	Bedrock depth (feet)
1	Well #29 (60)	42°41´00´´ 79°02´50´´	–	-3
2	S.C. Eaton J.R. #1	42°50´55´´ 79°07´30´´	43	43
3	P.G. worlpole #16	42°46´31´´ 79°57´47´´	38	46
4	B. Port Dover #2	42°46´00´´ 80°08´27´´	29	38
5	B.W. Port Rowan #2	42°36´20´´ 80°19´50´´	10	263
6	Texas L.E. #39-4	42°35´14´´ 80°10´20´´	15	271
7	Great Lakes Institute L.P. #1	42°32´54´´ 80°02´40´´	–	391
8	New York State Natural Gas Co. well #1[1]	42°01´13´´ 80°24´12´´	?	36
9	Well #3[2]	42°00´30´´ 80°25´54´´	–	12
10	Well #2[2]	41°58´28´´ 80°30´10´´	–	-2
11	N #1	42°22´36´´ 80°25´04´´	45	336
12	B.A. #1	42°34´26´´ 80°21´26´´	–	283
13	C.C. Yankee Cleveland #10	42°39´04´´ 80°50´48´´	10	190
14	I.H.H. Harwish #1	42°19´06´´ 81°50´03´´	31	112
15	C. Harwish L.E. #1	42°15´33´´ 81°58´24´´	27	114
16	Midcon L.E. #2	42°12´57´´ 82°01´43´´	43	116
17	S. Dlucite #5	42°13´29´´ 82°05´54´´	44	115
18	Consolidated W.P.M. L.O. #20	42°05´50´´ 82°09´01´´	68	136
19	Consolidated W.P.M. L.O. #19	42°07´30´´ 82°09´52´´	68	132
20	Consolidated W.P.M. L.O. #3	42°09´43´´ 82°14´42´´	22	103
21	B.W. Leamington #1	41°59´40´´ 82°34´15´´	?	107
22	B.W. Kingsville #2	41°59´23´´ 82°40´53´´	34	88
23	B.W. Kingsville #1	42°01´11´´ 82°41´40´´	29	55
24	B.W. Kingsville #3	42°00´50´´ 82°42´04´´	30	50
25	Place Gas #1	42°01´00´´ 82°43´28´´	26	54
26	Place Gas #2	42°01´00´´ 82°44´50´´	5	38
27	Philips L.E. #5	41°58´51´´ 82°48´55´´	30	65
28	Philips P. Britalta #2	41°57´27´´ 82°55´10´´	32	69
29	F.P.A. N. Harbour #24	41°50´50´´ 82°54´20´´	35	85
30	Philips P. Britalta #1	41°56´34´´ 82°50´39´´	33	73
31	Place Gas Colchester #2	41°59´24´´ 82°57´19´´	15	60
32	Place Gas Colchester #3	41°59´54´´ 82°58´.6´´	10	61
33	F.P.A. Rivermouth #1	41°58´14´´ 83°03´10´´	18	35

Note: Bottom and bedrock depths are referred to the Lake Erie level of 572 feet above sea level.

1. Personal communication, G. Blatt, Secretary of Internal Affairs, Geological Survey of Pennsylvania

2. Fettke and Wagner, 1961

Table A-2. Values of velocity gradient a.

Profile Number	Station Number	Value of a
13 E	55–58	0.08 sec^{-1}
16 E	57–58	0.06 sec^{-1}
27 E	30–31	0.08 sec^{-1}
28 E	3–6	0.13 sec^{-1}

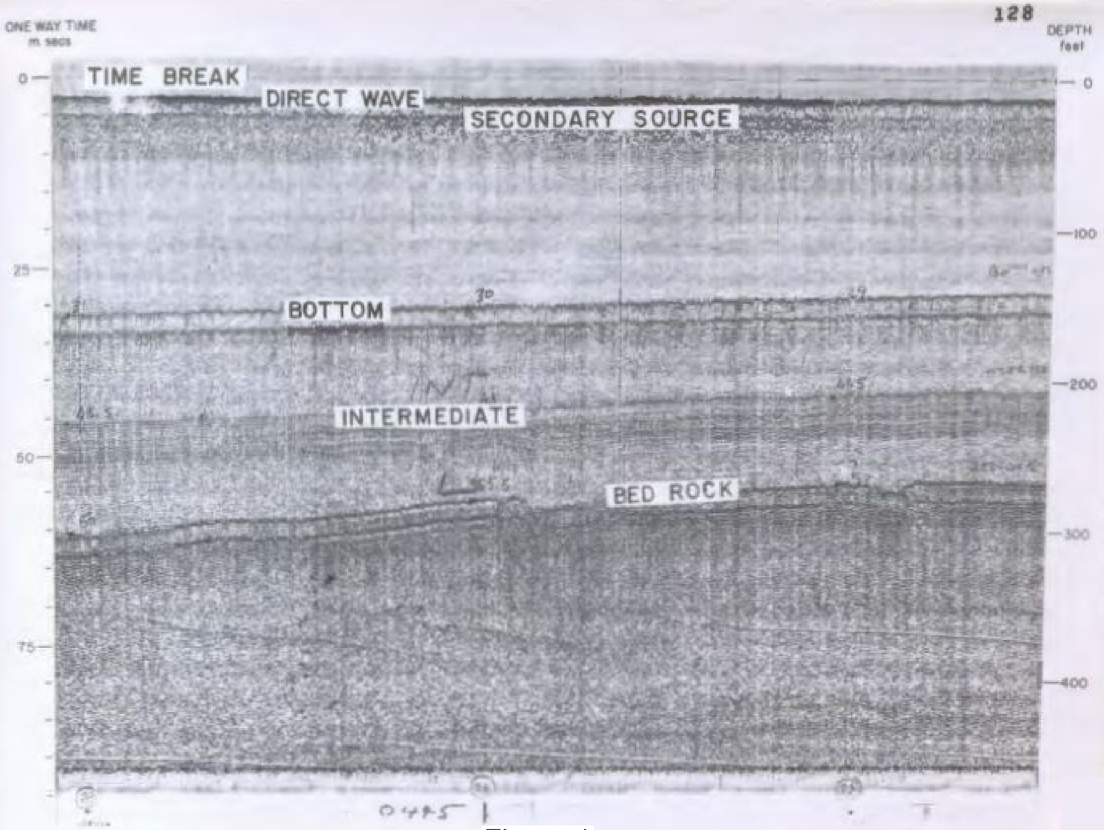

Figure 1
TYPICAL REFLECTION SPARKER RECORD

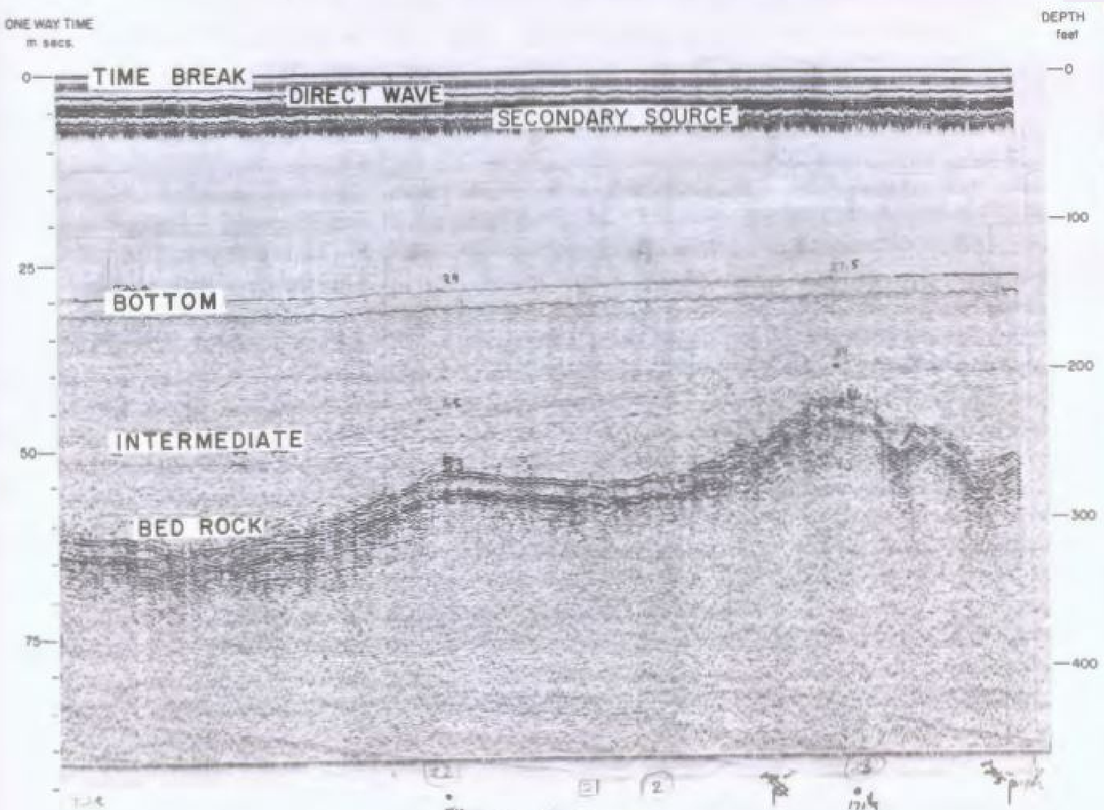

Figure 2
TYPICAL REFLECTION SPARKER RECORD

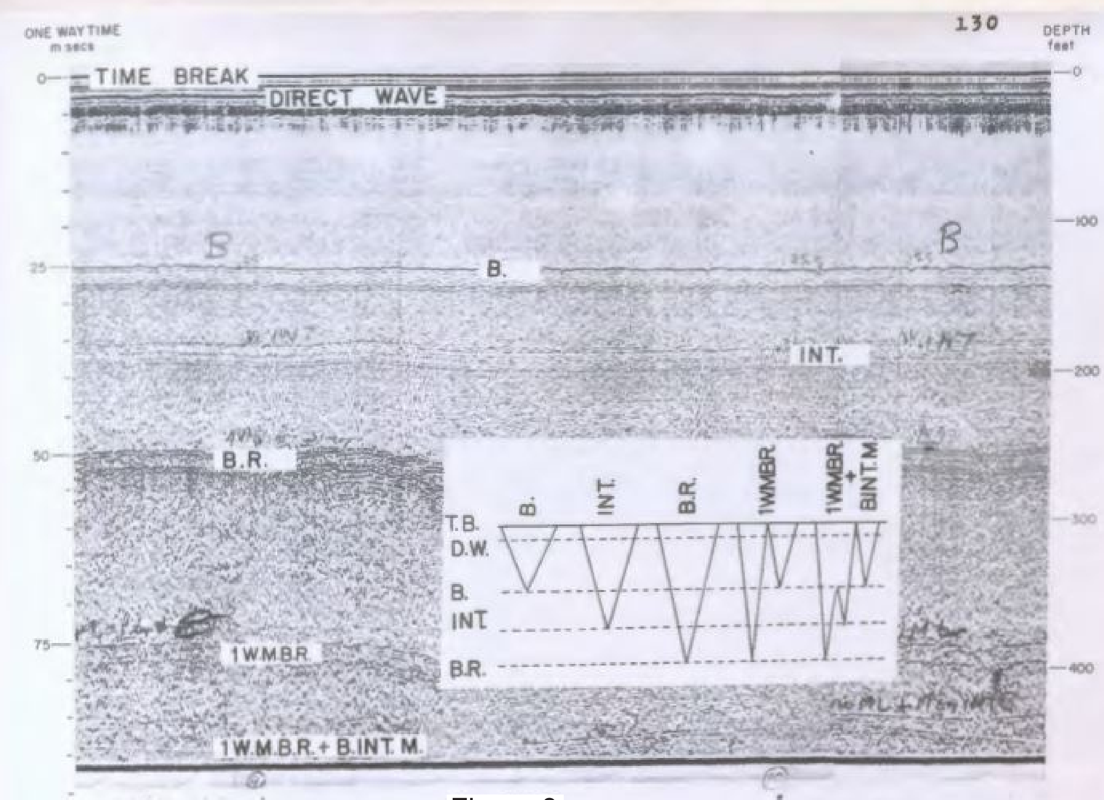

Figure 3

SPARKER RECORD SHOWING COMBINATIONS OF MULTIPLE REFLECTIONS

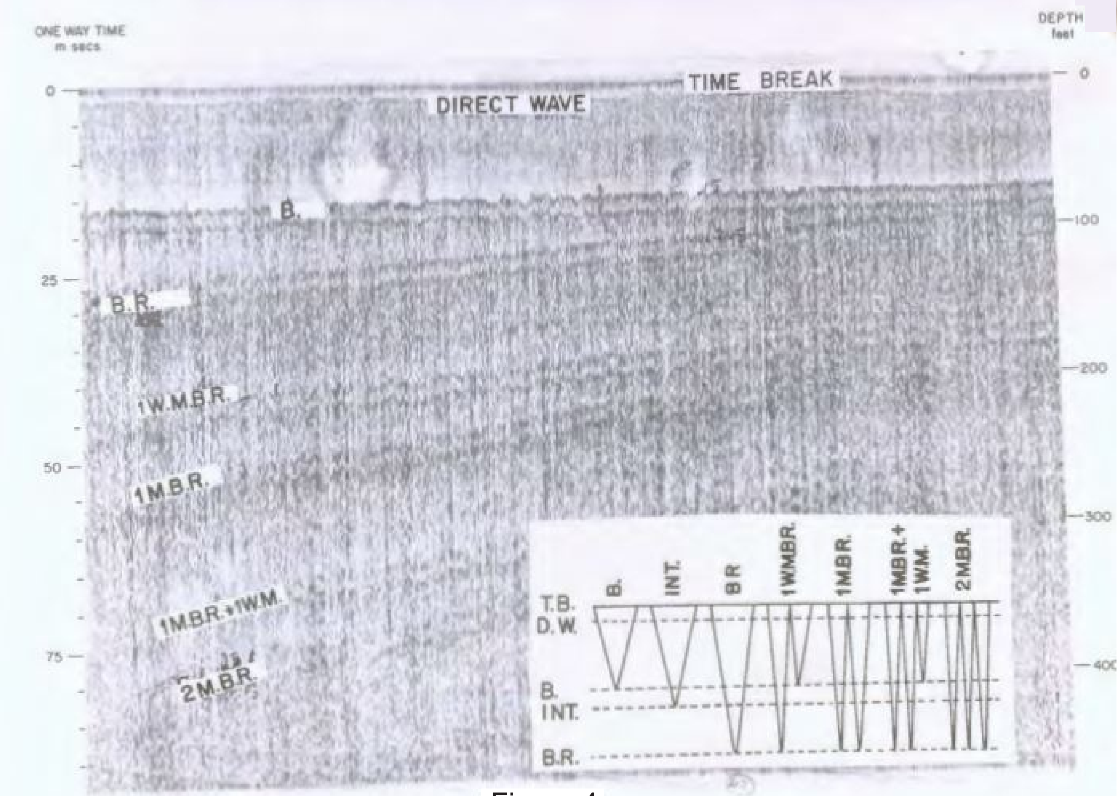

Figure 4

SPARKER RECORD SHOWING COMBINATIONS OF MULTIPLE REFLECTIONS

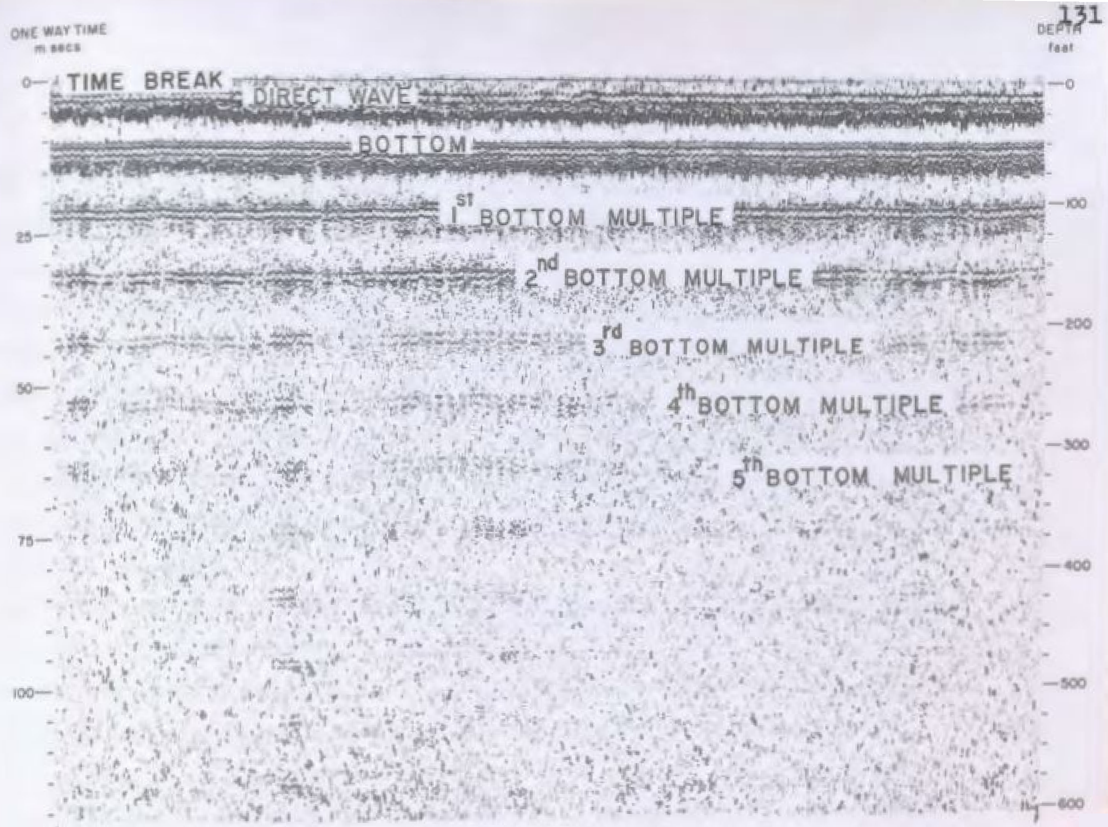

Figure 5

SPARKER RECORD SHOWING MULTIPLE REFLECTIONS FROM HORIZONTAL BOTTOM

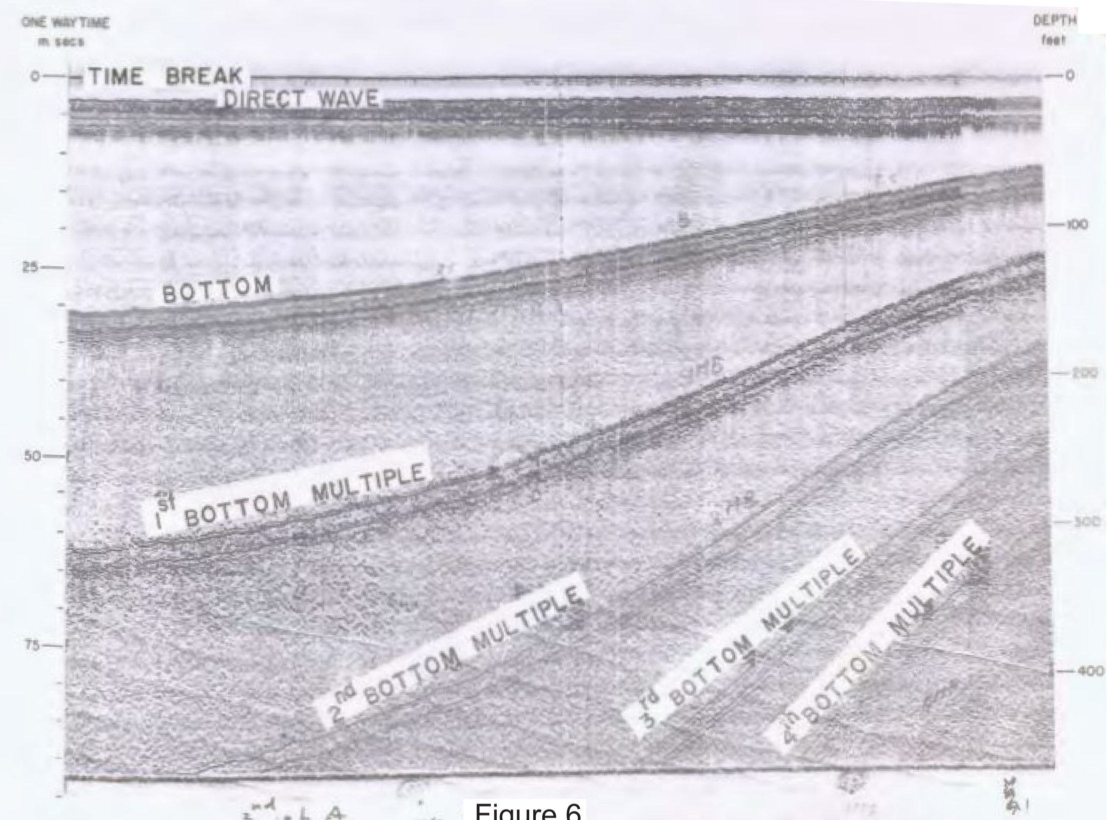

Figure 6

SPARKER RECORD SHOWING MULTIPLE REFLECTIONS FROM DIPPING BOTTOM

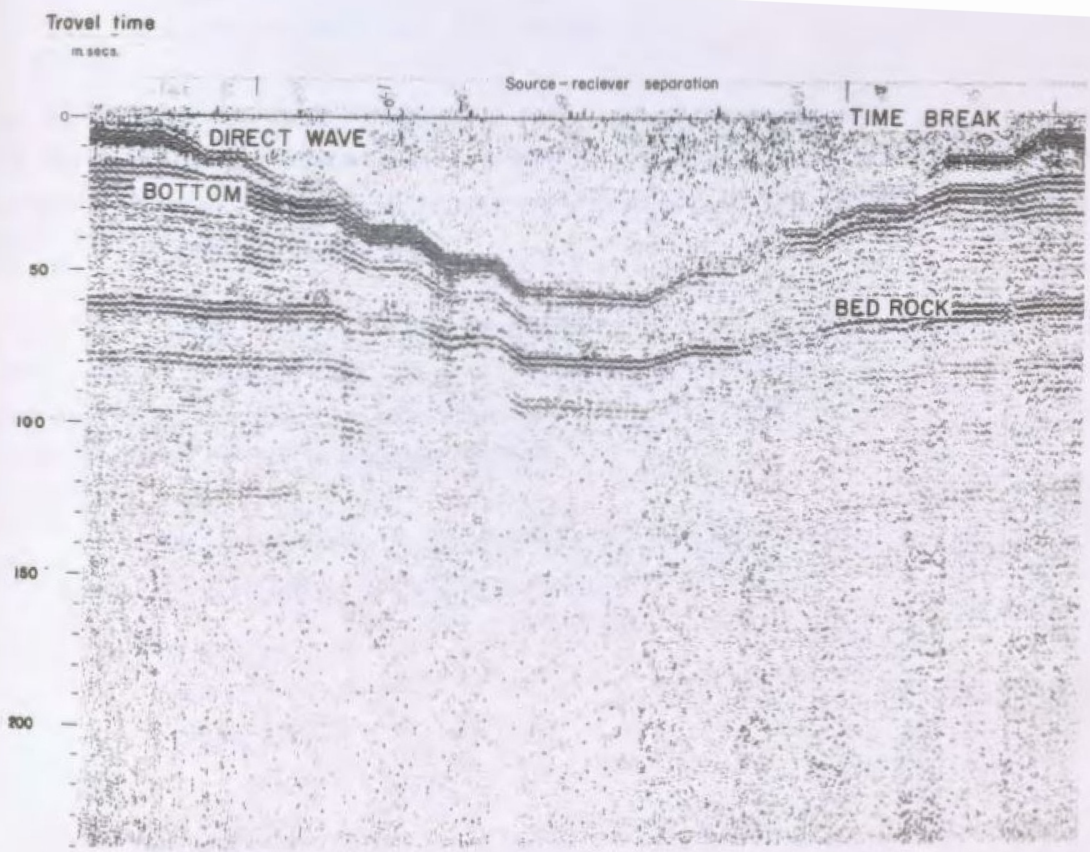

Figure 7

SPARKER RECORD ILLUSTRATING TYPICAL VELOCITY SURVEY

Appendix 2:

Obituary

Nabil Assad Morgan, Ph.D.

Published in Dallas Morning News from March 6–7, 2014

Dr. Nabil Assad Morgan of Richardson, TX died on Saturday, March 1, 2014. Born in Cairo, Egypt, he received degrees from the University of Alexandria and the University of Toronto. He married Erika Morgan in 1960; their love was an inspiration to all. In 1966 they moved to Richardson where they raised two children, Soraya and Amir. As a geophysicist, Dr. Morgan worked many years for Geophysical Services Incorporated/Texas Instruments. In recent years, he served as a substitute teacher in all Richardson Independent School District junior and senior high schools. He was a loving son, brother, father, grandfather, and friend. His kindness to all will be missed. A memorial service and reception will be held on March 8 at 3 pm at the Community Unitarian Universalist Church of Plano, 2875 E. Parker Rd., Plano, Texas. In lieu of flowers, a donation may be made in his name to CUUC or other worthy organizations.