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Seismostratigraphy of Quaternary sediments beneath Lake Simcoe, Ontario: results of 1992 and 1993 expeditions of the MV *J. Ross Mackay*

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ABSTRACT

A marine geophysical survey program was conducted in Lake Simcoe, Ontario in September 1992, and May and June, 1993 as part of a program to better understand the lake bottom and the sub-bottom geology. This Open File report provides a seismostratigraphic framework for the ongoing environmental assessment of Lake Simcoe and of similar lakes, and to assess seismic hazards in southern Ontario. A 4 km by 4 km survey grid covered the lake, with more closely-spaced survey lines in Kempenfelt Bay and Cook's Bay. High-resolution single- and multichannel seismic reflection profiling were used to delineate late- and post-glacial sedimentary strata, structures and lakefloor features. Acoustic basement is Ordovician sedimentary rock, overlain by three seismostratigraphic sequences within the unconsolidated sediments.

The lower, Purple Sequence sediments are widespread in Lake Simcoe and are shallowly buried, or outcrop on the lake floor, in eastern and northern Lake Simcoe. Prominent lake floor outcrops of Purple Sequence sediments up to 10 m in height occur throughout the lake. The steep cross-sectional shape of these mounds suggests that they may be drumlins related to the northeast-southwest oriented drumlin fields mapped by previous workers on land around Lake Simcoe. The distribution of the Purple Sequence, its reflection configuration and its drumlinized, unconformable surface suggests that it is analogous to the Newmarket Till mapped south of Lake Simcoe.

The middle, Green Sequence sediments extend over all of Lake Simcoe. Truncated reflections within the Green Sequence are widespread in the lake and characterize the Green Reflector sequence boundary as an erosional unconformity. In both Kempenfelt Bay and Cook's Bay, Green Sequence sediments reach a thickness of about 50 ms, or about 40 m. Seismic and borehole evidence from the Oak Ridges Moraine to the south of Lake Simcoe suggests that the relatively strong amplitude, parallel reflection configuration of the Green Sequence corresponds to glaciolacustrine fine sand, silt and clay of Late Wisconsinan age. Green Sequence sediments were deposited in a sheet drape, probably during late-glacial time in the Lake Simcoe basin.

The upper, Blue Sequence sediments do not extend into the northeastern portion of Lake Simcoe, either as a result of non-deposition or of erosion subsequent to deposition. The maximum Blue Sequence thickness of about 16 ms (TWT), or 12 m, occurs in the western part of the Lake Simcoe and in Kempenfelt Bay. Elsewhere, these sediments are a few metres in thickness. Based on stratigraphic position, acoustic simplicity and transparency, and based on comparison to similar seismostratigraphy mapped elsewhere, Blue Sequence sediments are interpreted to be mud deposited in a sheet drape during Holocene (post-glacial) time in Lake Simcoe.

1. INTRODUCTION

The glacial history of the Great Lakes Basin in southern Ontario has been studied for over a century (Johnston, 1916; Spencer, 1890, 1891). The digital compilation of the Quaternary geology of southern Ontario (Ontario Geological Survey, in prep.) summarizes the present state of subaerial mapping. Offshore sediment sampling and mapping has taken place in the lower Great Lakes (Thomas *et al.*, 1972a, 1972b, 1973a, 1973b ; Thomas, 1984; Hutchinson *et al.*, 1993; Dobson *et al.*, 1995; Lewis *et al.*, 1992, 1995; Blasco, 2001) and in the Kawartha Lakes (Todd and Lewis, 1993). However, the onshore-offshore correlation of Quaternary sediments and glacially-derived landforms is not possible without a sufficient coverage of geophysical survey lines (Lewis *et al.*, 1997).

Lake Simcoe is the largest lake (726 km²) within southern Ontario. In 1992 and 1993, the Geological Survey of Canada undertook a marine geophysical survey of Lake Simcoe to better understand the lake bottom and the sub-bottom geology. This Open File report provides a seismostratigraphic framework for the ongoing environmental assessment of Lake Simcoe and of similar lakes. For example, aquatic ecosystems and groundwater are experiencing increasing scrutiny under the ever-rising recreational, municipal and industrial use of Canadian water resources.

In the 1990s, concern was raised about the identification and documentation of neotectonic activity and related geological features in southern Ontario, one of the most populated areas of Canada (Wallach and Mohajer, 1990; Mohajer *et al.*, 1992). Although both subaerial and subaqueous geological evidence of neotectonism from several sites in eastern Canada have been reported (Adams, 1982a, 1982b, 1989; McFall and Allam, 1991; Shilts, 1984; Shilts *et al.*, 1989; Shilts *et al.*, 1992; Thomas *et al.*, 1989), systematic geophysical mapping of potential neotectonic features in southern Ontario has been lacking.

The lakes of southern Ontario contain a record of sedimentation in late-glacial (since about 14-12 ka) and postglacial time. Because of their clayey or organic composition and high water content, lacustrine sediments are highly deformable and are susceptible to disturbance during earthquakes (Shilts and Clague, 1992). Structural or sedimentological features may be created by movement resulting from earthquakes, and these features may be preserved in the sediments (Doig, 1991). Therefore, the lakes of southern Ontario should be potential sites for the detection and mapping of neotectonic features resulting from past seismic and faulting events. This paleoseismic geological record can be used to enhance the evaluation of the nature of future potential seismic activity in southern Ontario. The Lake Simcoe marine geophysical survey addresses the geological history and neotectonic record of the sediments in this southern Ontario lake near metropolitan

Toronto. The Greater Toronto Area (GTA) encompasses not only a high population density, but also a highly developed transportation corridor, industrial base and power generation and distribution system.

2. STUDY AREA

2.1 Physiographic Setting

Lake Simcoe (219 m asl) is situated in the West St. Lawrence Lowland and lies 40 km southeast of Georgian Bay and 70 km north of the Lake Ontario shoreline of Toronto (Fig. 1). The lake extends 45 km both west to east and south to north; it drains northward to Georgian Bay (176 m asl) via Lake Couchiching and the Severn River. Lake Simcoe is surrounded by clay plain and sand plain of glacial Lake Algonquin (Chapman and Putnam, 1984). The Lake Simcoe drainage basin forms a limestone plain with small scarps and thin sediment forming till plains.

2.2 Bedrock Geology

Lake Simcoe overlies Middle Ordovician limestone between 15 km and 60 km south of its contact with Precambrian (Grenville) metasedimentary and gneissic rocks (Fig. 1) (Ontario Geological Survey, 1991). The Precambrian bedrock surface is highly irregular (relief of 15-25 m), whereas the surface of the younger Ordovician carbonate rock strata is planar. These Ordovician rocks dip gently on a regional scale at 4-6 m km⁻¹ southwesterly (Johnson *et al.*, 1992). Local dips of Paleozoic rocks are greater where they are draped over Precambrian relief. The Paleozoic rock section thickens downdip towards the Appalachian and Michigan Basins south of Lake Ontario and west of Georgian Bay, respectively (Liberty, 1969; Johnson *et al.*, 1992; Sanford, 1992).

2.3 Surficial Geology

The Lake Simcoe area was glaciated by the Laurentide Ice Sheet with predominantly south to southwest ice flow (Chapman and Putnam, 1984; Karrow, 1989; Barnett, 1992). Subaerially exposed glaciogenic deposits in the study area are Wisconsinan in age and are undifferentiated tills with minor exposures of glaciofluvial ice-contact and outwash deposits (gravel and sand) and glaciolacustrine deposits (silt and clay, sand) (Deane, 1950; Gravenor, 1957; Barnett *et al.*, 1991). These deposits cover bedrock in the western Lake Simcoe area, but form a relatively thin to discontinuous veneer over bedrock in the eastern Lake Simcoe area.

South of Lake Simcoe in the Oak Ridges Moraine and Greater Toronto Area (Fig. 1), coordinated geoscience studies over the last decade have resulted in new concepts of the sedimentary architecture and event sequences in this region, and are key to understanding the seismostratigraphy beneath the lake. The Oak Ridges Moraine is built on a high-relief, erosional surface (unconformity)

consisting of drumlin uplands and a network of deep, steep-walled, interconnected valleys (tunnel channels) (Barnett *et al.*, 1998). The erosion surface/unconformity forms a distinct time datum in the Quaternary sequence and is attributed to regional-scale, subglacial meltwater flow events (Sharpe *et al.*, 1997, 2002, in prep.). The development of the moraine occurred in four stages: I - subglacial sedimentation; II - subaqueous fan sedimentation; III - fan to delta sedimentation; and IV - ice marginal sedimentation (Barnett *et al.*, 1998).

Following the erosion of the tunnel channels, major lake basins (Lake Ontario and Georgian Bay), the Niagara Escarpment (Fig. 1) and the retreating ice front combined to create deep, ice-marginal-lake conditions (Barnett *et al.*, 1998). Water levels and sedimentation were controlled first by glacial hydrology and later by regional outlet channels along the Niagara Escarpment. Subaqueous deposition in the Lake Simcoe Basin probably began at this time, prior to drainage through the Campbellford outlet (REF - Karrow, 1989). A water level decline with time is recorded within the moraine sediments.

Based on analysis of seismic reflection profiles with borehole control, sediments in and beneath the Oak Ridges Moraine are characterized by four seismic facies (Pugin, Pullan and Sharpe, 1999). High reflectivity facies (I) can be traced regionally and related to the eroded Newmarket Till. Medium (II) reflectivity facies are associated with coarse-grained glaciofluvial deposits. Low (III) reflectivity facies are associated with laterally-extensive, glaciolacustrine sequences of sand, silt, and clay. A chaotic facies (IV) is common within buried channels and is attributed to instability and/or rapid tunnel channel-fill deposition. Seismic profile interpretations are consistent with the scenario of sheet flow and channel cutting (facies I) by high-energy subglacial meltwater followed by channel infilling (facies IV) and regional deposits of gravel, sand and silt in succession (facies II and III) as the flows waned.

2.4 Lake Simcoe bathymetry

Lake Simcoe has a smooth, regular lakefloor and contains few islands (Fig. 2) (Canadian Hydrographic Service, 1987). The majority of the Lake Simcoe lakefloor is 5-9 m (16-30 feet) in depth; the northern and eastern portions of the lake are shallower than 18 m (60 feet). The lake deepens to over 30 m (100 feet) to the west. Two prominent bays on Lake Simcoe were surveyed during this study: Kempenfelt Bay is a deep (>35 m) northeast-southwest trending bay on the west shore of the lake and Cook's Bay (~9 m deep) extends north-south on the south side of the lake (Fig. 2). Waters shoal gradually around Thorah and Georgina Islands in eastern Lake Simcoe. At the north end of Cook's Bay, water depths reach 21 m (70 feet) adjacent to the west shores of Fox and Snake

Islands.

3. SURVEY METHODS

3.1 Survey vessel

The marine geophysical survey was conducted aboard the MV *J. Ross Mackay*, a 12 m, 14,000 kg aluminum hull research vessel (Fig. 3). Its draft of 0.75 m makes the vessel an ideal platform from which to conduct geophysical surveys in shallow inland waters. A system of deployable booms was constructed to enable the simultaneous towing of a suite of geophysical instruments (Figs. 4, 5). Table 1 lists the instruments deployed in 1992; Table 2 lists those deployed in 1993. The following sections describe the instrument functions.

3.2 Navigation

Electronic navigation used throughout the survey was the satellite-based Global Positioning System (GPS). In 1992, the navigation data were logged at a 60 second interval and stored in the GPS instrument (Trimble NavTrak XL). The data were transferred daily to portable computer and the ship's track was plotted. In 1993, a GPS antenna was mounted on the bridge of the survey vessel and a Magnavox MX 4200D GPS receiver and an IBM compatible 486 computer logged position, velocity and raw satellite data for each tracked satellite using the program GPSLOG (D. Heffler, Geological Survey of Canada Atlantic). Both navigation and raw data were written to disk every 30 seconds.

At the time of the surveys, the GPS obtained position fixes at a rate of one per second with an accuracy of 25 m (circular probable error, or CEP). The U.S. Department of Defence purposely degraded the accuracy of the system to 125 m (CEP) by initiating selective satellite availability at any time (King *et al.*, 1987). Accurate positioning was confirmed during the course of the survey by the successful reoccupation of survey tracks over distinct geological features and over identifiable bottom features visible through the water column from the lake surface. Estimated positional accuracy of the Lake Simcoe GPS data is 2 to 10 m.

ASCII files of the 1992 and 1993 navigation data are provided on this Open File CD-ROM under the folder Appendix B. The file names are 92NAV.ASC and 93NAV.ASC.

3.3 Boomer seismic system

A high-resolution single channel seismic reflection system was used to obtain detailed cross

sections of the Quaternary sediments (Table 3). The system consisted of an ORE Geopulse power supply (300 joules) connected to a Hunttec 4425 boomer mounted under a surface-towed surfboard. The receiver was an IKB Seistec “line-in-cone” array towed near-surface in a catamaran. The system operated over a frequency range of 1800 Hz to 6-8 kHz and was fired at a 0.75 s interval with a survey speed of 3.0 to 3.5 km hr⁻¹ (1.6-1.9 knots) thereby sampling the subsurface 1.2-1.35 m horizontally. Data were displayed on two EPC 1600 graphic recorders, one with a 100 ms sweep and one with a 50 ms sweep, and were recorded with a Hewlett Packard 3968 8-channel analogue tape recorder at 3.75 in s⁻¹ (9.5 cm s⁻¹). In ideal geological settings in unconsolidated sediments, the Seistec system nominally resolves strata with thicknesses approximately 0.25 m in water depths of 2-100 m accompanied by depth penetration of up to 80 m (Simpkin and Davis, 1993). In the consolidated sediments beneath Lake Simcoe, depth penetration of the Seistec system was less, attaining a maximum of 40 m in some locations. This penetration, combined with the high degree of both vertical and horizontal resolution, made the Seistec system an excellent tool to delineate Quaternary sedimentary strata and structures throughout Lake Simcoe.

3.4 Compressed air seismic system

A high-resolution compressed air seismic reflection system was used in Lake Simcoe to penetrate un lithified Quaternary sediments more deeply than the boomer seismic system. The frequency of the seismic energy source (tens to hundreds of hertz) does not attenuate with depth as quickly as that of the higher frequency Seistec boomer source. Consequently, the depth of penetration of sound energy into the subsurface is greater, but the vertical resolution of the reflecting horizons is less than that of the boomer system. In 1992, the seismic energy source was a 10 in³ (164 cm³) Bolt 600B airgun operated at a pressure of 1800 psi and fired at a 15 second rate at a towed depth of 1.5 m. At the survey speed of 3.0 to 3.5 km hr⁻¹ (1.6-1.9 knots), airgun shots were spaced 15.4 m horizontally. In 1993, a 20 in³ (328 cm³) Bolt airgun was used for the first few survey lines. Penetration was not improved with this larger volume source, therefore the 10 in³ (164 cm³) airgun was reinstalled.

The seismic reflection data were digitally recorded using an EG&G ES2401 engineering seismograph. The record length was 400 ms using a 0.2 ms sampling rate. Frequency spectra of shot records showed a frequency content of 400-600 Hz. The data were stored on hard disk on the seismograph and processed each day. The vertical resolution of this system was 1.5-2.5 m with a depth penetration of almost 100 m. The compressed air seismic reflection system provided details of the sediment/bedrock interface which were beyond the capability of the Seistec system on the majority of the survey lines.

The multi-channel seismic reflection profiling system was composed of an EG&G R24 Strataview seismograph recording signals received from a seismic eel. Power was supplied to the seismograph by a Lambda EWS 300-12 switching regulator DC power supply fed by ship's power. The seismograph contains instantaneous floating point amplifiers with a 32 bit floating point digital signal processor. Preamplifier gain was set at 36 dB with a maximum input signal of 300 mV peak-to-peak. When operating in its marine mode, the seismograph operates with a replace function and an autosave function. These features allow recording and storage of records in less than 5 seconds. Each seismic record consists of 24 channels with 1024 samples per channel at a 0.2 millisecond (ms) sample rate. The record length was 400 ms and the file size is 106 kilobytes. Using a 0.25 ms sample rate provides a recorded bandwidth of 2-1200 Hz with a dynamic range of 104 dB. To avoid clipping the recorded seismic signal, the seismograph used a trigger lockout time of 4.8 seconds that prevented the seismograph from triggering on the Seistec pulse. The Seistec was disabled as the airgun shot was received by the seismograph, and the Seistec was then enabled. The Seistec firing rate was 0.25 seconds.

Within the seismograph is an IBM-compatible computer using an 80486 processor with a data storage capacity of 340 megabytes and 8 megabytes of RAM. A SCSI interface allowed external data storage on a 1.2 gigabyte drive, thereby allowing storage of a large number of records without leaving the "record" mode on the seismograph. In the evening, seismic data were downloaded from the 1.2 gigabyte drive to 150 megabyte Bernoulli disks in an external twin Bernoulli drive. Approximately 1400 records were stored on each Bernoulli disk.

The receiver was a refraction/reflection 12-channel eel developed by the Geological Survey of Canada (Good *et al.*, 1984). The layback from the GPS antenna was 21.5 m to the airgun/sleeve gun, and 29 m to group 1 on the eel. The seismic eel consists of 24 receivers spaced at a 5 metre interval (115 m live section) The hydrophone array is housed inside a neutrally-buoyant oil-filled hose having an outer diameter of 3.2 cm. Each receiver consists of 2 AQ-16 hydrophones wired in parallel with a 0.5 metre separation. Each hydrophone has a frequency response of ± 0.5 dB from 0.5 Hz to 3 kHz, a sensitivity of -97 dB referenced to 1 V per microbar, a capacitance of 3500 picofarads, and a depth rating of 1828 metres. The output signal from each pair of hydrophones passes into an AQ-300 differential input/output preamplifier. The preamplifier has an input impedance of 30 M Ω , a gain of 20.8 dB with a 20 k Ω resistor installed, a bandwidth of 3 dB points 0.3 Hz to 14 kHz, a current of 750 microamps, a voltage of 8-30 V and a common mode rejection ratio of greater than 80 dB.

The seismic information was also recorded using a Nova Scotia Research Foundation

(NSRF) 7 m eel (Nova Scotia Research Foundation, 1981) and displayed on an EPC recorder while underway (Table 4).

3.5 Other geophysical methods

In addition to the two seismic systems described above, shallow, high-resolution data were recorded using a Raytheon RTT 1000 subbottom profiler with a frequency of 7 kHz at a rate of 534 soundings per minute. A vertical resolution of about 1 m was obtained with this profiler but its depth penetration was only a few metres (Table 5). Sidescan sonar data were also collected using an EG&G 260 sidescan sonar (Table 6). The sidescan images provided a plan view of the lakefloor morphology and information on the type and distribution of sediment in a swath 200 or 400 m wide, centred on the ship's track. The sidescan images were, in general, featureless because most of the lakefloor is mantled with unconsolidated sediment (Blue Sequence sediments described in Sections 4.2 and 5.1) which does not lend itself to sidescan sonar imaging because of signal attenuation. However, where more consolidated sediments of the Green Sequence (Sections 4.2 and 5.2), the Purple Sequence (Sections 4.2 and 5.3), and the Red Sequence (Sections 4.2 and 5.4) outcrop on the lakefloor, the more signal is reflected and the resulting sidescan sonar information enabled determination of the strike of the outcropping layers as well as other structural details. As well, slumped sediments in Kempenfelt Bay and gas-venting pockmarks in Cook's Bay were imaged by the sidescan sonar. Sidescan sonar evidence of these, and other, features is presented graphically and discussed in Todd *et al.* (in prep.).

To investigate the magnetic signature of the Quaternary sediments beneath Lake Simcoe, a GSM-19D marine magnetometer manufactured by GEM systems Inc. (Richmond Hill, Ontario) was deployed on all the 1993 geophysical survey lines except line 93-16. The sealed fish contained an Overhauser sensor; signals generated in the sensor were processed in a fish-mounted microprocessor and transferred digitally through the tow cable (which also served as the power cable). The value of the magnetic field was logged each second and magnetometer profiles were plotted. The data were processed and mapped subsequent to the survey. Although not presented in this Open File focussing on seismostratigraphy, the magnetic survey results will be discussed in a subsequent report.

3.6 Survey design

In September of 1992, the MV *J. Ross Mackay* was used to complete a reconnaissance geophysical survey of Lake Simcoe (Fig. 6). One set of survey lines ran east to west across the lake from the mouth of the Trent Canal to the city of Barrie (lines 92-1, 92-2, 92-6). Another set of survey

lines ran south to north from Cook's Bay to the town of Orillia (lines 92-3, 92-7, 92-4, 92-5). The instruments deployed in 1992 are given in Table 1. The Seistec record inventory is provided in Table 3 and the sidescan sonar inventory is provided in Table 6. The Raytheon RTT 1000 subbottom profiler records are tabulated in Table 5. Intersections of the 1992 survey lines with the 1993 survey lines are given in Table 7. The seismic profiles obtained in 1992 enabled informed decisions to be made on the design for a more extensive marine geophysical survey in 1993.

In May and June of 1993, the MV *J. Ross Mackay* was back in Lake Simcoe for the crew to undertake a detailed, grid survey pattern (Fig. 7). In the main body of the lake, north-south and east-west oriented lines, spaced approximately 4 kilometres apart, were planned based on the requirement for complete coverage of the lake and the extent of navigable waters. Cook's Bay and Kempenfelt Bay provided a more challenging survey environment. Both bays were surveyed with a zigzag line pattern, with a considerable line coverage accumulated in Kempenfelt Bay (Fig. 8). The combination of zigzag and gridded survey patterns was designed to detect and map the lateral limits of offshore extensions of north-south trending channels mapped south of Lake Simcoe (Barnett *et al.*, 1998). Cook's Bay in southern Lake Simcoe (Fig. 1) is the northern end of a deep, glacially- incised channel which was rapidly filled with thick sand sequences (Russell, 2001) and now hosts Holland Marsh.

The instruments deployed in 1993 are given in Table 2. The Seistec record inventory is provided in Table 3 and the sidescan sonar inventory is provided in Table 6. The NSRF eel records are tabulated in Table 4. Intersections of the 1993 survey lines with all other lines are given in Table 8.

4. DATA ANALYSIS

4.1 Seismostratigraphic principles

Seismostratigraphic terms employed in this report are briefly described here. The terms “reflection” and “reflector” are applied in the following way: “reflections” are acoustic phenomena recorded in the seismic reflection profiles, and “reflectors” are the physical property changes (acoustic impedance contrasts) within the sediment column which cause the reflections. Reflectors are physical boundaries within the sediments which are thought to be geologically meaningful; they are inferred or interpreted from the acoustic reflections. Another seismostratigraphic term commonly used in the description of reflections is “amplitude”. Amplitude is controlled by the magnitude of acoustic impedance contrast across a boundary. A high amplitude reflection appears as a large excursion on a seismic trace; conversely, a low amplitude reflection exhibits a small excursion. For example, a high amplitude reflection would be recorded across a mud/rock interface and a low amplitude reflection would be recorded across the boundary between two muds. “Acoustic basement” refers to the deepest more-or-less horizontally continuous seismic reflection; acoustic basement is often an unconformity below which seismic energy returns are poor or absent. Finally, an absence of reflections on a seismic profile is referred to as “transparent”.

4.2 Digitizing and interpretation of reflections

The Lake Simcoe seismic reflection profiles were interpreted following the seismostratigraphic principles outlined by Mitchum, Vail and Sangree (1977) and Mitchum, Vail and Thompson (1977). Reflections are assumed to be conformable with sedimentary bedding and are chronostratigraphic horizons which can be traced from place to place and utilized for correlation between sites within depositional basins. Reflections which are regional in extent and/or which truncate underlying reflections define the boundaries of packages or sequences of sediment. Five such regional reflectors were identified in the Lake Simcoe seismic data. Commonly, sediment sequences between reflecting boundaries are named for their upper bounding reflector. In this report, we use the colour designations illustrated in Figure 9; in order of increasing depth and age, the seismostratigraphic column comprises Blue, Green, Purple, Red and Brown Sequences. The top of the Blue Sequence is designated the Blue Horizon, and the four other horizons are similarly denoted.

An example interpreted Seistec IKB high-resolution seismic profile from Cook’s Bay is shown in Figure 10. For comparison of seismic system results, an example airgun seismic profile, also from Cook’s Bay, is shown in Figure 11. Acoustic basement is, in the Seistec example of Figure

10, Purple Sequence, whereas the airgun seismic system penetrates the Purple Sequence and the Red Sequence is acoustic basement (Fig. 11). The top of Red Sequence is uneven and the reflection configuration within the sequence is chaotic with some subtle suggestions here and there of coherent reflections. The Red Sequence is interpreted to be till and its upper surface, the Red Reflector, is interpreted to be an unconformity. The same reflection configuration and geological interpretation pertains to the Purple Sequence. In marked contrast, the overlying Green Sequence exhibits a parallel internal reflection configuration. The Green Sequence reflections conformably drape the irregular top of the Purple Sequence and the drape becomes more subdued, or flattened, towards the top of the Green Sequence.

In the centre of the Seistec IKB high-resolution seismic profile (Fig. 10) is a feature within the Green Sequence consisting of a tangential oblique progradational reflection configuration. This is described as a prograding clinoform pattern comprising steep-dipping reflections terminating updip near a nearly-flat upper surface and downdip by passing into gently-dipping underlying reflections. This seismic reflection geometry can be interpreted as a barrier complex which would have formed in southern Lake Simcoe when the lake level was approximately 25 to 30 metres lower than at present, due presumably to some combination of either tilting of the basin prior to postglacial isostatic recovery, and/or a climatic period in which there was no overflow, or reduced overflow, from the lake. Within both the Purple and Green Sequences, gas in the sediments has masked the horizontal continuity of reflections. Based on the overall geometry of the seismic profile, and the regional interpretation, it is assumed that reflectors of the Green Sequence are continuous across the masked zone.

Sediments of the Blue Sequence overlie the top of the Green Sequence in Figures 10 and 11. The internal reflection configuration is parallel, but with a subdued amplitude compared with the Green Sequence. Reflections within the Blue Sequence downlap on the Green Reflector, therefore this surface is interpreted to be an unconformity.

The upper bounding reflections, or sequence boundaries, for all the profiles in Lake Simcoe were interpreted based on the single- and multichannel seismic data, Raytheon RTT 1000 subbottom profiles, and associated sidescan sonar records. The interpreted sequence boundaries were digitized, and are provided in Figure 12 (a-z). The vertical and horizontal scales in Figure 12 vary from line to line. The vertical scale on the left is two-way reflection travel time in milliseconds. This was converted to approximate depth in metres below lake surface (right vertical scale) assuming a sound velocity of 1500 ms^{-1} in both water and sediments. The horizontal scales for lines oriented south-north are UTM Northing in metres. Similarly, the horizontal scales for lines oriented west-east are

UTM Easting in metres. The horizontal scale for the remaining lines is distance along line in metres.

Accompanying this report are fifteen sheets of uninterpreted seismic profiles recorded with the multichannel seismic system (Appendix A). It is important to note that these sheets display only one channel (channel 4) of the 24 channels recorded digitally. The offset from the airgun source was 20 m. An automatic gain control with an 80 ms window and a 100-600 Hz bandpass filter were applied to the data. Processing costs did not allow multichannel processing of the entire suite of data; nonetheless the fifteen seismic profile sheets harbour an abundance of geological information.

4.3 Structural contour and isopach maps

Although it is not possible to include the voluminous original field data in the Open File report, the distilled information contained in Figure 12 (a-z) is computationally more useful. The digitized interpreted profiles were processed to produce structural contour maps of horizons and isopach maps of sequences using software developed by the Ocean Mapping Group at the Geological Survey of Canada (Atlantic). This software utilizes GRASS (Geographic Resources Analysis Support System) software, now in the public domain, developed by the US Army Constructional Engineering Research Laboratories. The structural contour and isopach maps are described in Section 5.

5. DESCRIPTION AND INTERPRETATION OF SEISMOSTRATIGRAPHIC SEQUENCES

In the following description, the Lake Simcoe seismostratigraphic sequences are discussed from youngest (Blue Sequence) to oldest (Brown Sequence). It is important to note that, in Cook's Bay at the south end of Lake Simcoe, masking of reflections by gas affects the accuracy within the bay of the maps described in this section. Interpretation of the single- and multichannel seismic reflection profiles indicates that Cook's Bay contains, in places, 40 m (or more) of Blue and Green Sequence sediments; this thickness is under-represented in the maps. Gas also masks Green Sequence sediments east of Georgina Island (Fig. 12t).

5.1 Blue Sequence

Blue Sequence sediments do not extend into the northeastern portion of Lake Simcoe (Figure 13a), either as a result of non-deposition or of erosion subsequent to deposition. The maximum Blue Sequence thickness of about 16 ms (TWT), or 12 m, occurs in the western part of the Lake Simcoe and in Kempenfelt Bay (Fig. 13b). Elsewhere, these sediments are a few metres in thickness.

Based on stratigraphic position, acoustic simplicity and transparency, and based on comparison to similar seismostratigraphy mapped in the Kawartha Lakes (Todd and Lewis, 1993) and in Lake Winnipeg (Lewis and Todd, 1996; Todd *et al.*, 1998), Blue Sequence sediments are interpreted to be mud deposited in a sheet drape during Holocene (post-glacial) time in Lake Simcoe.

5.2 Green Sequence

Green Sequence sediments extend over all of Lake Simcoe (Figure 13c) except along Line 8a in northern Lake Simcoe (Fig. 12n). Here, truncated reflections within the Green Sequence indicate that material was removed by erosion. In fact, truncated reflections within the Green Sequence are widespread in the lake and characterize the Green Reflector sequence boundary as an erosional unconformity. In both Kempenfelt Bay and Cook's Bay, Green Sequence sediments reach a thickness of about 50 ms (TWT), or about 40 m.

Seismic and borehole evidence from the Oak Ridges Moraine to the south of Lake Simcoe (Pugin, Pullan and Sharpe, 1999) suggests that the relatively strong amplitude, parallel reflection configuration of the Green Sequence corresponds to glaciolacustrine fine sand, silt and clay of Late Wisconsinan age. Green Sequence sediments were deposited in a sheet drape, probably during late-glacial time in the Lake Simcoe basin.

5.3 Purple Sequence

Purple Sequence sediments are widespread in Lake Simcoe and are shallowly buried, or outcrop on the lake floor, in eastern and northern Lake Simcoe (Fig. 13e). Prominent lake floor outcrops of Purple Sequence sediments up to 10 m in height occur throughout the lake (e.g. Fig. 12a, e, j). The steep cross-sectional shape of these mounds suggests that they may be drumlins related to the northeast-southwest oriented drumlin fields mapped by previous workers on land around Lake Simcoe (Barnett *et al.*, 1991). Within Kempenfelt Bay, the top of the Purple Sequence reaches depths of about 50 m in places, though the base of the sequence is not seismically detectable due to gas masking (Fig. 12y).

The distribution of the Purple Sequence, its reflection configuration and its drumlinized, unconformable surface suggests that it is analagous to the Newmarket Till mapped south of Lake Simcoe (Barnett *et al.*, 1998, Pugin, Pullan and Sharpe, 1999; Pugin *et al.*, 1999; Sharpe *et al.*, in prep.).

5.4 Red and Brown Sequences

Red Sequence sediments occur in many places in Lake Simcoe (Fig. 13g). These sediments were not detected in Cook's Bay but were observed at depth in Kempenfelt Bay. Red Sequence sediments rarely outcrop on the lakefloor, with the exception of Line 93-15a in the area of Snake and Fox Islands (Fig. 12x) in southwestern Lake Simcoe.

Brown Sequence sediments (Fig. 13h) were detected only on lines 92-1, 92-4, 92-5 and 93-5 (Figs. 12a, d, e, k). These sediments are interpreted as the oldest till within Lake Simcoe detected in the Seistec profiles.

5.5 Discussion

The regional seismostratigraphy of the Lake Simcoe basin described in this report is in accord with the depositional model developed for the Oak Ridges Moraine (Barnett *et al.*, 1998). Tunnel channels (e.g. Cook's Bay) were eroded into Newmarket Till by subglacial meltwater flood events. The streamlined upland surface (i.e. drumlins) were also eroded by subglacial meltwater. As the margin of the Late Wisconsinan ice retreated, sediments were shed into ice-marginal lakes or from beneath a floating ice shelf. Glaciolacustrine sand, silt and clay (Green Sequence) were deposited in the Lake Simcoe Basin at this time. Kempenfelt Bay, the northeast-southwest trending bay in

western Lake Simcoe, was submerged during Lake Algonquin time (12,000 to 10,000 B.P.) (Fitzgerald, 1985). A regional unconformity marks the top of the Green Sequence sediments and may be the result of a post-Algonquin lowstand. The overlying Blue Sequence muds reflect open water deposition, distal to the retreating ice front, and merging with modern lake sedimentation.

Based on seismic profiles on the Oak Ridges Moraine (Pugin, Pullan and Sharpe, 1999), the assumption of a velocity of 1500 ms^{-1} applies to the Blue Sequence Holocene muds and the Green Sequence Late Wisconsinan glaciolacustrine fine sand, silt and clay. However, for the Purple Sequence Newmarket Till, a velocity of more than 2000 ms^{-1} is more appropriate. Therefore, using 1500 ms^{-1} for the seismic profiles illustrated in this report (Figs. 12 a-z) underestimates the thicknesses of the Newmarket Till.

6. FUTURE WORK

Lake Simcoe studies are ongoing. To advance our lithostratigraphic understanding, a suite of sediment cores was obtained in 1997 and 1998 at strategic sites in the lake. These cores have been described geologically and pollen analysis is underway; the results will be published in a Geological Survey of Canada Open File report (Todd *et al.*, in prep.).

Recently, the Ontario Geological Survey has made available to the Geological Survey of Canada the Lake Simcoe region of their Geographic Information System (ESRI ArcView 8) compilation of the surficial geology of southern Ontario (Ontario Geological Survey, in prep.). Based on this information, the Geological Survey of Canada has developed a Lake Simcoe GIS project, including the seismostratigraphic mapping reported in this Open File. In the future, the two organizations plan to release a joint Open File report on the onshore-offshore surficial geology correlation.

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Table 1. Deployment of survey instruments in 1992.

Date	Day of the Year	Line No.	Instruments deployed			
			Seistec	Seismic	Sidescan	RTT 1000
Sept 15	259	92-1	√	√	√	√
Sept 16	260	92-2	√	√	√	√
Sept 17	261	92-3	√	√	√	√
Sept 17	261	92-4	√	√	√	√
Sept 18	262	92-5	√	√	√	√
Sept 23	267	92-6	—	√	—	—
Sept 24	268	92-7	—	√	—	—

Table 2. Deployment of survey instruments in 1993.

Date	Day of the Year	Line No.	Instruments deployed				
			Seistec	Seismic	Sidescan	Mag	NSRF eel
May 26	146	93-12W	√	—	√	√	—
May 27	147	93-1	√	√	√	√	—
		93-1b	√	—	—	√	—
May 28	148	93-13	√	√	—	√	√
May 29	149	93-11	√	√	√	√	√
May 30	150	93-3	√	√	√	√	√
May 31	151	93-10	√	√	√	√	√
June 1	152	93-14a	√	√	√	√	√
June 2	153	93-2	√	√	√	√	√
June 3	154	93-4	√	√	√	√	√
June 4	155	93-14b	√	√	√	√	√
June 6	157	93-9	√	√	√	√	√
June 7	158	93-15b	√	√	√	√	√
June 8	159	93-7, 8a, 8b	√	√	√	√	√
June 9	160	93-5, 12E	√	√	√	√	√
June 10	161	93-15a	√	√	√	√	√
June 11	162	93-6	√	√	√	√	√
June 12	163	93-16	√	√	√	—	√

Table 3. Seistec record inventory.

Line No.	Year	Date	Day of the Year	Record length (s)	Record No.	Start time	End time
92-1	1992	September 15	259	0.05	1	1901 (Fix 1)	2014 (Fix 69)
					2	2022 (Fix 77)	2126 (Fix 137)
				0.10	3	1901 (Fix 1)	2014 (Fix 69)
					4	2022 (Fix 77)	2126 (Fix 137)
92-2	1992	September 16	260	0.05	5	1400 (Fix 138)	2115 (Fix 572)
				0.10	6		
92-3	1992	September 17	261	0.05	7	1406 (Fix 573)	1713 (Fix 761)
				0.10	8		
92-4	1992	September 17	261	0.05	9	1847 (Fix 762)	2100 (Fix 894)
				0.10	10		
92-5	1992	September 18	262	0.05	11	1330 (Fix 1001)	1614 (Fix 1165)
				0.10	12		
93-1a	1993	May 27	147	0.05	13	1557	1844
				0.10	14		
93-1b	1993	May 27	147	0.05	15	1903	2000
				0.10	16		

Line No.	Year	Date	Day of the Year	Record length (s)	Record No.	Start time	End time
93-2	1993	June 2	153	0.05	17	1555	1935
				0.10	18		
93-3	1993	May 30	150	0.05	19	1453	1910
				0.10	20		
93-4	1993	June 3	154	0.05	21	1414	1845
				0.10	22		
93-5	1993	June 9	160	0.05	23	1506	1738
				0.05	24	1741	1823
				0.10	25	1505	1823
93-6	1993	June 11	162	0.05	26	1451	1815
				0.10	27		
93-7	1993	June 8	159	0.05	28	1901	1946
				0.10	29		
93-8a, b	1993	June 8	159	0.05	30	1530	1901
				0.10	31		
93-9	1993	June 6	157	0.05	32	1456	1822
				0.10	33		
93-10	1993	May 31	151	0.05	34	1538	2029
				0.10	35		

Line No.	Year	Date	Day of the Year	Record length (s)	Record No.	Start time	End time
93-11	1993	May 29	149	0.05	36	1732	2023
				0.10	37		
93-12E	1993	June 9	160	0.05	38	1824	1917
				0.10	39		
93-12W	1993	May 26	146	0.05	40	1646	2102
				0.10	41		
93-13	1993	May 28	148	0.05	42	1705	2000
				0.10	43		
93-14a	1993	June 1	152	0.05	44	1423	1726
				0.10	45		
93-14b	1993	June 4	155	0.05	46	1330	1830
				0.10	47		
93-15a	1993	June 10	161	0.05	48	1404	1824
				0.10	49		
93-15b	1993	June 7	158	0.05	50	1405	1832
				0.10	51		
93-16	1993	June 12	163	0.05	52	1350	1800
				0.10	53		

Table 4. 1993 seismic NSRF eel record inventory.

Line No.	Year	Date	Day of the Year	Record No.	Start time	End time
93-2	1993	June 2	153	1	1555	1935
93-3	1993	May 30	150	2	1453	1910
93-4	1993	June 3	154	3	1414	1845
93-5	1993	June 9	160	4	1506	1738
93-6	1993	June 11	162	5	1451	1815
93-7	1993	June 8	159	6	1901	1946
93-8a, b	1993	June 8	159	7	1530	1901
93-9	1993	June 6	157	8	1456	1822
93-10	1993	May 31	151	9	1538	2029
93-11	1993	May 29	149	10	1732	2023
93-12E	1993	June 9	160	11	1824	1917
93-13	1993	May 28	148	12	1705	2000
93-14a	1993	June 1	152	13	1423	1726
93-14b	1993	June 4	155	14	1330	1830
93-15a	1993	June 10	161	15	1404	1824
93-15b	1993	June 7	158	16	1405	1832
93-16	1993	June 12	163	17	1350	1800

Table 5. 1992 RTT 1000 record inventory.

Line No.	Date	Day of the Year	Record No.	Start time	End time
92-1	Sept 15	259	1	1901 (Fix 1)	2126 (Fix 137)
92-2	Sept 16	260	2	1400 (Fix 138)	2115 (Fix 572)
92-3	Sept 17	261	3	1406 (Fix 573)	1713 (Fix 761)
92-4	Sept 17	261	3	1847 (Fix 762)	2100 (Fix 894)
92-5	Sept 18	262	4	1330 (Fix 1001)	1614 (Fix 1165)
92-6	Sept 23	267	5	1452 (Fix 2005)	1822 (Fix 2757)
92-7	Sept 24	268	6	1454 (Fix 5)	1927 (Fix 999)

Table 6. Sidescan sonar record inventory.

Line No.	Year	Date	Day of the Year	Record No.	Start fix/time	End fix/time
92-1	1992	September 15	259	1a	1	69
				1b	77	137
92-2	1992	September 16	260	2	138	571
92-3	1992	September 17	261	3	573	762
92-4	1992	September 17	261	4	763	896
92-5	1992	September 18	262	5	1001	1165
93-1a	1993	May 27	147	6	1557	1844
93-2	1993	June 2	153	7	1427	1730
				8	1730	1935
93-3	1993	May 30	150	9	1508	1730
				10	1734	1913
93-4	1993	June 3	154	11	1414	1845
93-5	1993	June 9	160	12	1505	1823
93-6	1993	June 11	162	13	1451	1815
93-7	1993	June 8	159	14	1901	1946
93-8a, b	1993	June 8	159	15	1530	1901
93-9	1993	June 6	157	16	1456	1822
93-10	1993	May 31	151	17	1538	2111
93-11	1993	May 29	149	18	1732	2023
93-12E	1993	June 9	160	19	1824	1917
93-12W	1993	May 26	146	20	1646	2102
93-14a	1993	June 1	152	21	1423	1726
93-14b	1993	June 4	155	22	1330	1830
93-15a	1993	June 10	161	23	1404	1824
93-15b	1993	June 7	158	24	1405	1832
93-16	1993	June 12	163	25	1350	1800

Table 7. Line intersections of 1992 survey lines.

1992 survey line				Tie lines			
Line	Day of the year	Time (hr min)	Fix	Line	Day of the year	Time (hr min sec)	Fix
92-1	259	21 05	119	93-4	154	16 13 00	—
		20 25	80	93-10	151	17 16 22	—
		20 15	70	93-5	160	16 55 22	—
		19 25	20	93-6	162	16 03 22	—
92-2	260	21 05 43	562	93-14b	155	17 26 40	—
		21 03 07	559	93-16	163	14 55 22	—
		20 45 37	541	93-16	163	14 19 52	—
		20 42 55	539	93-16	163	15 55 40	—
		20 42 25	539	93-14b	163	18 17 40	—
		20 38 36	535	93-14b	155	16 53 40	—
		20 19 37	513	93-16	163	16 23 16	—
		20 17 31	510	93-14b	155	16 22 52	—
		20 04 07	497	93-16	163	16 32 34	—
		19 53 12	486	93-14b	155	15 43 10	—
		19 42 37	475	93-16	163	16 59 10	—
		19 28 06	460	93-14b	155	15 16 32	—
		19 26 36	458	93-16	163	17 13 22	—
		19 03 36	435	93-14b	155	14 40 58	—
		18 35 44	408	93-14b	155	14 11 22	—
		18 15 06	391	93-14a	152	17 02 52	—
		18 05 06	381	93-11	149	19 59 52	—
		17 56 06	372	93-14a	152	16 17 52	—
		17 19 05	335	93-1a	147	18 06 52	—
		16 59 07	315	92-4	261	20 31 10	865
		16 19 11	277	93-2	153	17 37 52	—

1992 survey line				Tie lines			
Line	Day of the year	Time (hr min)	Fix	Line	Day of the year	Time (hr min sec)	Fix
		15 15 07	213	93-3	150	17 15 52	—
		14 17 05	155	93-4	154	16 13 22	—
92-3	261	17 05 06	752	93-15b	158	14 22 52	—
		16 56 35	744	93-15b	158	14 41 22	—
		16 40 04	727	93-15b	158	15 22 52	—
		16 29 04	716	93-15b	158	15 40 22	—
		16 19 35	706	93-15b	158	15 56 22	—
		16 09 05	696	93-15b	158	16 20 52	—
		15 35 18	662	93-15b	158	17 08 52	—
		15 15 38	642	93-15b	158	17 48 52	—
		14 50 05	617	93-13	148	17 26 22	—
		14 29 10	596	93-15a	161	17 11 52	—
		14 26 40	594	92-4	261	18 49 06	764
92-4	261	18 49 06	764	92-3	261	14 26 40	594
		19 49 05	824	93-14a	152	15 46 52	—
		19 57 05	832	93-1a	147	17 48 52	—
		20 12 05	847	93-11	149	19 23 22	—
		20 31 10	865	92-2	260	16 59 07	315
		20 56 35	890	93-1b	147	19 43 52	—
92-5	262	13 46 35	1018	93-10	151	19 38 52	—
		14 01 37	1032	93-2	153	17 04 52	—
		14 29 06	1060	93-9	157	17 37 22	—
		15 13 36	1104	93-8	159	17 55 52	—
		15 51 36	1142	93-7	159	19 17 52	—

Table 8. Line intersections of 1993 survey lines.

1993 survey line			Tie lines			
Line	Day of the year	Time (hr min)	Line	Day of the year	Time (hr min sec)	Fix
93-1a	147	18 31 30	93-10	151	20 07 52	—
		18 06 52	92-2	260	17 19 05	335
		17 56 52	93-11	149	19 28 52	—
		17 48 52	92-4	261	19 57 05	832
		17 39 52	93-14a	152	15 39 22	—
		17 23 22	93-12W	146	17 52 22	—
		17 04 22	93-15a	161	17 38 22	—
		16 46 22	93-13	148	18 00 22	—
		16 41 52	93-15a	161	15 58 52	—
93-1b	147	18 31 30	93-10	151	19 51 22	—
		19 43 52	92-4	261	20 56 35	890
93-2	153	16 41 22	93-9	157	17 52 52	—
		17 04 52	92-5	262	14 01 37	1032
		17 18 30	93-10	151	19 29 22	—
		17 37 52	92-2	260	16 19 11	277
		17 54 22	93-11	149	18 50 52	—
		18 28 22	93-12W	146	18 25 22	—
		18 45 52	93-15a	161	18 13 22	—
		19 04 22	93-13	148	18 41 22	—
		19 26 52	93-15a	161	15 03 22	—
93-3	150	15 44 22	93-8a	159	17 47 22	—
		16 23 52	93-9	157	17 10 22	—
		17 01 52	93-10	151	18 45 52	—
		17 15 52	92-2	260	15 15 07	213
		17 39 52	93-11	149	18 09 00	—

1993 survey line			Tie lines			
Line	Day of the year	Time (hr min)	Line	Day of the year	Time (hr min sec)	Fix
		18 15 52	93-12W	146	19 06 22	—
		18 52 52	93-12	148	19 19 22	—
93-4	154	14 46 52	93-8a	159	17 05 00	—
		15 26 22	93-9	157	16 26 52	—
		16 07 22	93-10	151	17 55 52	—
		16 13 22	92-1	259	21 03 00	117
		16 13 22	92-2	260	14 17 05	155
		16 48 22	93-11	149	17 27 52	—
		18 22 22	93-13	148	19 32 52	—
93-5	160	15 35 52	93-8a	159	16 26 00	—
		16 17 52	93-9	157	15 41 22	—
		16 55 22	92-1	259	20 15 08	70
		16 57 22	93-10	151	17 10 52	—
		17 40 52	93-11	149	16 46 52	—
93-6	162	15 33 52	93-9	157	15 02 22	—
		16 03 22	92-1	259	19 25 04	20
		16 12 22	93-10	151	16 36 22	—
		16 55 52	93-11	149	16 06 52	—
		17 37 52	93-12E	160	18 59 52	—
93-7	159	19 17 52	92-5	262	15 51 36	1142
93-8a	159	17 55 52	92-5	262	15 13 36	1104
		17 47 22	93-3	150	15 44 22	—
		17 05 00	93-4	154	14 46 52	—
		16 26 00	93-5	160	15 35 52	—
93-9	157	17 52 52	93-2	153	16 41 22	—
		17 37 22	92-5	262	14 29 06	1060
		17 10 22	93-3	150	16 23 52	—

1993 survey line			Tie lines			
Line	Day of the year	Time (hr min)	Line	Day of the year	Time (hr min sec)	Fix
		16 26 52	93-4	154	15 26 22	—
		15 41 22	93-5	160	16 17 52	—
		15 02 22	93-6	162	15 33 52	—
93-10	151	20 07 52	93-1a	147	18 31 30	—
		19 51 22	93-1b	147	19 32 22	—
		19 38 52	92-5	262	13 46 35	1018
		19 29 22	93-2	153	17 18 30	—
		18 45 52	93-3	150	17 01 52	—
		17 55 52	93-4	154	16 07 22	—
		17 16 22	92-1	259	20 25 06	80
		17 10 52	93-5	160	16 57 22	—
		16 36 22	93-6	162	16 12 22	—
93-11	149	20 05 22	93-14a	152	16 59 52	—
		19 59 52	92-2	260	18 05 06	381
		19 50 52	93-14a	152	16 13 52	—
		19 28 52	93-1a	147	17 56 52	—
		19 23 22	92-4	261	20 12 05	847
		18 50 52	93-2	153	17 54 22	—
		18 09 00	93-3	150	17 39 52	—
		17 27 52	93-4	154	16 48 22	—
		16 46 52	93-5	160	17 40 52	—
		16 06 52	93-6	162	16 55 52	—
93-12E	160	18 59 52	93-6	162	17 37 52	—
93-12W	146	17 51 22	93-1a	147	17 23 52	—
		18 10 52	93-14a	152	15 05 52	—
		18 25 22	93-2	153	18 28 22	—
		19 06 22	93-3	150	18 15 52	—

1993 survey line			Tie lines			
Line	Day of the year	Time (hr min)	Line	Day of the year	Time (hr min sec)	Fix
93-13	148	17 26 22	92-3	261	14 50 05	617
		17 49 52	93-15a	161	16 09 52	—
		18 00 22	93-1a	147	16 46 22	—
		18 41 22	93-2	153	19 04 22	—
		19 19 22	93-3	150	18 52 52	—
		19 32 52	93-4	154	18 22 22	—
93-14a	152	15 05 52	93-12W	146	18 10 52	—
		15 39 22	93-1a	147	17 39 52	—
		15 46 52	92-4	261	19 49 05	824
		16 13 52	93-11	149	19 50 52	—
		16 17 52	92-2	260	17 56 06	372
		16 59 52	93-11	149	20 05 22	—
		17 02 52	92-2	260	18 15 06	391
		17 14 52	93-14b	155	13 52 34	—
93-14b	155	13 52 34	93-14a	152	17 14 52	—
		14 11 22	92-2	260	18 35 44	408
		14 26 22	93-16	163	17 57 22	—
		14 40 58	92-2	260	19 03 36	435
		14 58 52	93-16	163	13 25 40	—
		15 07 52	93-16	163	13 27 28	—
		15 16 22	93-16	163	17 11 22	—
		15 16 32	92-2	260	19 28 06	460
		15 41 34	93-16	163	16 50 04	—
		15 43 10	92-2	260	19 53 12	486
		15 52 58	93-16	163	13 38 22	—
		16 21 04	93-16	163	13 45 52	—
		16 22 16	93-16	163	16 24 04	—

1993 survey line			Tie lines			
Line	Day of the year	Time (hr min)	Line	Day of the year	Time (hr min sec)	Fix
		16 22 52	92-2	260	20 17 31	510
		16 46 46	93-16	163	16 19 04	—
		16 53 40	92-2	260	20 38 36	535
		16 54 22	93-14b	155	18 20 22	—
		16 55 37	93-16	163	14 15 22	—
		16 57 04	93-16	163	15 22 52	—
		16 57 52	93-16	163	15 53 46	—
		17 26 40	92-2	260	21 05 43	562
		17 26 52	93-16	163	14 52 22	—
		17 28 37	93-16	163	14 42 22	—
		17 29 22	93-14b	155	17 57 52	—
		17 57 52	93-14b	155	17 29 22	—
		18 00 52	93-16	163	14 38 22	—
		18 10 22	93-16	163	14 27 22	—
		18 17 16	93-16	163	15 55 42	—
		18 17 40	92-2	260	20 42 25	539
		18 20 22	93-14b	155	16 54 22	—
93-15a	161	15 03 22	93-2	153	19 26 52	—
		15 58 52	93-1a	147	16 41 52	—
		16 09 52	93-13	148	17 49 52	—
		16 36 22	92-3	261	14 32 05	599
		17 11 52	92-3	261	14 29 10	596
		17 38 22	93-1a	147	17 04 22	—
		18 13 22	93-2	153	18 45 52	—
93-15b	158	14 22 52	92-3	261	17 05 06	752
		14 41 22	92-3	261	16 56 35	744
		16 22 52	92-3	261	16 40 04	727

1993 survey line			Tie lines			
Line	Day of the year	Time (hr min)	Line	Day of the year	Time (hr min sec)	Fix
		15 40 22	92-3	261	16 29 04	716
		15 56 22	92-3	261	16 19 35	706
		16 20 52	92-3	261	16 09 05	696
		17 08 52	92-3	261	15 35 18	662
		17 48 52	92-3	261	15 15 38	642
93-16	163	13 25 40	93-14b	155	14 58 52	—
		13 27 28	93-14b	155	15 07 52	—
		13 38 22	93-14b	155	15 52 58	—
		13 45 52	93-14b	155	16 21 04	—
		14 15 22	93-14b	155	16 55 37	—
		14 17 22	93-16	163	15 55 22	—
		14 19 52	92-2	260	20 45 37	541
		14 27 22	93-14b	155	18 10 22	—
		14 38 22	93-14b	155	18 00 52	—
		14 42 22	93-14b	155	17 28 37	—
		14 52 22	93-14b	155	17 26 52	—
		14 55 22	92-2	260	21 03 07	559
		15 21 52	93-16	163	15 54 10	—
		15 22 52	93-14b	155	16 57 04	—
		15 53 46	93-14b	155	16 57 52	—
		15 54 10	93-16	163	15 21 52	—
		15 55 22	93-16	163	14 17 22	—
		15 55 40	92-2	260	20 42 55	539
		15 55 42	93-14b	155	18 17 16	—
		16 04 52	93-16	163	16 13 04	—
		16 13 04	93-16	163	16 04 52	—
		16 19 04	93-14b	155	16 46 46	—

1993 survey line			Tie lines			
Line	Day of the year	Time (hr min)	Line	Day of the year	Time (hr min sec)	Fix
		16 23 16	92-2	260	20 19 37	513
		16 24 04	93-14b	155	16 22 16	—
		16 32 34	92-2	260	20 04 07	497
		16 50 04	93-14b	155	15 41 34	—
		16 59 10	92-2	260	19 42 37	475
		17 11 22	93-14b	155	15 16 22	—
		17 13 22	92-2	260	19 26 36	458
		17 57 22	93-14b	155	14 26 22	—

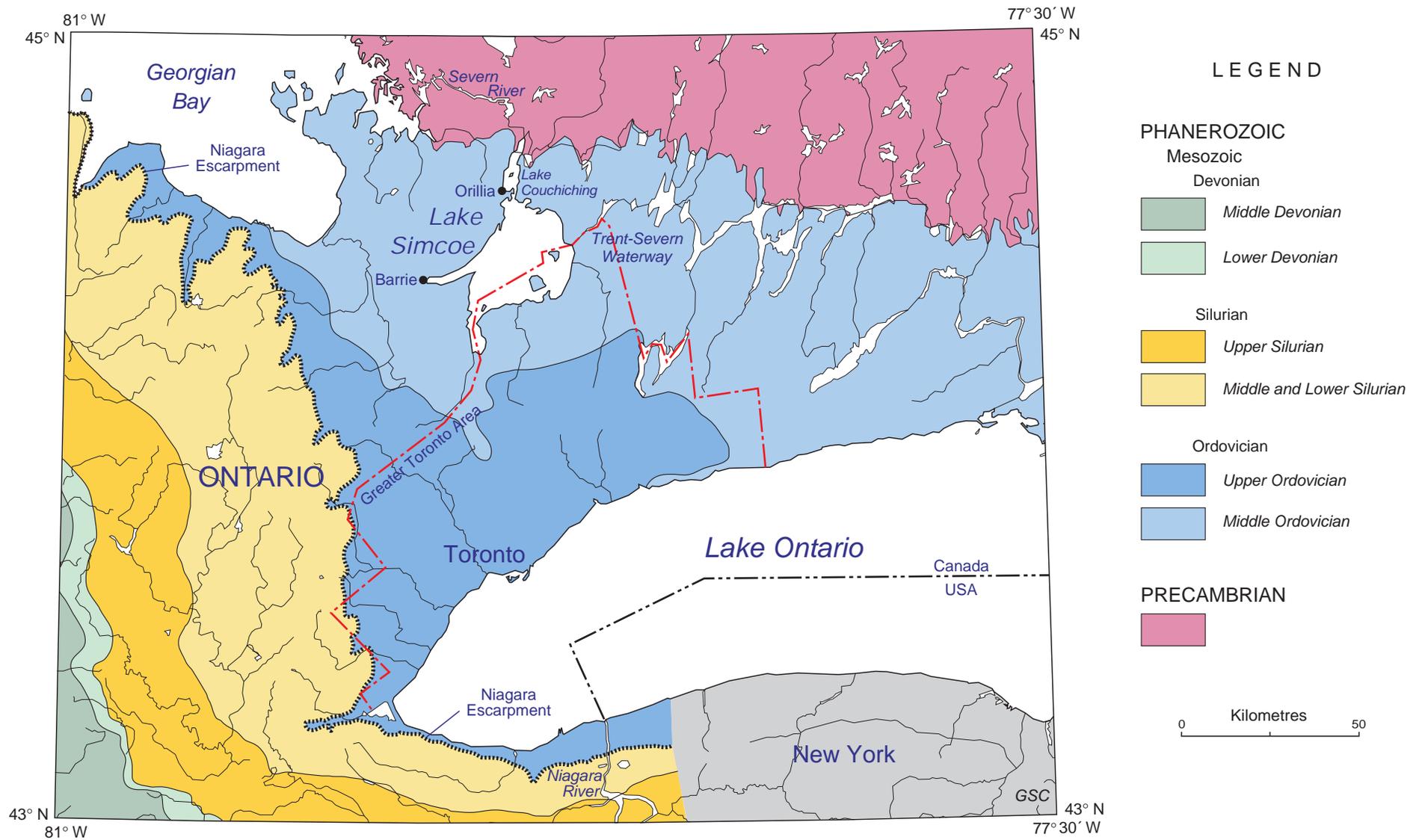


Figure 1. Location map of Lake Simcoe in southern Ontario. Note that the political boundary of the Greater Toronto Area includes southern Lake Simcoe. The Precambrian Grenville Province of the Canadian Shield lies north of the lake. Paleozoic sedimentary rocks overlain by Quaternary sediments occupy southern Ontario. Geological boundaries adapted from Ontario Geological Survey (1991).

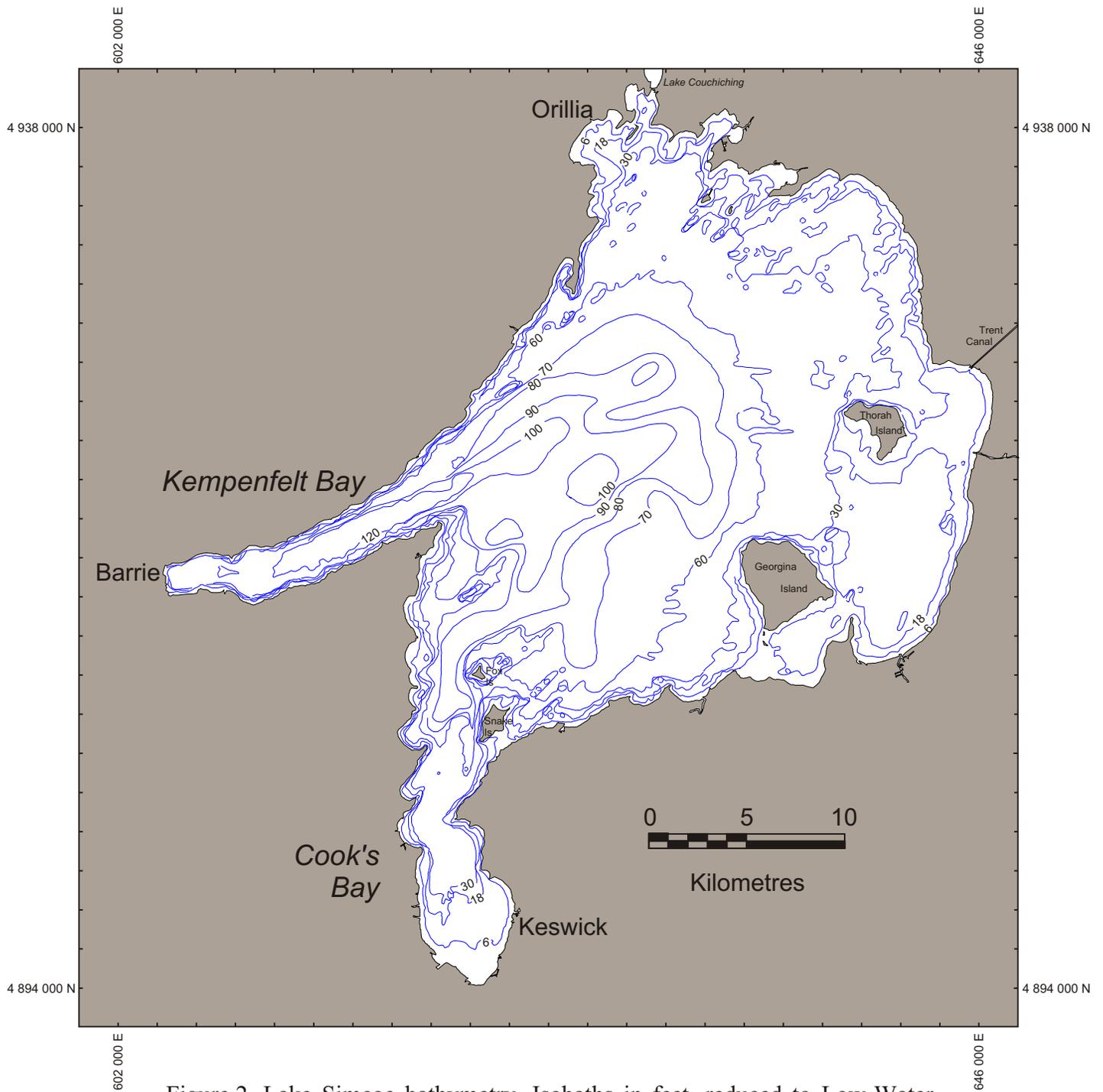


Figure 2. Lake Simcoe bathymetry. Isobaths in feet, reduced to Low Water Datum. Lake elevation is 218.7 m or 717.5 feet. UTM Projection, Zone 17, North American Datum 1927. Digitized and interpolated from Canadian Hydrographic Service Chart 2028, Lake Simcoe, 1987.

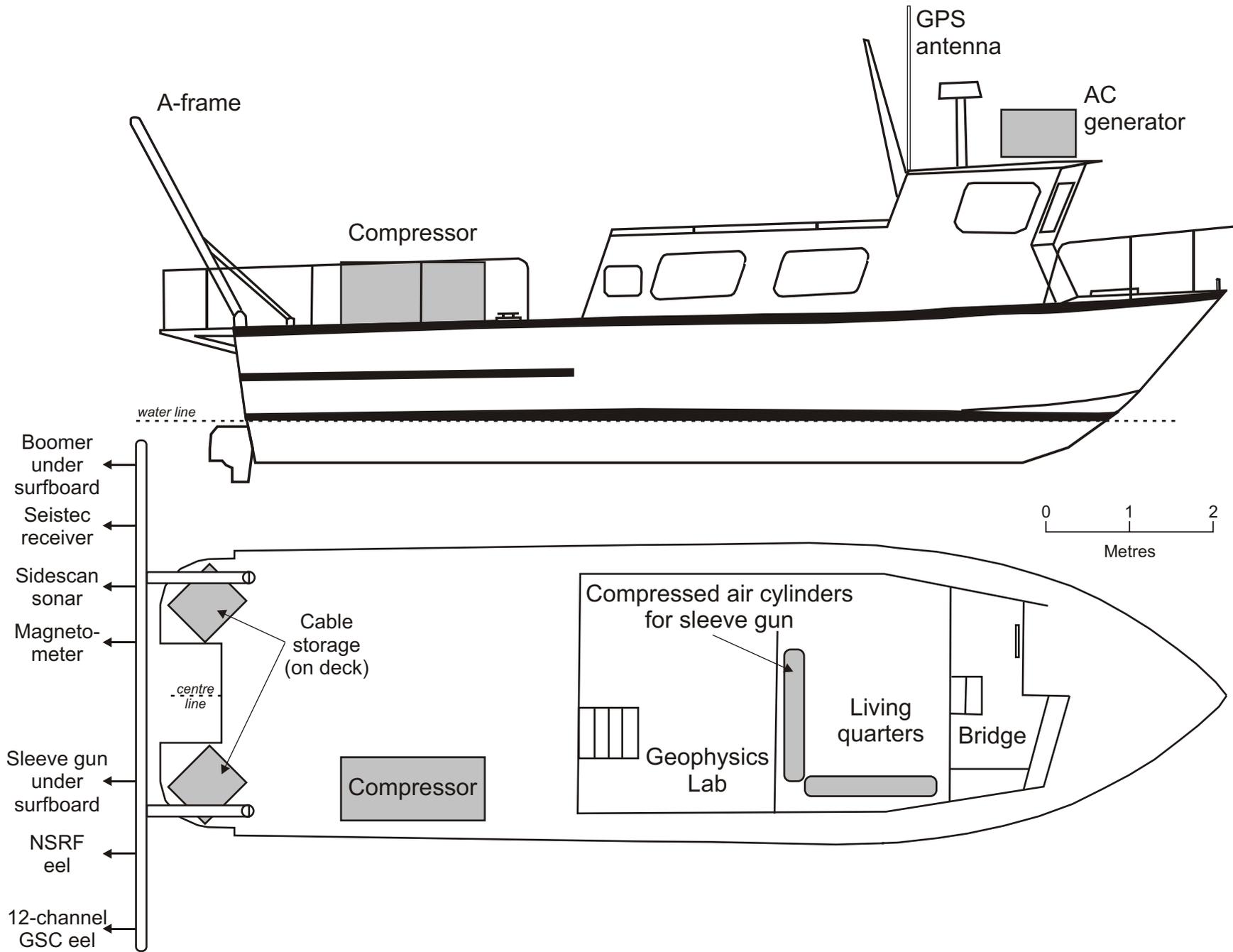


Figure 3. Elevation and plan view of MV *J. Ross Mackay* showing survey equipment layout.



Figure 4. MV *J. Ross Mackay* underway in Lake Simcoe, June, 1993.

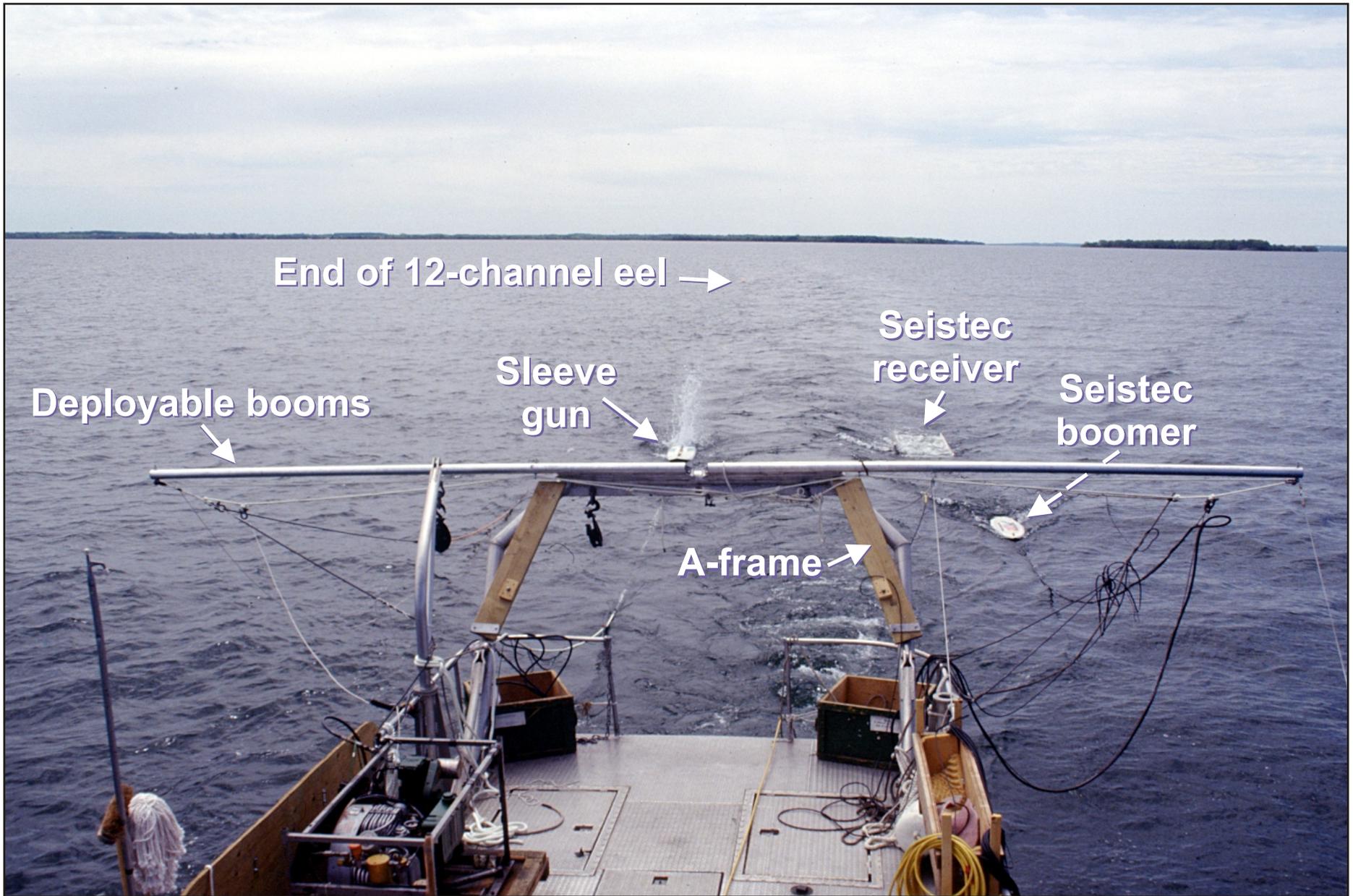


Figure 5. View aft of the MV *J. Ross Mackay* illustrating towing of geophysical instruments from deployable booms.

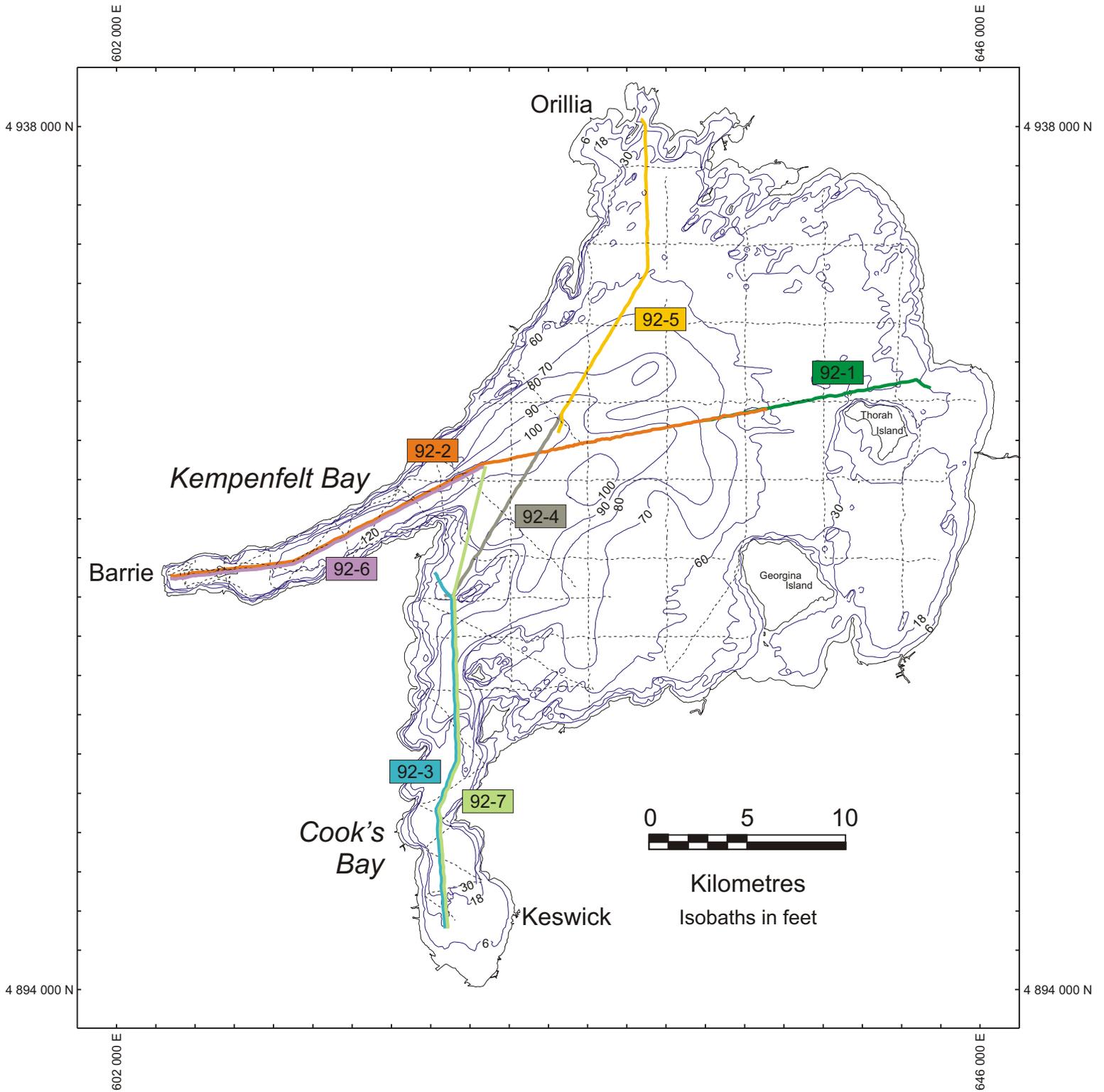


Figure 6. Lake Simcoe 1992 survey lines.

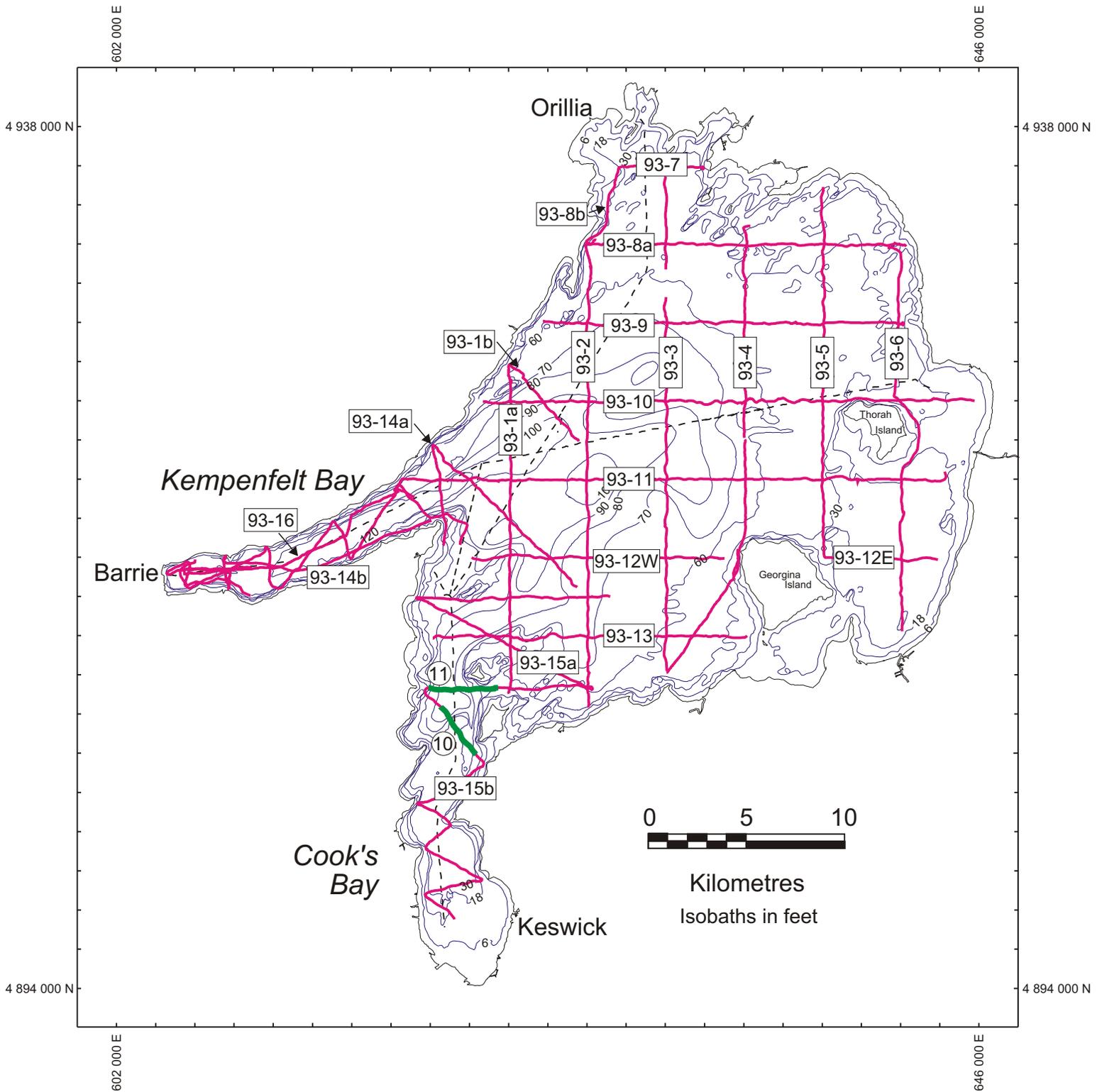


Figure 7. Lake Simcoe 1993 survey lines. The two sections of line 93-15b highlighted in green indicate the locations of the seismic profiles illustrated in Figures 10 and 11.

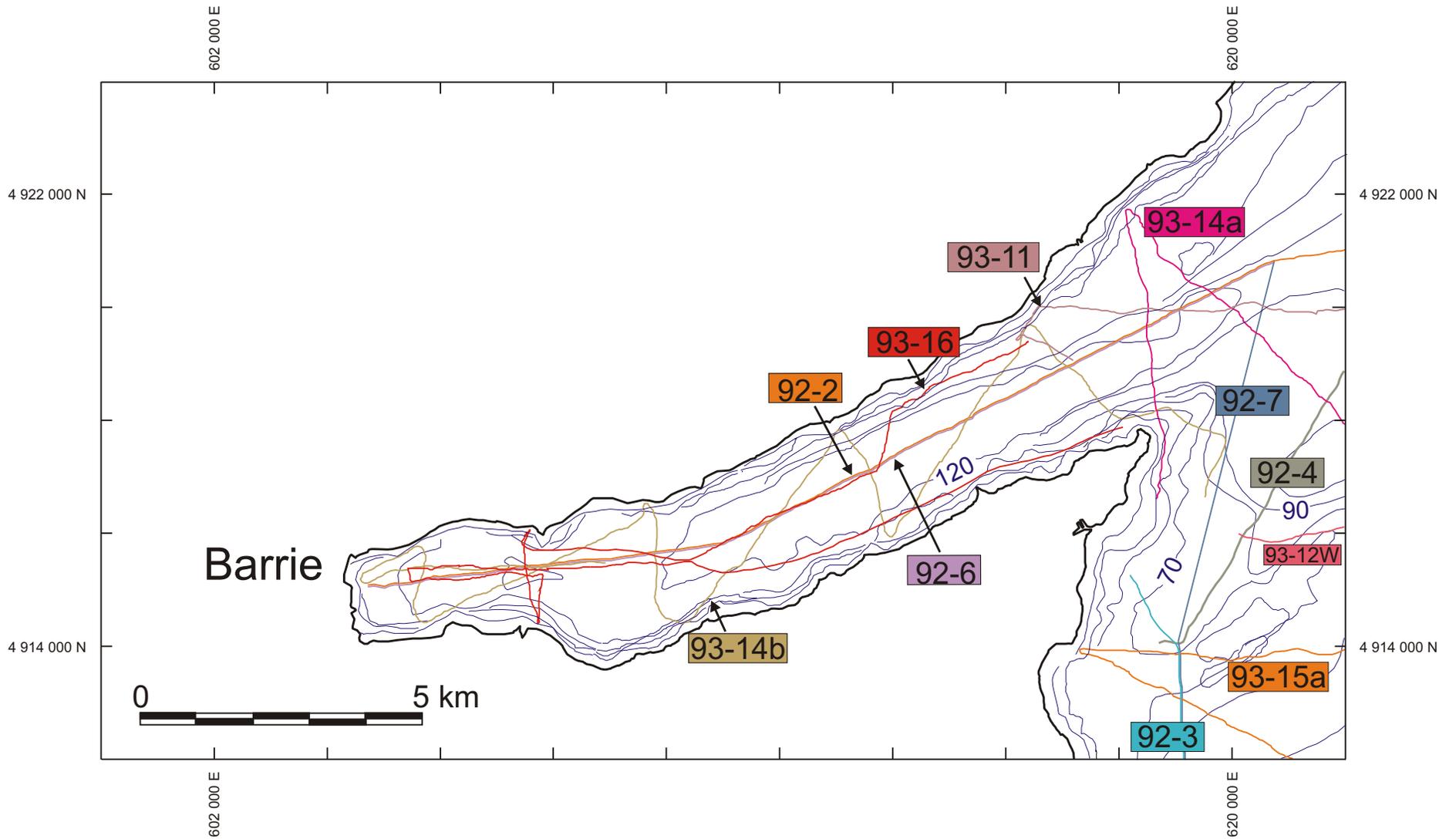


Figure 8. Kempenfelt Bay survey lines, 1992 and 1993.

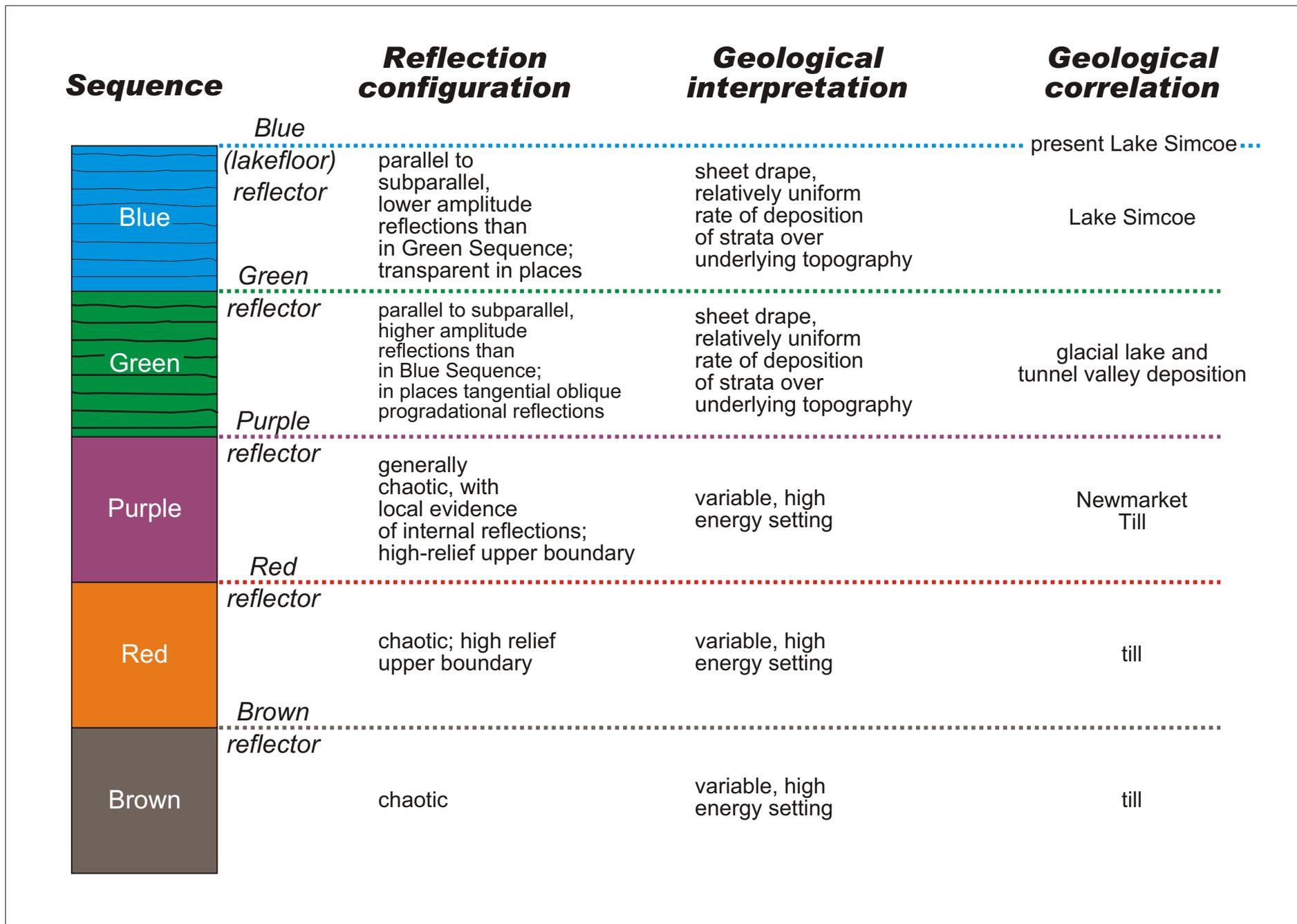


Figure 9. Lake Simcoe seismostratigraphic sequences, reflection configuration, geological interpretation and geological correlation.

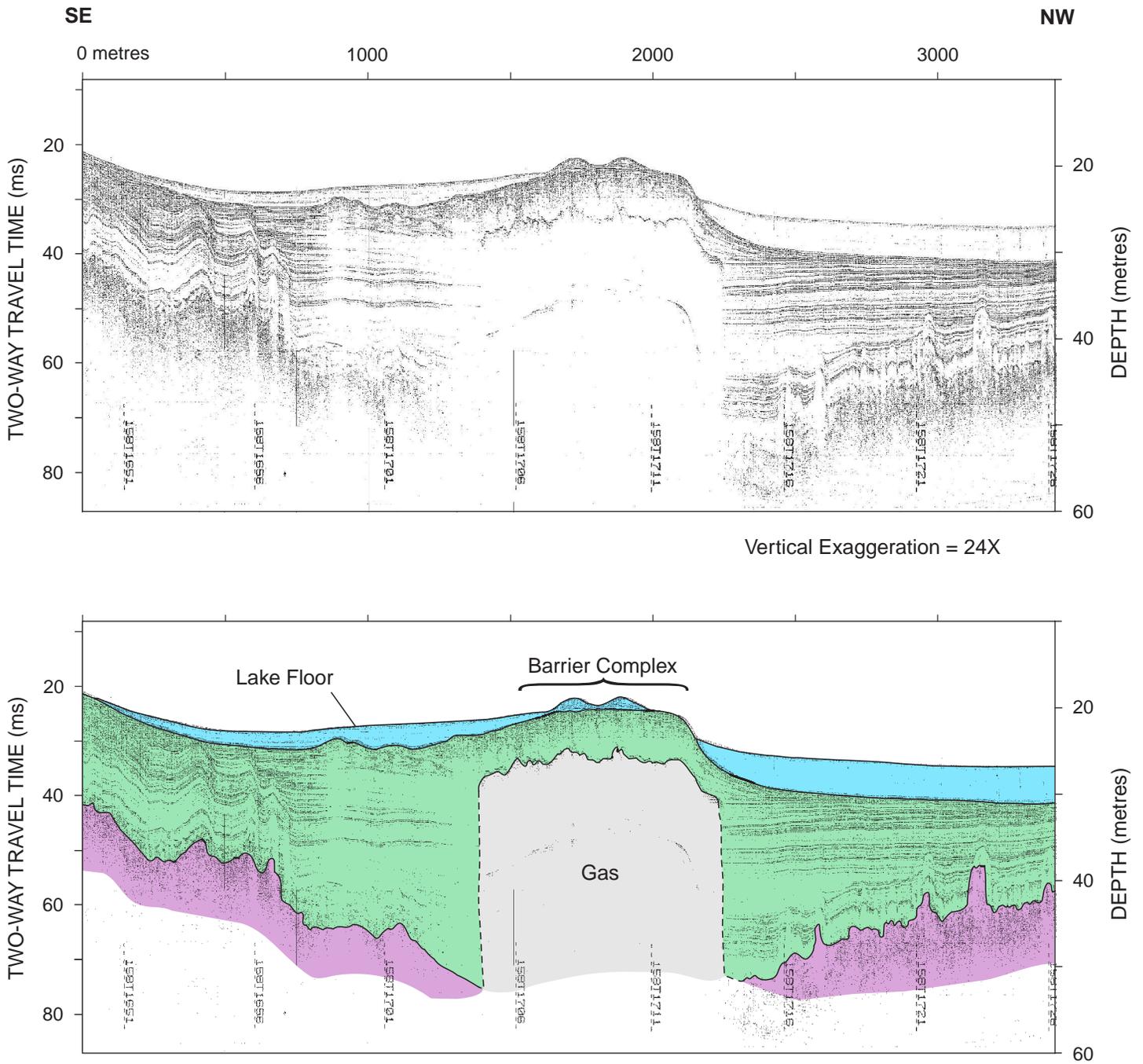


Figure 10. Seistec IKB seismic reflection profile (upper) and interpretive cross section showing stratigraphic relations (lower) across possible drowned barrier complex in Cook's Bay in southern Lake Simcoe. Acoustic basement is Purple Sequence, overlain by Green and Blue Sequences. Reflections beneath the barrier are masked by the presence of gas in the sediments. See Figure 7 for location of profile (Line 93-15b, day 158, 1650-1726).

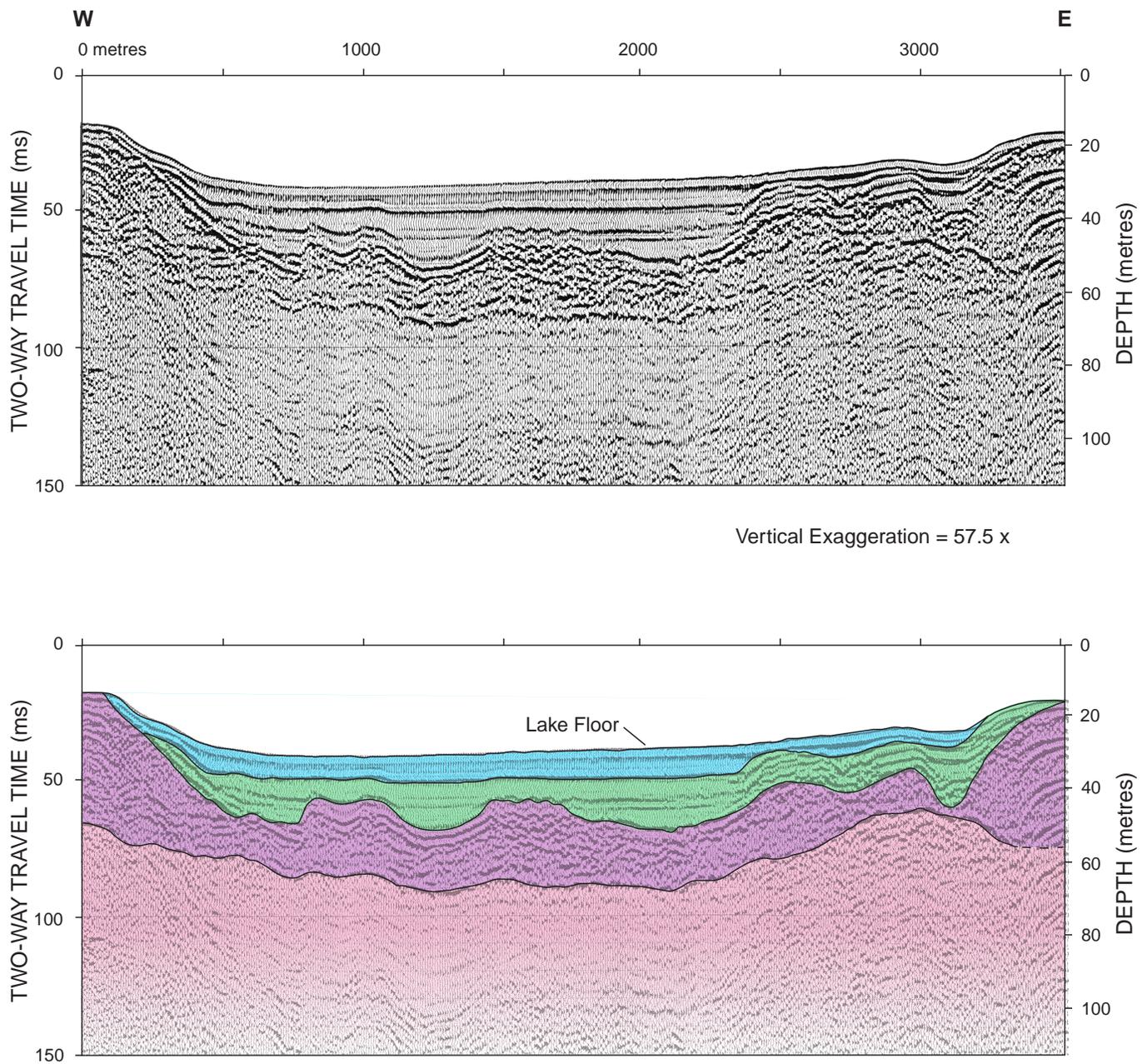
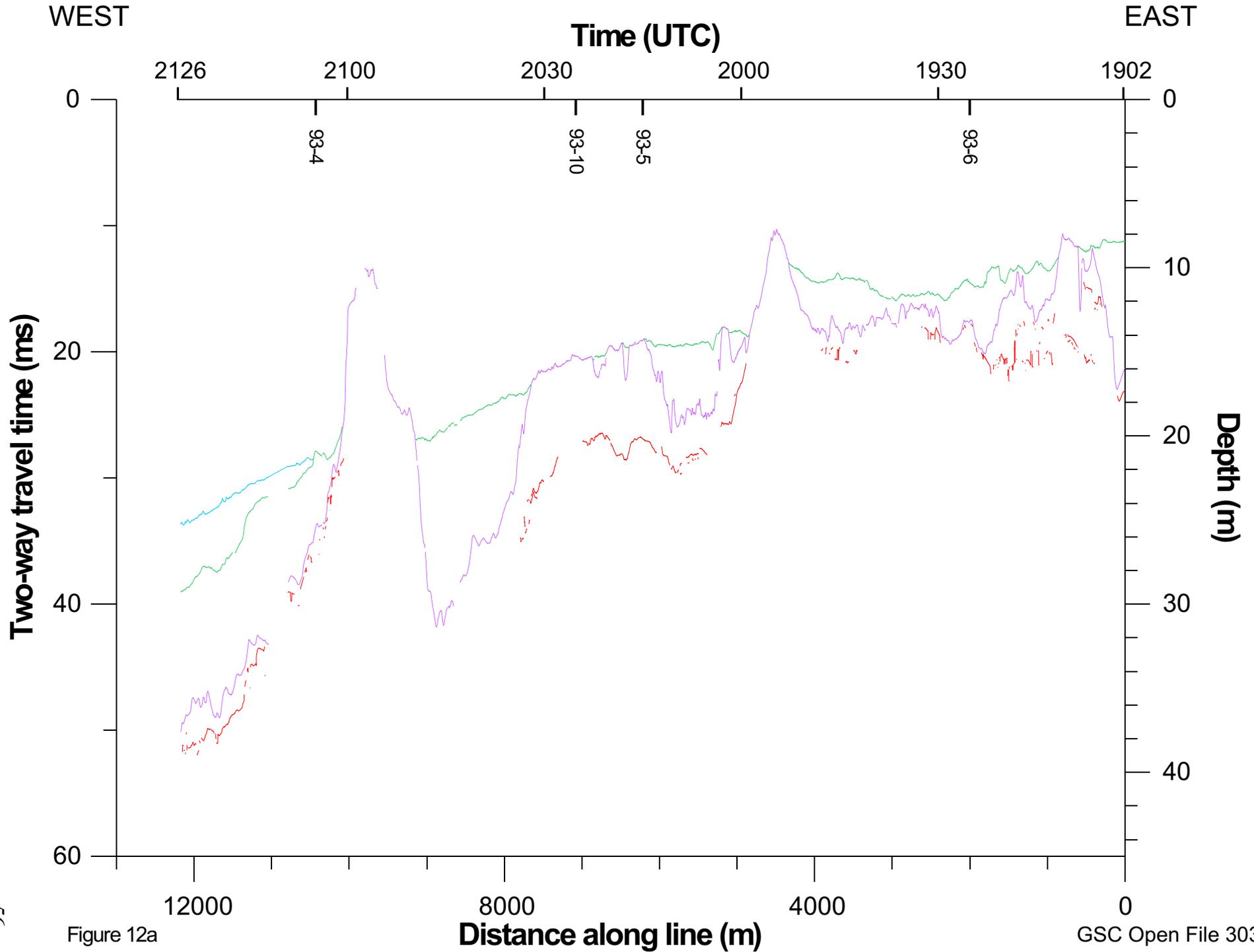
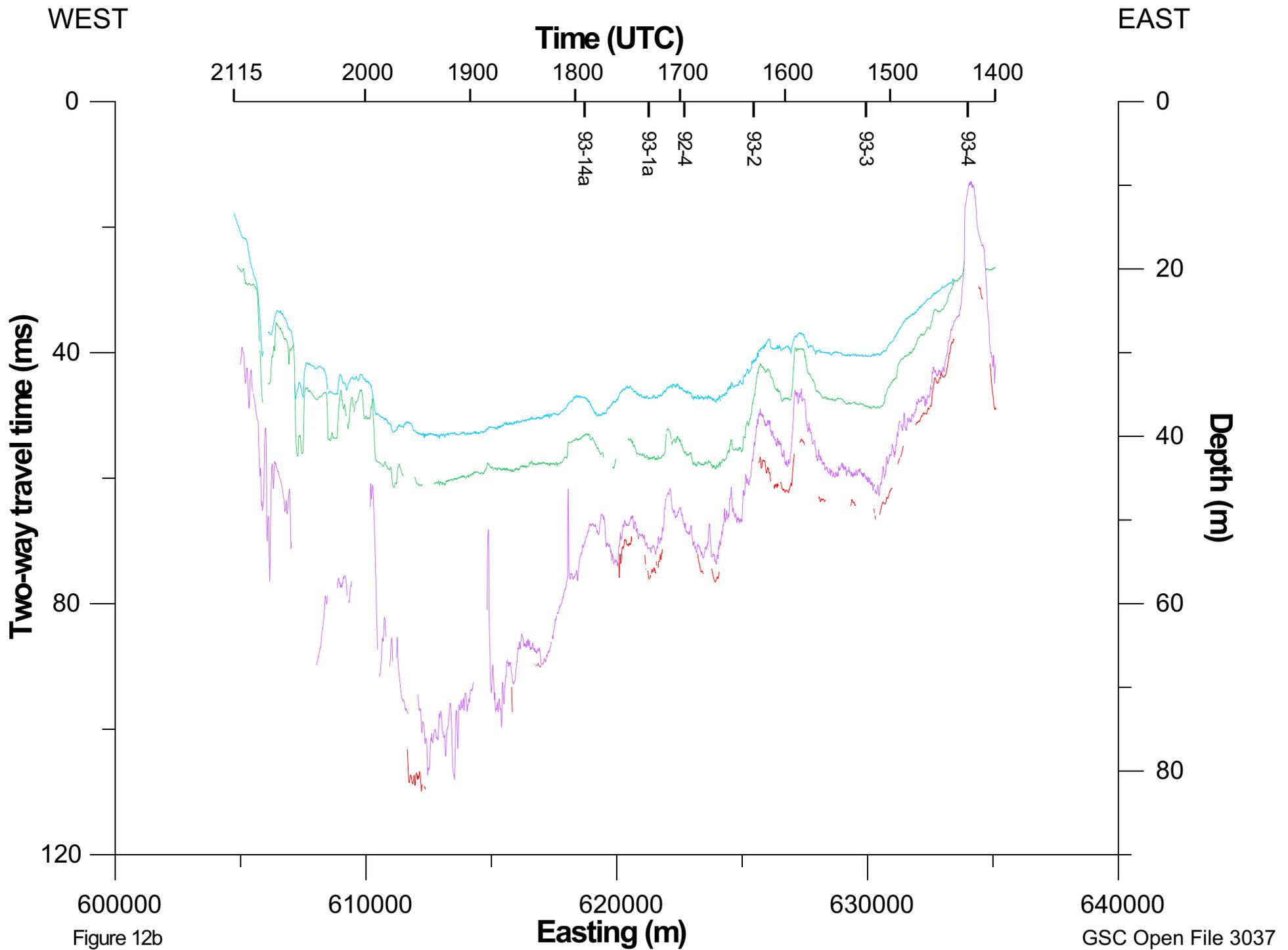


Figure 11. Airgun single-channel seismic reflection profile (upper) and interpretive cross-section showing stratigraphic relations (lower) in Cook's Bay in southern Lake Simcoe. Acoustic basement is Red Sequence, overlain by Purple, Green and Blue Sequences. See Figure 7 for location of profile (Line 93-15b, day 158, 1735-1811).

Lake Simcoe - Line 92-1



Lake Simcoe - Line 92-2

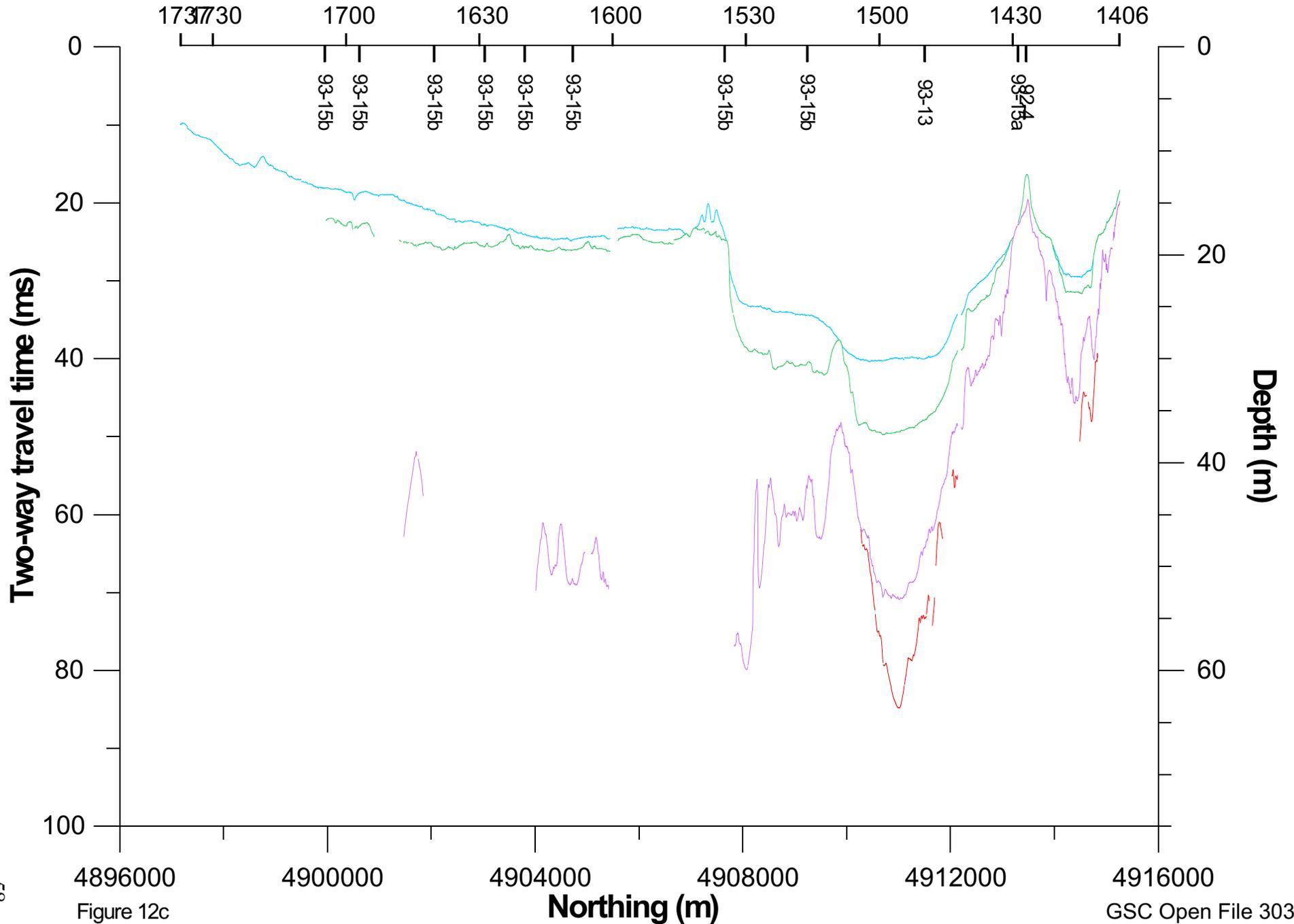


Lake Simcoe - Line 92-3

SOUTH

NORTH

Time (UTC)



58

Figure 12c

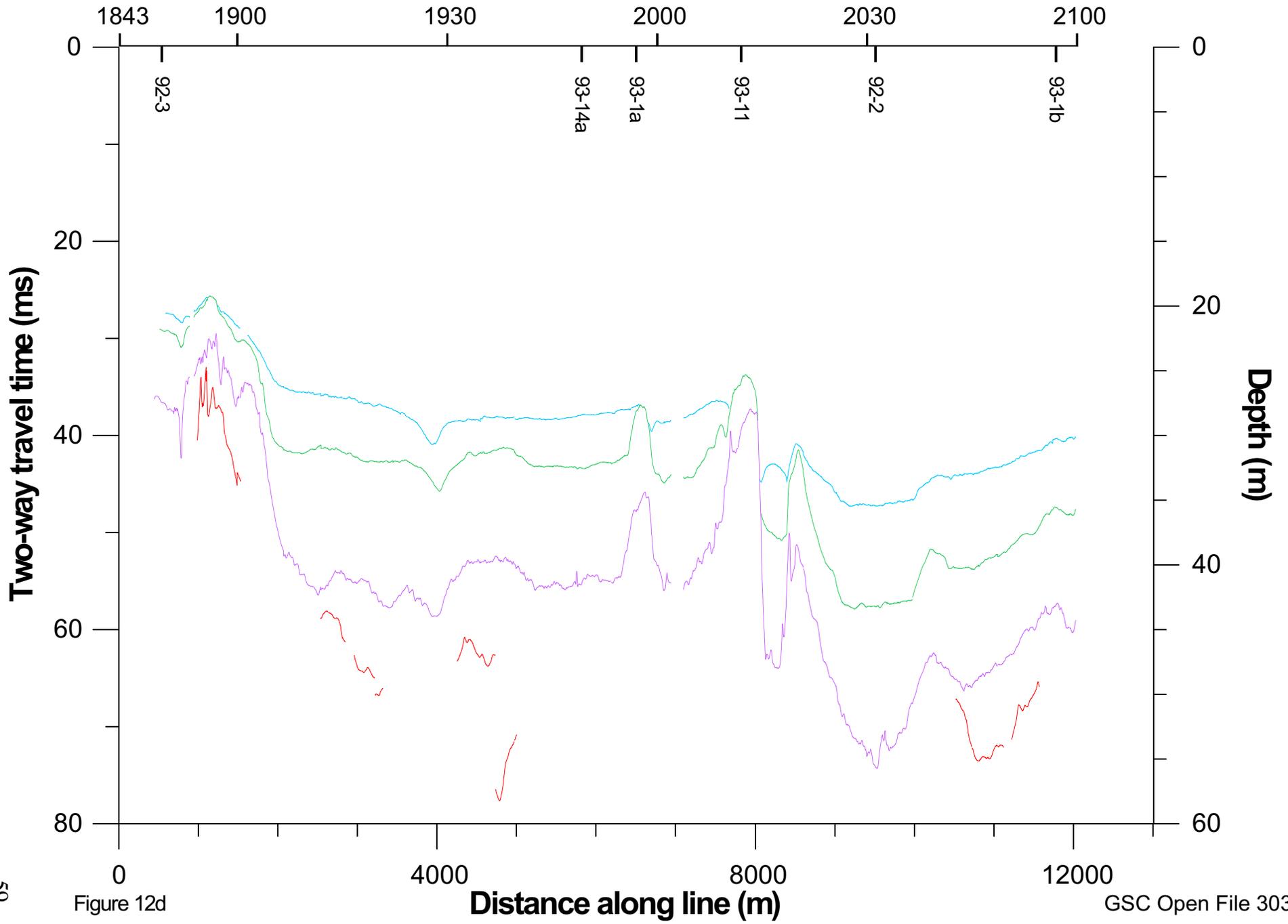
GSC Open File 3037

Lake Simcoe - Line 92-4

SOUTH

NORTH

Time (UTC)



Lake Simcoe - Line 92-5

SOUTH

NORTH

Time (UTC)

1330

1400

1430

1500

1530

1600

1614

0

0

93-10

93-2

93-9

93-8

93-7

Two-way travel time (ms)

20

40

60

80

Depth (m)

20

40

60

0

4000

8000

12000

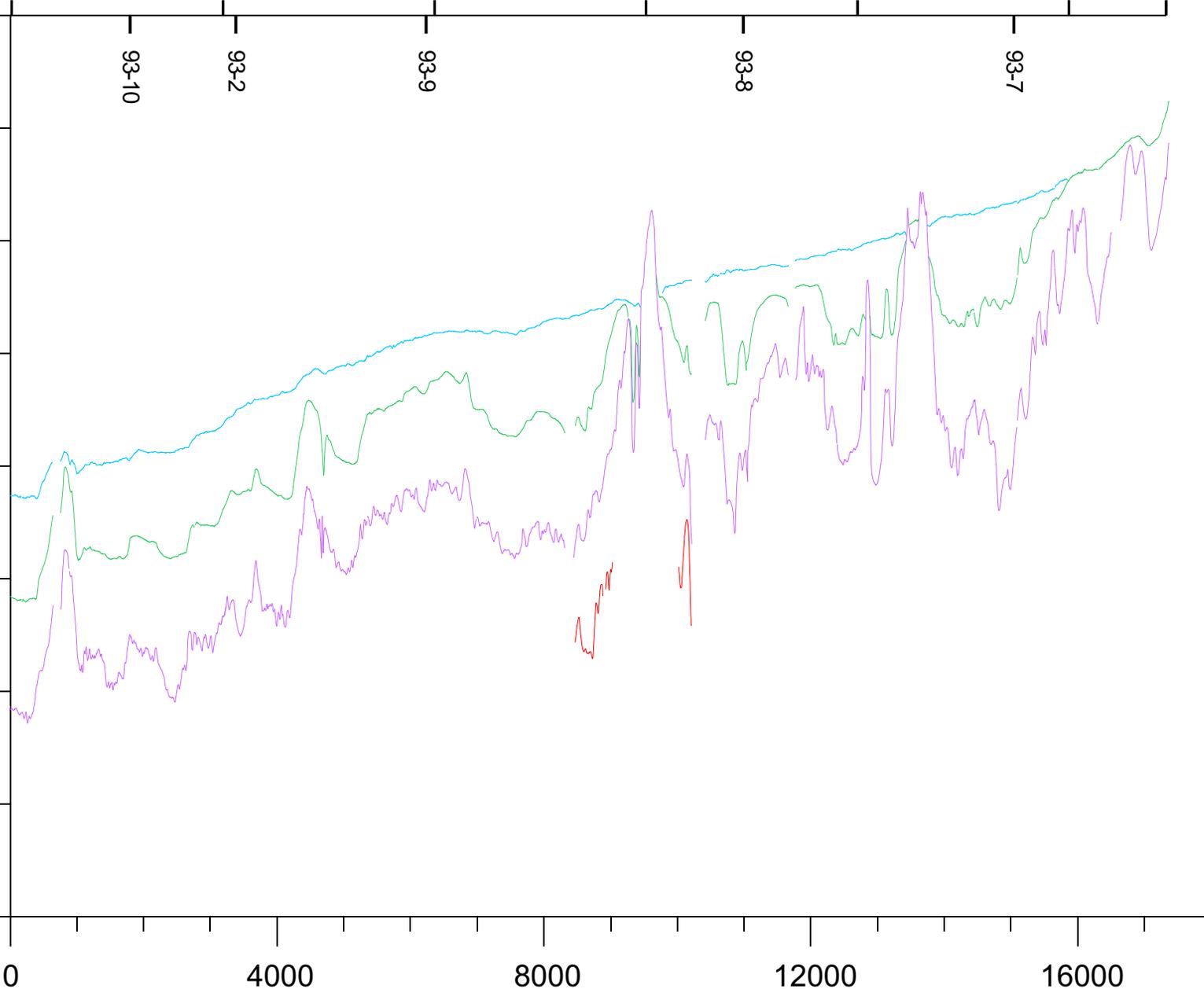
16000

Distance along line (m)

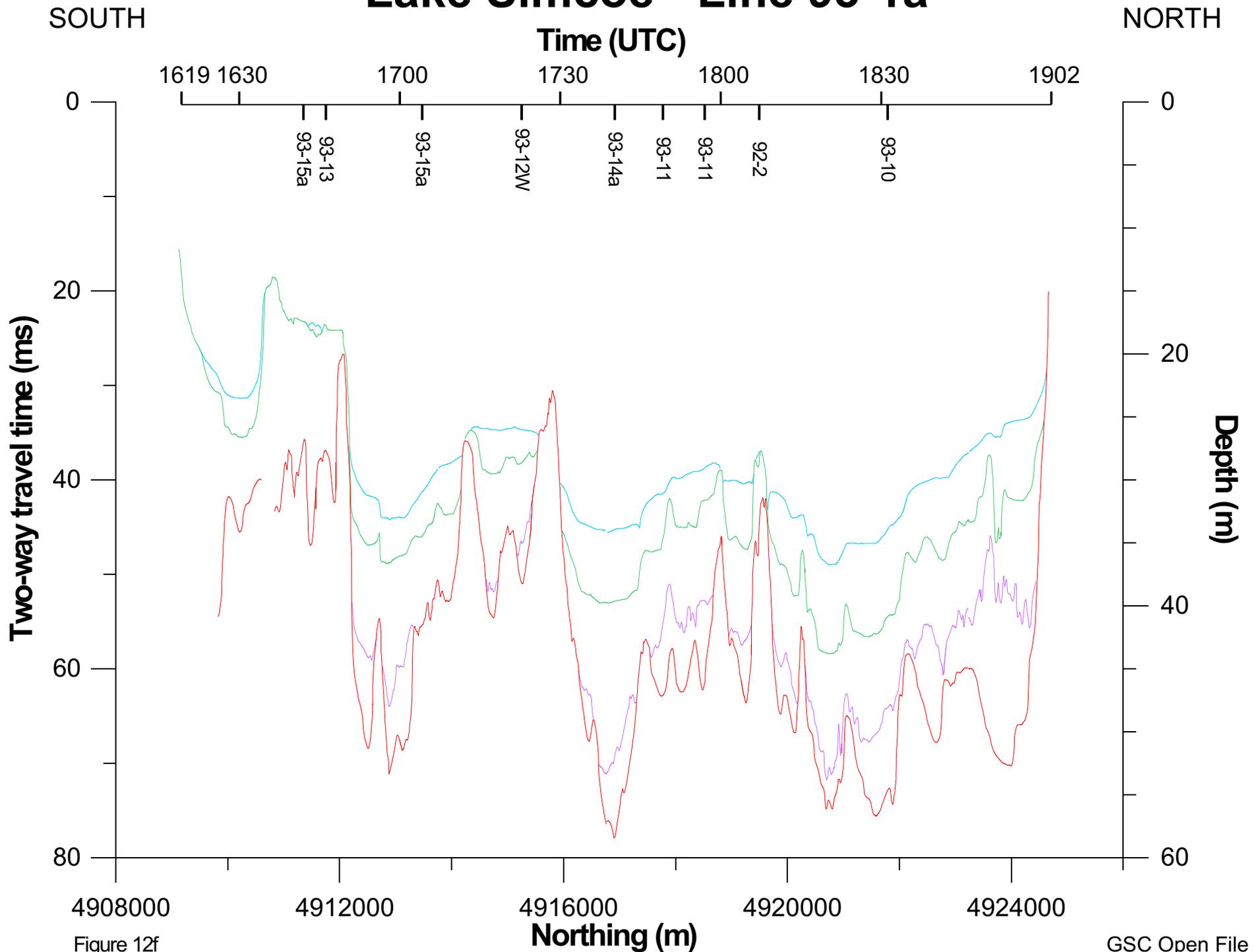
09

Figure 12e

GSC Open File 3037



Lake Simcoe - Line 93-1a



Lake Simcoe - Line 93-1b

SOUTHEAST

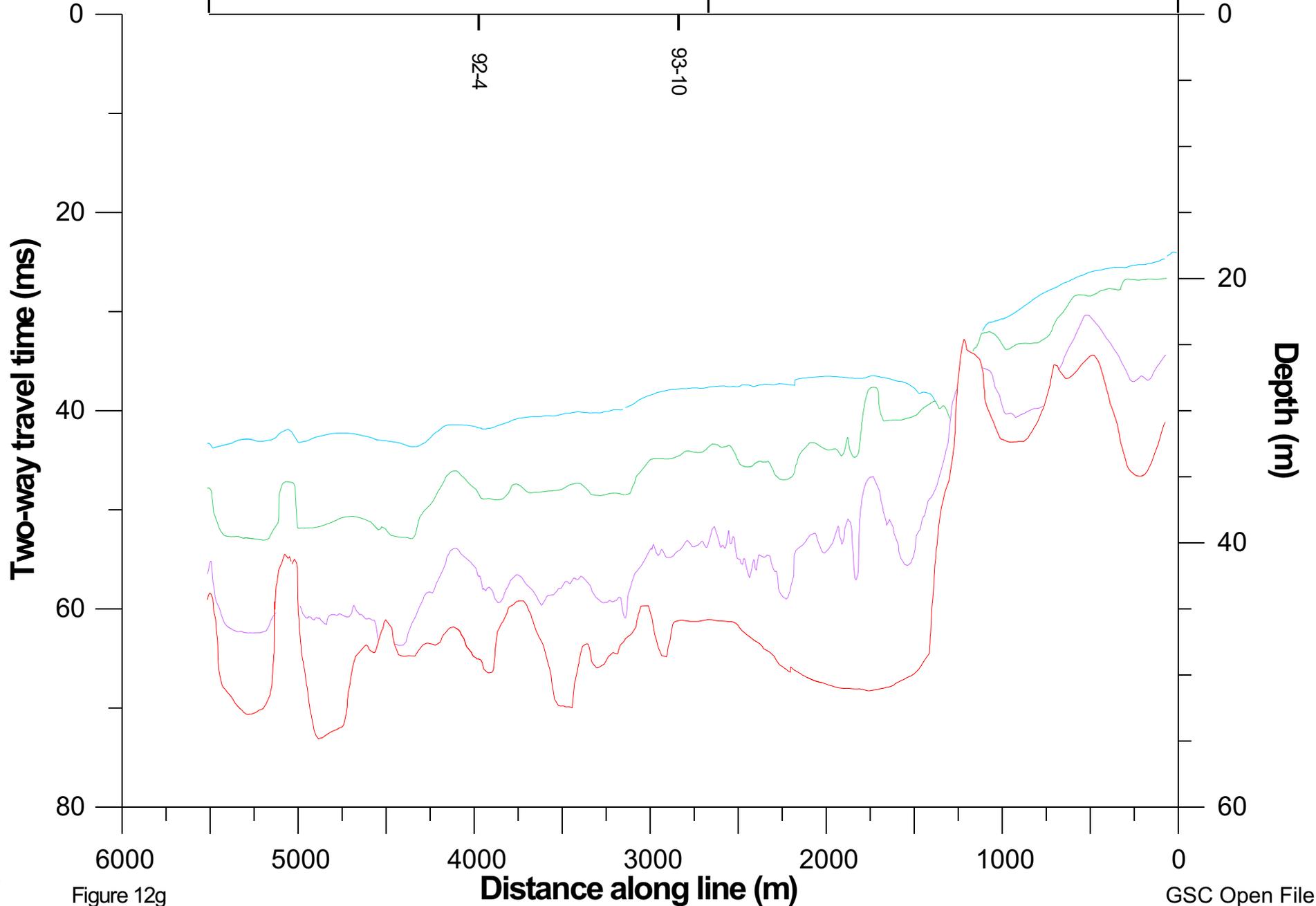
NORTHWEST

Time (UTC)

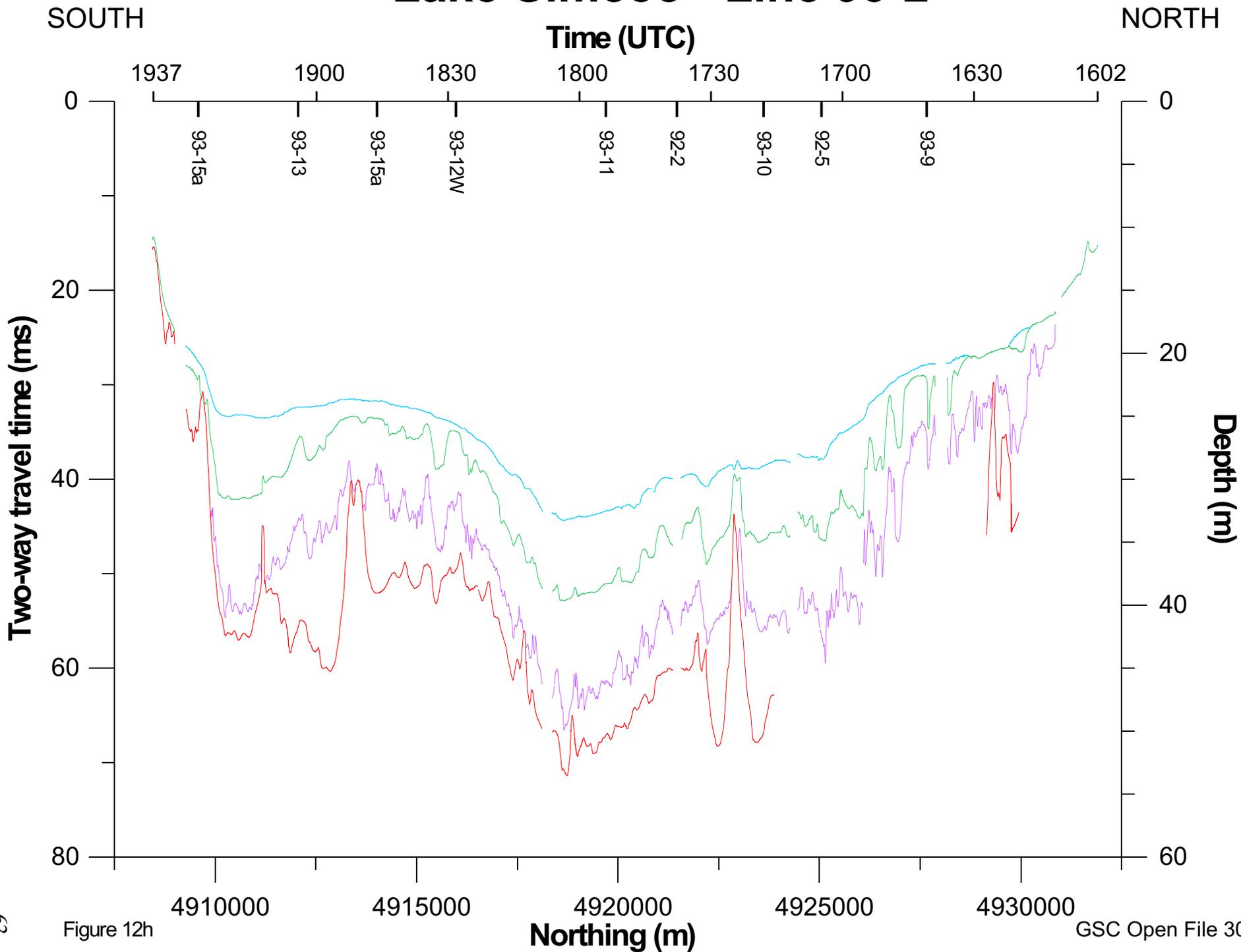
2000

1930

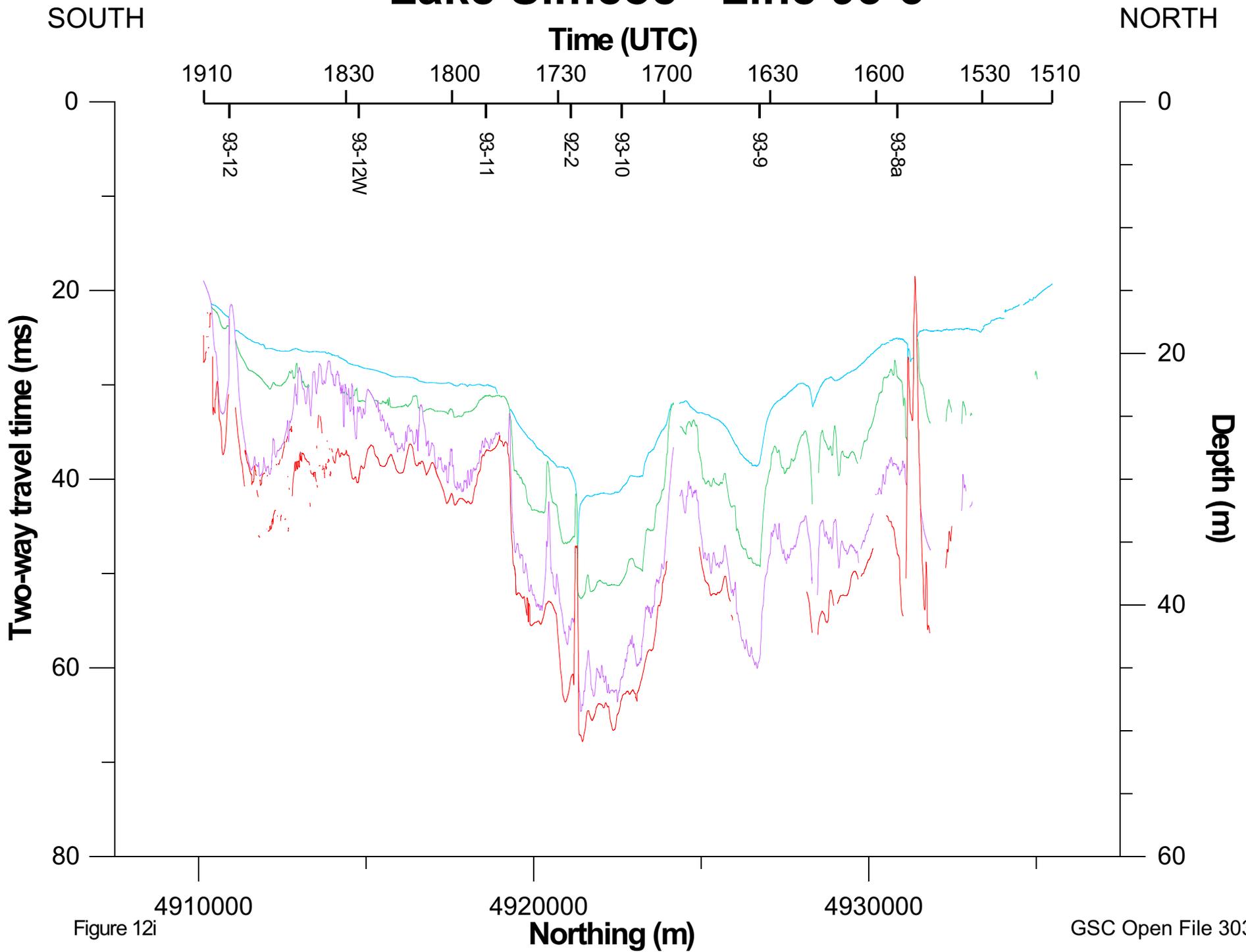
1902



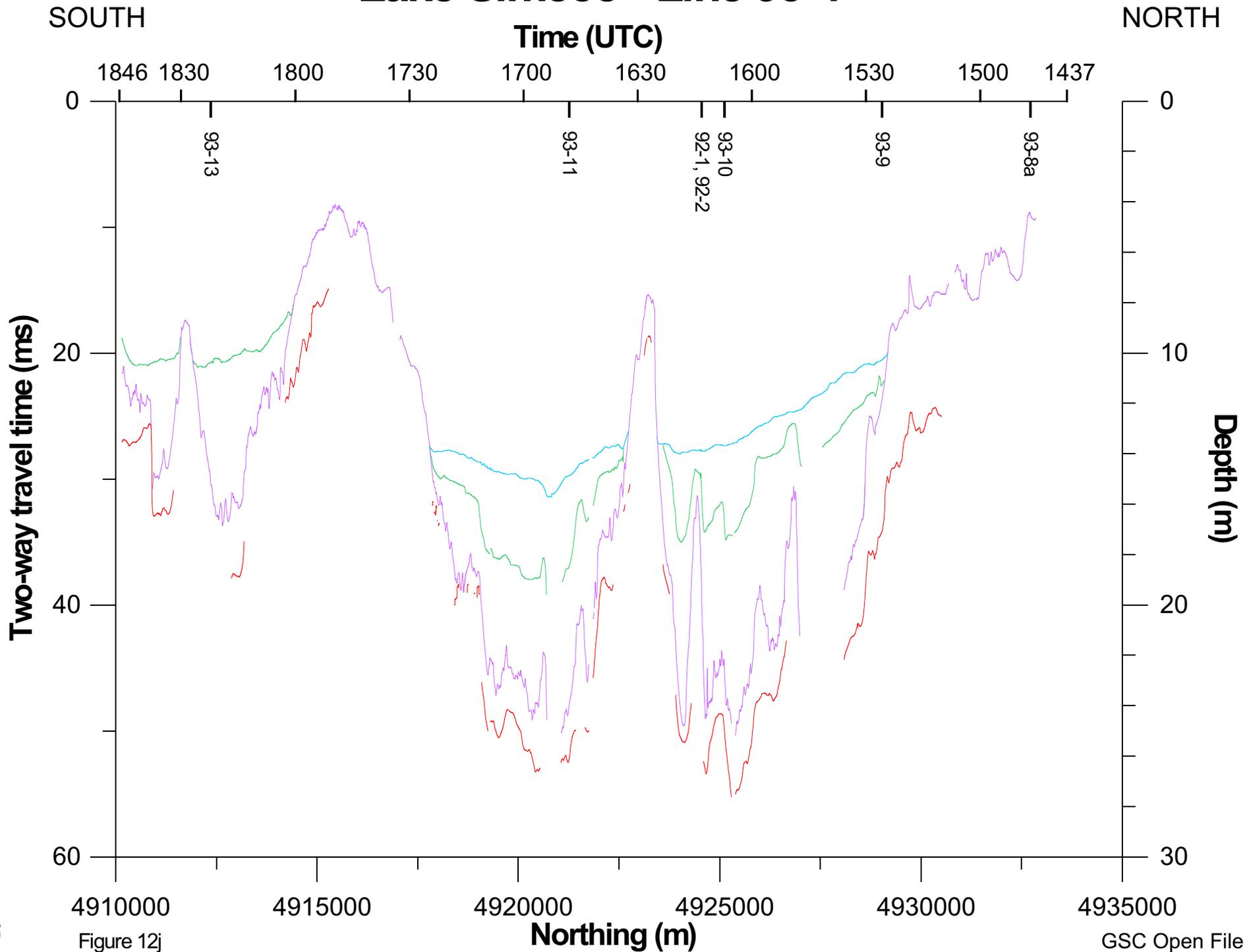
Lake Simcoe - Line 93-2



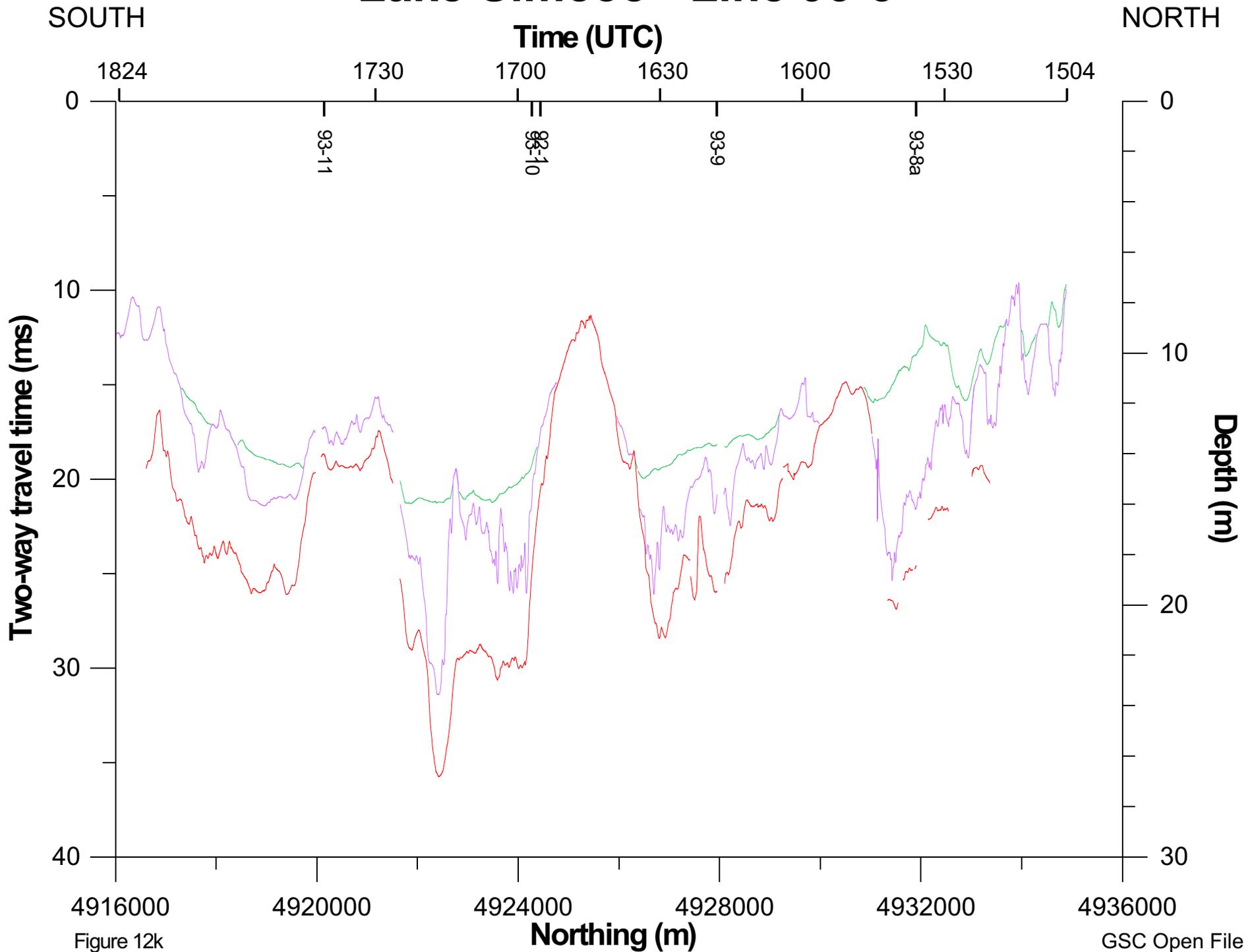
Lake Simcoe - Line 93-3



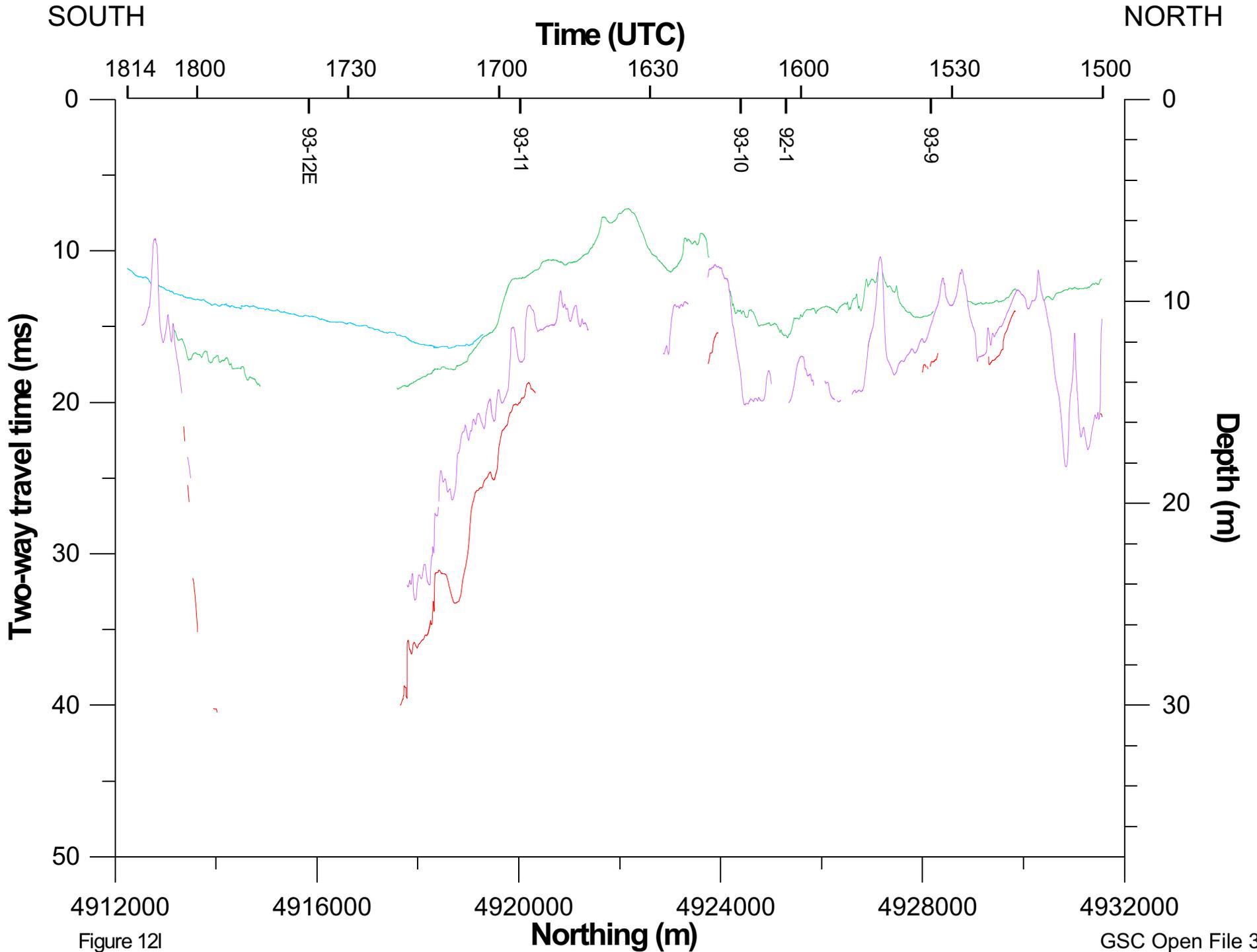
Lake Simcoe - Line 93-4



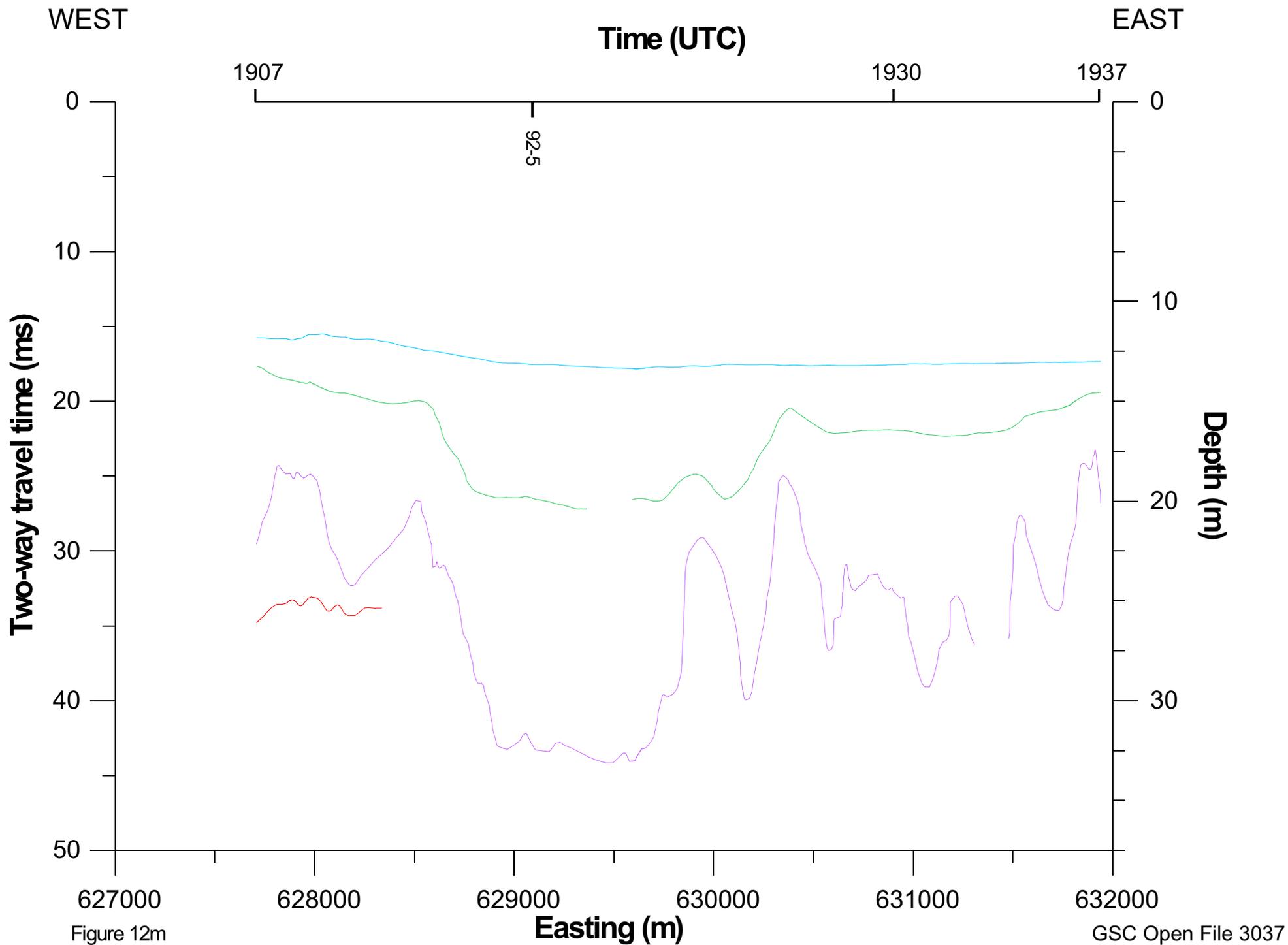
Lake Simcoe - Line 93-5



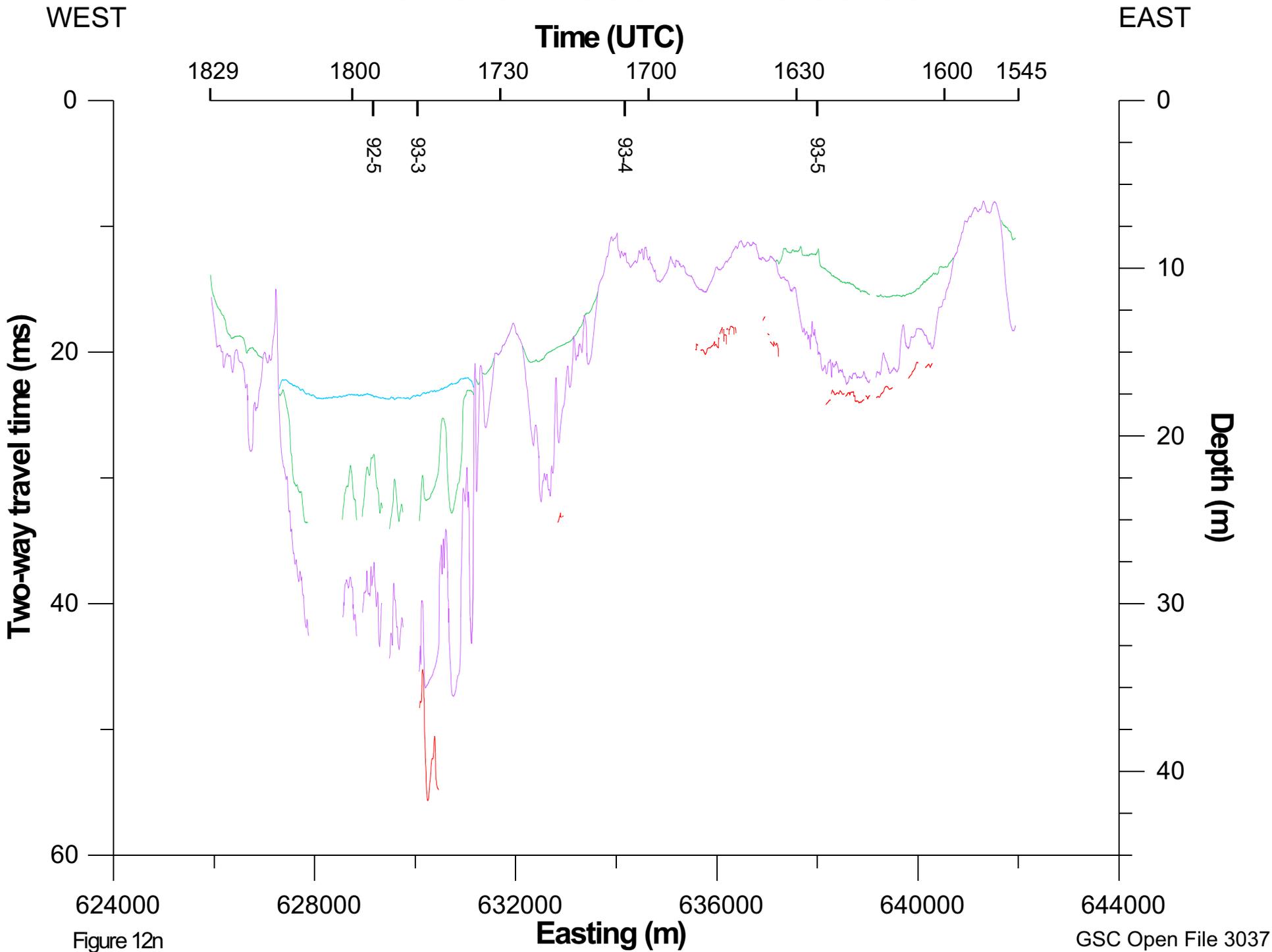
Lake Simcoe - Line 93-6



Lake Simcoe - Line 93-7



Lake Simcoe - Line 93-8a



Lake Simcoe - Line 93-8b

SOUTH

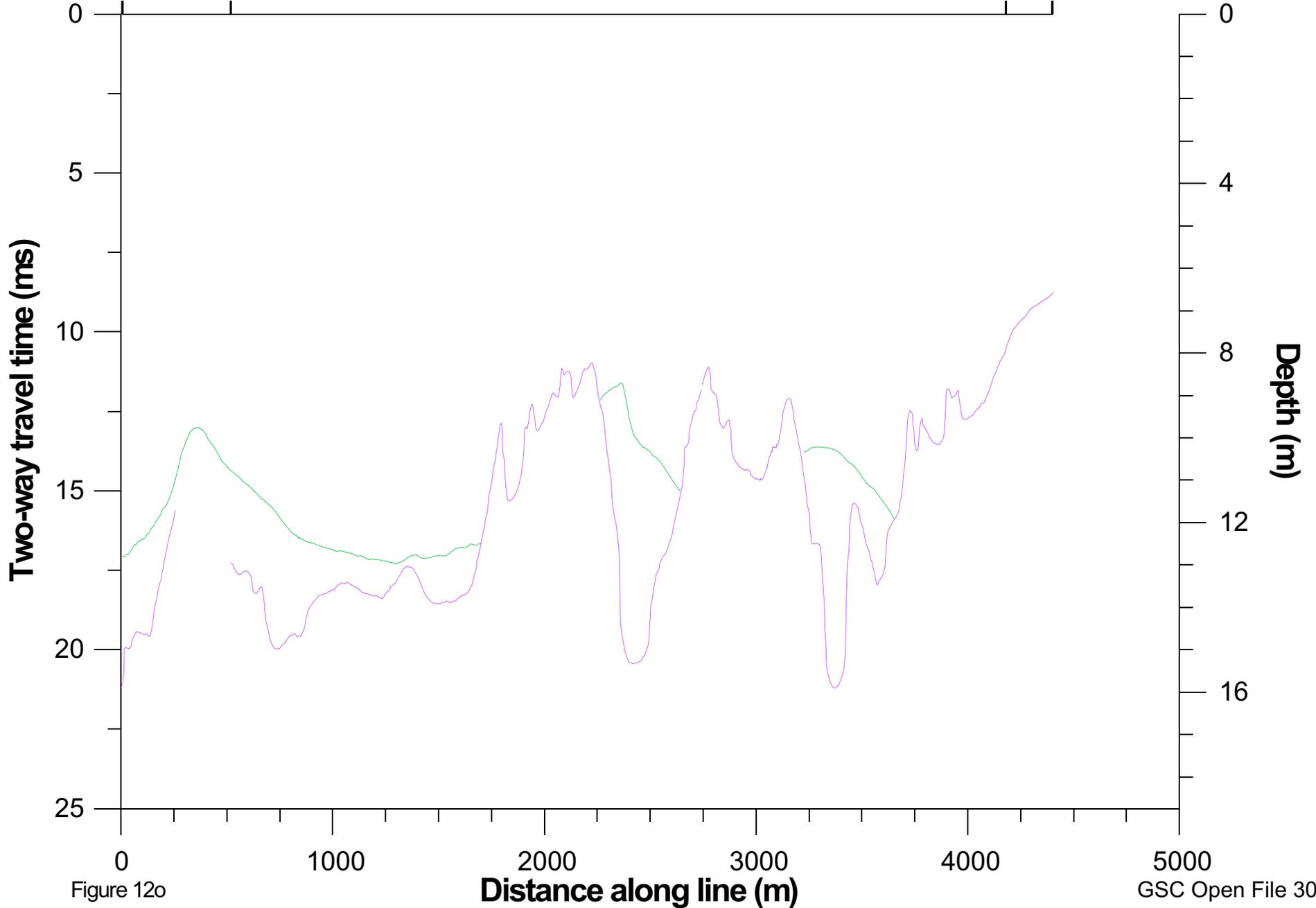
NORTH

Time (UTC)

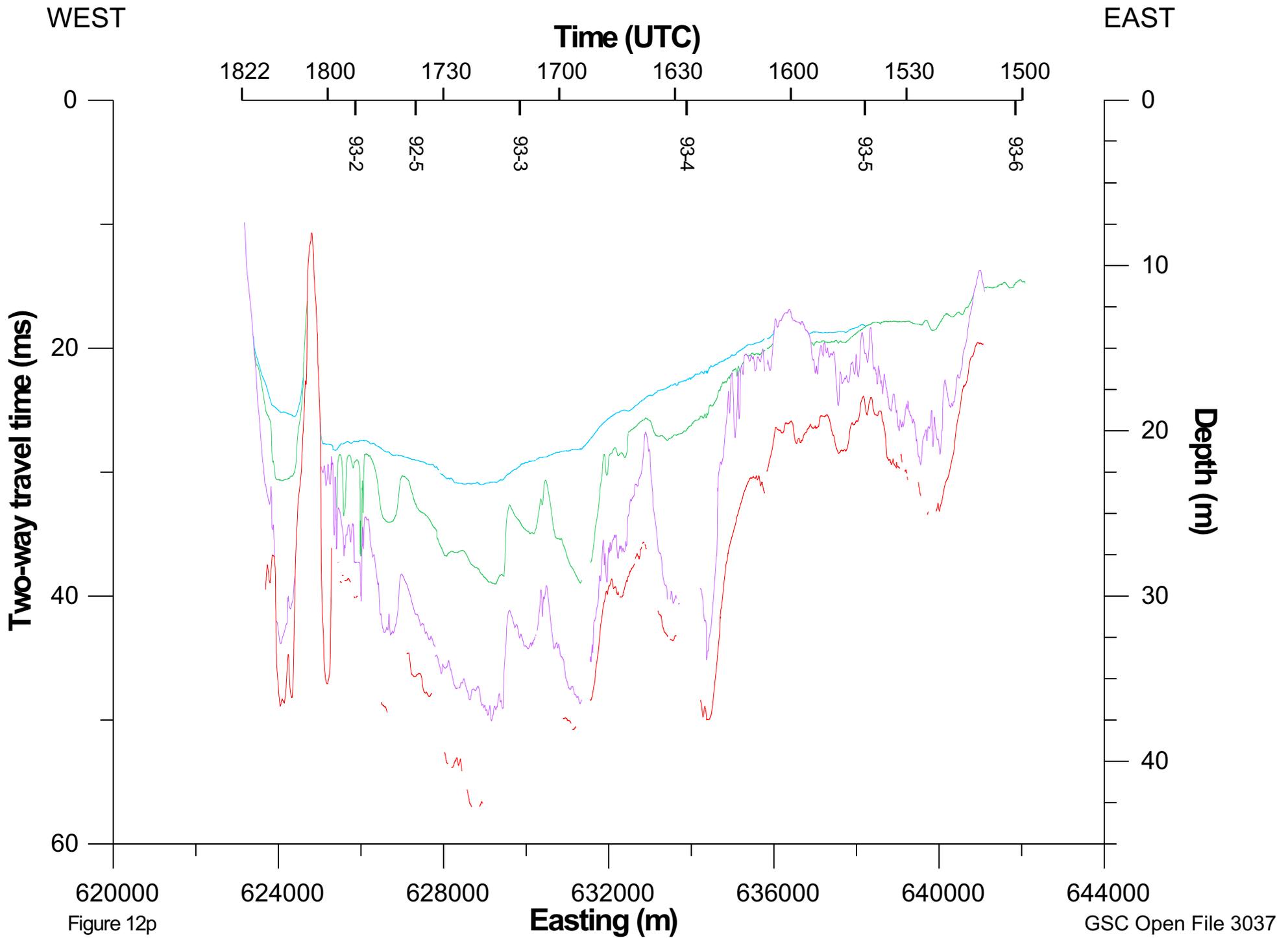
1826

1830

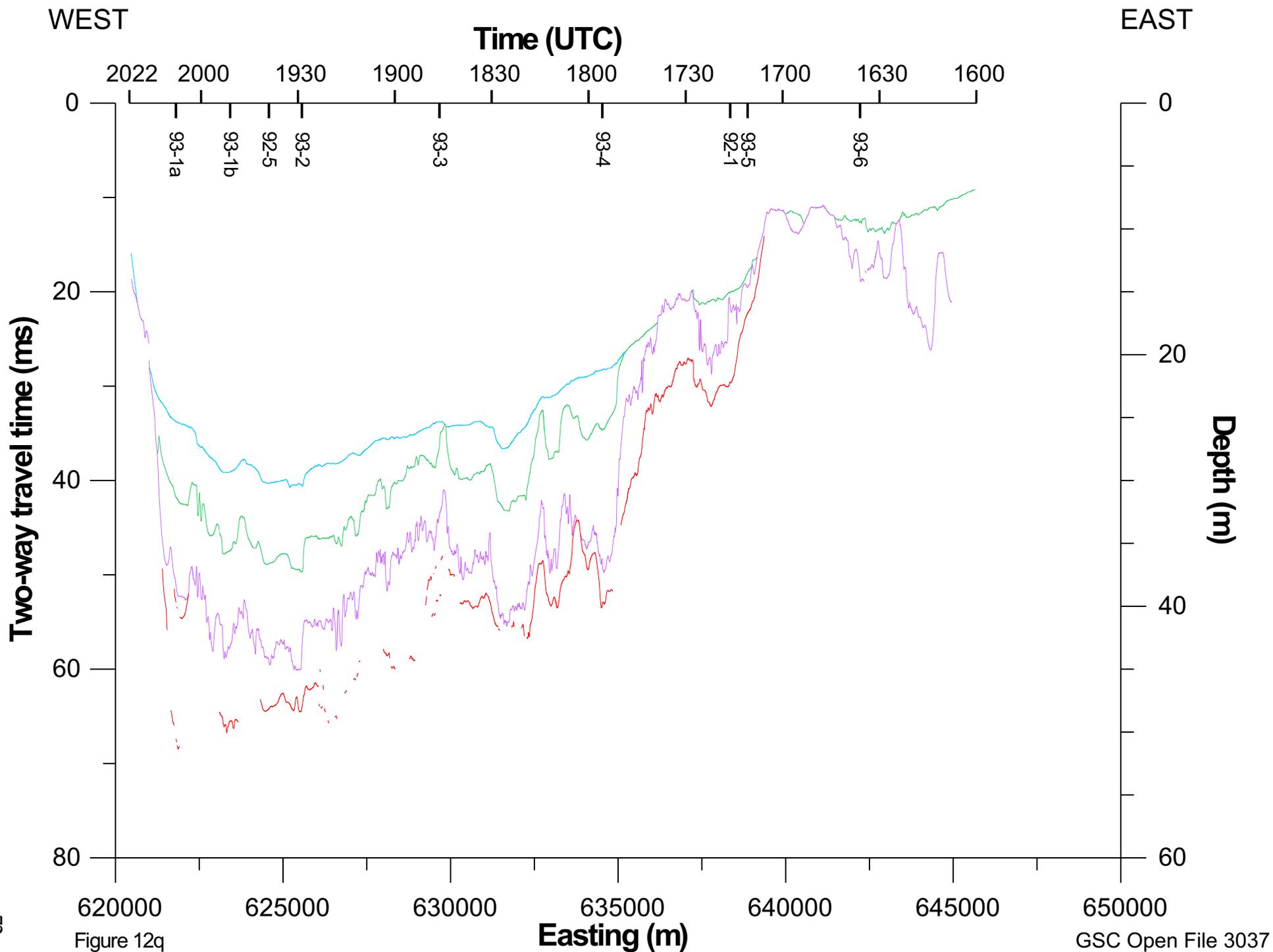
1900 1902



Lake Simcoe - Line 93-9



Lake Simcoe - Line 93-10

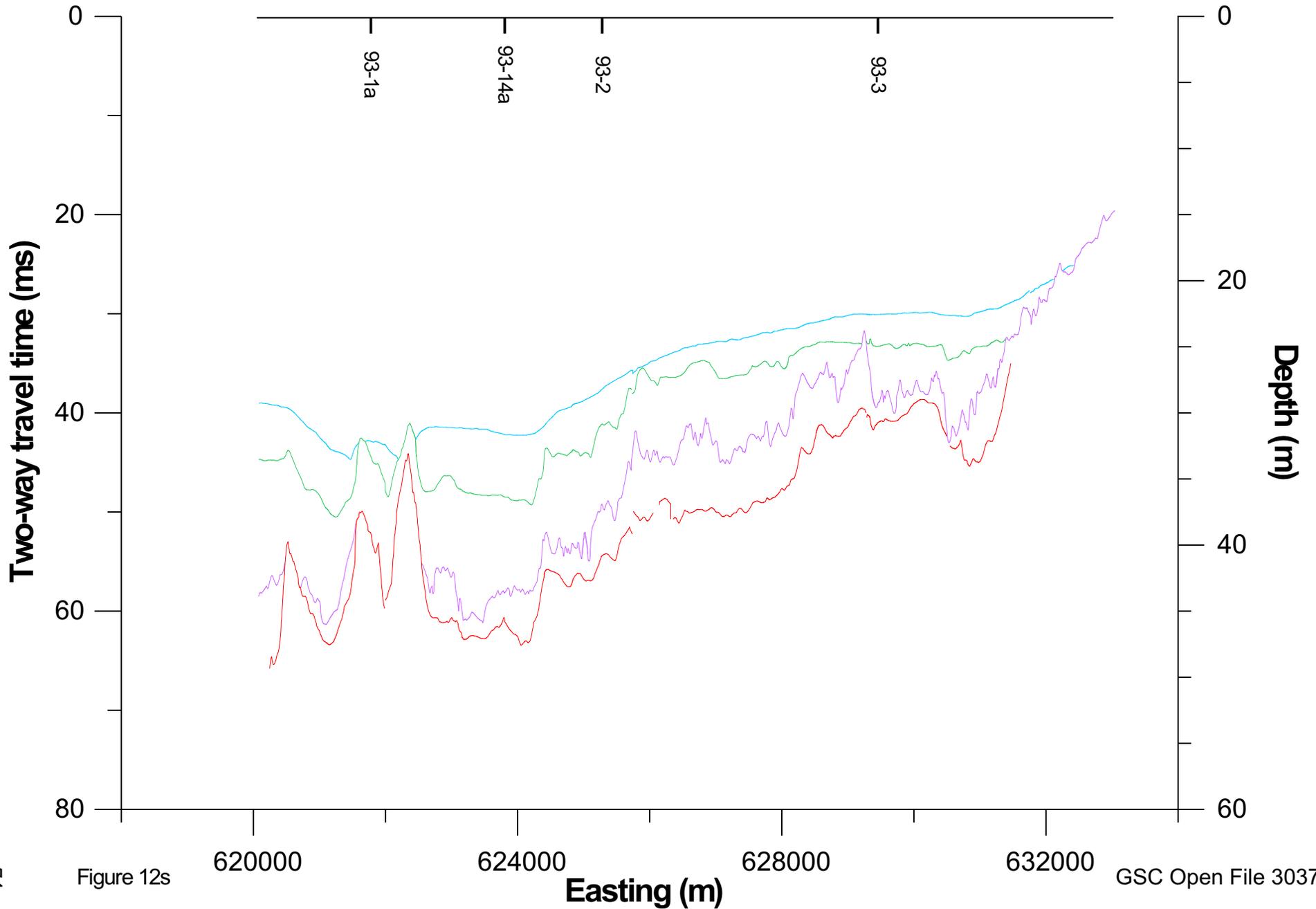


Lake Simcoe - Line 93-12W

WEST

EAST

Time (UTC)

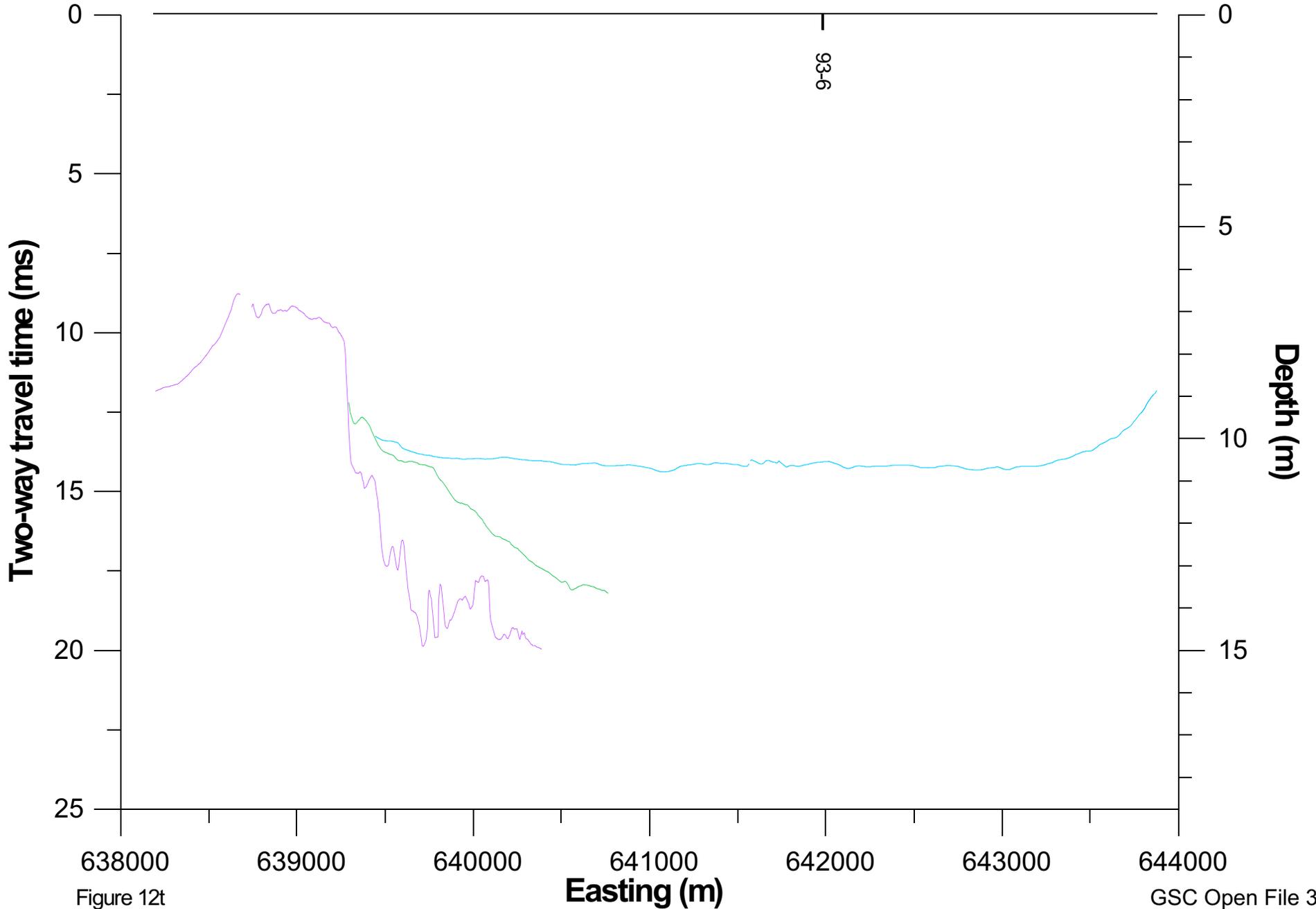


Lake Simcoe - Line 93-12E

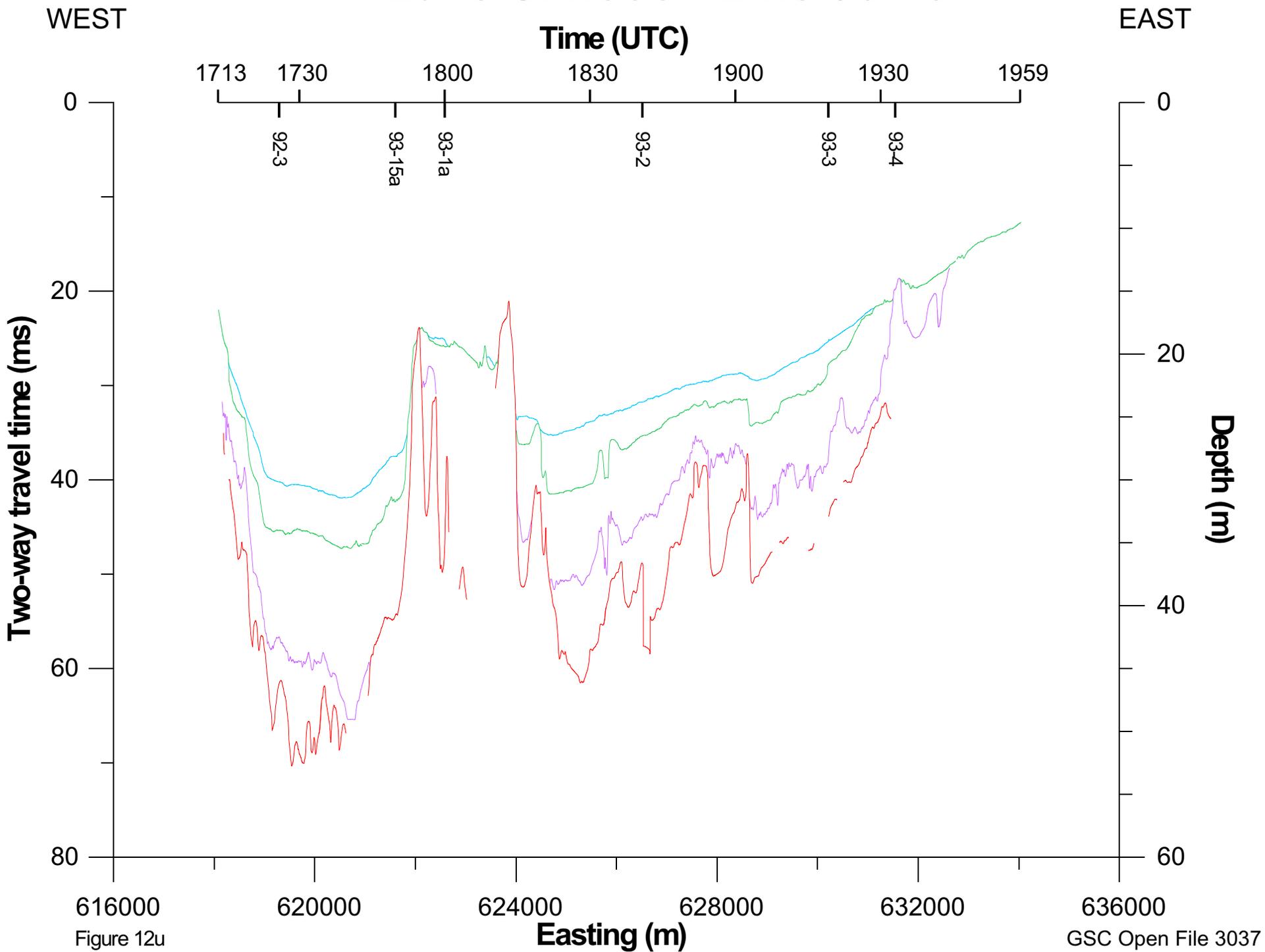
WEST

EAST

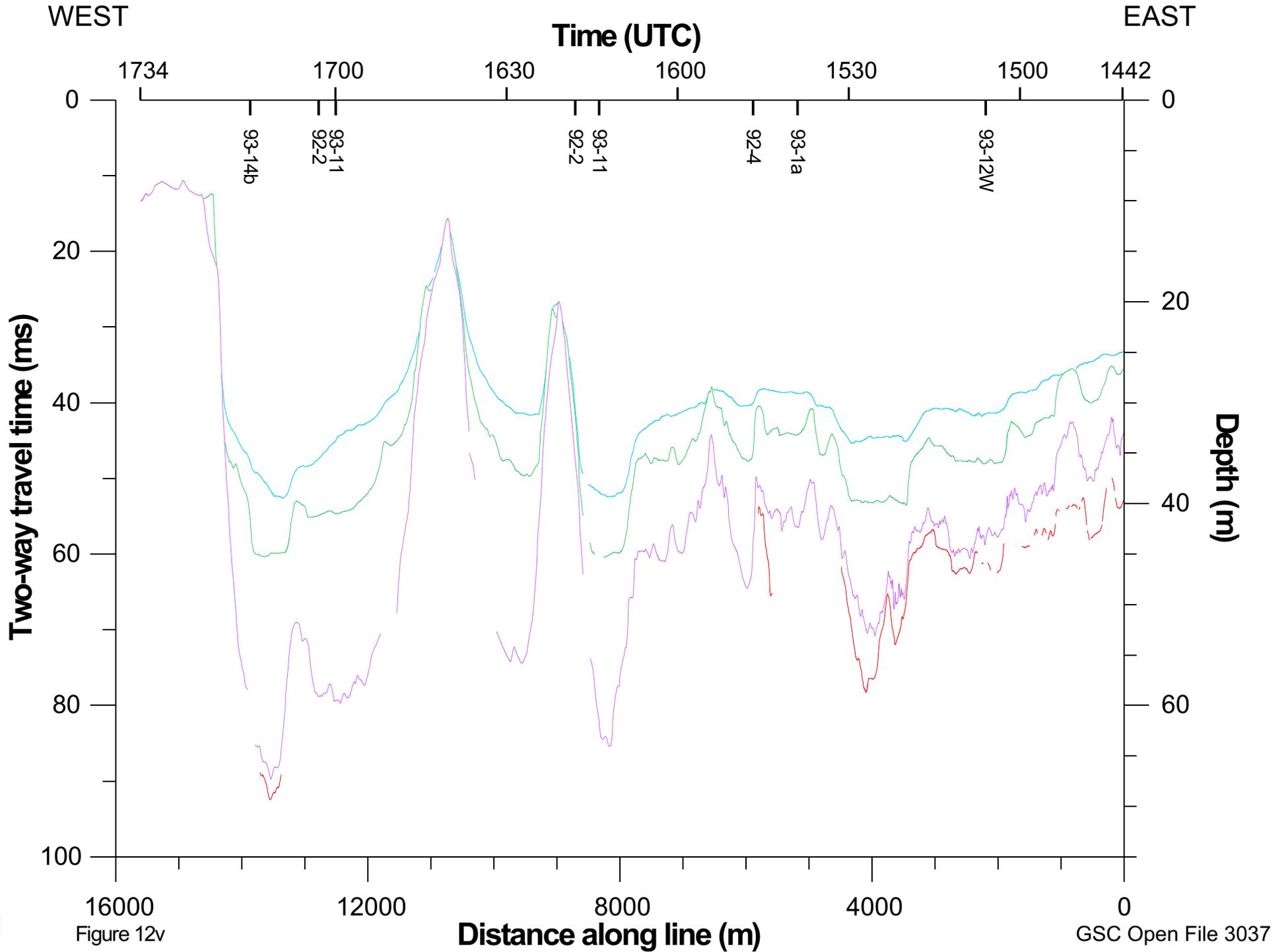
Time (UTC)



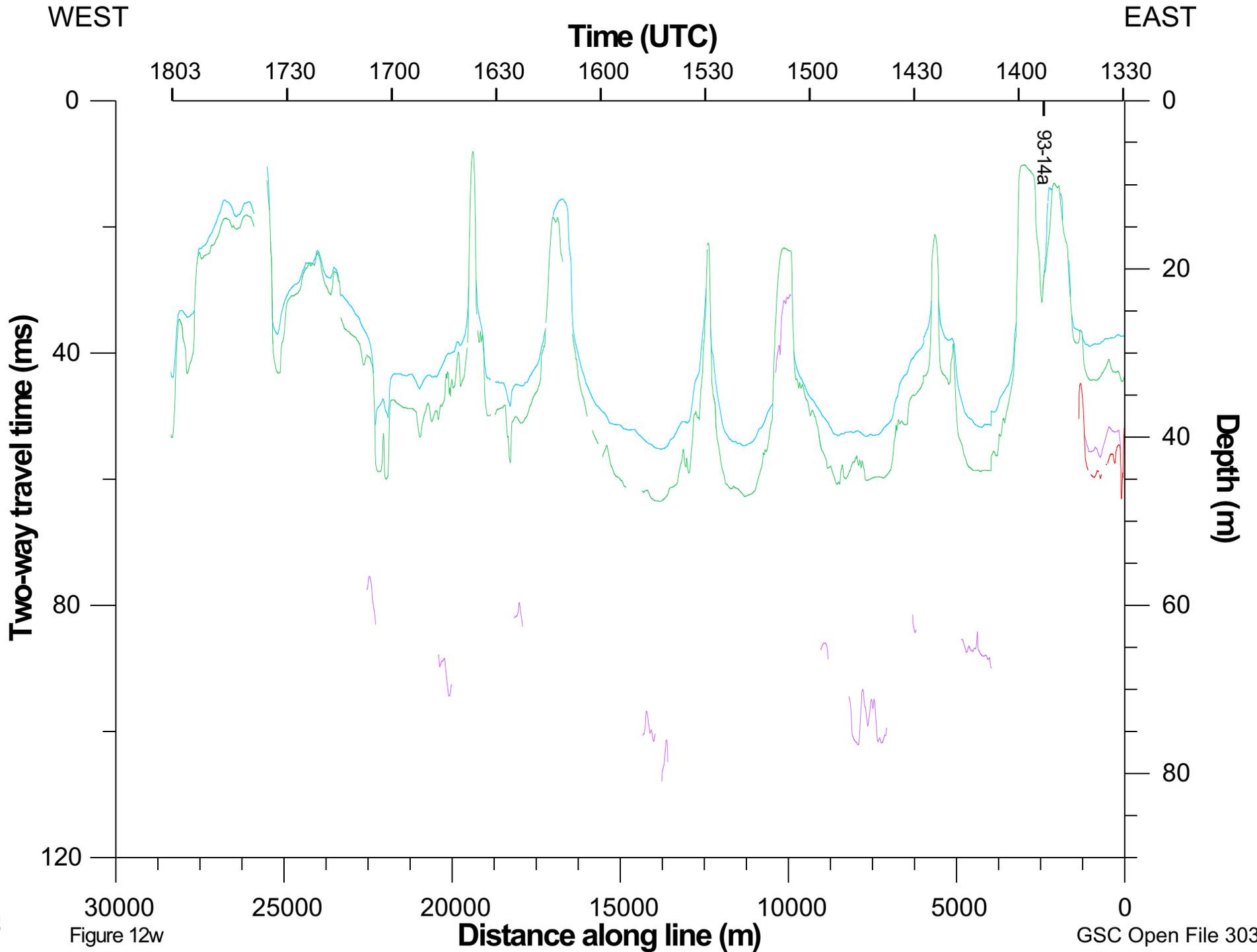
Lake Simcoe - Line 93-13



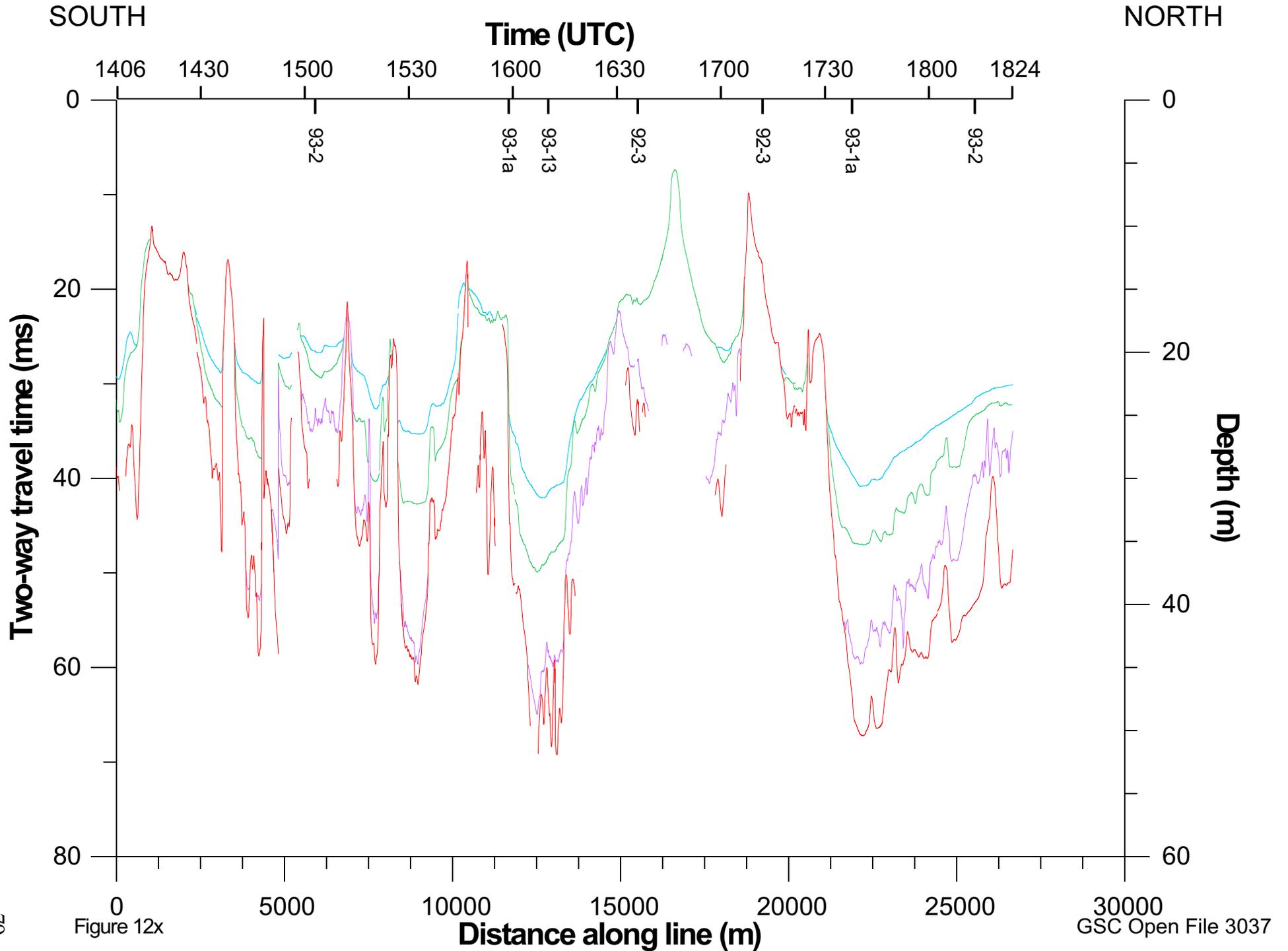
Lake Simcoe - Line 93-14a



Lake Simcoe - Line 93-14b



Lake Simcoe - Line 93-15a



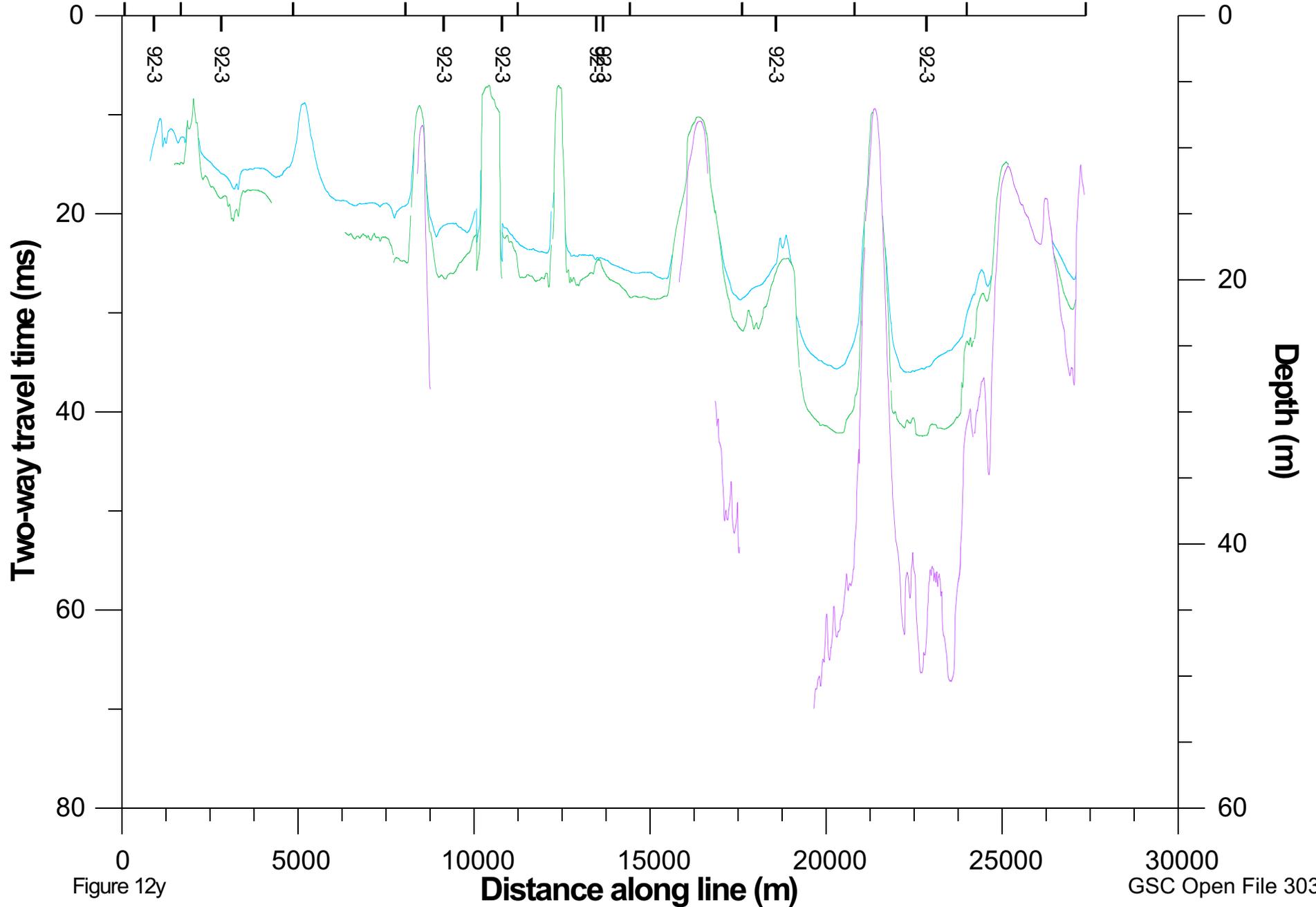
Lake Simcoe - Line 93-15b

SOUTH

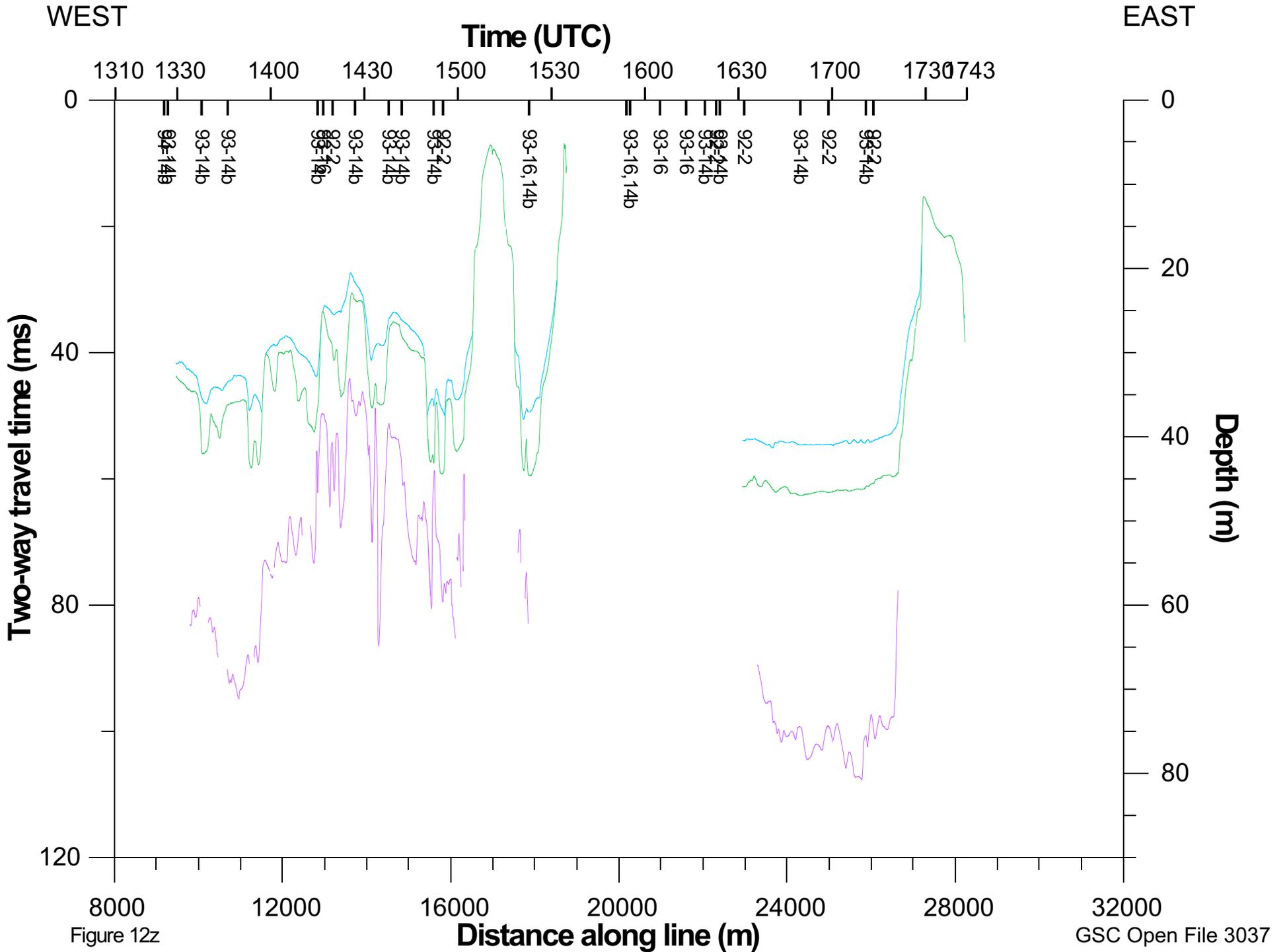
NORTH

Time (UTC)

1415 1430 1500 1530 1600 1630 1700 1730 1800 1832



Lake Simcoe - Line 93-16



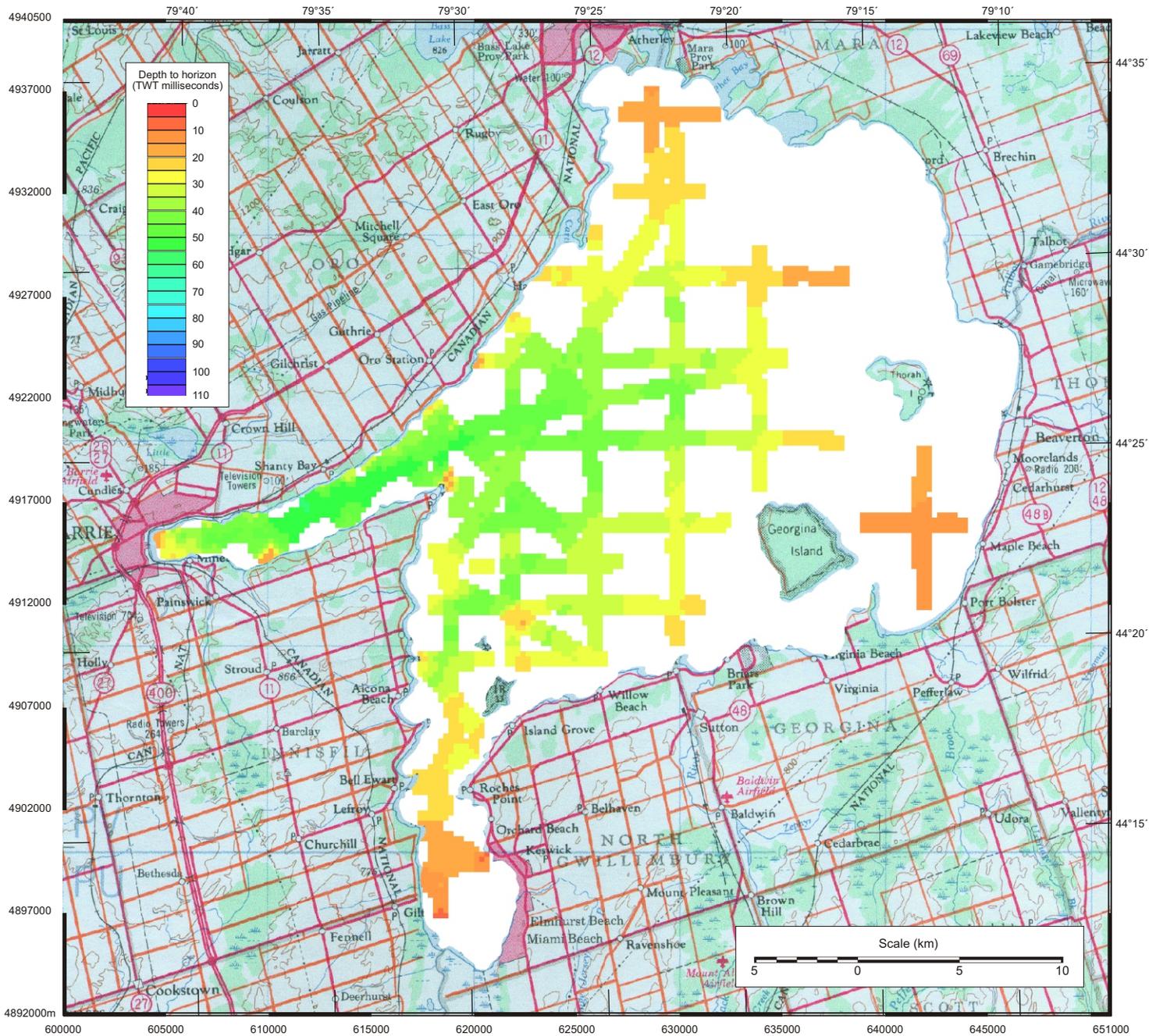


Figure 13a. Extent and depth of Blue Sequence sediments.

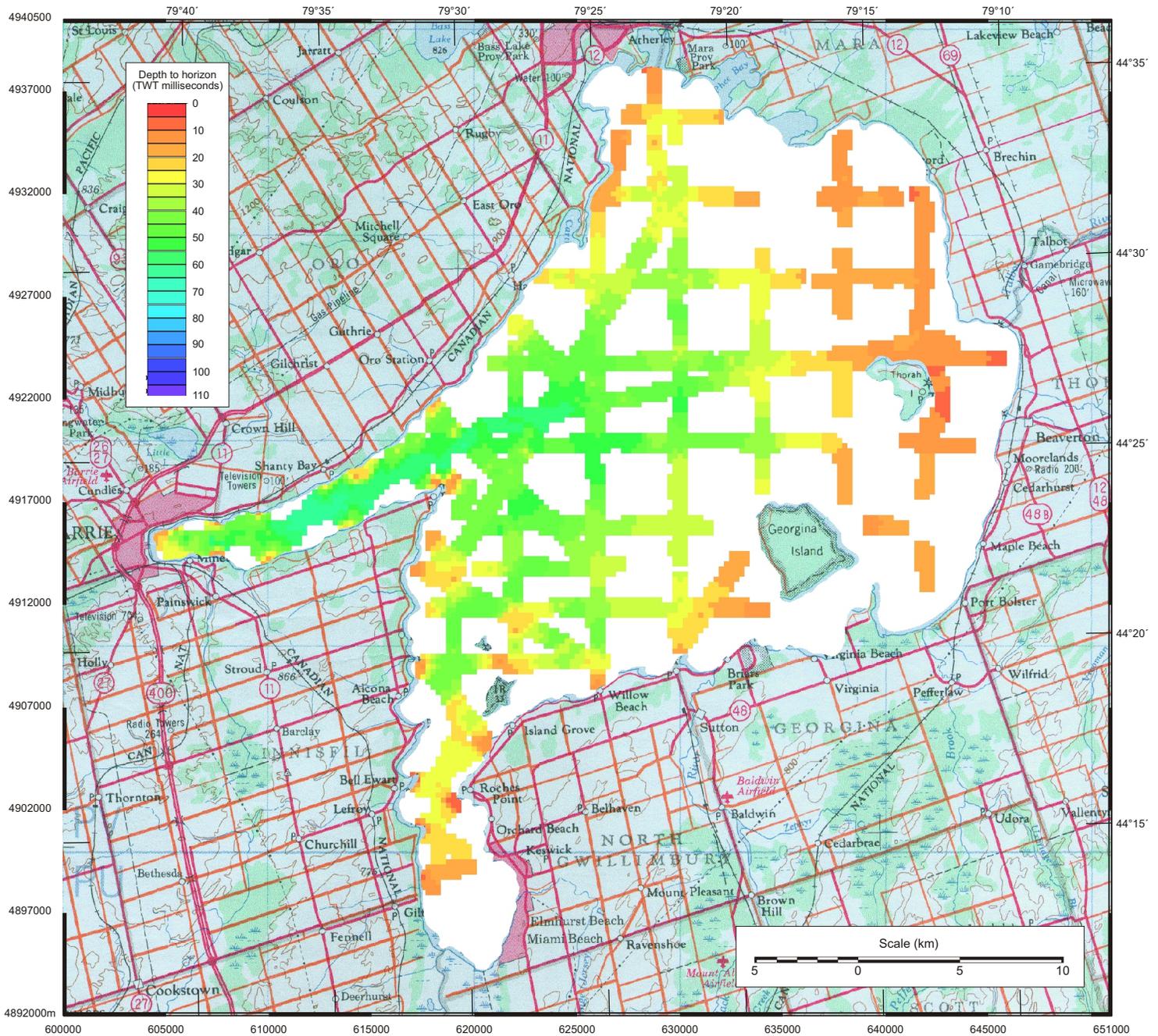


Figure 13c. Extent and depth of Green Sequence sediments.

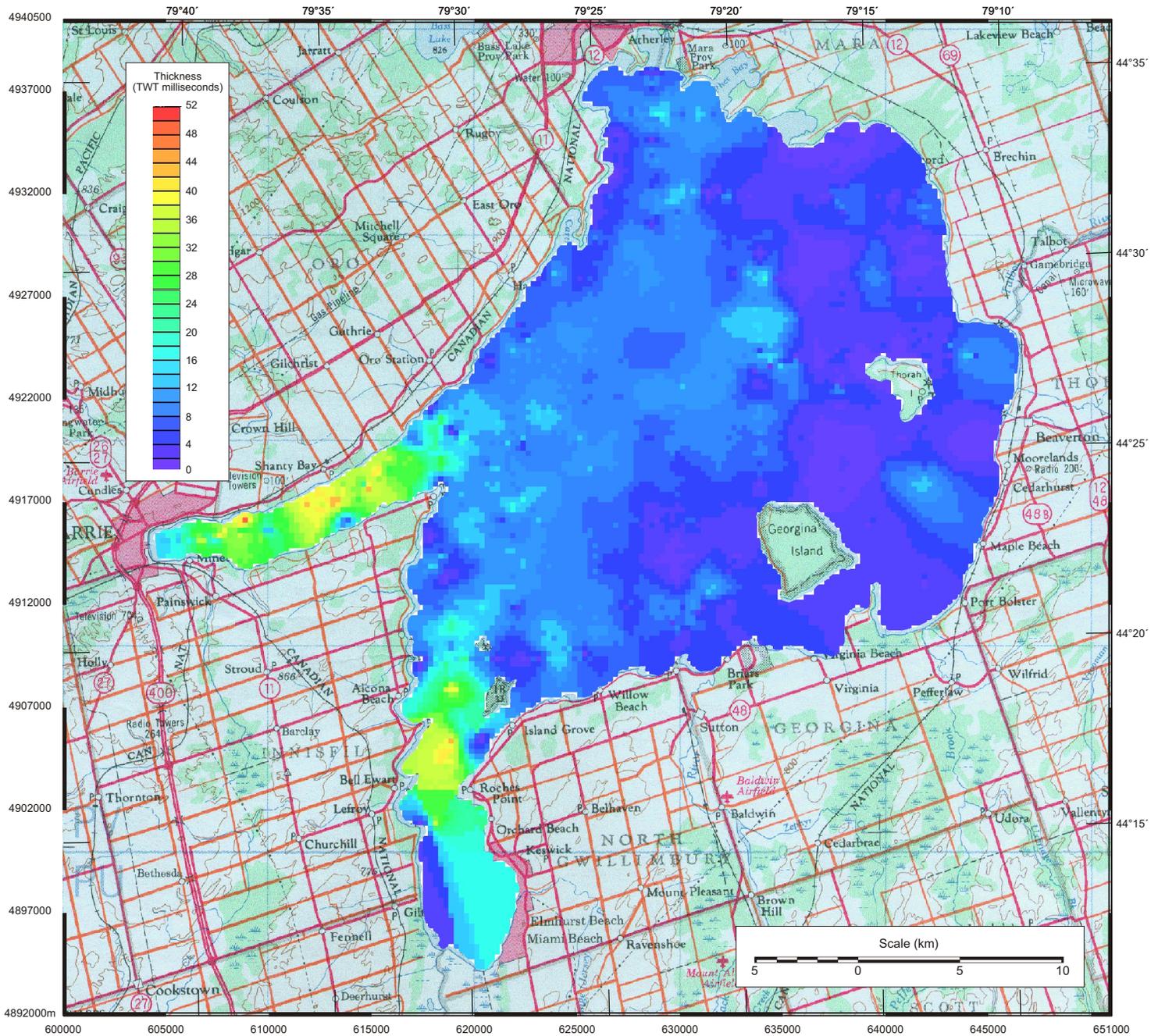


Figure 13d. Isopach of Green Sequence sediments.

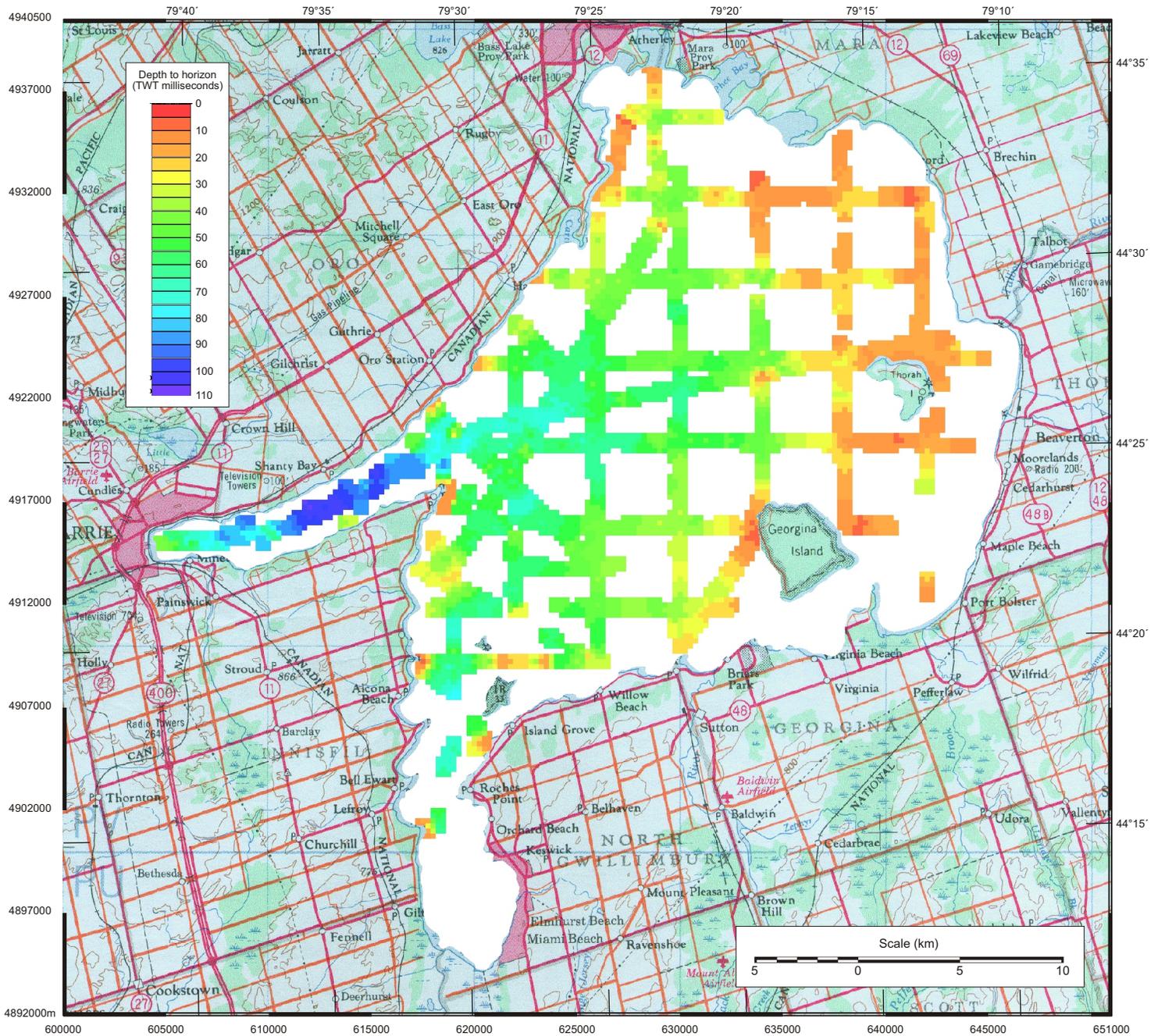


Figure 13e. Extent and depth of Purple Sequence sediments.

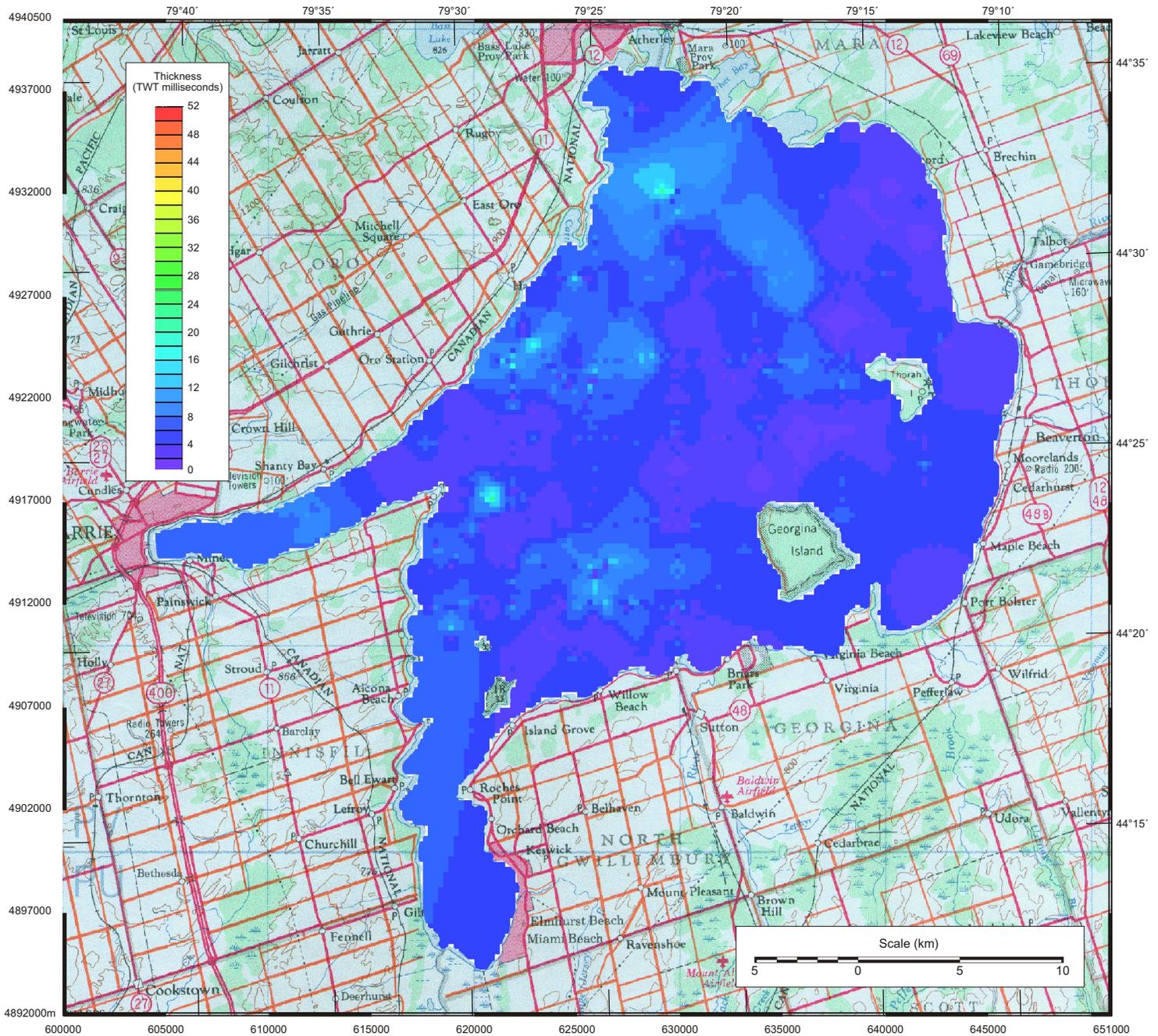


Figure 13f. Isopach of Purple Sequence sediments.

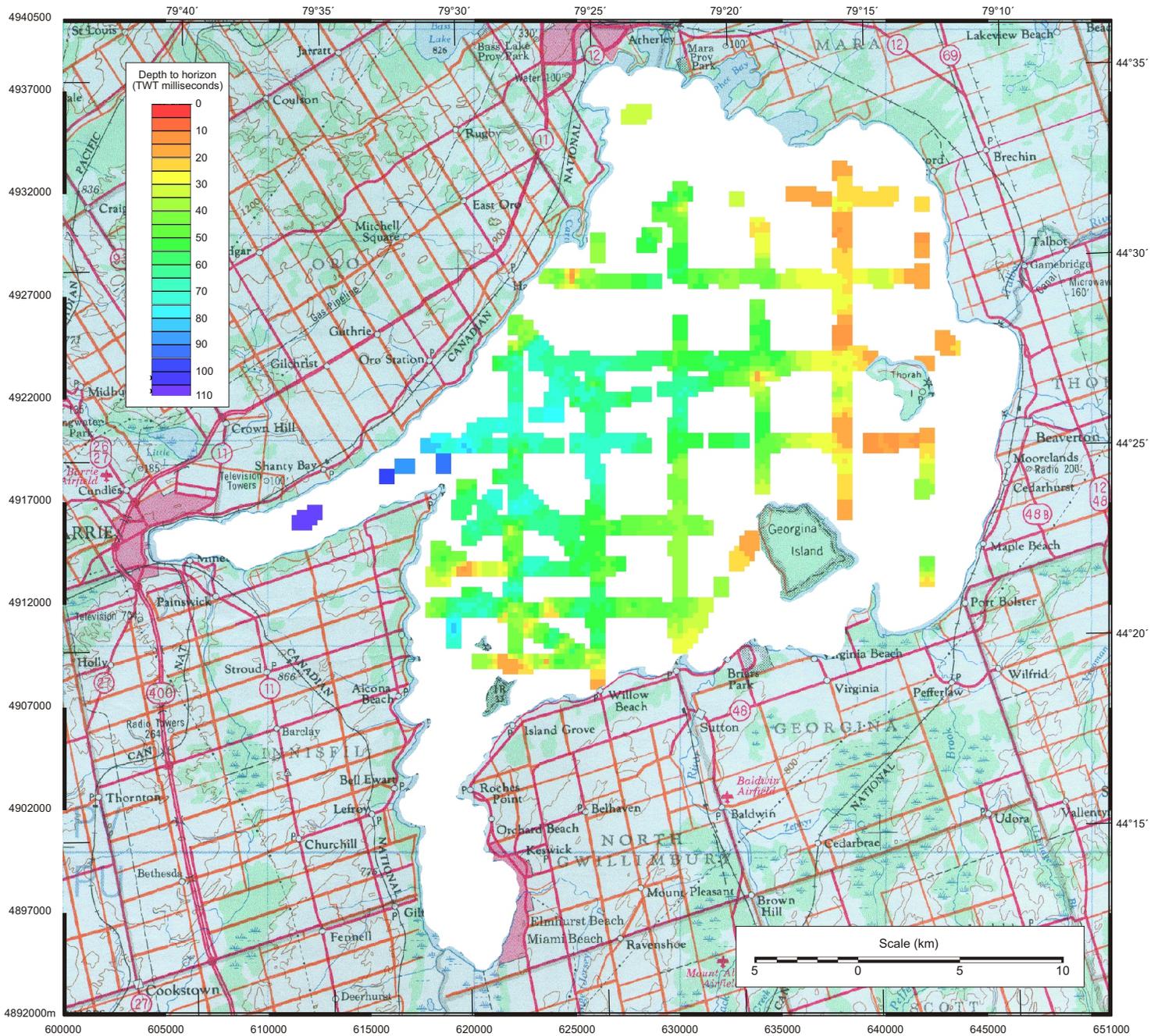


Figure 13g. Extent and depth of Red Sequence sediments.

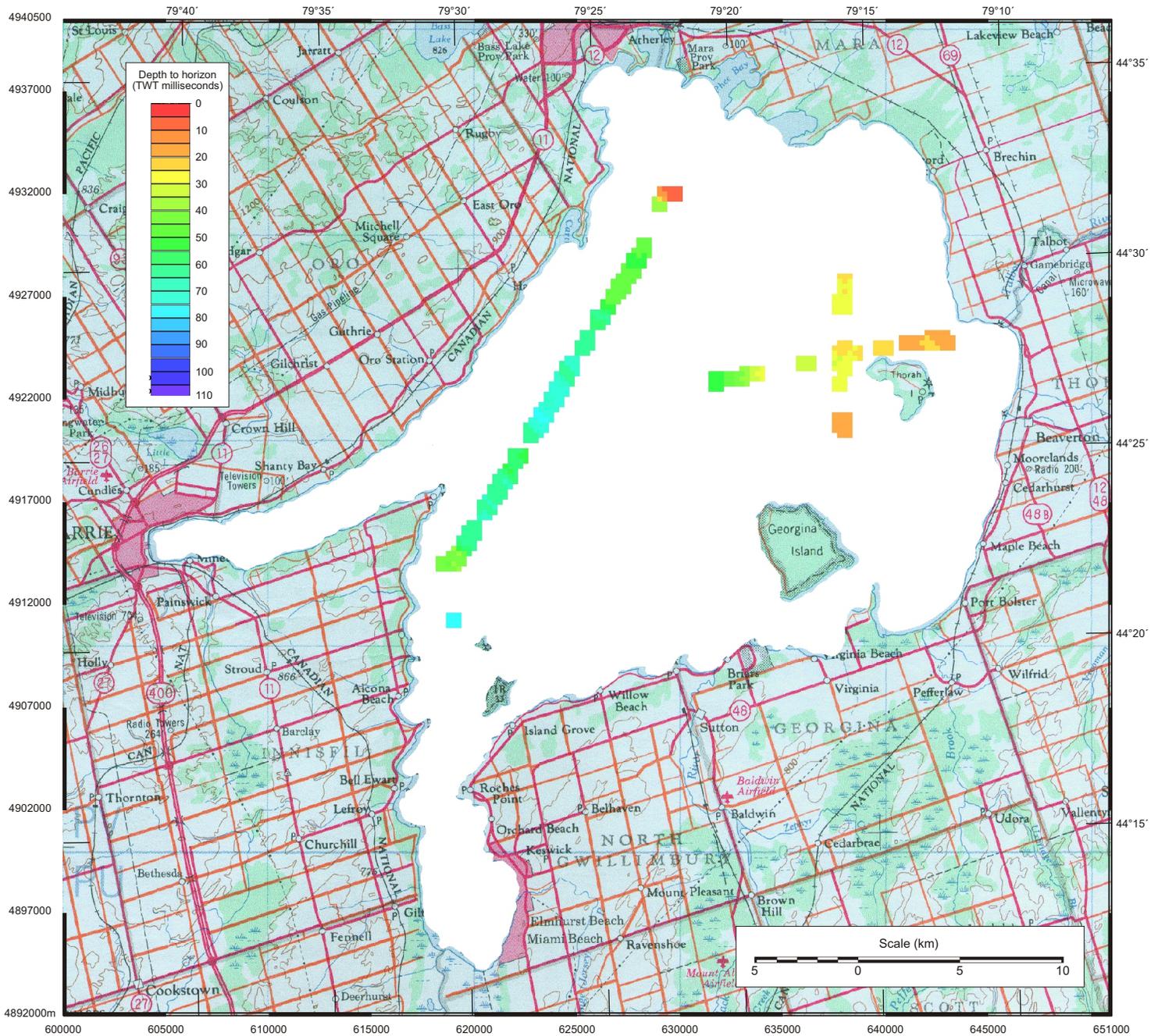


Figure 13h. Extent and depth of Brown Sequence sediments.

Appendix A: Airgun seismic profiles

Single-channel - common offset gathers

Trace number = 2

Offset from source = 34 m

Automatic gain control with 80 ms window

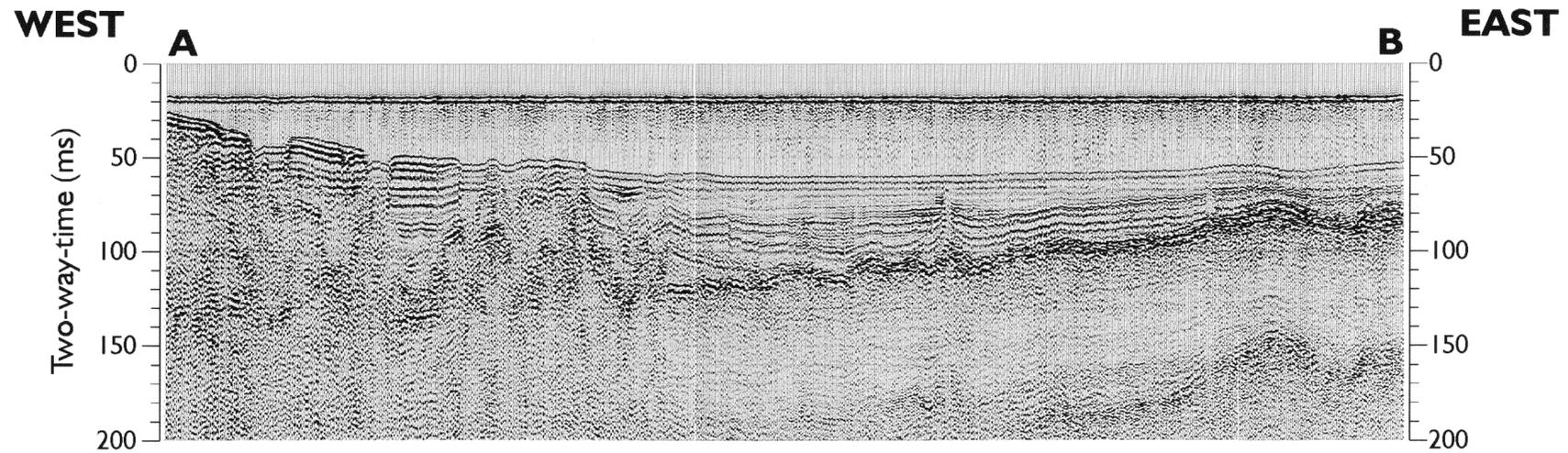
Digital bandpass filter 100-800 Hz



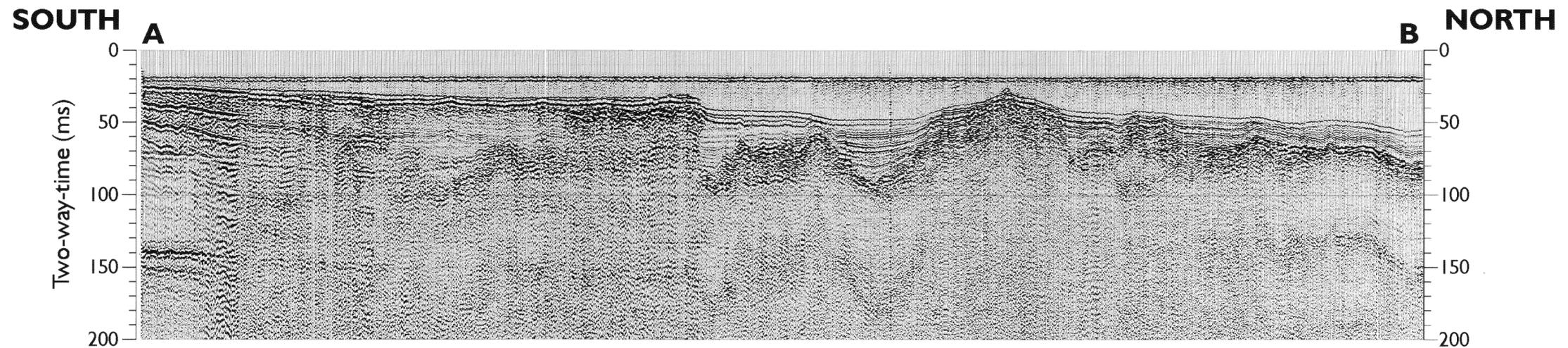
LAKE SIMCOE SEISMIC PROFILES



LINE 92-6



LINE 92-7



V.E. (@1500 m/s) = 11.4X



Distance (km)

To accompany GSC Open File 3037



Natural Resources Canada / Ressources naturelles Canada

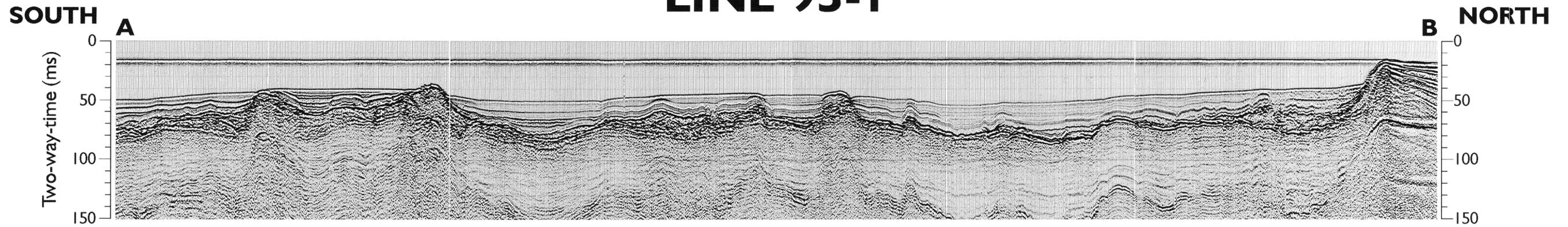
Copies of this sheet may be obtained from the Geological Survey of Canada: 601 Booth Street, Ottawa, Ontario K1A 0E6



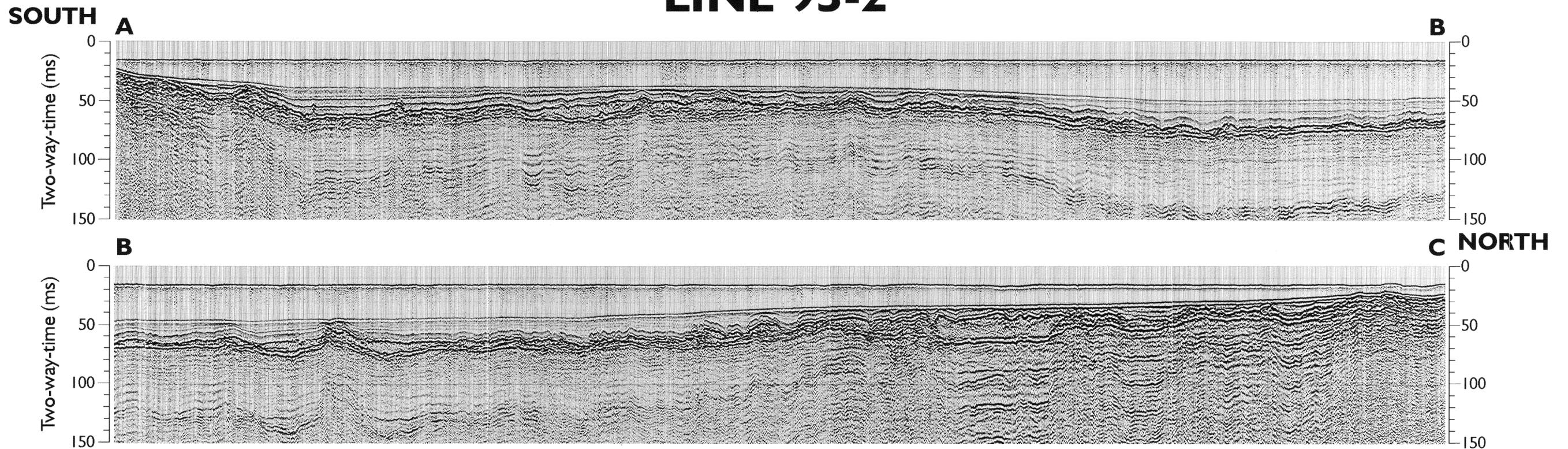
LAKE SIMCOE SEISMIC PROFILES



LINE 93-1



LINE 93-2



V.E. (@1500 m/s) = 11.6X



Distance (km)

To accompany GSC Open File 3037



Natural Resources Canada / Ressources naturelles Canada

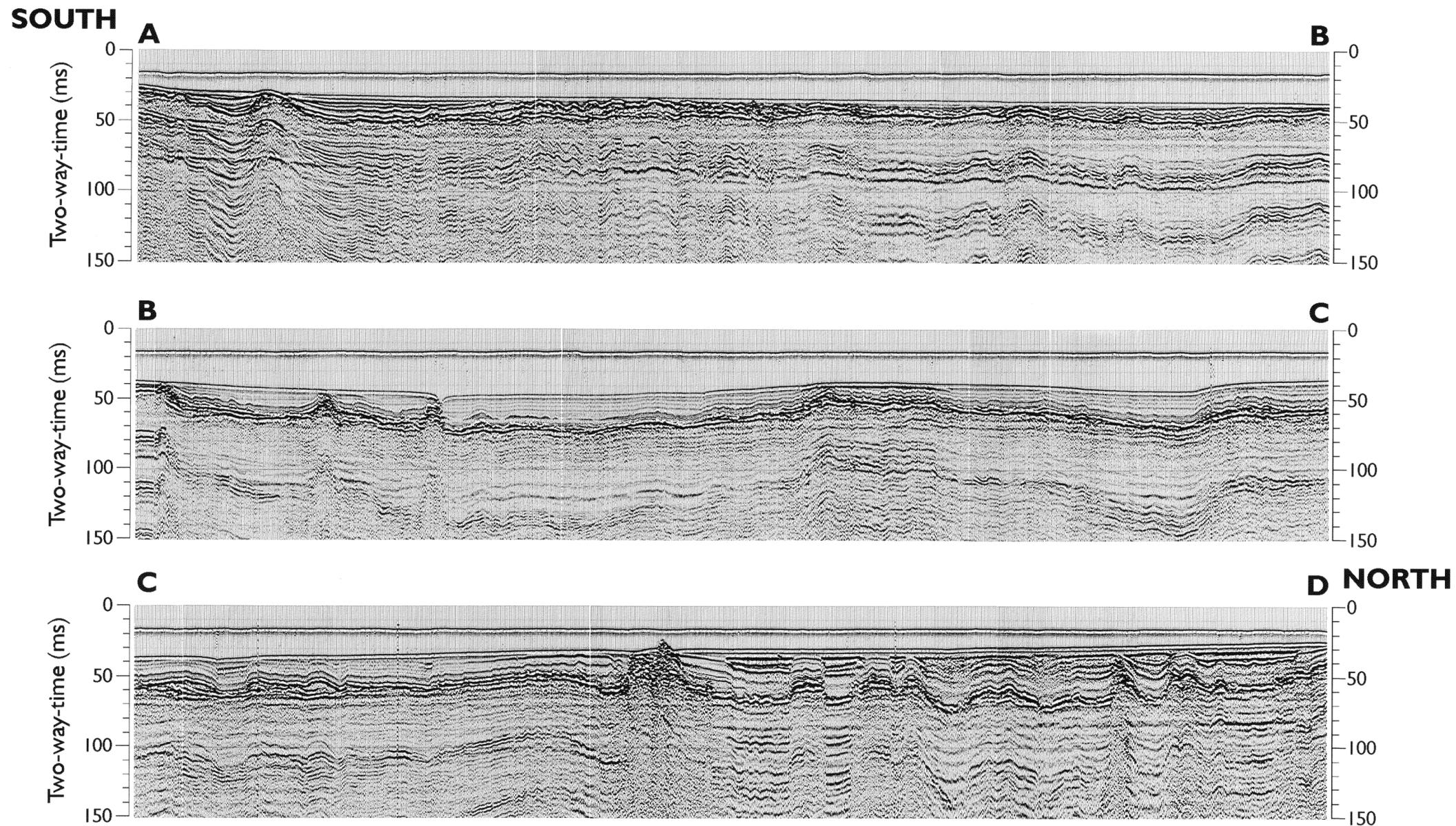
Copies of this sheet may be obtained from the Geological Survey of Canada: 601 Booth Street, Ottawa, Ontario K1A 0E8



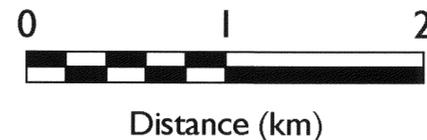
LAKE SIMCOE SEISMIC PROFILES



LINE 93-3



V.E. (@1500 m/s)=11.6X



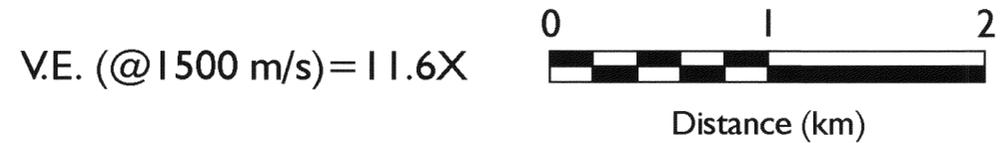
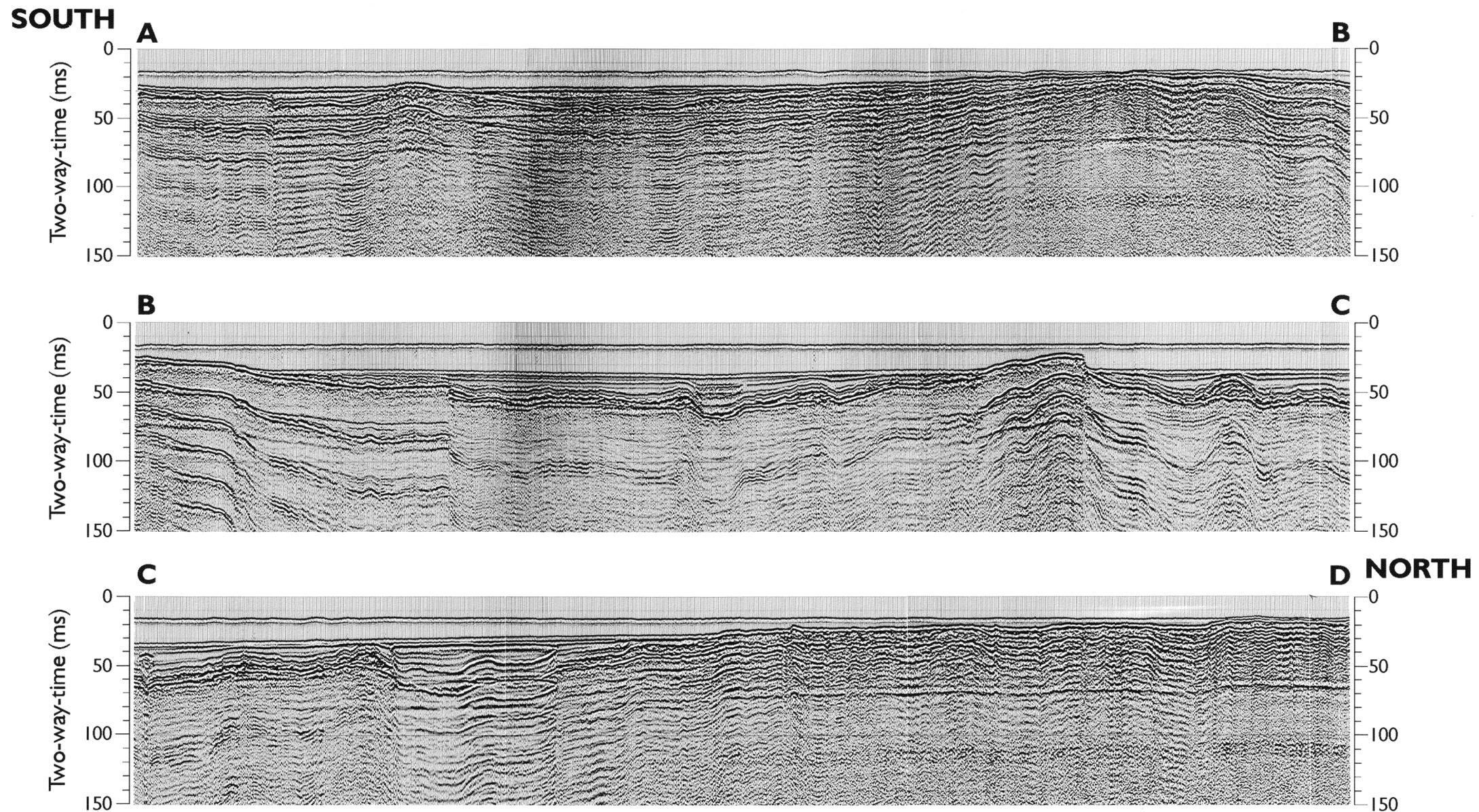
To accompany GSC Open File 3037



LAKE SIMCOE SEISMIC PROFILES



LINE 93-4



To accompany GSC Open File 3037

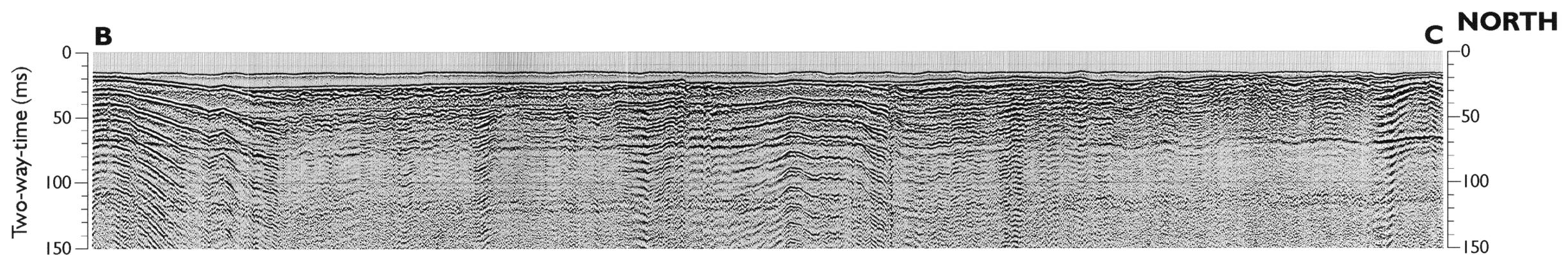
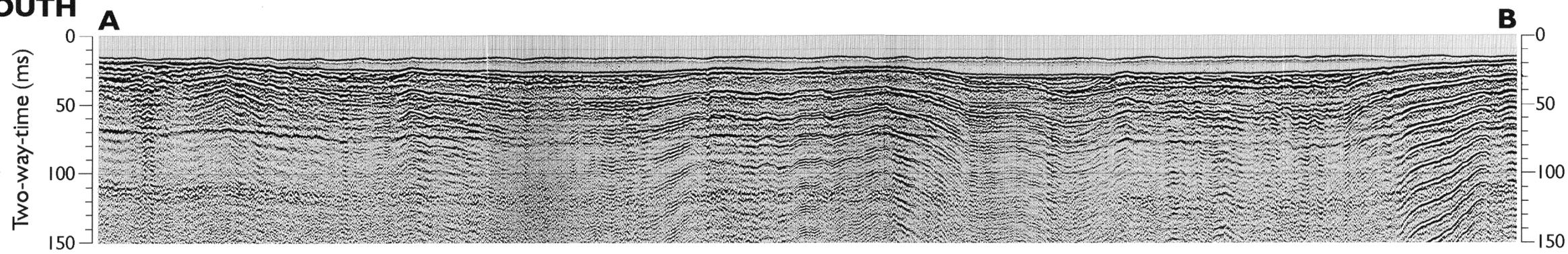


LAKE SIMCOE SEISMIC PROFILES

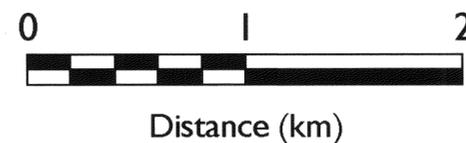


LINE 93-5

SOUTH



V.E. (@ 1500 m/s) = 11.6X



To accompany GSC Open File 3037



LAKE SIMCOE SEISMIC PROFILES

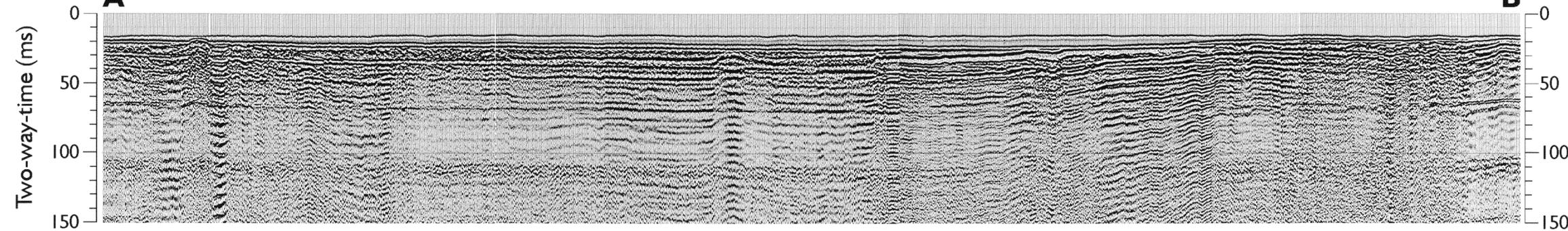


LINE 93-6

SOUTH

A

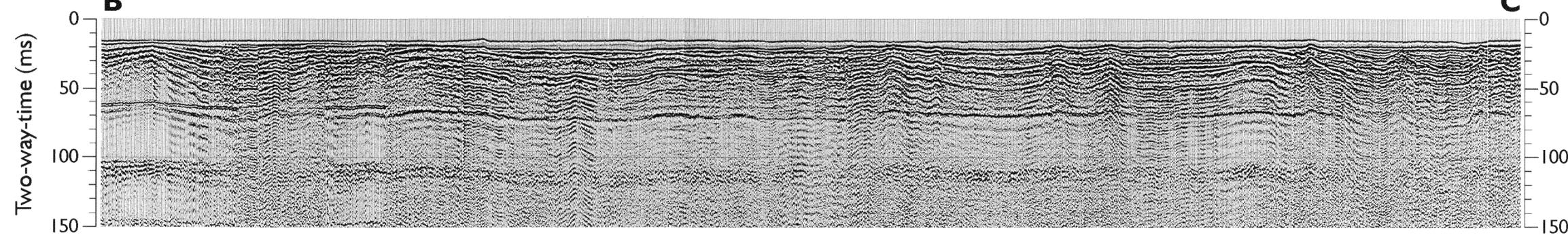
B



B

C

NORTH



V.E. (@1500 m/s)=11.6X



To accompany GSC Open File 3037



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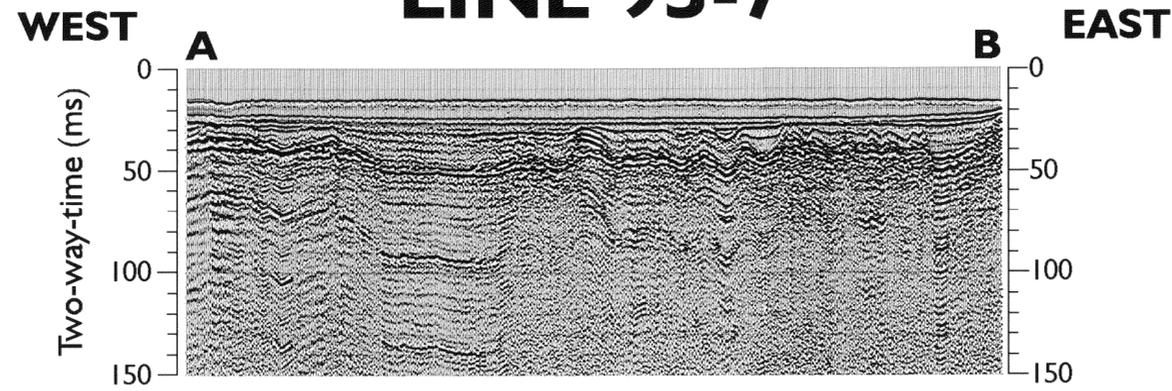
Copies of this sheet may be obtained from the Geological Survey of Canada: 601 Booth Street, Ottawa, Ontario K1A 0E8



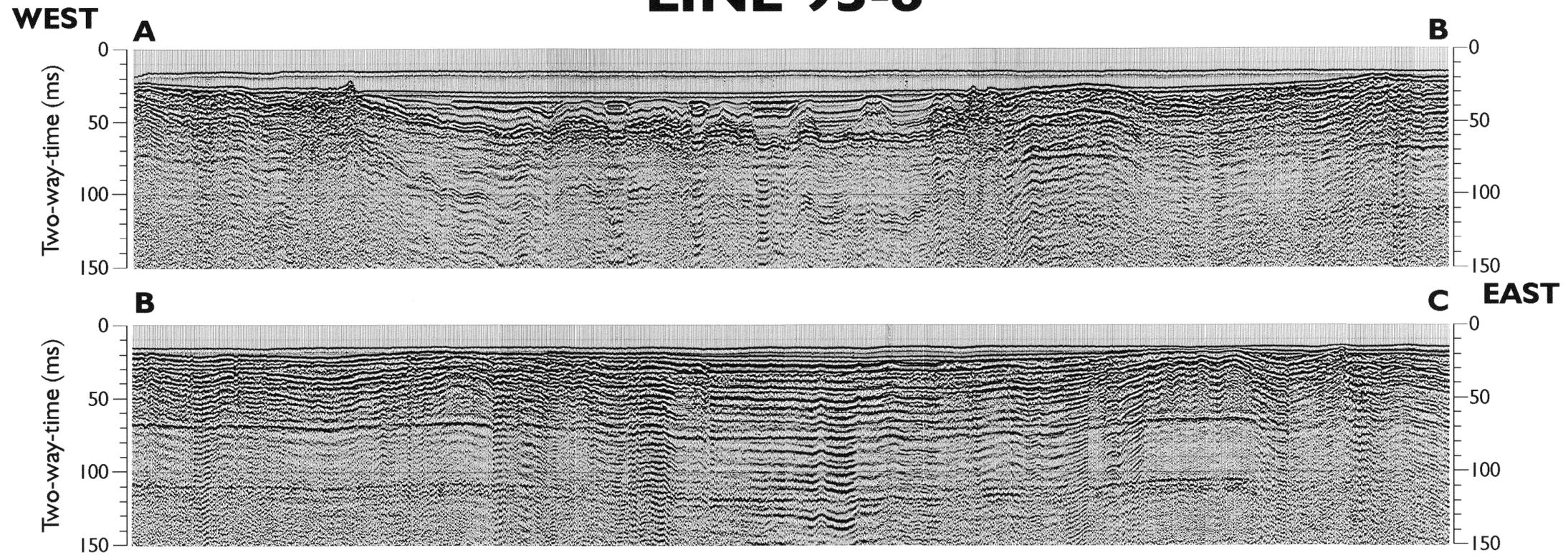
LAKE SIMCOE SEISMIC PROFILES



LINE 93-7



LINE 93-8



V.E. (@1500 m/s) = 11.6X



Distance (km)

To accompany GSC Open File 3037



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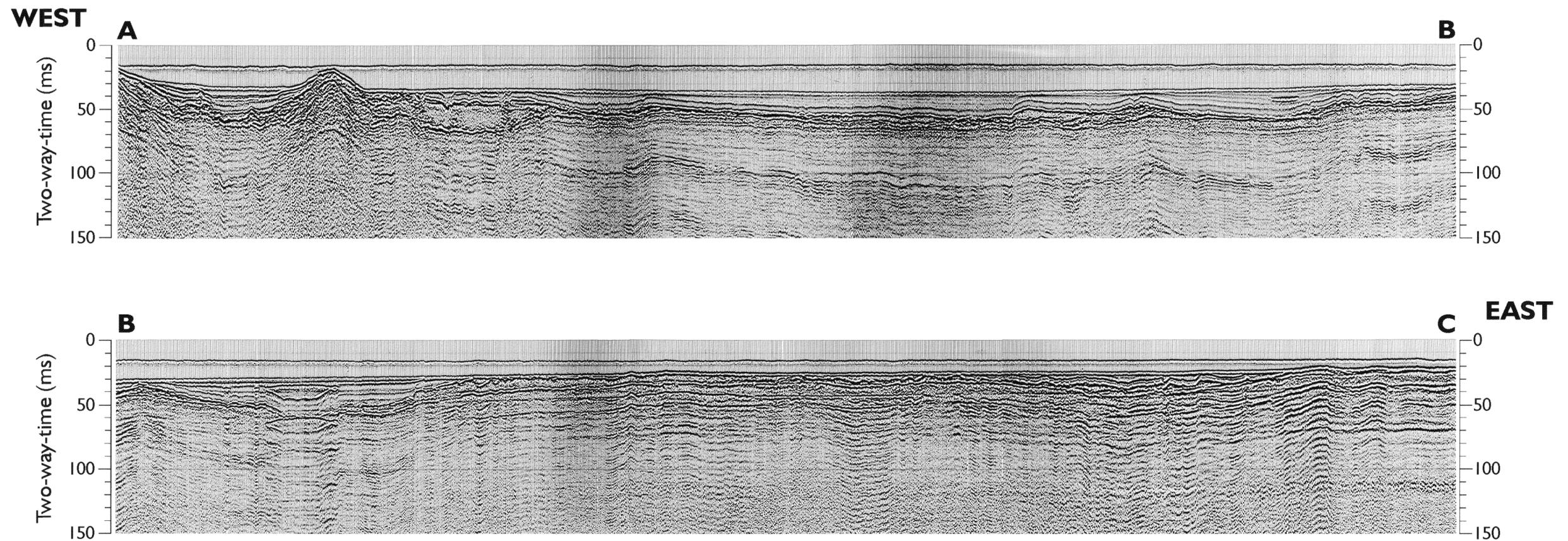
Copies of this sheet may be obtained from the Geological Survey of Canada: 601 Booth Street, Ottawa, Ontario K1A 0E8



LAKE SIMCOE SEISMIC PROFILES



LINE 93-9



V.E. (@1500 m/s) = 11.6X



To accompany GSC Open File 3037

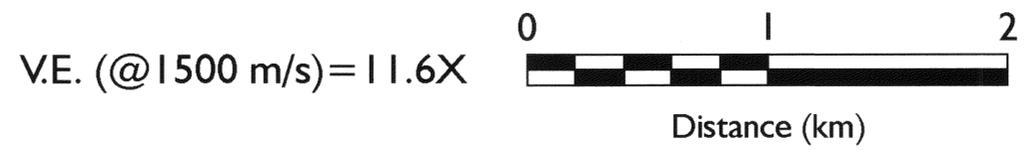
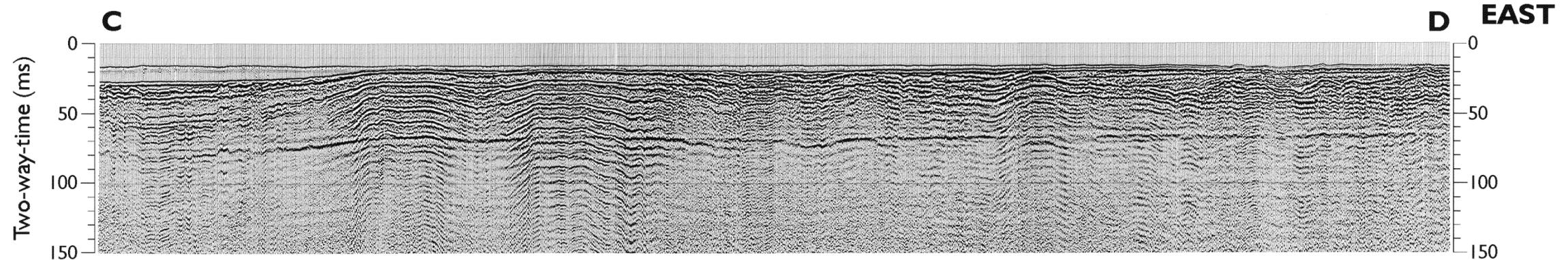
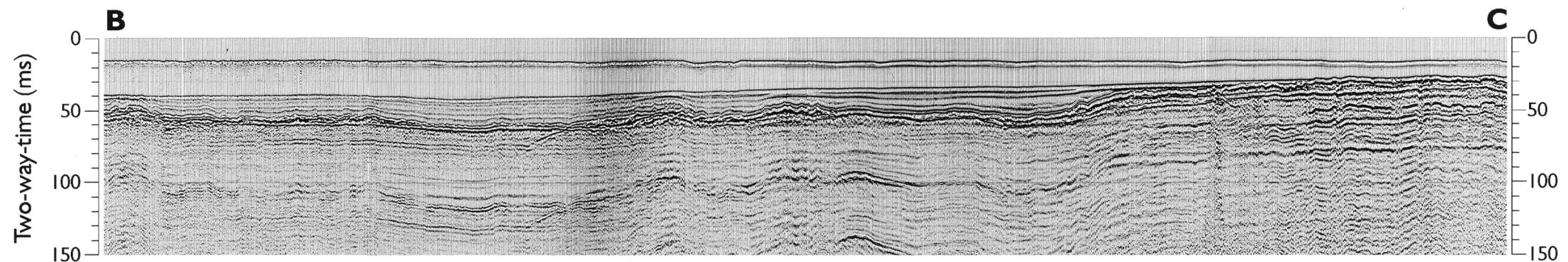
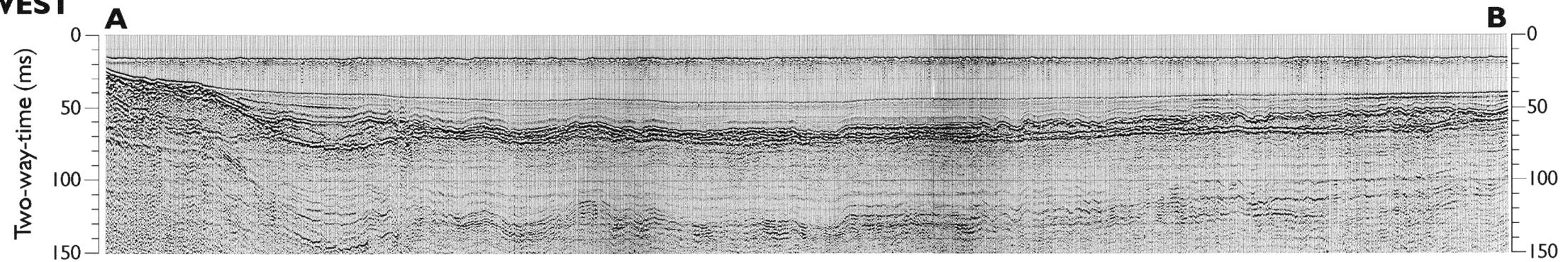


LAKE SIMCOE SEISMIC PROFILES



LINE 93-10

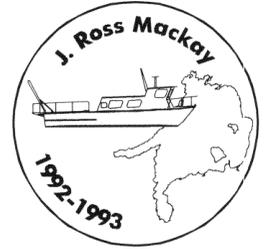
WEST



To accompany GSC Open File 3037

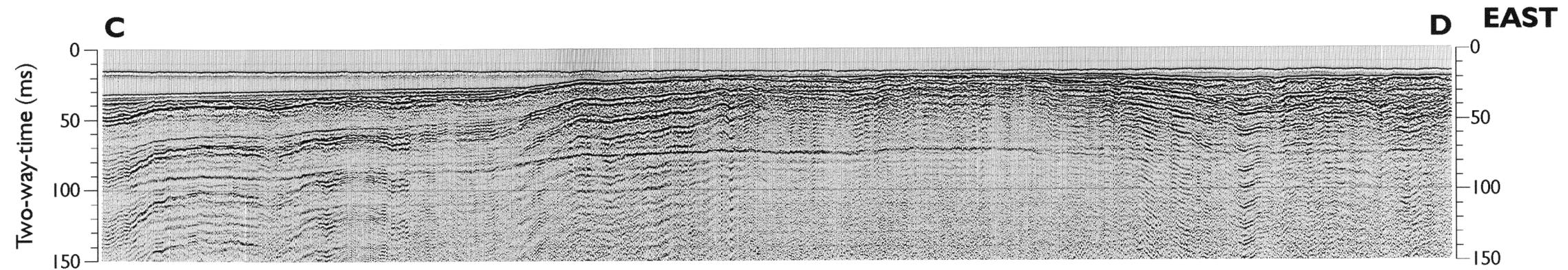
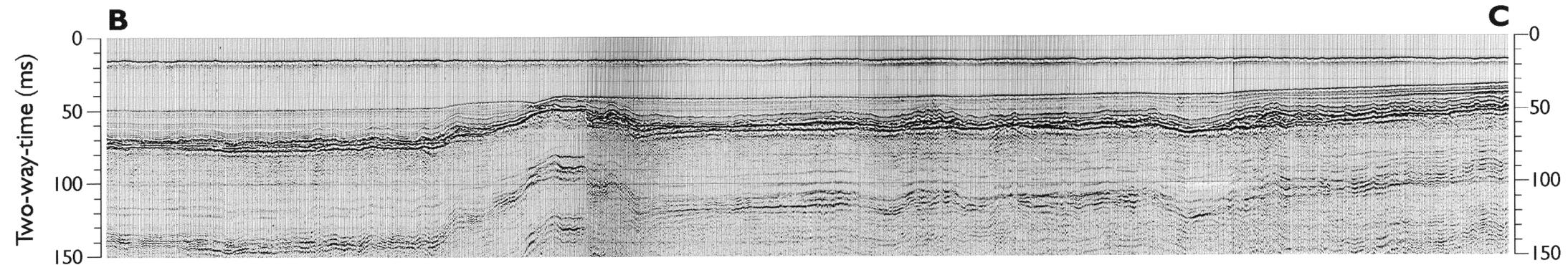
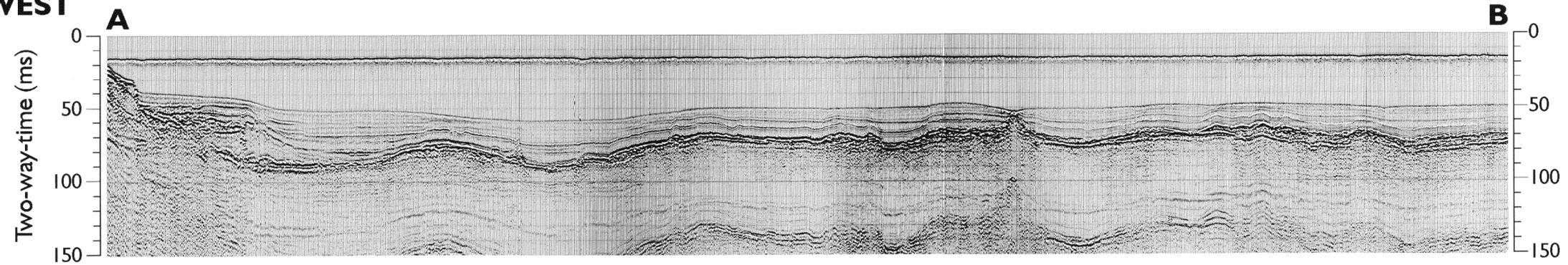


LAKE SIMCOE SEISMIC PROFILES

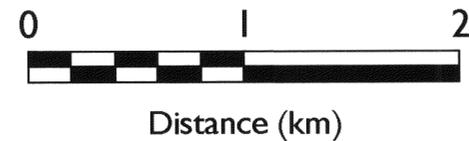


LINE 93-11

WEST



V.E. (@1500 m/s)=11.6X



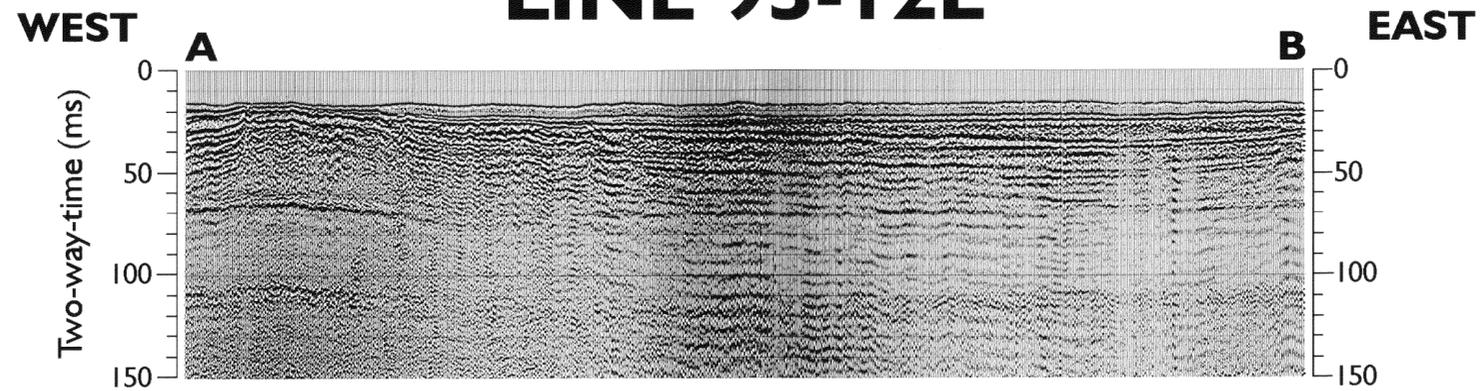
To accompany GSC Open File 3037



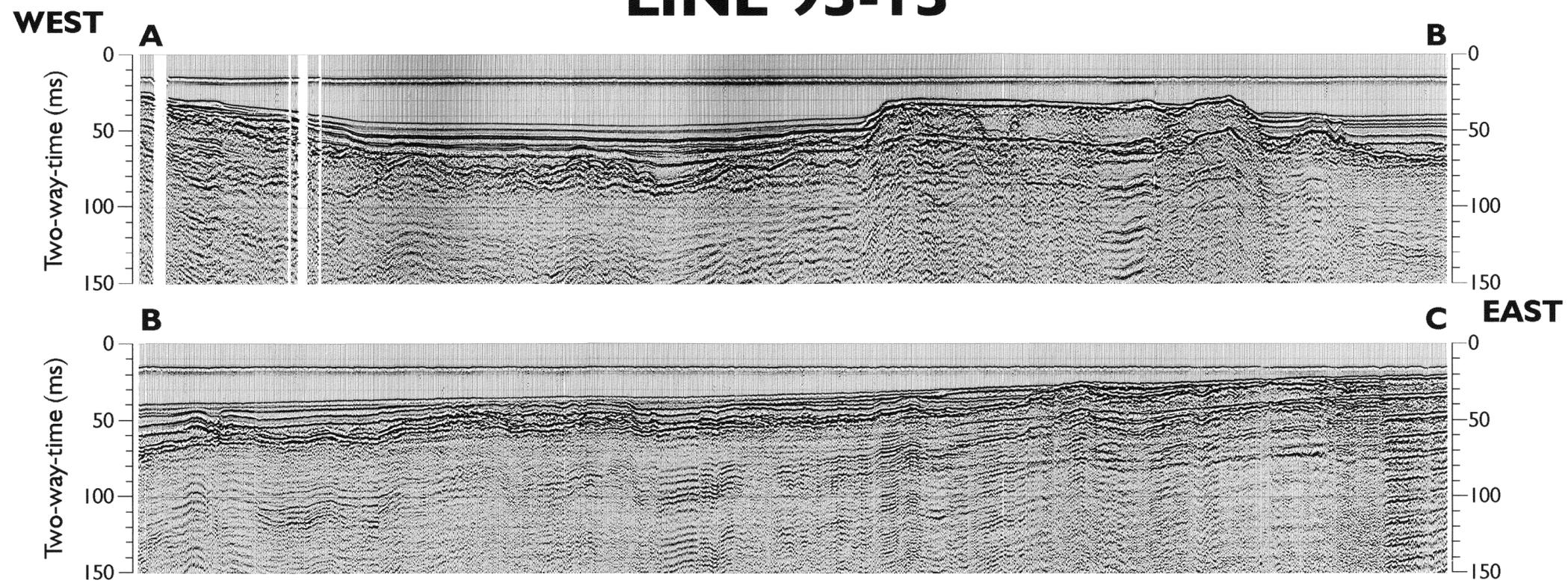
LAKE SIMCOE SEISMIC PROFILES



LINE 93-12E



LINE 93-13



V.E. (@1500 m/s) = 11.6X



Distance (km)

To accompany GSC Open File 3037



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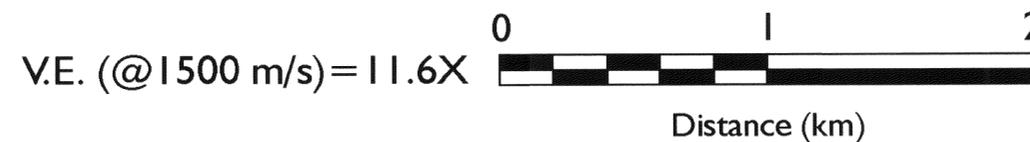
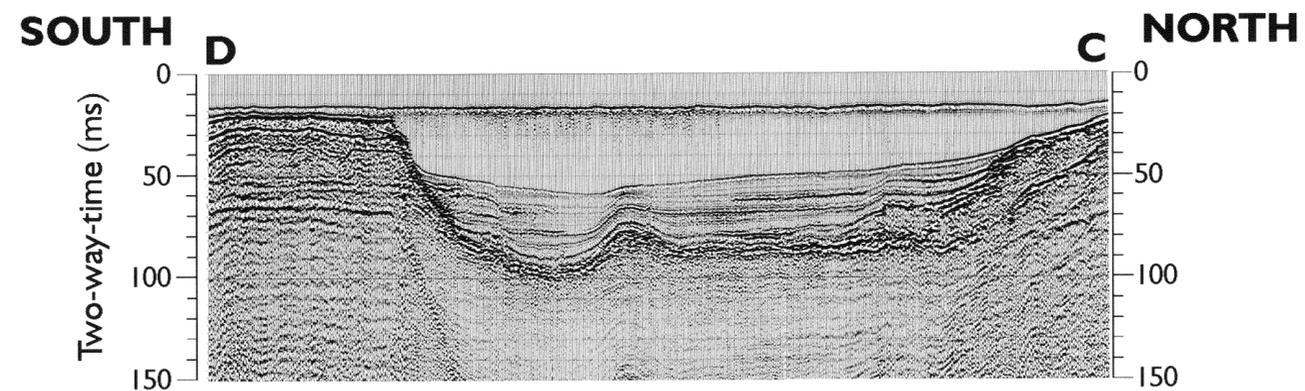
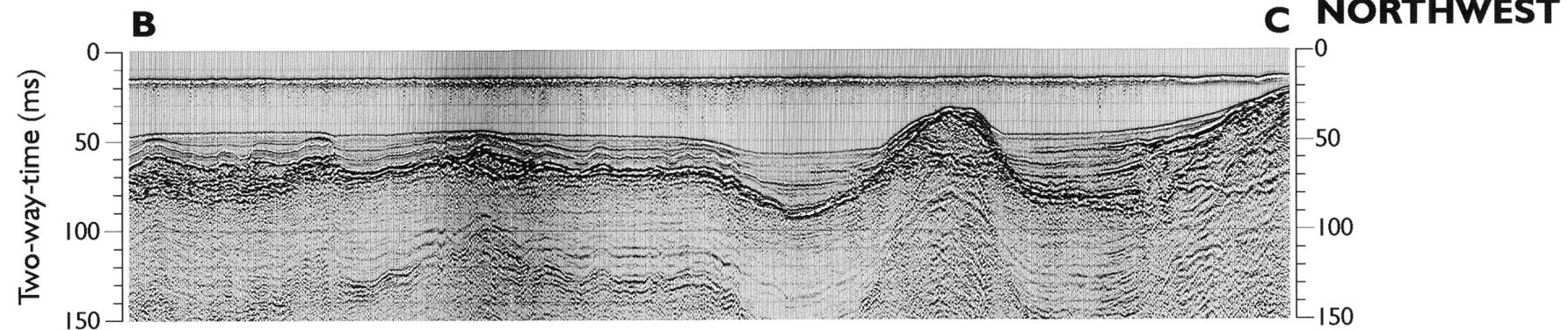
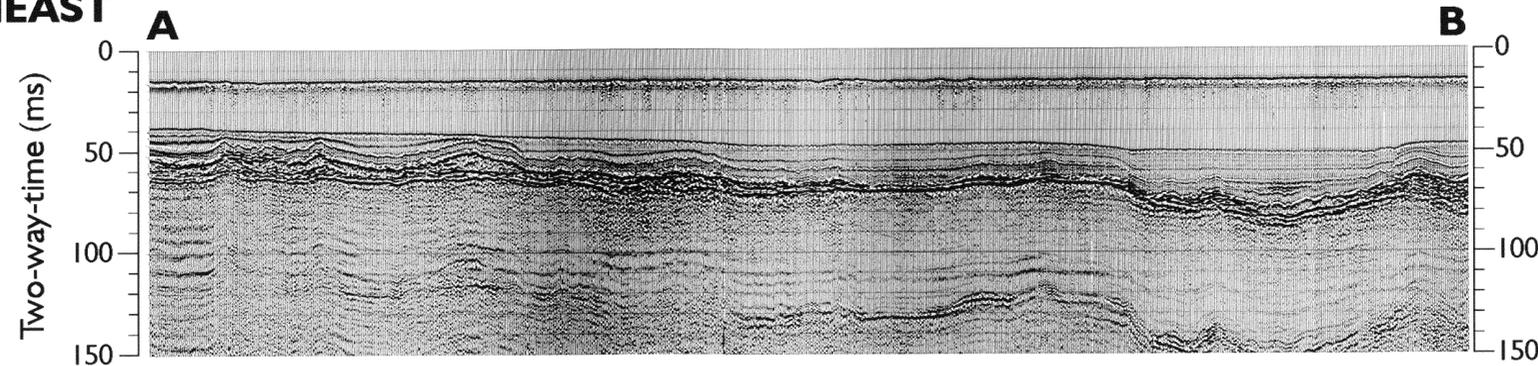


LAKE SIMCOE SEISMIC PROFILES



LINE 93-14a

SOUTHEAST



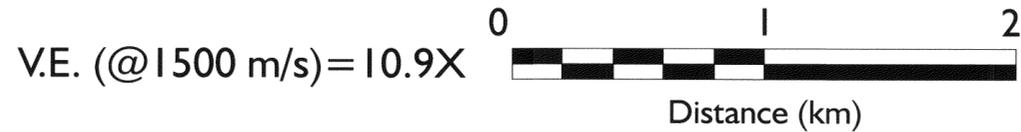
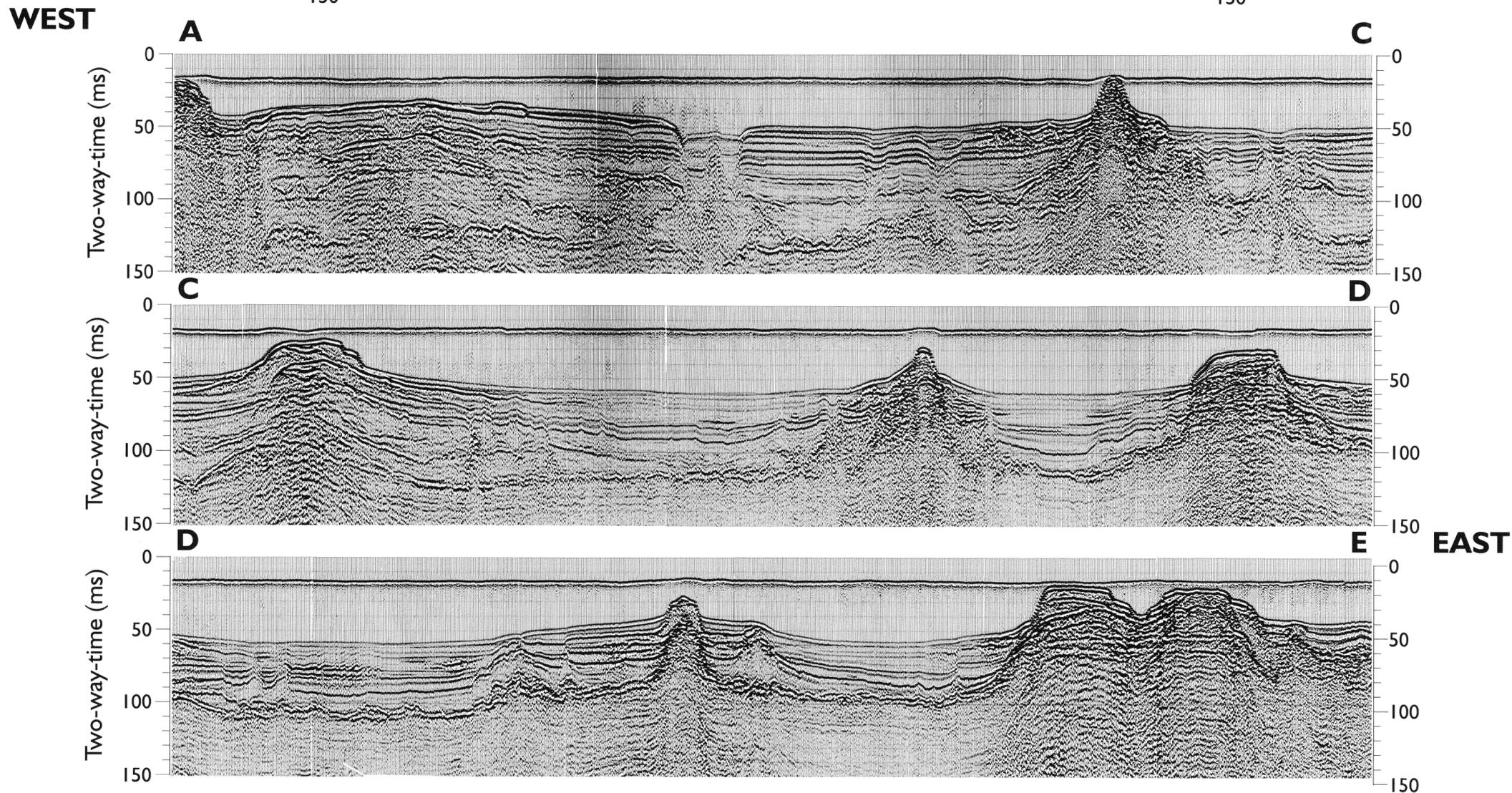
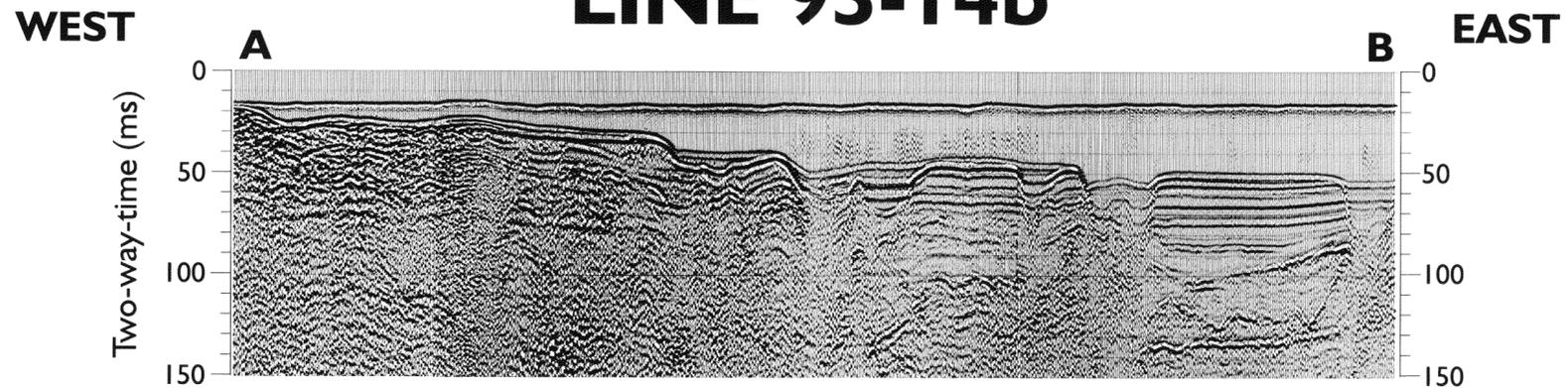
To accompany GSC Open File 3037



LAKE SIMCOE SEISMIC PROFILES



LINE 93-14b



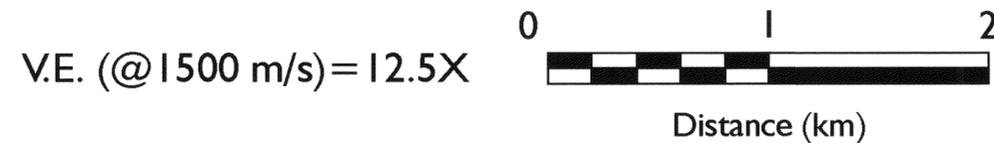
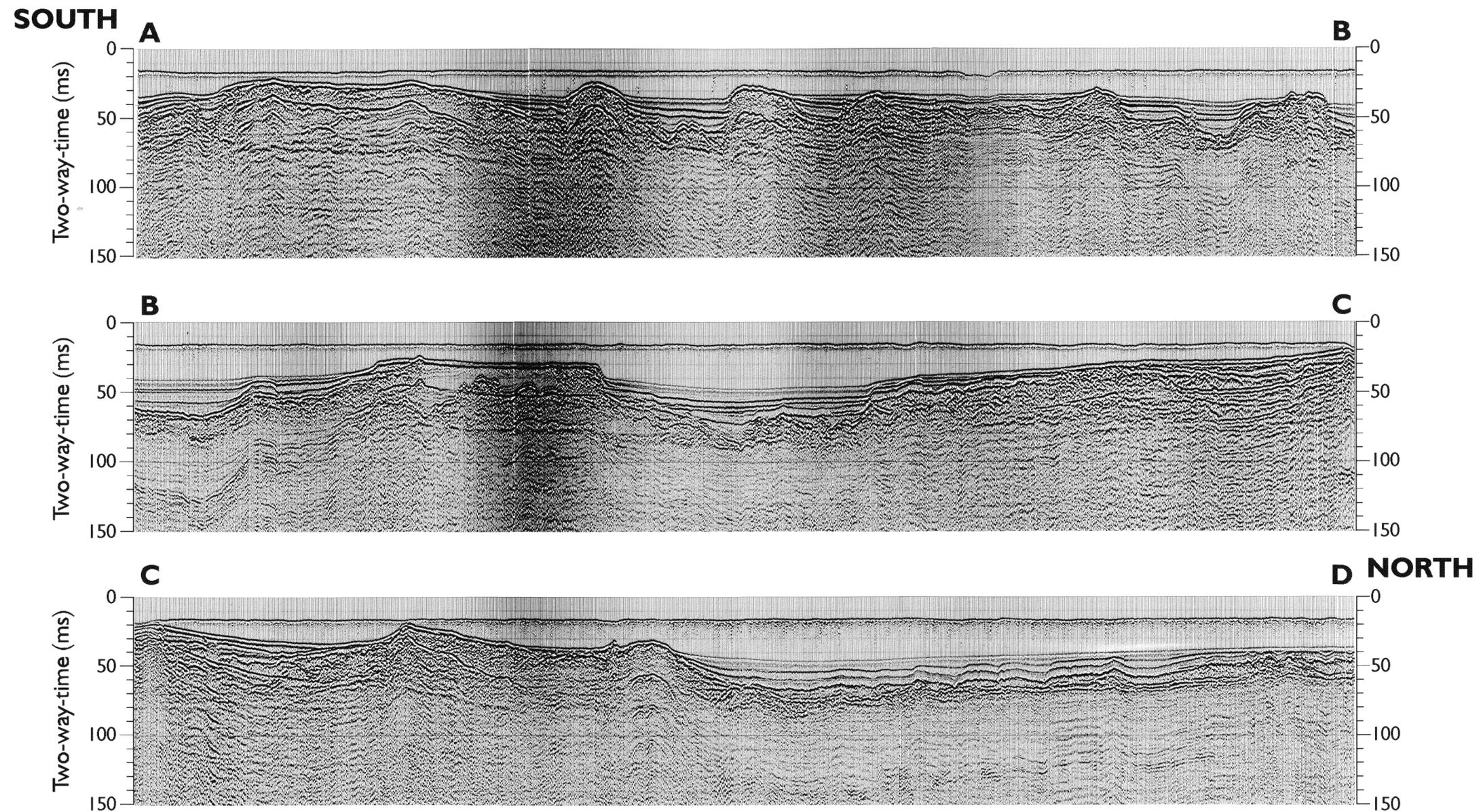
To accompany GSC Open File 3037



LAKE SIMCOE SEISMIC PROFILES



LINE 93-15a



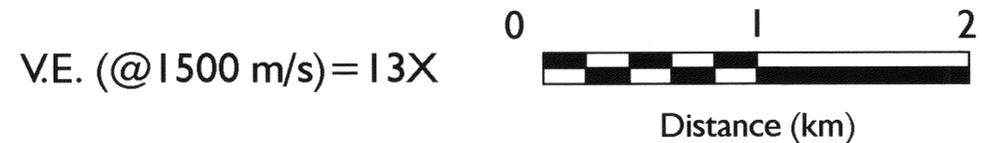
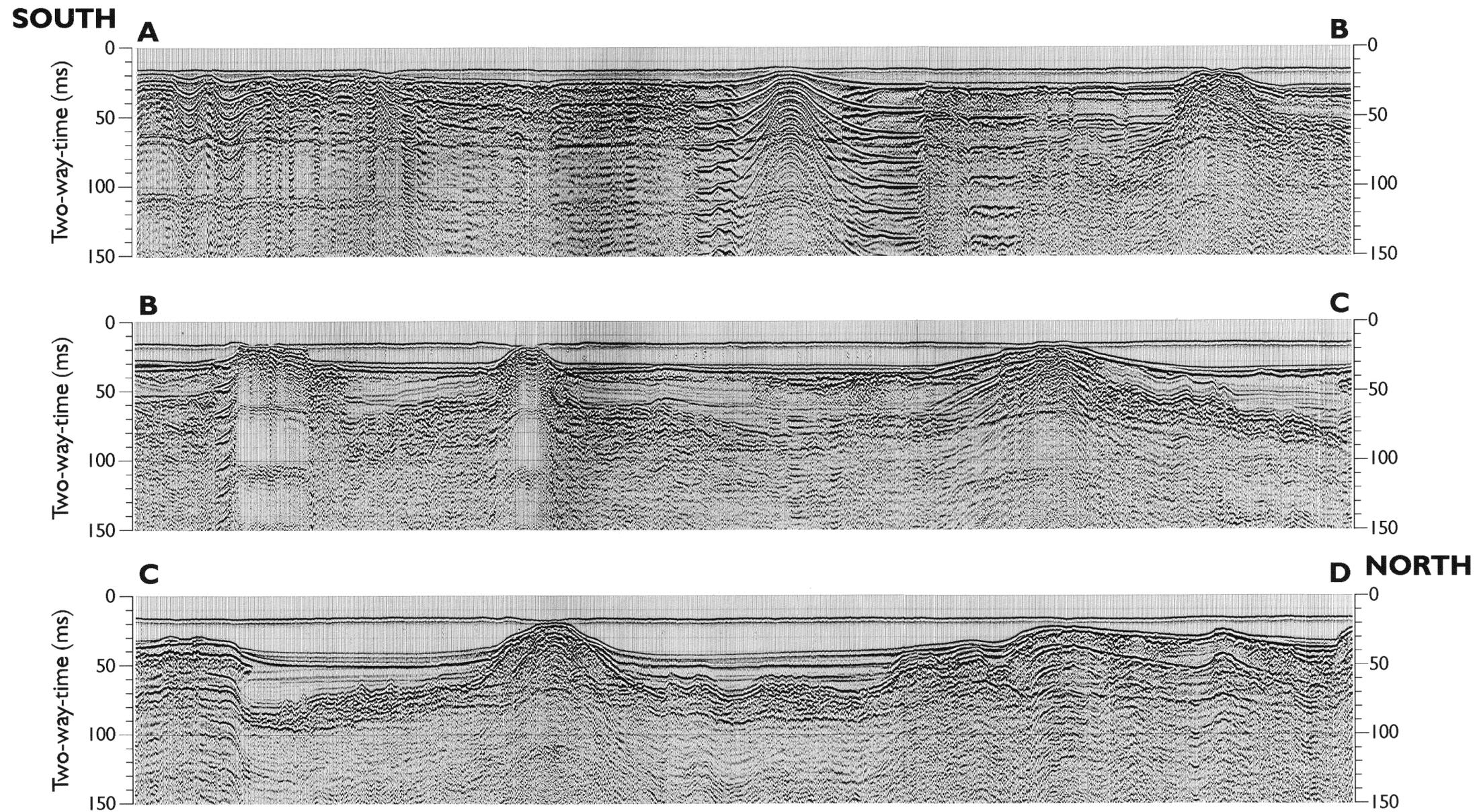
To accompany GSC Open File 3037



LAKE SIMCOE SEISMIC PROFILES



LINE 93-15b



To accompany GSC Open File 3037