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Sedimentology of Quaternary sediments beneath Lake Simcoe, Ontario: results of 1997 and 1998 sampling operations

Brian J. Todd and C.F. Michael Lewis

Geological Survey of Canada (Atlantic),
Bedford Institute of Oceanography,
P.O. Box 1006, Dartmouth, Nova Scotia B2Y 4A2

Thane W. Anderson

25 Dexter Drive, Ottawa, Ontario K2H 5W3

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Geological Survey of Canada (Atlantic)
1 Challenger Drive
Dartmouth, Nova Scotia B2Y 4A2

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ABSTRACT

Limited sediment cores and grabs were collected in Lake Simcoe, south-central Ontario between Lake Ontario and Georgian Bay, with a focussed sampling strategy based on interpreted seismostratigraphy from a previous 4 km by 4 km gridded marine geophysical survey program that used high-resolution single- and multichannel seismic reflection profiling to delineate late- and post-glacial sedimentary strata, structures and lake floor features. The seismic survey and the subsequent coring work are part of a baseline program to better understand the lake bottom and the sub-bottom geology for application to issues such as climate change and seismic hazard.

Lake Simcoe (726 km^2, 219 asl, draining to Georgian Bay) has a smooth lake floor with water depths generally 5-9 m but deepening to 30 m in the west. Two prominent bays lie to the west (Kempenfelt Bay) and south (Cook's Bay). Acoustic basement in Lake Simcoe is Ordovician sedimentary rock. The overlying unconsolidated Quaternary sediments are seismostratigraphically designated, from oldest to youngest, as the Red, Purple, Green and Blue Sequences. The first three sequence sediments are widespread but Blue Sequence sediments are restricted to the deepest, western part of the basin. Their interpretations are based on stratigraphic position, acoustic character, and on comparison with similar seismostratigraphy mapped in Canadian lakes and with known stratigraphy to the south in the Oak Ridges moraine. Samples of Green Sequence sediments have a sticky consistency and are grey-brown muds with lamination character ranging from weak to distinct rhythmites, characteristic of glaciolacustrine deposits. Blue Sequence sediments are massive, soft, grey muds, typical of Holocene large-lake deposition.

Samples were extracted from eight cores and processed for exploratory pollen study. Pollen percentages in the Lake Simcoe samples were compared with a radiocarbon-dated pollen record from a borehole in nearby Cookstown Bog, southwest of Lake Simcoe, and with other dated pollen records in south-central Ontario. This comparison made it feasible to assign inferred radiocarbon ages to the Lake Simcoe stratigraphy. The oldest Red Sequence sediments have an inferred age of 12 to 12.4 ka, indicating the beginning of glacial Lake Algonquin deposition. The top of the Upper Green sequence is estimated at 11.8 ka. Younger inferred ages are based on the bimodal pollen trends of *Tsuga* (hemlock).

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, 2003) 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 and associated sediment samples (Lewis *et al*., 1997).

Lake Simcoe is the largest lake (726 km^2) 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. The seismostratigraphy of Quaternary sediments beneath the lake is given in Todd *et al.* (2003) and reviewed briefly here in Section 4. In 1997 and 1998, lake sediment coring and sampling was conducted on specific seismostratigraphic targets identified from the previous investigation. This Open File report describes the lithostratigraphy of short sediment cores from Lake Simcoe. This lithostratigraphic information enhances the previously-defined seismostratigraphic framework and aids in 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 and subsequent geological sampling program addressed 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 at 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 consists of a limestone plain with small scarps covered by thin till and drumlins in its eastern section; thicker glacial deposits dominate its western section.

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 in south-central Ontario thickens downdip towards the Allegheny and Michigan Basins south and west, respectively, of the Algonquin Arch (Fig. 1) (Liberty, 1969; Johnson *et al*., 1992; Sanford, 1992, 1993).

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 ice-recessional Oak Ridges Moraine is built on a high-relief, erosional surface (unconformity) on the Newmarket Till which is thought to have been previously deposited during and after the last glacial maximum event about 21 to 18 ka. The erosion surface consists 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 erosional surface also forms a low divide between the Georgian Bay – Lake Simcoe and Lake Ontario basins. The development of the moraine on this divide 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 into the surface of the Newmarket Till, a long east-west crack and separation developed in the thinned ice cover east of the Niagara Escarpment (Fig. 1) over the low divide on the subglacial erosion surface between Georgian Bay – Lake Simcoe and Lake Ontario basins. The separation of the ice cover created deep, ice-marginal lake environments with an elongated east-west trend that filled with glaciofluvial and glaciolacustrine sediments to form the Oak Ridges Moraine (Fig. 1) (Barnett *et al.*, 1988). Water levels and sedimentation were controlled first by glacial hydrology and later by regional overflow channels along the Niagara Escarpment to the Lake Erie basin about 13.4 to 13.2 ka. Subaqueous deposition in the Lake Simcoe basin probably began at, or shortly after, this time, prior to its drainage, as part of the Kirkfield phase of Lake Algonquin, through the Campbellford outlet to the Lake Ontario basin (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 *et al.*, 1999a). 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 western shores of Fox and Snake Islands.

2.5 Marine geophysical surveys

A detailed description of the Lake Simcoe marine geophysical surveys are given in Todd *et al.* (2003); a summary is provided here.

The marine geophysical survey was conducted in 1992 and 1993 aboard the MV *J. Ross Mackay*, a 12 m, 14,000 kg aluminum-hulled research vessel. 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. Electronic navigation used throughout the survey was the satellite-based Global Positioning System (GPS). 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.

In September of 1992, the MV *J. Ross Mackay* was used to complete a reconnaissance geophysical survey of Lake Simcoe (red lines, Fig. 2). One set of survey lines ran east to west across the lake from the mouth of the Trent Canal to the city of Barrie. Another set of survey lines ran south to north from Cook’s Bay to the town of Orillia. The instruments deployed in 1992 included a Seistec IKB seismic reflection system, an air gun seismic reflection system, a sidescan sonar and an RTT 1000 sub-bottom profiler. The 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 (green lines, Fig. 2). The instruments deployed in 1993 included a Seistec IKB seismic reflection system, an air gun seismic reflection system, a sidescan sonar and a marine magnetometer. 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. 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. 2) 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.

3. SAMPLING METHODS

3.1 Sampling vessels and methods

On August 28, 1997, sampling was conducted from an open motor boat piloted by Mike Emms of Perkinsfield, Ontario. The sampling crew consisted of Mike Lewis (GSCA) and John Easton of Dixon Hydrogeology Limited, Barrie, Ontario. The mini van Veen grab (van Veen, 1933) and the Benthos gravity corer (Blomqvist, 1991) were prepared on board (Fig. 3) and then deployed over the side of the vessel once the predetermined position was reached (Fig. 4, Table 1). The mini van Veen grab and the Benthos gravity corer were retrieved from the lake floor by pulling on an attached line until the device came free of the surrounding sediment. Once on board, cores were kept vertical and excess core liner was removed (Fig. 5). The liner was sealed at top and bottom and labelled with the station number and the core up direction. Material in the core cutter was bagged and labelled with the station number. On August 29, 1997, the Lake Simcoe samples (one van Veen grab, four Benthos gravity cores and three cutter bags, Table 1) were driven to the Canada Centre for Inland Waters, Burlington, Ontario, and stored vertically in the refrigerated cooler of Technical Operations, National Water Research Institute.

On June 27 and 28, 1998, Benthos gravity core sampling was conducted from the MV *J. Ross Mackay*, similar to that described in section 2.5. Ron Good and Marten Douma (TSD, GSC) conducted coring operations (Figs. 6, 7). A Knudsen 320M seismic reflection profiling system was used to conduct square-shaped surveys around the predetermined coring locations in order to provide very detailed seismostratigraphic information. Some of these seismic profiles are illustrated and discussed in Section 5. The Benthos gravity corer was prepared on the afterdeck of the vessel and deployed and recovered using an electrical winch and a block suspended from the stern A-frame (Fig. 7). Three gravity cores and two cutter bags were recovered (Table 1). Similar to operations in 1997, cores retrieved form the lake floor were sealed at each end, labelled and stored vertically. On June 28, 1998, the cores and cutter bags were driven to the Canada Centre for Inland Waters, Burlington, Ontario, and stored vertically in the Technical Operations cooler.

The 1997 and 1998 Lake Simcoe cores and grab samples were shipped to the Geological Survey of Canada (Atlantic) by refrigerated transport in 1998. The cores and samples were placed in cold storage in the GSCA core laboratory. The cores were split, photographed and described on February 12, 2002, by Adam MacDonald. On April 18, 2002, the cores were subsampled for pollen analysis by Kate Jarrett (GSCA) and twenty-three samples were shipped to Harvey Thorleifson (TSD, Ottawa) for study by Thane Anderson.

3.2 Navigation

In 1997, navigation was recorded using the satellite-based Global Positioning System (GPS). The receiver on board the vessel was a Trimble Ensign provided by Jim Hunter (TSD, GSC). Predetermined sampling positions were entered into the GPS unit as waypoints and the vessel navigated from waypoint to waypoint. Fluctuations in the GPS readout were noticeable at slow boat speeds. It is estimated that sampling positions were occupied with a reduced accuracy of about 100 m.

In 1998, GPS satellite signals were received on the MV *J. Ross Mackay* using a Trimble Pro XL and recorded on a Trimble TDC1 data logger. Real time differential correction data were received from the Canadian Coast Guard base at Wiarton, Ontario. Data were transferred to laptop computer at the end of each day's operation and track plots were prepared. Estimated positional accuracy of the 1998 Lake Simcoe GPS data is 2 to 10 m.

ASCII files of the 1998 navigation data are provided on this Open File CD-ROM under the folder Appendix B.

4. SEISMOSTRATIGRAPHIC SETTING

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, where reflections in a zone on a seismic profile are absent, the zone is referred to as "transparent".

4.2 Lake Simcoe seismostratigraphy

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 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 8; 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.

The upper bounding reflections, or sequence boundaries, for all the profiles in Lake Simcoe were interpreted based on the single- and multichannel seismic data, Knudsen 320M subbottom profiles, and associated sidescan sonar records (Todd *et al.*, 2003). An example interpreted airgun seismic profile from western Lake Simcoe is shown in Figure 9. Acoustic basement is Red Sequence; 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 or glacial sediments 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, possibly the Newmarket Till. 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. Sediments of the Blue Sequence overlie the top of the Green Sequence. 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.

In the following description, the Lake Simcoe seismostratigraphic sequences are discussed from youngest (Blue Sequence) to oldest (Brown Sequence).

4.2.1 Blue Sequence

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.

4.2.2 Green Sequence

Green Sequence sediments extend over all of Lake Simcoe. Seismic and borehole evidence from the Oak Ridges Moraine to the south of Lake Simcoe (Pugin *et al*., 1999a) 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. Truncated reflections within the Green Sequence are widespread in the lake and characterize the Green Reflector sequence boundary as an erosional unconformity, indicating that the lake which deposited the Green Sequence sediments fell to a low level.

4.2.3 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. Prominent lake floor outcrops of Purple Sequence sediments up to 10 m in height occur throughout the lake. The cross-sectional shape of these mounds with steep side slopes 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). The distribution of the Purple Sequence, its reflection configuration and its drumlinized, unconformable surface suggests that it is equivalent to the Newmarket Till mapped south of Lake Simcoe (Barnett *et al*., 1998, Pugin *et al*., 1999a; Pugin *et al*., 1999b; Sharpe *et al*., in prep.).

4.2.4 Red Sequence

Red Sequence sediments occur in many places in Lake Simcoe. 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 the area of Snake and Fox Islands in southwestern Lake Simcoe (Fig. 2). These sediments are interpreted as till or other glacial sediments.

5. CORE AND GRAB SAMPLE DESCRIPTIONS

5.1 Stations 1 and 2

Stations 1 and 2 are located in shallow water (about 15 m) along line 92-3 in the centre of northern Cook's Bay, 1.4 kilometres west of Snake Island (Figs. 2, 10, 11, Table 1). Blue Sequence sediments overlie Green Sequence sediments; the latter outcrop in west-east band, highlighted by the dark-toned area on the sidescan sonar record (Fig. 12). The van Veen grab at Station 1 retrieved soft, grey mud. The Benthos gravity core at Station 2 penetrated 84 cm into Blue Sequence sediment, consisting of olive grey mud with shell fragments disseminated throughout the core (Fig. 13, Appendix A). Faint horizontal banding is visible in the bottom few centimetres of the core.

5.2 Stations 3, 4a and 4b

Stations 3, 4a and 4b are located in deep water (about 25 m) in western Lake Simcoe off the mouth of Kempenfelt Bay (Figs. 2, 14). Here, Green Sequence sediments are exposed on the lake floor (Fig. 15). Stations 4a and 4b cores recovered grey-brown mud from lower Green Sequence sediments; Station 3 core is laminated mud with soft consistency (Fig. 16, Appendix A). Station 2 was located off the line of seismic cross section and sampled Blue Sequence sediment (Fig. 14). Station 4a mud has a sticky consistency and is laminated (possibly rhythmically) throughout the core (Fig. 17, Appendix A), and Station 4b mud consists of repeated couplets of thinner dark layers over thicker light layers (rhythmites).

5.3 Station 4

Station 4 is located in western Lake Simcoe in about 25 m of water on an exposure of Red Sequence sediment on the lake floor (Figs. 2, 19, 20). The outcrop of Red Sequence sediment is a ridge oriented southwest-northeast (Fig. 21), similar in orientation to drumlins northeast of Lake Simcoe (Deane, 1950). The dark tone on the sidescan sonar record (Fig. 21) suggests that the outcrop zone of "Red Sequence" sediment is acoustically rougher than the surrounding Blue Sequence sediment. The grey-brown mud collected at Station 4 (Fig. 22, Appendix A) may represent a remnant of Blue Sequence sediment which overlies the Red Sequence seismic unit.

5.4 Station 5

Station 5 is located in northwestern Lake Simcoe in about 17 m of water adjacent to an exposure of Purple Sequence sediment on the lake floor (Figs. 2, 23, 24). Similar to the outcrop of Red Sequence sediment at Station 4 described in the previous section, the outcrop of Purple Sequence sediment at Station 5 is a ridge oriented southwest-northeast (Fig. 25). The dark tone of the Purple Sequence sediment on the sidescan sonar record (Fig. 21) suggests that the outcrop zone is acoustically rougher than the surrounding Blue Sequence sediment. The massive, olive-grey to grey-brown mud collected at Station 5 (Fig. 26, Appendix A) is from lower Blue Sequence sediment where the Blue Sequence pinches out over Green Sequence sediment (Fig. 24).

5.5 Station 7

Station 7 is located in northwestern Lake Simcoe in about 26 m of water just east of Oro Reef (Figs. 2, 27, 28). The sample site is at an outcrop of the Purple Sequence seismostratigraphic unit, interpreted to be an equivalent of the Newmarket Till (Fig. 8). As the Purple unit is not well stratified, it is probable that the rhythmically layered core sediment is from a basal section of the overlying Green Sequence which is too thin to be resolved in the seismic profile.

5.6 Station 13

Station 13 is located in eastern Lake Simcoe, 2.5 km northwest of Thorah Island (Figs. 2, 30). This sample attempted to core the crest of an outcrop of the Red Sequence seismostratigraphic unit. Only a small amount of surface sediment was recovered in the cutter of the corer.

6. POLLEN INVESTIGATIONS

6.1 Introduction

Twenty-three samples of 2 cc volume were selected from the Lake Simcoe gravity cores for pollen investigations. The objective was to process the samples for pollen content, identify and tabulate the pollen taxa, assign radiocarbon age estimates to the samples based on a comparison with other radiocarbon-dated pollen records in south-central Ontario, and apply the palynological investigations to interpret environmental conditions during late- and post-glacial deposition in Lake Simcoe.

6.2 Methods

The sediment samples were processed using the standard methods of sediment treatment for pollen extraction including the addition of *Lycopodium* tablets to determine concentrations as outlined in Anderson and Lewis (1985). Pollen percentages were based on a sum of 200 to 225 tree, shrub and herb pollen excluding aquatics. Samples from stations 4a, 4b, 7 and 13 were sieved with a 10 µ mesh to concentrate the pollen for greater ease of counting. Figure 33 shows pollen percentages versus core depths of all pollen taxa as well as total pollen concentrations (grains/cc) for the Lake Simcoe samples. Figure 34 shows percentages of the dominant pollen taxa at Cookstown Bog, located about 10 km west of Cook's Bay, Lake Simcoe (Fig. 1).

6.3 Description and interpretation of pollen diagram

The lowermost sample analyzed, GC0013, is characterized by comparatively low *Picea* and high *Betula*, *Quercus, Acer* and *Ambrosia.* The relatively high percentages of *Betula, Quercus, Acer,* and especially *Ambrosia,* suggests this sample was contaminated by younger (modern-day) sediments.

Core GC007 up to the top of Core GC004A is dominated by relatively high *Picea* and continued presence of *Alnus, Salix* and several herb pollen taxa including Gramineae, Tubuliflorae, *Ambrosia*, *Artemisia*, Cyperaceae and Polypodiaceae. *Pinus* and *Quercus* percentages can be unusually high during the *Picea* dominance, as is the situation here. A large portion of these percentages may reflect long-distance transport from sources to the south. The sample at 30 cm depth in GC007 registered extremely low concentrations of *Picea* and herb pollen, although highest percentages of *Artemisia*, suggesting this sample was at, or near, the proglacial lake/till contact. This sample is taken to indicate the beginning of Lake Algonquin deposition at this core site and thus an age of 12 to 12.4 ka (Lewis *et al*., 1994) is inferred for this level. The pollen sequence in cores GC007, GC004B and upward to the top of core GC004A is very similar to that characterizing pollen zone 4 in Cookstown Bog. This bog had developed on the Algonquin lake plain following the draining of Lake Algonquin and the basal sediments of pollen zone 4 time were deposited by Lake Algonquin when it inundated the southern Georgian Bay-Lake Simcoe region (Karrow *et al*., 1975). The dominance of *Picea* and herb pollen at the base of the Cookstown Bog and in these Lake Simcoe core samples imply an open spruce forest had bordered Lake Algonquin; exposed, xeric sites along the Algonquin shoreline may have provided suitable habitats where shrubs and herbs, such as, *Shepherdia canadensis* (Buffalo Berry), *Shepherdia argentea* (Rabbit Berry), *Potentilla* (Cinquefoil), *Sanguisorba* (Bunet), *Urtica* (Nettle), *Thalictrum* (Meadow-Rue), chenopods, composites and crucifers could have become established. The presence of pollen from these plants suggests the landscape bordering Lake Algonquin when it occupied Lake Simcoe basin likely resembled forest-tundra.

The *Picea* peak and subsequent *Pinus* peak, which characterize pollen zones 3 and 2 in Cookstown Bog, are missing in the Lake Simcoe suite of samples. The lower boundary of the *Picea* peak (pollen zone 4/3 boundary) dates approximately 11.8 ka based on a comparison with an AMS date of 11,770 ± 90 BP for the same pollen horizon at Decoy Lake, near Paris, Ontario (Szeicz and MacDonald, 1991). Thus the 11.8 ka estimate is tentatively place at the top of core GC004A based on comparison with the pollen trends of *Picea* and *Pinus* at the top of zone 4 in Cookstown Bog.

The interval encompassed by core GC005 through to the top of core GC002 shows a pollen record that encompasses an increase in *Tsuga*, a *Tsuga* minimum and a second increase of *Tsuga.* The uppermost sample in core GC004, which shows higher incidences of *Picea* and *Tsuga* than the next deeper sample, is interpreted to have been contaminated by younger, modern-day sediments. If this sample is accepted as being partially contaminated (± 5 %) by younger-aged sediments, the core 5-core 2 interval demonstrates the typical bimodal *Tsuga* profile which is characteristic of middle to late Holocene pollen records in eastern North America. The same bimodal *Tsuga* profile is present, although undated, in nearby Victoria Road Bog, originally published in Terasmae (1968) and redrawn in Anderson (1995). However, the first *Tsuga* increase is dated at 7.6 ka at Edward Lake (McAndrews, 1981) and at Kincardine Bog (Karrow *et al*., 1975). The *Tsuga* decline is reliably established at 4.8 ka throughout eastern North America (Davis, 1981). The estimate of 3.4 ka for the second *Tsuga* increase in the Lake Simcoe samples is based on a date of 3445 ± 115 for the same pollen horizon at Graham Lake (Fuller, 1997) located less than 200 km northeast of Lake Simcoe.

6.4 Discussion and conclusions

The higher percentages of *Picea* and *Tsuga* in the uppermost samples than in the adjacent deeper samples in cores GC003 and GC004 provide some indication that the seismic reflection layers and cores obtained from these horizons may be contaminated by a thin surface layer (± 5 cm)of younger sediments; likewise, the same may apply for the high percentages of *Betula, Quercus, Acer* and *Ambrosia* which dominate the core GC0013 sample. In contrast, the uppermost samples at 10 cm depth in cores GC002, 4a, 4b and 7 show no apparent contamination. Thus the second and subsequent samples in each core are considered to be the more reliable representatives of the contemporary pollen spectra in each core segment. Comparisons of the Lake Simcoe pollen sequence with similar pollen successions from other nearby sites are undertaken with this in mind.

The core GC007 to GC004A sequence of samples exhibit excellent correlation with the basal pollen succession in Lake Algonquin-aged sediments in Cookstown Bog. Particularly apparent are the upward trends of *Picea, Pinus, Quercus* and *Fraxinus* in core GC004A which closely mimic the same taxa near the top of pollen zone 4 (zone 2B in Karrow *et al*., 1975) in Cookstown Bog.

Similar pollen taxa supported by plant macrofossils of the same taxa were extracted from Algonquin-aged sediments near Clarksburg, Ontario (Karrow *et al*., 1995) located about 80 km west of Lake Simcoe. The pollen and plant macrofossils assemblage provided clear evidence for an open spruce forest with open-ground tundra shrubs and herbs. The assemblage of pollen and plant macrofossils presently ranges no farther north than treeline. The Clarksburg plant macrofossils represent plants that typically inhabit arctic sites suggesting the landscape was forest-tundra.

The concept of sampling successively deeper, older seismic reflectors to delineate the late- and postglacial sequence of sediments was for the most part successful and is supported by pollen analysis. The pollen stratigraphy shows a successively younging sequence from core GC007 through to the top of core GC002.

The Lake Simcoe record is clearly missing the timeframe encompassed by the *Picea* and *Pinus* peaks which are present in Cookstown Bog (pollen zones 3 and 2). Based on the age estimates for the lower and upper boundaries of this timeframe, a span of 4.2 ka is missing in the Lake Simcoe suite of samples, *i.e.*, between cores GC004A and GC005.

7. ACKNOWLEDGEMENTS

Successful coring in Lake Simcoe was a result of cooperation between the Geological Survey of Canada (Atlantic) in Dartmouth, Nova Scotia, and the Terrain Sciences Division (TSD) of the Geological Survey of Canada in Ottawa, Ontario. In August, 1997, Michael Emms of Perkinsfield, Ontario, operated his vessel and John Easton, Dixon Hydrogeology Limited, Barrie, Ontario, assisted with the coring operations We thank Marten Douma and Ron Good of TSD for their efforts in obtaining cores 4a, 4b, 7 and 13 in June of 1998. We thank Gary Grant, GSCA Electronic Publishing, for assistance with preparing illustrations for this report. One of us (Anderson) kindly thanks Barbara Medioli (TSD) and Brian Todd for transferring / restoring pollen diagram files to a more useful digital format. Walli Rainey and Sheila Hynes, GSCA, built the Lake Simcoe GIS project and prepared the detailed core site maps for this report. John Coakley, Canada Centre for Inland Waters, Burlington, Ontario, kindly allowed the Lake Simcoe cores to be stored and facilitated their shipment to the Bedford Institute of Oceanography. Adam MacDonald and Kate Jarrett assisted with core processing and descriptions at GSC Atlantic. Photographs of coring activities in 1997 were contributed by John Easton. Photographs of coring activities in 1998 were contributed by Marten Douma. We thank Robert O. Miller and Michael Parsons (GSCA) for their reviews of this Open File report.

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Table 1. Lake Simcoe sediment cores, samples, and associated data

Station	Sample type	Date / Time	Seismostrati-graphic Sequence target	Postion (UTM Zone 17, NAD 27) Easting / Northing (m)	Position (NAD 83) North Latitude West Longitude	Core Length (cm)	Material	Geophysical tie	
								Line No.	Fix or Day / Time
1	van Veen grab	28/08/97 @ 10:08 local	Blue Sequence Cook’s Bay	619272 4907494	44.313° 79.505°	—	soft grey mud	92-3	660
2	Benthos gravity core and cutter bag	28/08/97 @ 10:35 local	Blue Sequence Cook's Bay	619244 4907386	44.312° 79.505°	84	grey brown silt with shells	92-3	661
3	Benthos gravity core	28/08/97 @ 12:10 local	Lower Green Sequence	622506 4919825	44.423° 79.461°	34	laminated grey to brown clay	92-4	844
4	Benthos gravity core and cutter bag	28/08/97 @ 13:53 local	Red Sequence peak	622053 4915755	44.387° 79.468°	48	faintly laminated grey-brown clay mud	93-1a	147 / 17:20:22
4a	Benthos gravity core	27/06/98 @ 14:55:20 UTC	Upper Green Sequence	622510.6 4919732	44.422° 79.461°	73	laminated grey-brown clay mud	92-4	843
4b	Benthos gravity core	27/06/98 @ 16:08:00 UTC	Lower Green Sequence	622581.6 4919868	44.424° 79.460°	69	rhythmically laminated grey-brown clay mud and silt	92-4	845
5	Benthos gravity core and cutter bag	28/08/97 @ 16:30 local	Purple Sequence Peak	628995 4931043	44.523° 79.377°	58	soft grey clay	92-5	1093.5
7	Benthos gravity core and cutter bag	28/06/98 @ 13:19:39 UTC	Red Sequence peak	622786.6 4925117.5	44.471° 79.456°	38	clay rhythmites	1998 survey	179 / 13:19:39
13	cutter bag	28/06/98 @ 20:09:34 UTC	Red Sequence peak	637990.1 4925474	44.471° 79.265°	—	?	93-5	160 / 16:42:37

Note: Benthos gravity core inside diameter is 6 cm; 1997 is GSCA expedition 97-804; 1998 is TSD MV *J. Ross Mackay* expedition

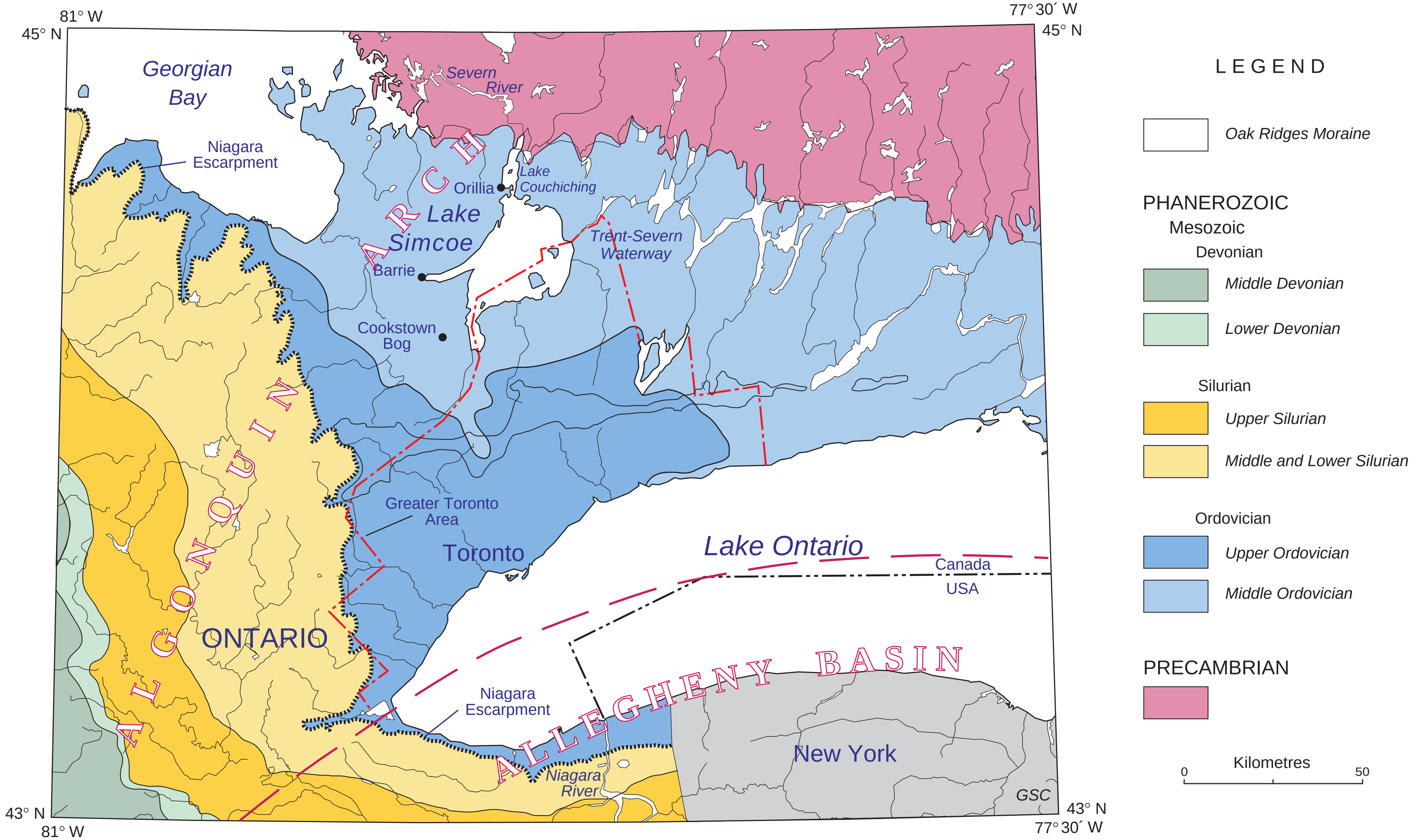


Figure 1. Location map of Lake Simcoe in south-central Ontario. Note that the political boundary of the Greater Toronto Area includes southern Lake Simcoe. The Grenville Province of the Precambrian Canadian Shield lies northof the lake. Tectonic elements from Sanford (1993). Paleozoic sedimentary rocks overlain by Quaternary sediments occupy southern Ontario; geological boundaries adapted from Ontario Geological Survey (1991). Outline of Oak Ridges Moraine from Barnett *et al.* (1998). Location of Cookstown Bog from Karrow *et al.* (1975).

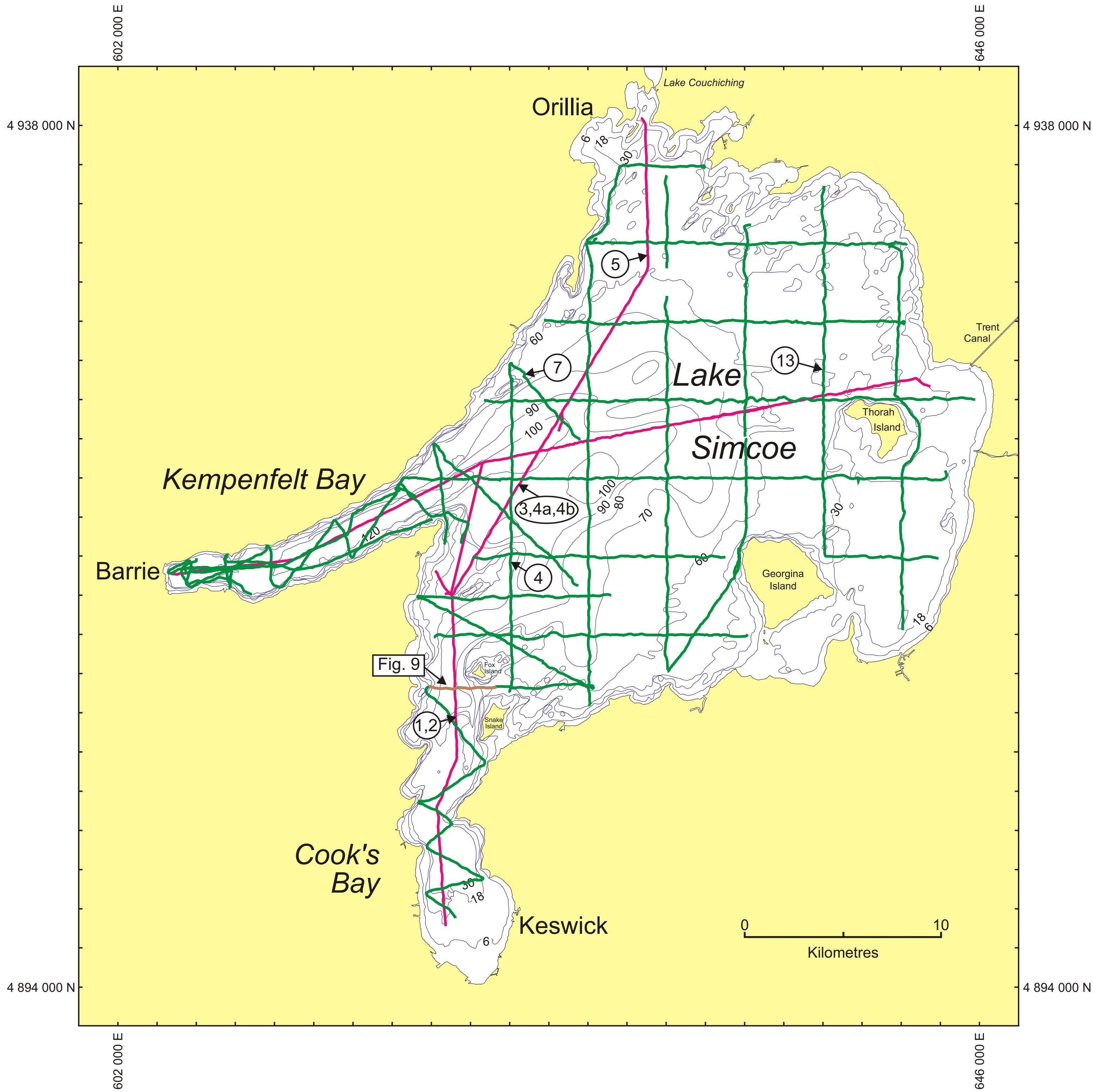


Figure 2. Lake Simcoe 1992 (red) and 1993 (green) geophysical survey lines. Sample locations 1, 2, 3, 4 , 4a, 4b, 5, 7 and 13 are indicated along the survey lines by numbered circles and arrows. More detailed location maps for each sample location are included later in this report. Location of seismic profile in Figure 9 indicated by labelled brown line. Isobaths are 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. Mike Lewis (GSCA) preparing gravity corer, August 28, 1997 (Photo: John Easton).

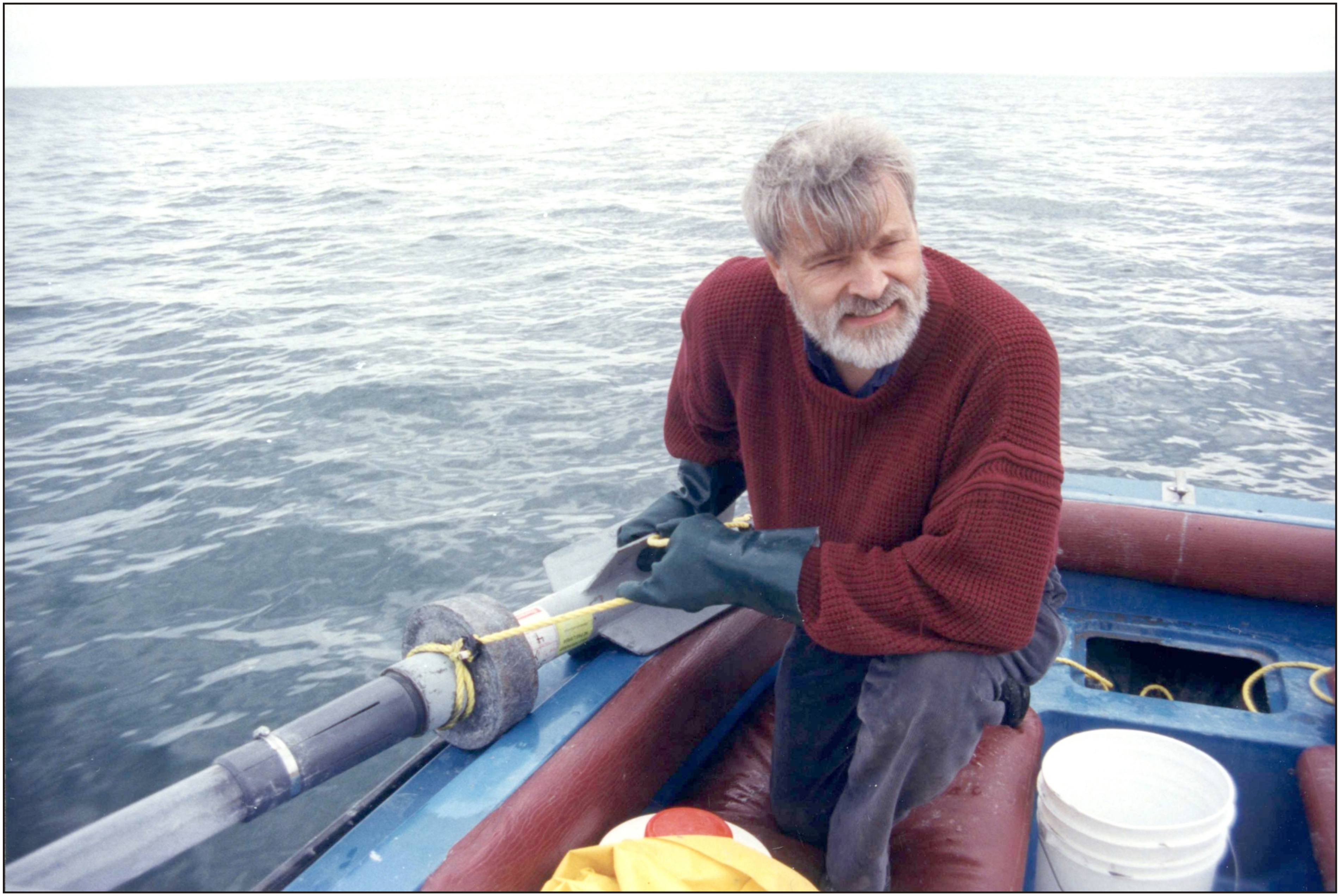


Figure 4. Mike Lewis (GSCA) about to deploy gravity corer, August 28, 1997 (Photo: John Easton).

Figure 5. Mike Emms (left) and Mike Lewis (right) removing excess core liner (upper) from sediment-filled liner (lower), August 28, 1997 (Photo: John Easton).

Figure 6. MV *J. Ross Mackay* departing Big Bay Point en route to coring operations, June 27, 1998 (Photo: Marten Douma).

Figure 7. Captain Ron Good (GSC, TSD) supervising coring operations, June 27, 1998 (Photo: Marten Douma).

Sequence		Reflection configuration	Geological interpretation	Geological correlation
	Blue (lakefloor) reflector			present Lake Simcoe
Blue		parallel to subparallel, lower amplitude reflections than in Green Sequence; transparent in places	sheet drape, relatively uniform rate of deposition of strata over underlying topography	Lake Simcoe
	Green reflector			
Green		parallel to subparallel, higher amplitude reflections than in Blue Sequence; in places tangential oblique progradational reflections	sheet drape, relatively uniform rate of deposition of strata over underlying topography	glacial lake and tunnel valley deposition
	Purple reflector			
Purple		generally chaotic, with local evidence of internal reflections; high-relief upper boundary	variable, high energy setting	Newmarket Till (?)
	Red reflector			
Red		chaotic; high relief upper boundary	variable, high energy setting	till / glacial sediments (?)
	Brown reflector			
Brown		chaotic	variable, high energy setting	till / glacial sediments (?)

Figure 8. Lake Simcoe seismostratigraphic sequences, reflection configuration, geological interpretation and geological correlation.

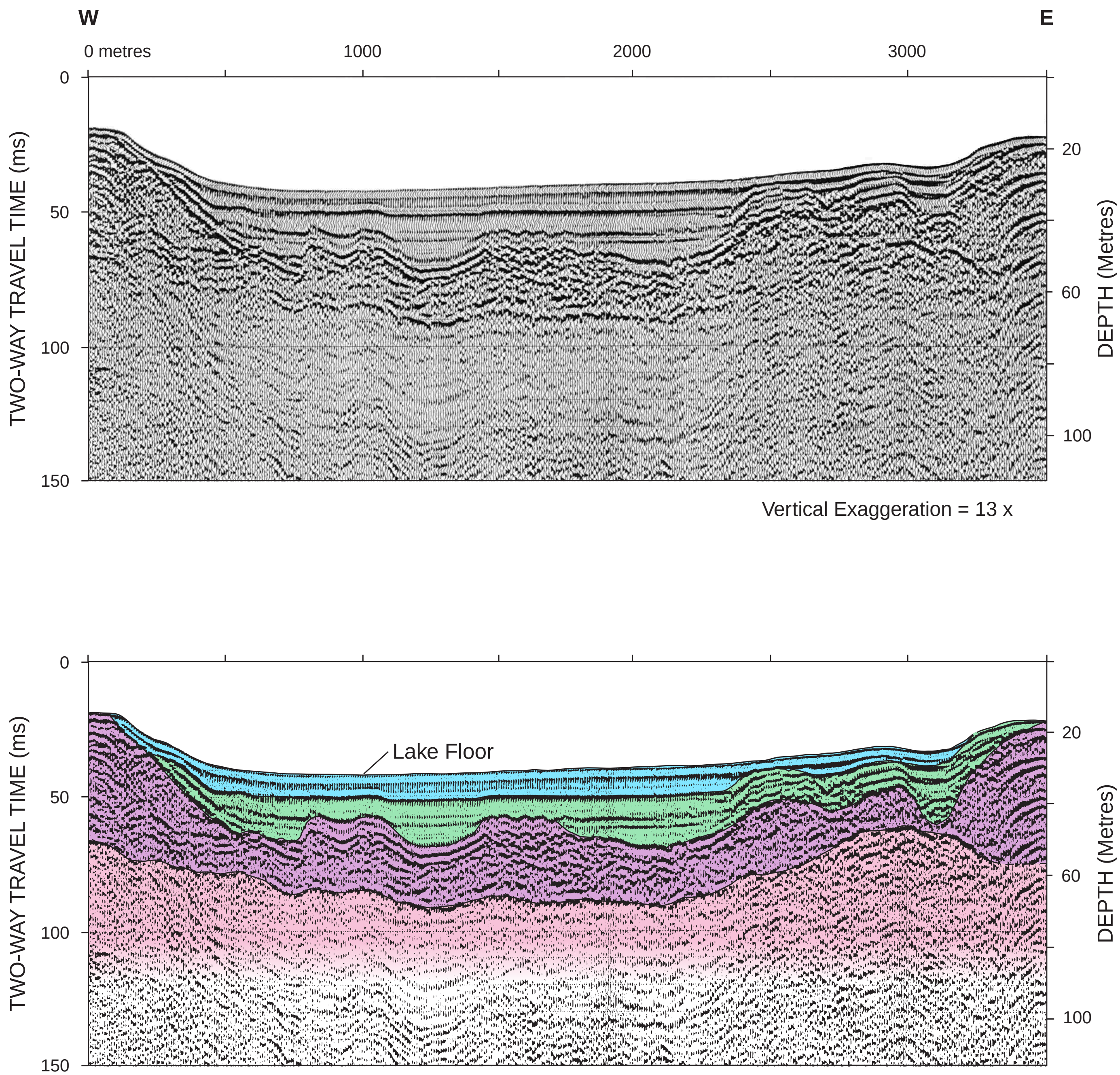


Figure 9. Airgun seismic reflection profile (upper) and interpretive cross section showing stratigraphic relations (lower), western Lake Simcoe. Acoustic basement is Red Sequence, overlain by Purple, Green and Blue Sequences. See Figure 2 for location of profile (Line 93-15b, day 158, 1735-1811).

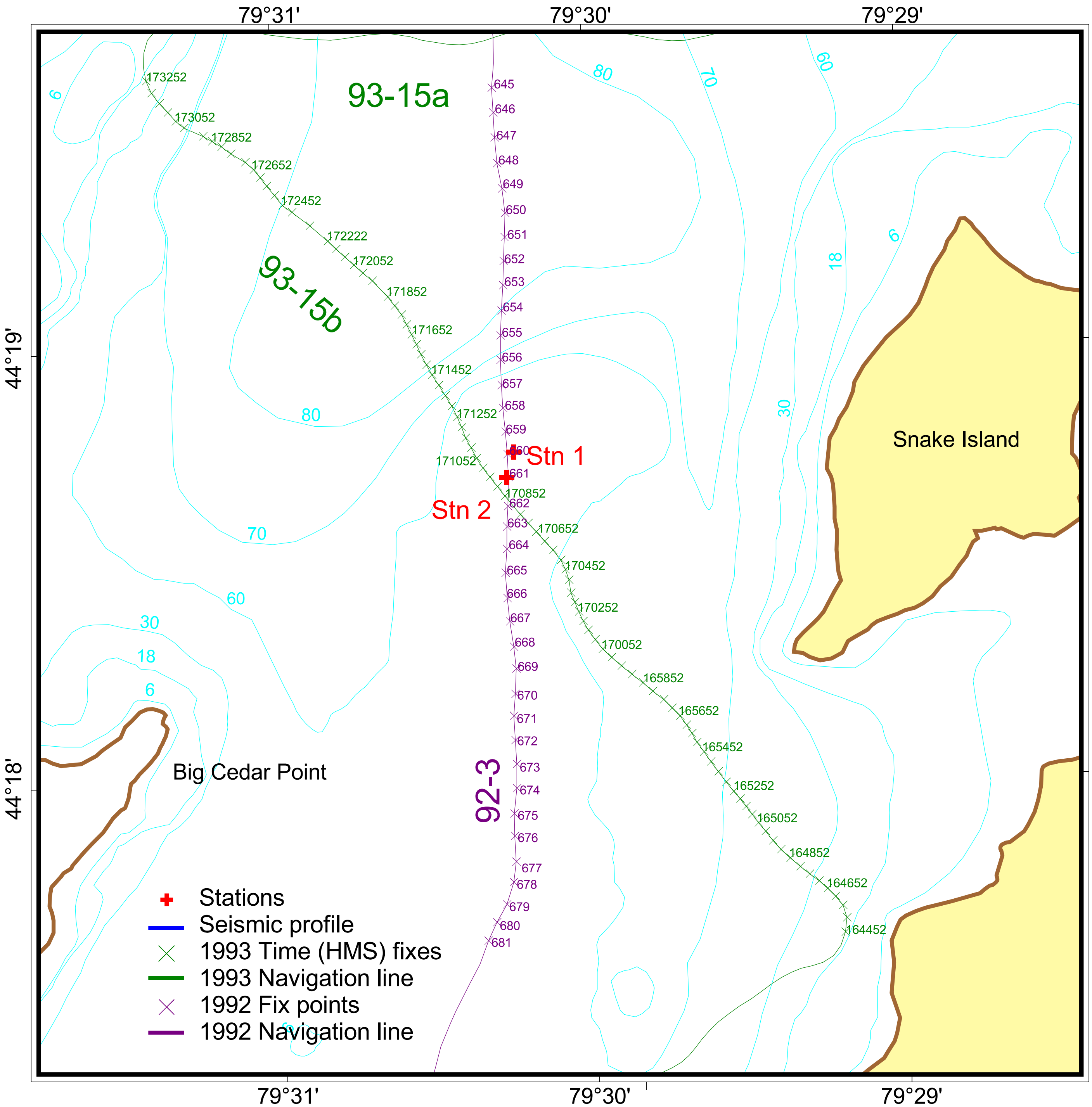


Figure 10. Location of Stations 1 and 2 on line 92-3. Blue along line 92-3 highlights location of seismic profile shown in Figure 11. Isobaths in feet.

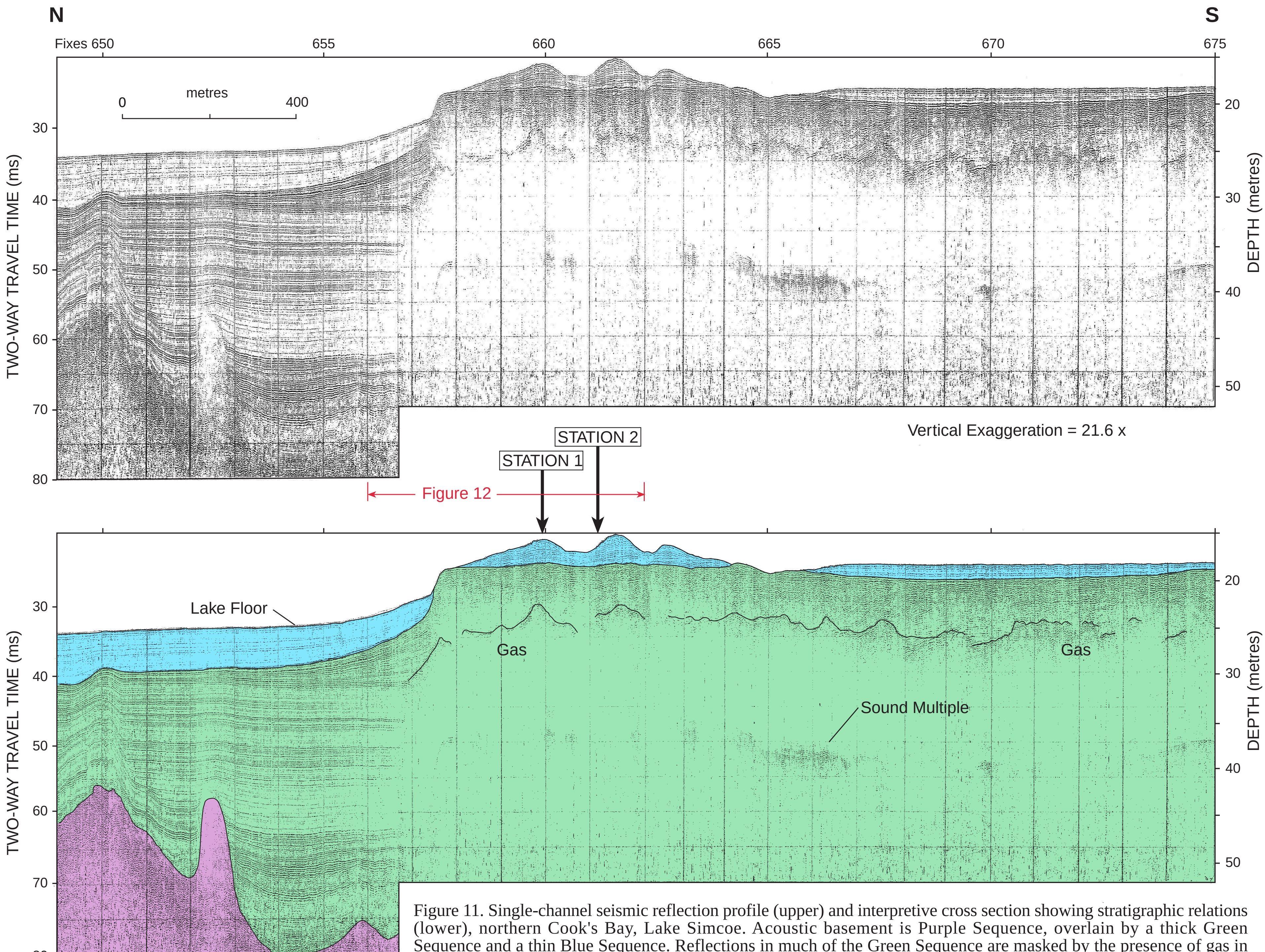


Figure 11. Single-channel seismic reflection profile (upper) and interpretive cross section showing stratigraphic relations (lower), northern Cook's Bay, Lake Simcoe. Acoustic basement is Purple Sequence, overlain by a thick Green Sequence and a thin Blue Sequence. Reflections in much of the Green Sequence are masked by the presence of gas in the sediments. The locations of Stations 1 and 2 are indicated. Extent of sidescan sonar record in Figure 12 is shown by red arrows. See Figure 10 for location of stations and of profile (Line 92-3, day 158, fixes 649-675).

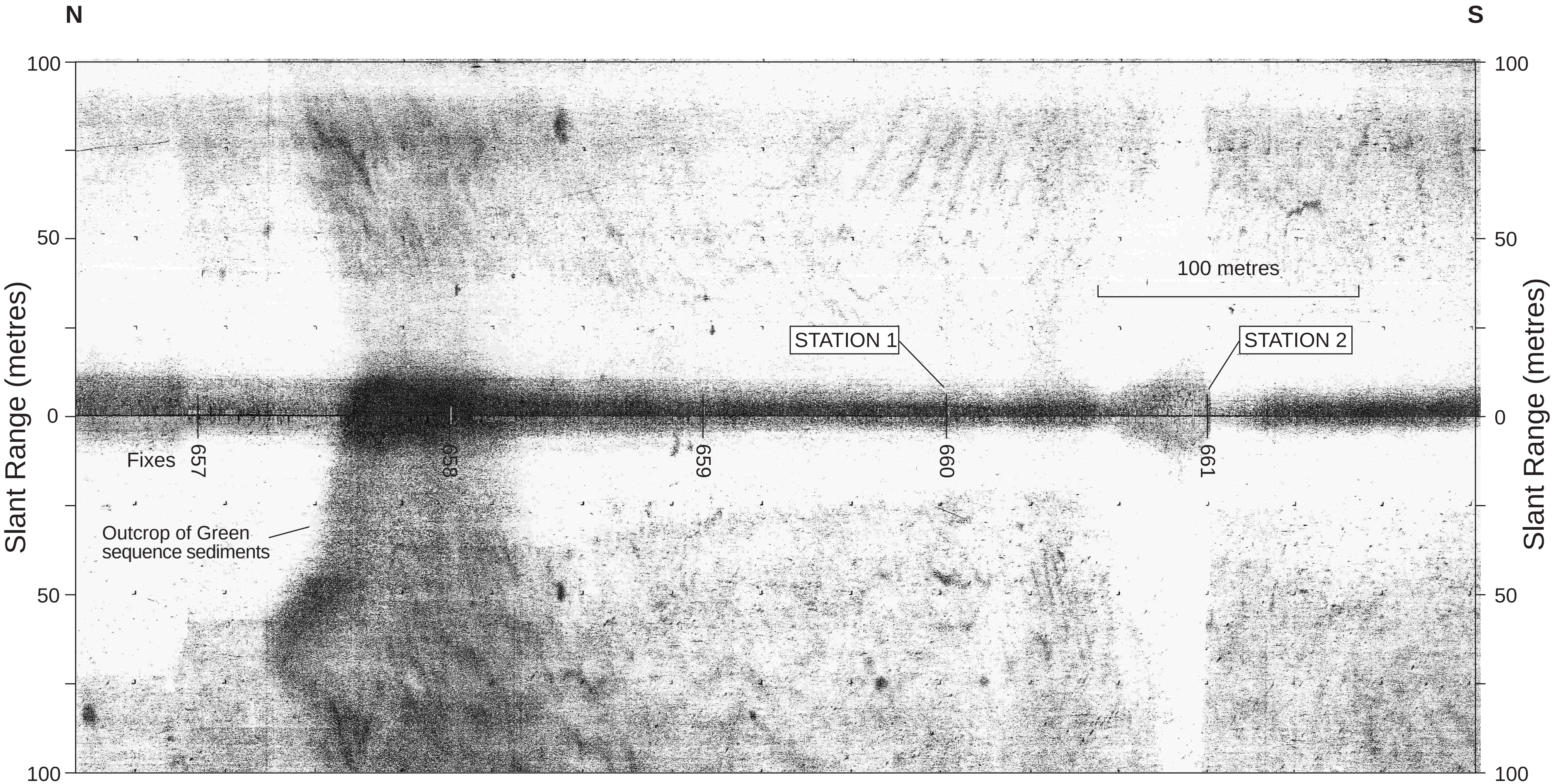


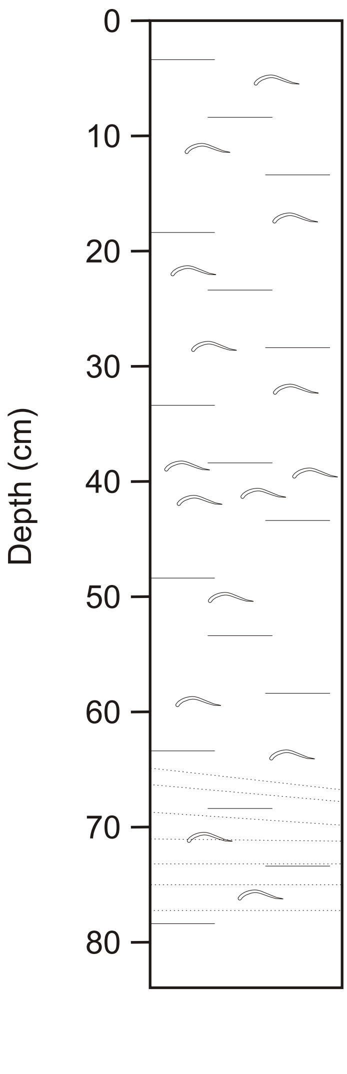
Figure 12. Sidescan sonar record corresponding to a portion (around 880 m) of the seismic profile in Figure 11. Outcrop of Green Sequence sediment near fix 658 appears as a dark-toned band oriented east-west. Blue Sequence sediments on the lake floor appear light-toned. Stations 1 and 2 are located at fixes 660 and 661, respectively (Line 92-3, day 158, fixes 656-662).

Station 2

Latitude: 44° 18.0697´ N
Longitude: 79° 30.3244´ W
Lake Level, Depth: 219 m asl, 17 m
Date: August 28, 1997

Gravity Core (GC): 10x173 cm
GC Apparent Penetration: 88 cm

Lithology:



0-84 cm **Mud**; olive grey (5Y4/2) to grey brown with shell fragments or shells throughout.

39-41 cm Layer richer in shells.

65-84 cm Fainter, lighter banding.

Figure 13. Summary lithologic log for Benthos gravity core, Station 2, Lake Simcoe.

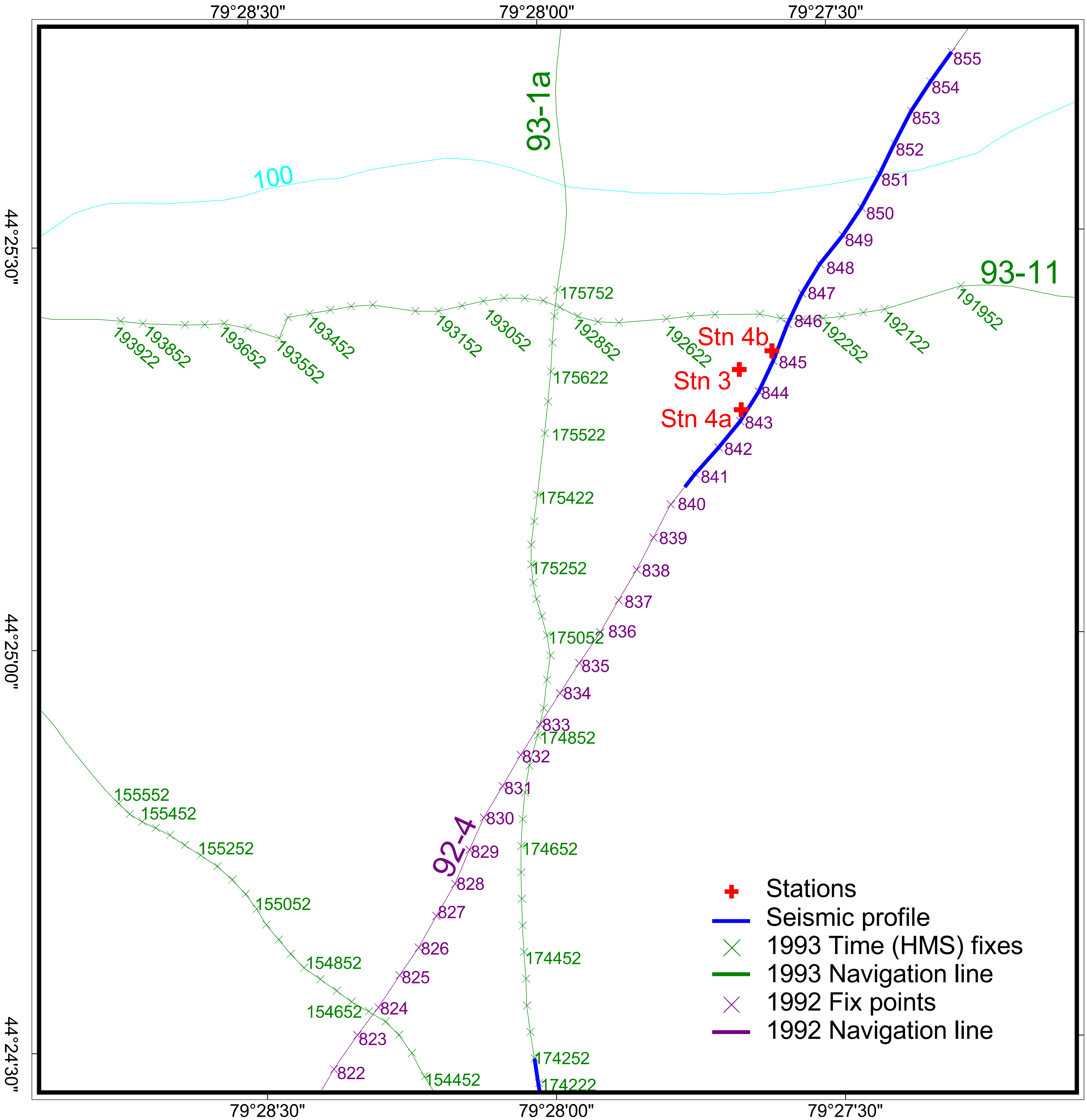


Figure 14. Location of Stations 3, 4a, and 4b. Blue along line 92-4 highlights location of seismic profile shown in Figure 15. Isobath in feet.

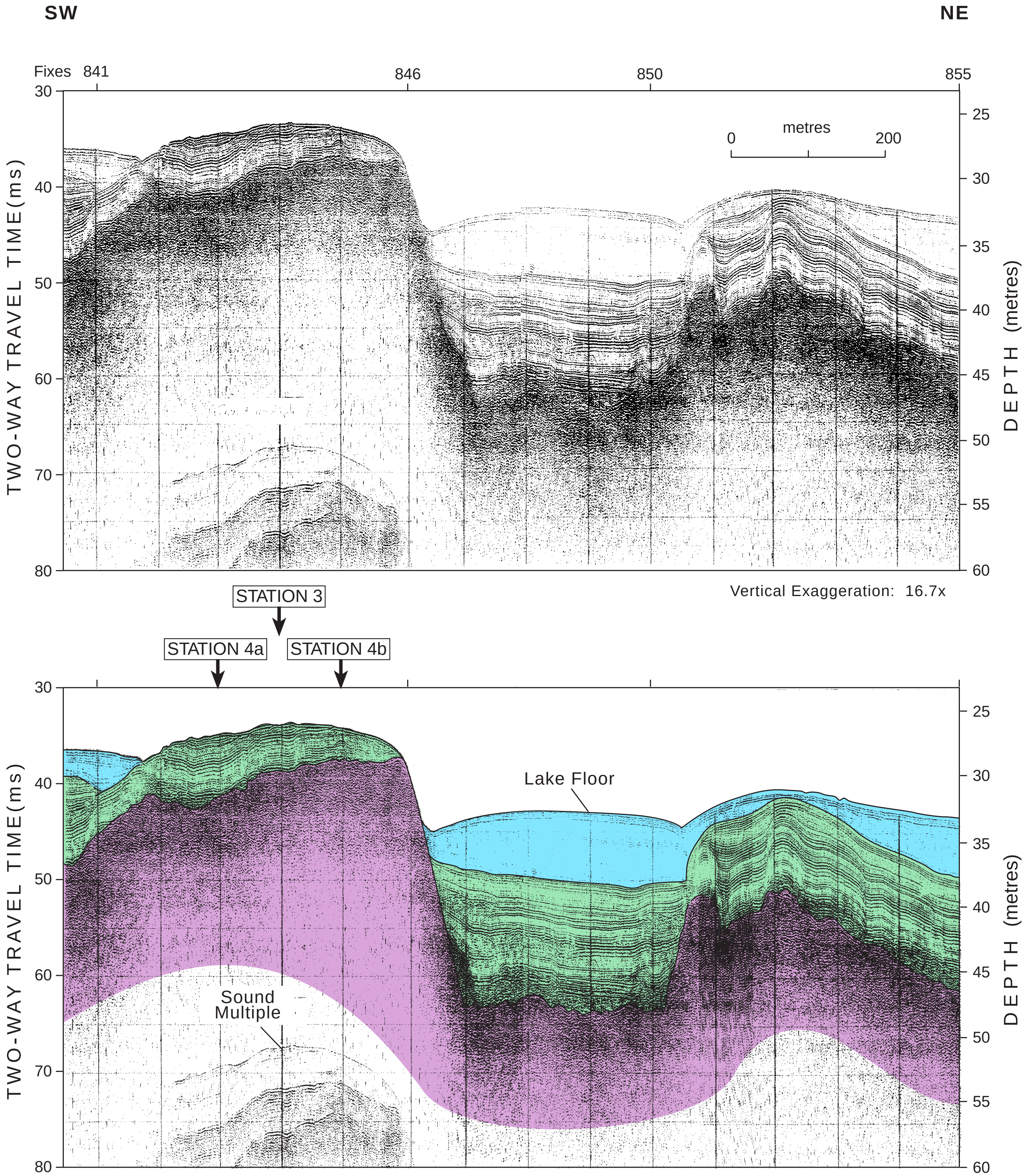
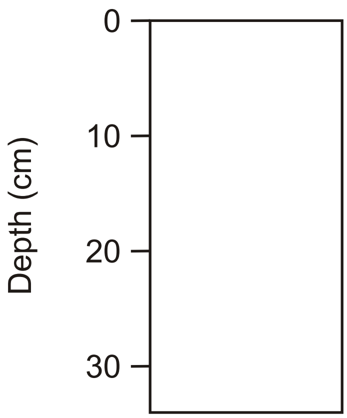


Figure 15. Knudsen 320 M seismic reflection profile (upper) and interpretive cross section showing stratigraphic relations (lower), western Lake Simcoe. Acoustic basement is Purple Sequence, overlain by Green and Blue Sequences. Locations of Stations 4a and 4b are indicated. Station 3 is projected onto the line of section. See Figure 14 for location of profile and core stations (1998 survey, June 27, 13:55:59-14:02:59).

Station 3

Latitude:	44° 24.7527´ N	Gravity Core (GC):	10x173 cm
Longitude:	79° 27.6965´ W	GC Apparent Penetration:	46 cm
Lake Level, Depth:	219 m asl, 26 m		
Date:	August 28, 1997		

Lithology:



0-34 cm **Mud**; dark grey to brown (2.5Y5/2), soft consistency, laminated 0 to 14+ (?) cm, grey (2.5Y5/1) below 26 cm.

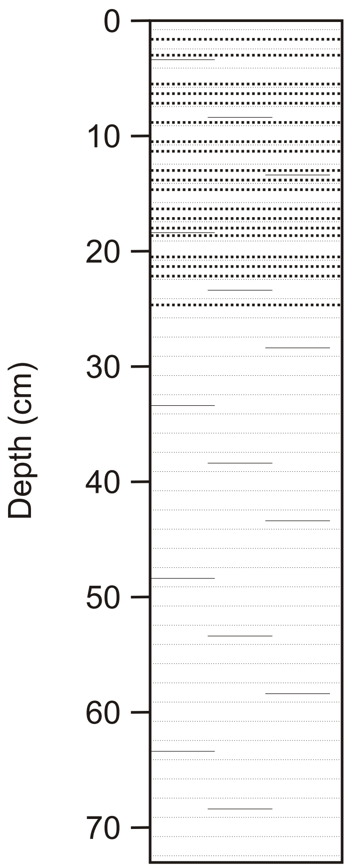
Figure 16. Summary lithologic log for Benthos gravity core, Station 3, Lake Simcoe.

Station 4a

Latitude: 44° 24.7024´ N
Longitude: 79° 27.6944´ W
Lake Level, Depth: 219 m asl, 27 m
Date: June 27, 1998

Gravity Core (GC): 10x173 cm
GC Apparent Penetration: 80 cm

Lithology:



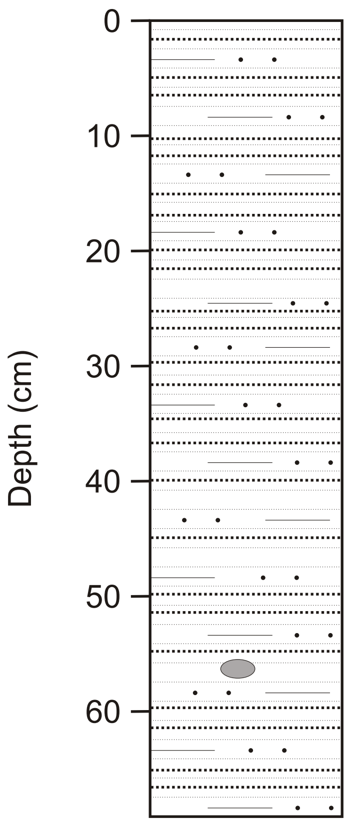
0-73 cm **Clay mud**; alternating laminae (rhythmites?) of lighter and darker grey brown (2.5Y5/2) clay. Sticky consistency. From 5-35 cm, lighter colour layers are cm-scale up to 3 cm thick, darker layers are mm- to sub-cm-scale; elsewhere layers are sub-cm- to mm-scale. Silt laminae in upper 25 cm.

Figure 17. Summary lithologic log for Benthos gravity core, Station 4a, Lake Simcoe.

Station 4b

Latitude:	44° 24.7751´ N	Gravity Core (GC):	10x173 cm
Longitude:	79° 27.6390´ W	GC Apparent Penetration:	76 cm
Lake Level, Depth:	219 m asl, 26 m		
Date:	June 27, 1998		

Lithology:



0-69 cm **Clay mud**; rhythmites consisting of repeated couplets of mm-scale darker over cm- to sub-cm-scale lighter grey brown (2.5Y5/2) layers, lighter layers increase to 3 cm thickness below 60 cm depth. Silty mud and silt layers common. Mud contains carbonate (reacts with 10% HCl). Two-cm dropstone at 56 cm depth.

Carbonate rock, 2 cm.

Figure 18. Summary lithologic log for Benthos gravity core, Station 4b, Lake Simcoe.

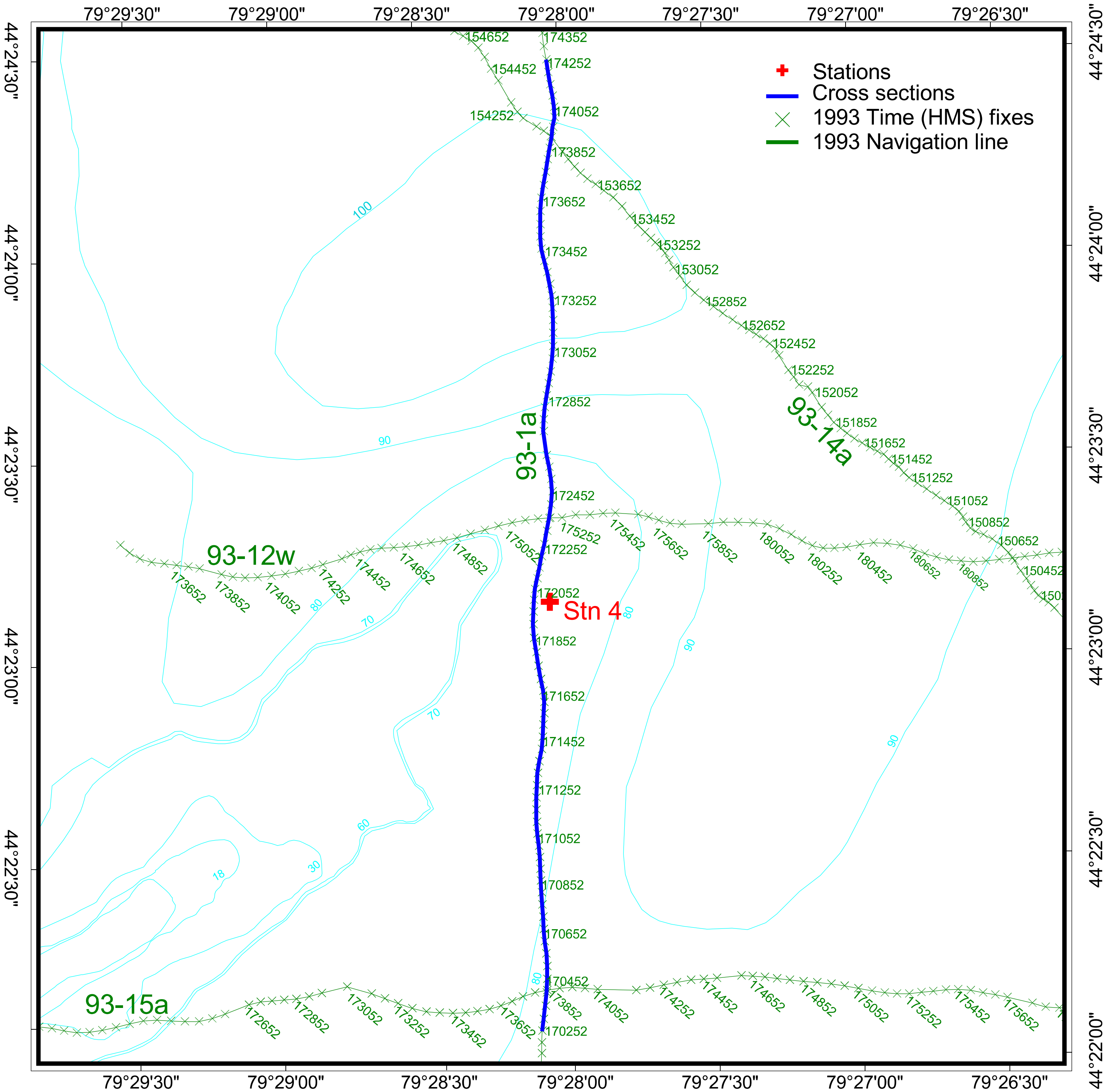


Figure 19. Location of Station 4. Blue along line 93-1a highlights location of seismic profile shown in Figure 20. Isobaths in feet.

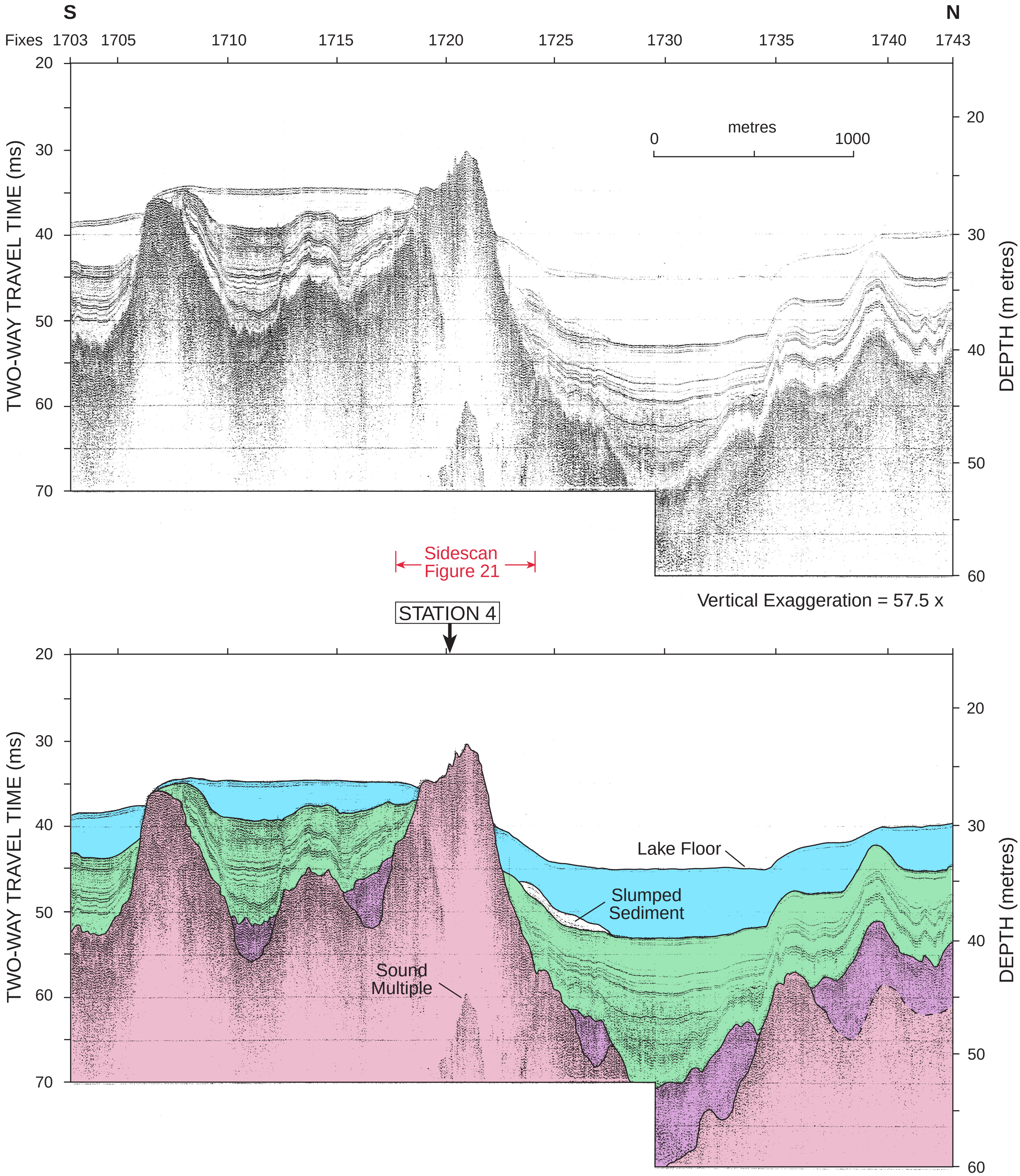


Figure 20. Single-channel seismic reflection profile (upper) and interpretive cross section showing stratigraphic relations (lower), western Lake Simcoe. Acoustic basement is Red Sequence, overlain by Purple, Green and Blue Sequences. The location of Station 4 is indicated. Extent of sidescan sonar record in Figure 21 is shown by red arrows. See Figure 19 for location of profile and core station (Line 93-1a, day 147,1703-1743).

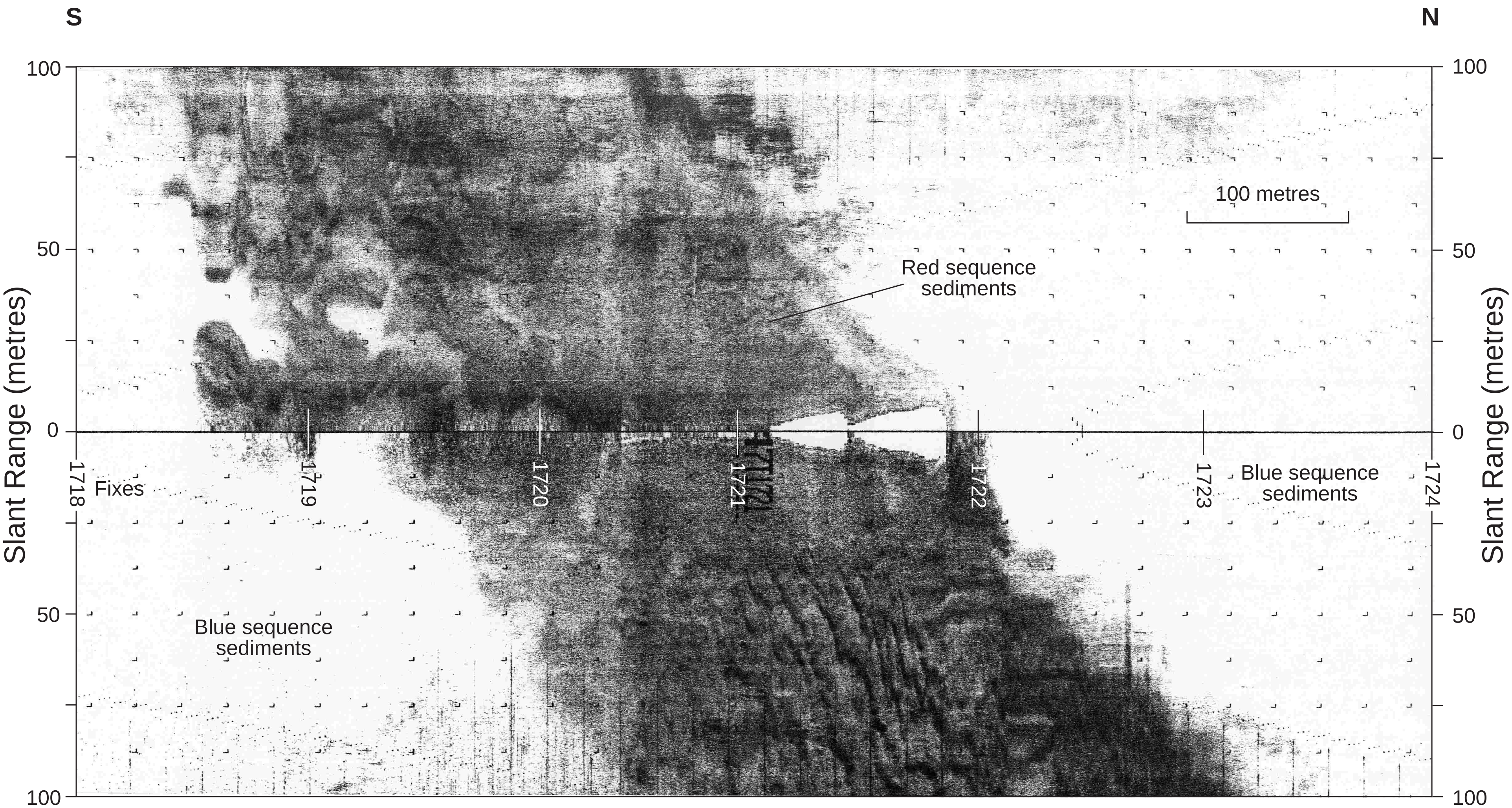


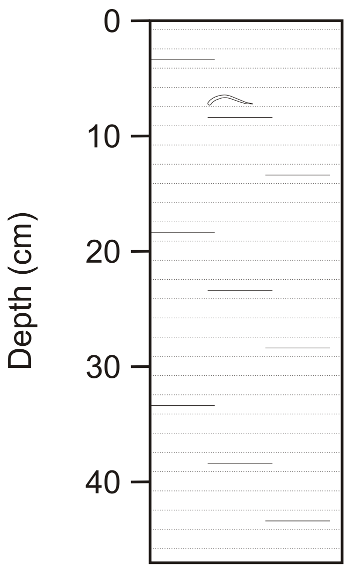
Figure 21. Sidescan sonar record corresponding to the seismic profile in Figure 20. Red Sequence sediment out cropping above the surrounding lake floor appears as a dark-toned band oriented southwest-northeast. Blue Sequence sediments on the lake floor appear light-toned (Line 93-1a, day 147, 1718-1724).

Station 4

Latitude: 44° 22.5600´ N
Longitude: 79° 28.0951´ W
Lake Level, Depth: 219 m asl, 23 m
Date: August 28, 1997

Gravity Core (GC): 10x173 cm
GC Apparent Penetration: 55 cm

Lithology:



0-48 cm **Clay mud**; faintly laminated grey (5Y5/1) and grey brown clay under 3 contorted layers of dark grey brown, grey, and light grey brown mud (0-3 cm).

Figure 22. Summary lithologic log for Benthos gravity core, Station 4, Lake Simcoe.

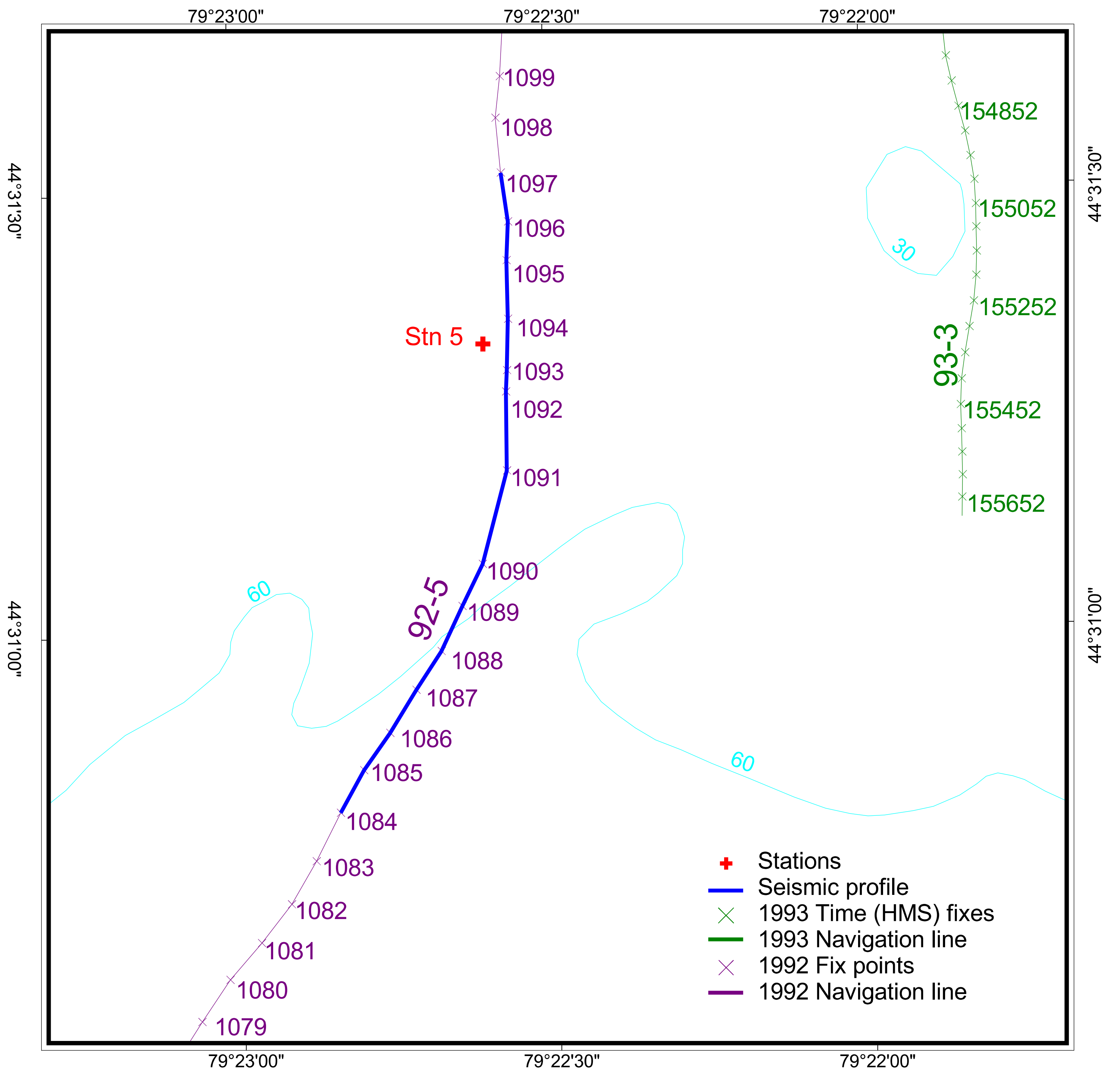


Figure 23. Location of Station 5. Blue along line 92-5 highlights location of seismic profile shown in Figure 24. Isobaths in feet.

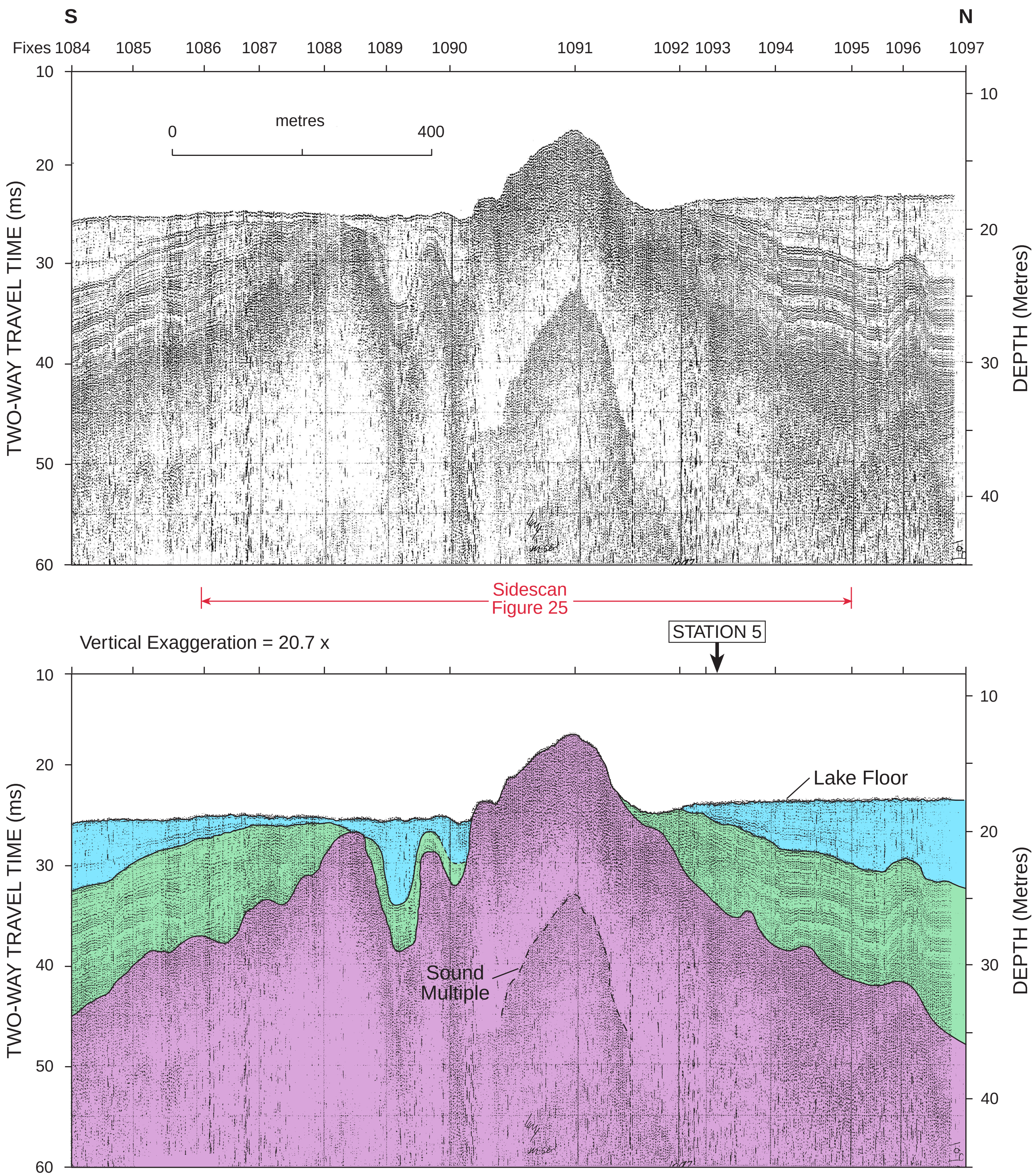


Figure 24. Single-channel seismic reflection profile (upper) and interpretive cross section showing stratigraphic relations (lower), northwestern Lake Simcoe. Acoustic basement is Purple Sequence, overlain by Green and Blue Sequences. Location of Station 5 is indicated. Extent of sidescan sonar record in Figure 25 is shown by red arrows. See Figure 23 for location of core station and profile (Line 92-5, day 262, fixes 1084-1097).

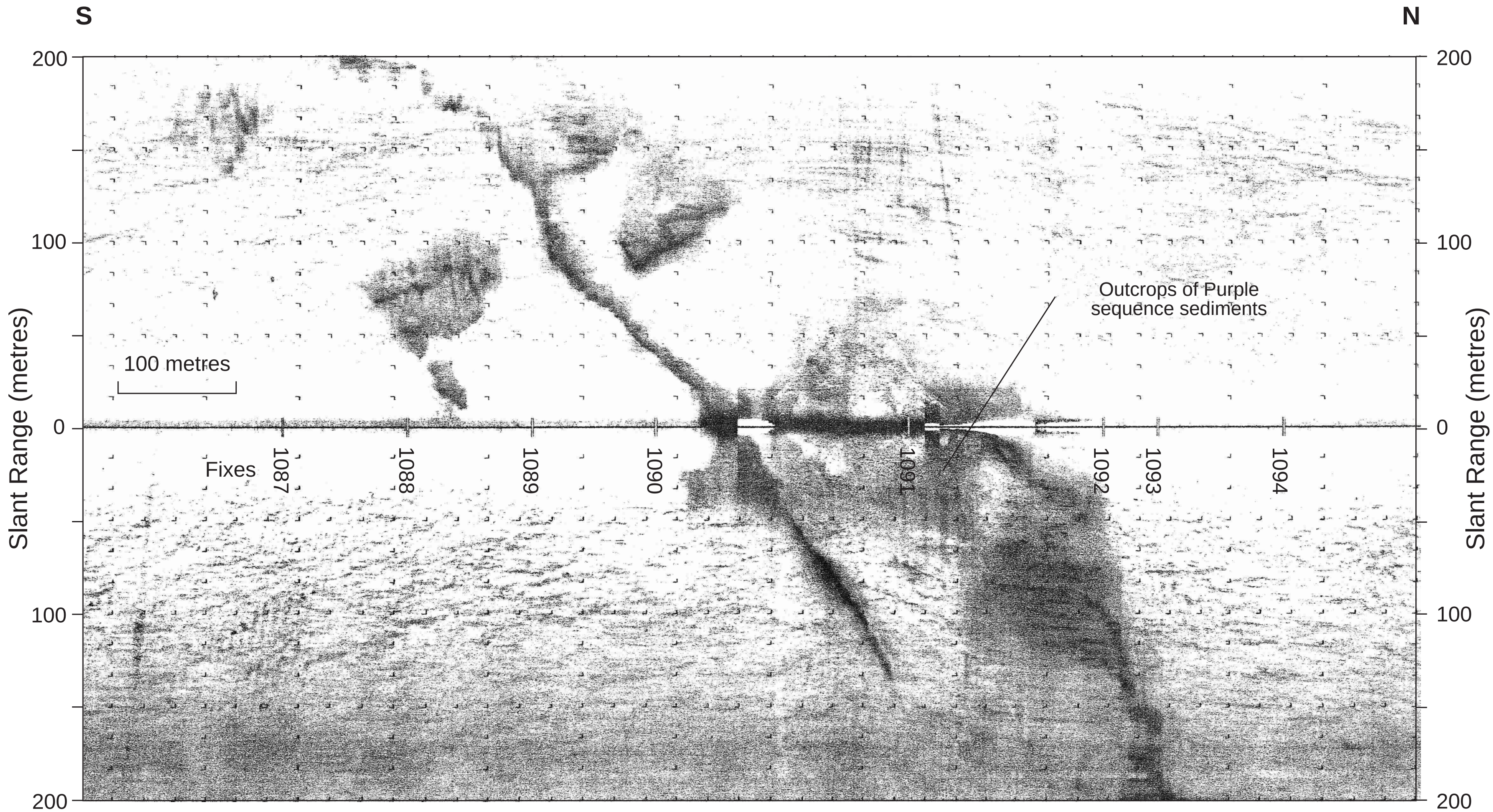


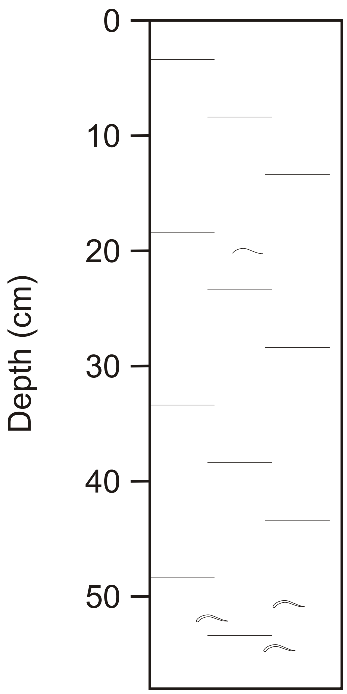
Figure 25. Sidescan sonar record corresponding to the seismic profile in Figure 24. Purple Sequence sediment outcropping above the surrounding lake floor appears as a dark-toned band oriented southwest-northeast. Blue Sequence sediments on the lake floor appear light-toned (Line 92-5, day 262, fixes 1086-1095).

Station 5

Latitude: 44° 30.7410´ N
Longitude: 79° 22.6416´ W
Lake Level, Depth: 219 m asl, 17 m
Date: August 28, 1997

Gravity Core (GC): 10x173 cm
GC Apparent Penetration: 64 cm

Lithology:



0-58cm **Mud**; olive grey (5Y5/2) to brown grey (lighter below 22 cm), soft, massive.

Minor shell fragments.

Figure 26. Summary lithologic log for Benthos gravity core, Station 5, Lake Simcoe.

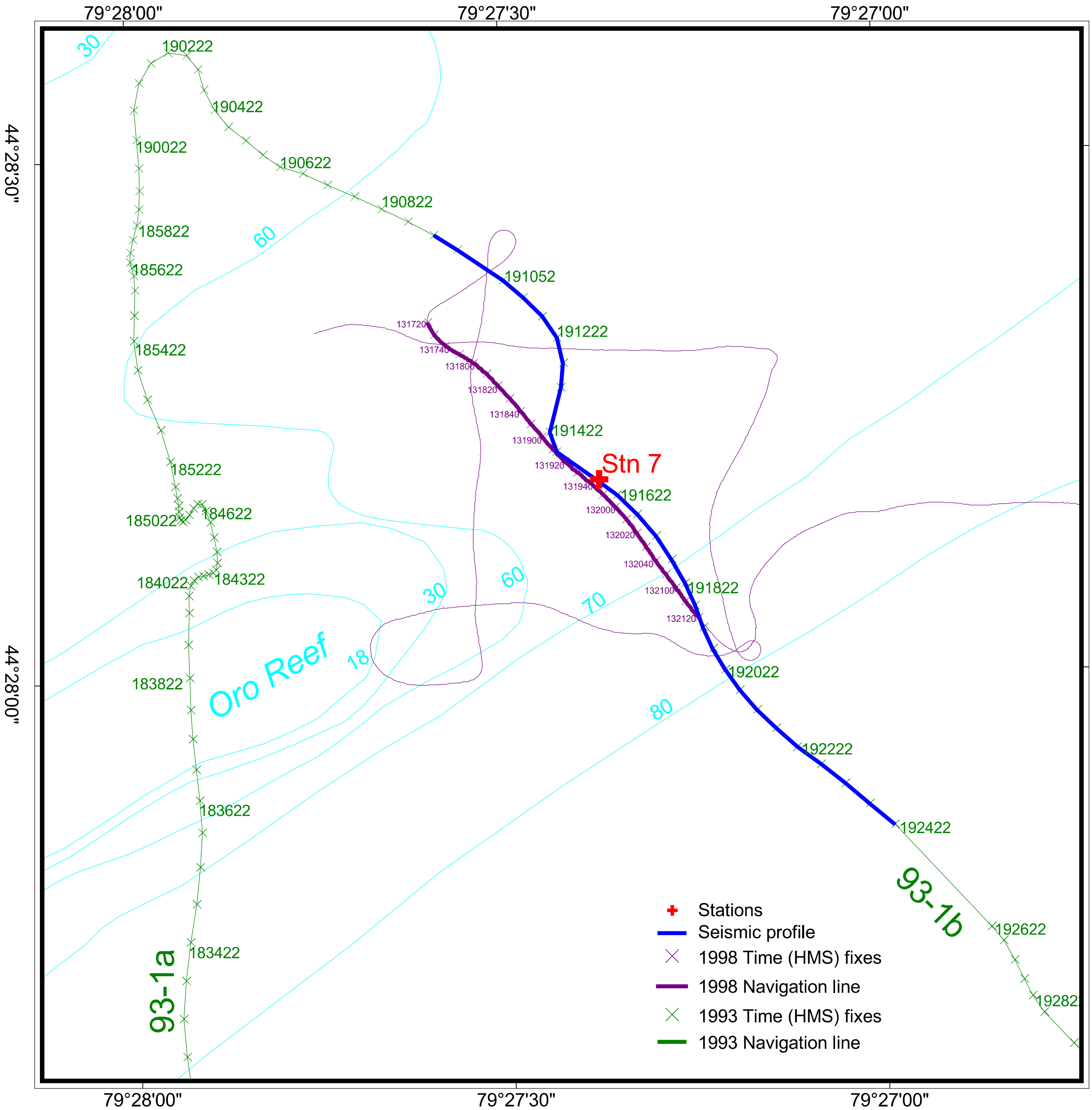


Figure 27. Location of Station 7. Blue along 1998 survey line highlights location of seismic profile shown in Figure 28. Isobaths in feet.

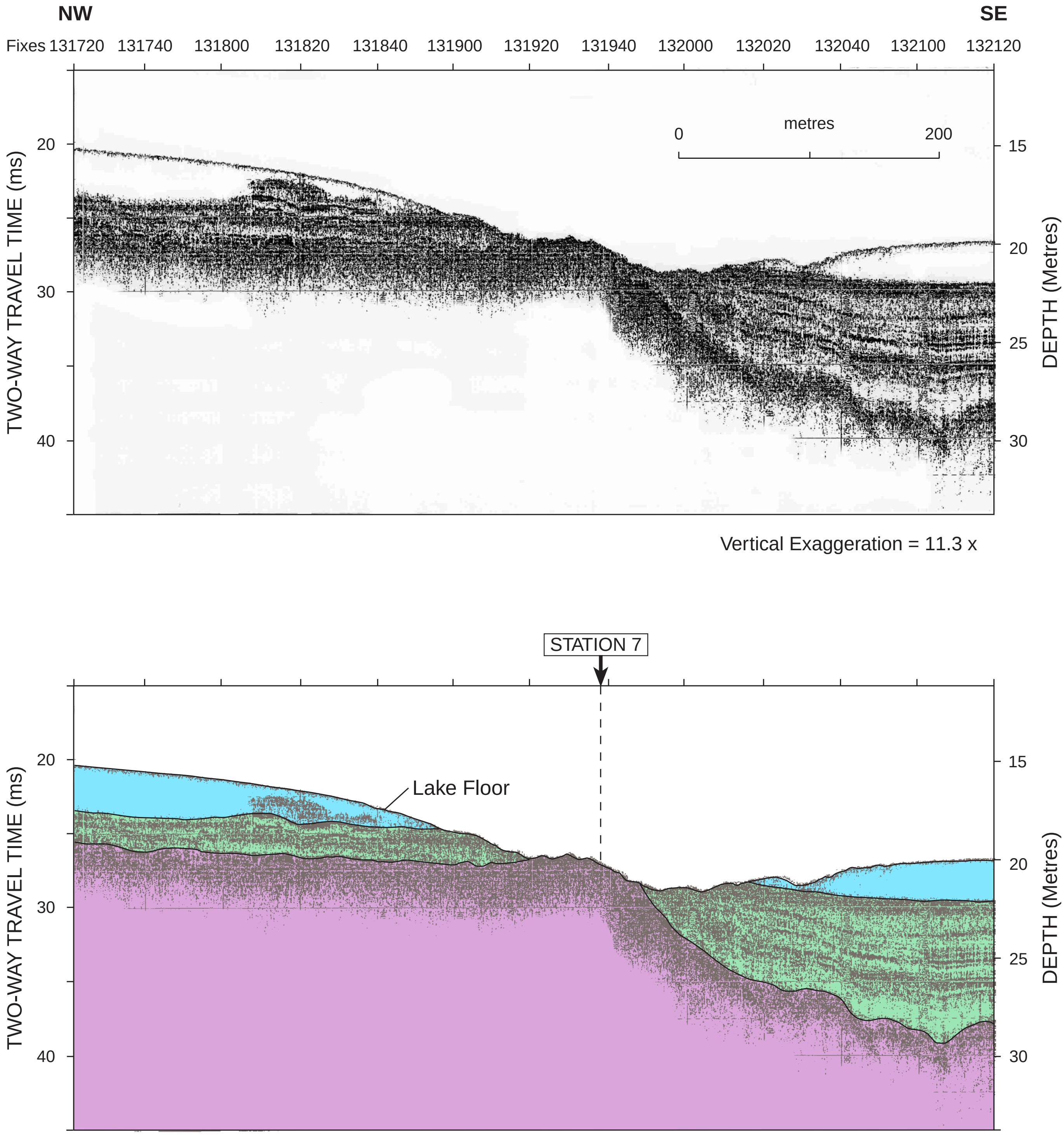
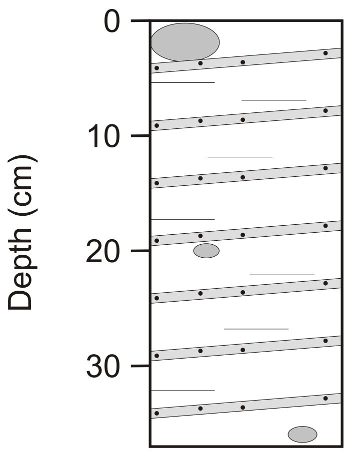


Figure 28. Knudsen 320 M seismic reflection profile (upper) and interpretive cross section showing stratigraphic relations (lower), northwestern Lake Simcoe. Acoustic basement is Purple Sequence, overlain by Green and Blue Sequences. Location of Station 7 is indicated. See Figure 27 for location of profile (1998 survey, June 28, 13:17:20-13:21:20).

Station 7

Latitude:	44° 27.7240´ N	Gravity Core (GC):	10x173 cm
Longitude:	79° 27.4097´ W	GC Apparent Penetration:	42 cm
Lake Level, Depth:	219 m asl, 27 m		
Date:	June 28, 1998		

Lithology:



0-38 cm **Clay mud**; 28 grey brown (2.5Y5/2) rhythmites comprising couplets of thicker (cm-scale) lighter layers over thinner (mm-scale) darker layers commonly with lithic granules, and silt granules and pebbles (very light). Lighter layers thicken downcore. Clay mud contains carbonate. Large carbonate dropstones (1.5-2 cm) at top and bottom of core.

Figure 29. Summary lithologic log for Benthos gravity core, Station 7, Lake Simcoe.

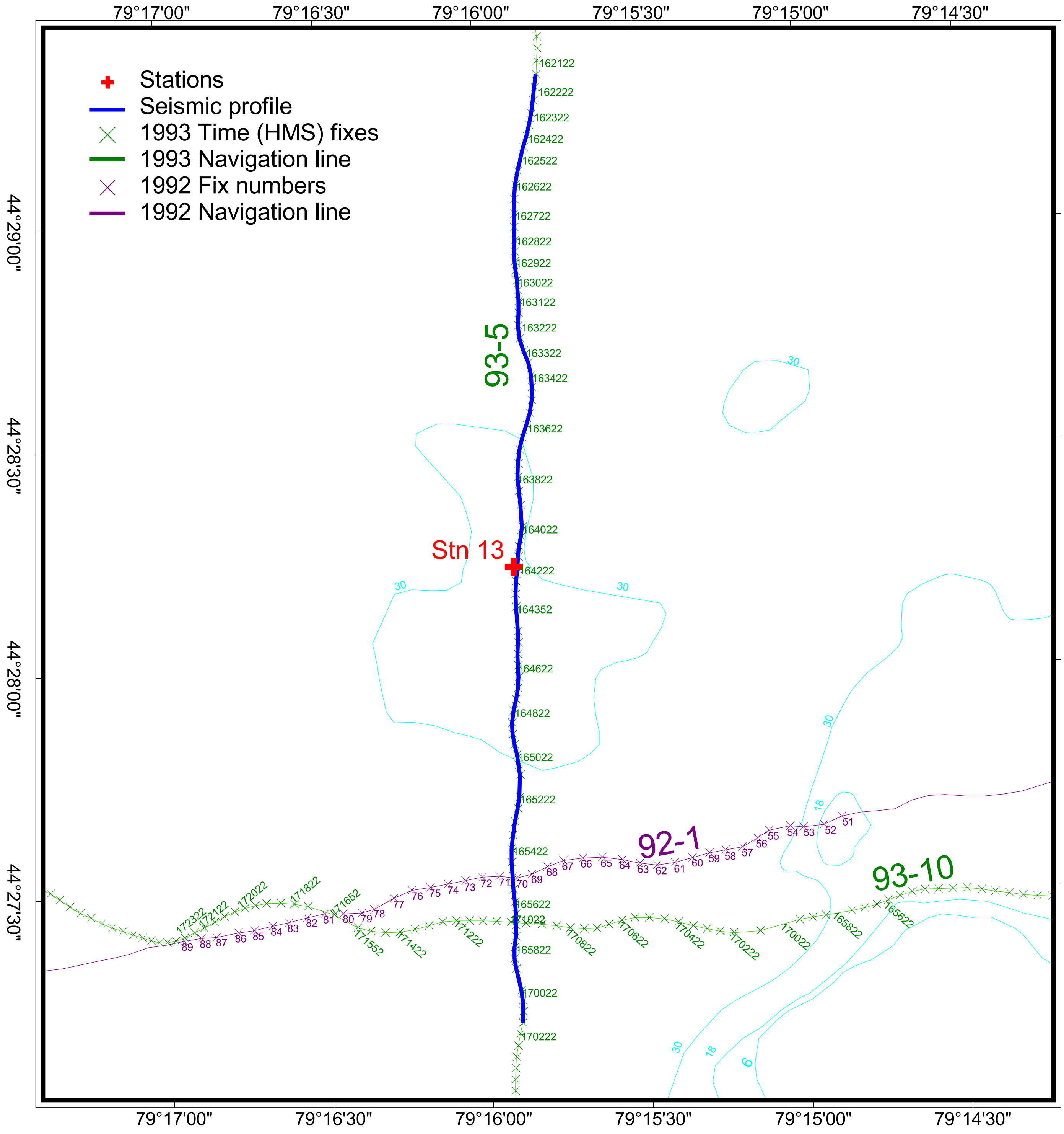


Figure 30. Location of Station 13. Blue along line 93-5 (day 160) highlights location of seismic profile shown in Figure 31. Isobaths in feet.

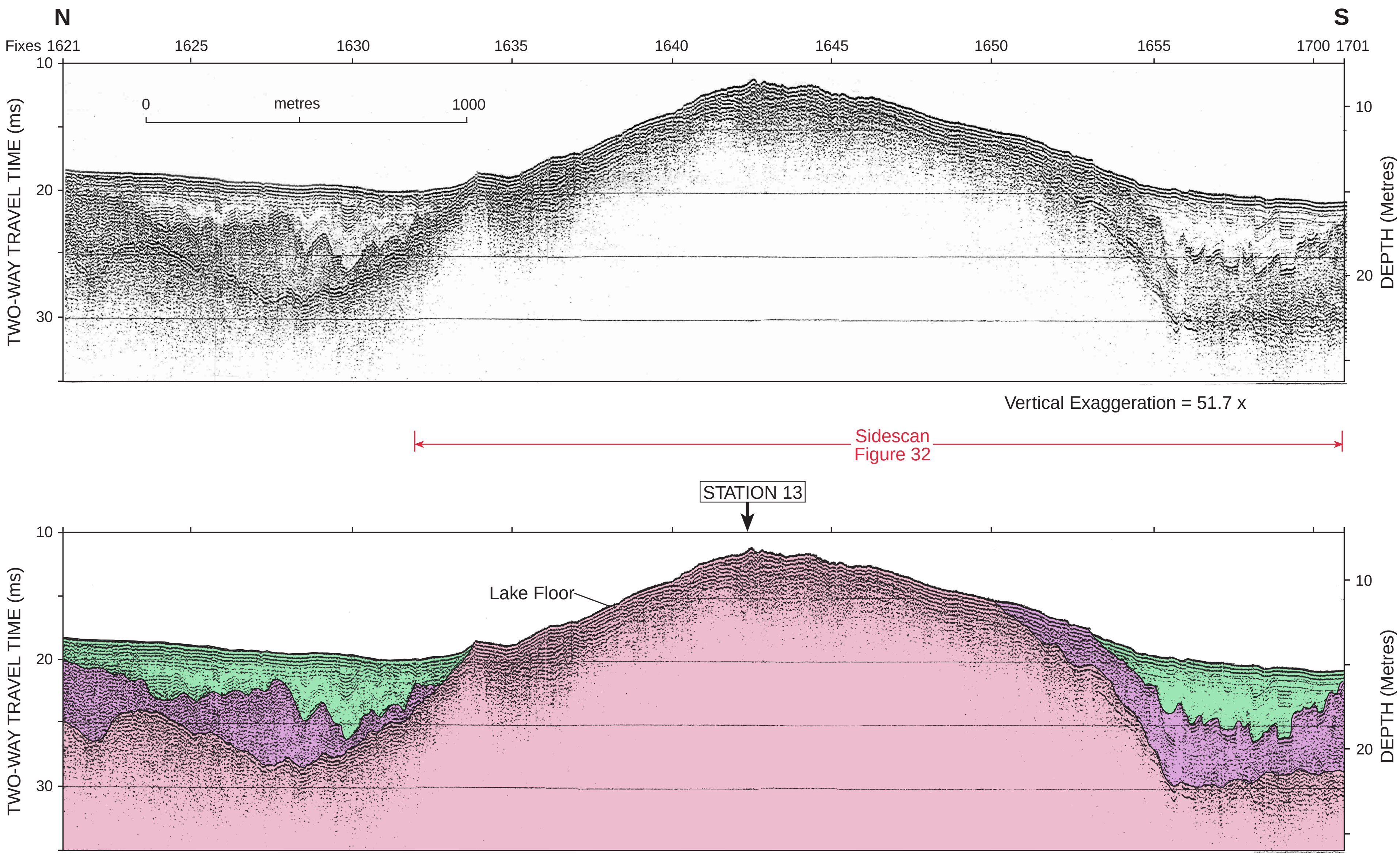


Figure 31. Single-channel seismic reflection profile (upper) and interpretive cross section showing stratigraphic relations (lower), eastern Lake Simcoe. Acoustic basement is Red Sequence, overlain by Purple and Green Sequences. Location of Station 13 is indicated. Extent of sidescan sonar record in Figure 32 is shown by red arrows. See Figure 30 for location of profile (Line 93-5, day 160, 1621-1701).

Figure 32. Sidescan sonar record corresponding to the seismic profile in Figure 31. Red Sequence sediment outcropping above the surrounding lake floor appears as a dark-toned band with an irregular surface. Green Sequence sediments on the lake floor appear lighter toned (Line 93-5, day 160, 16:31:30-17:01:45).

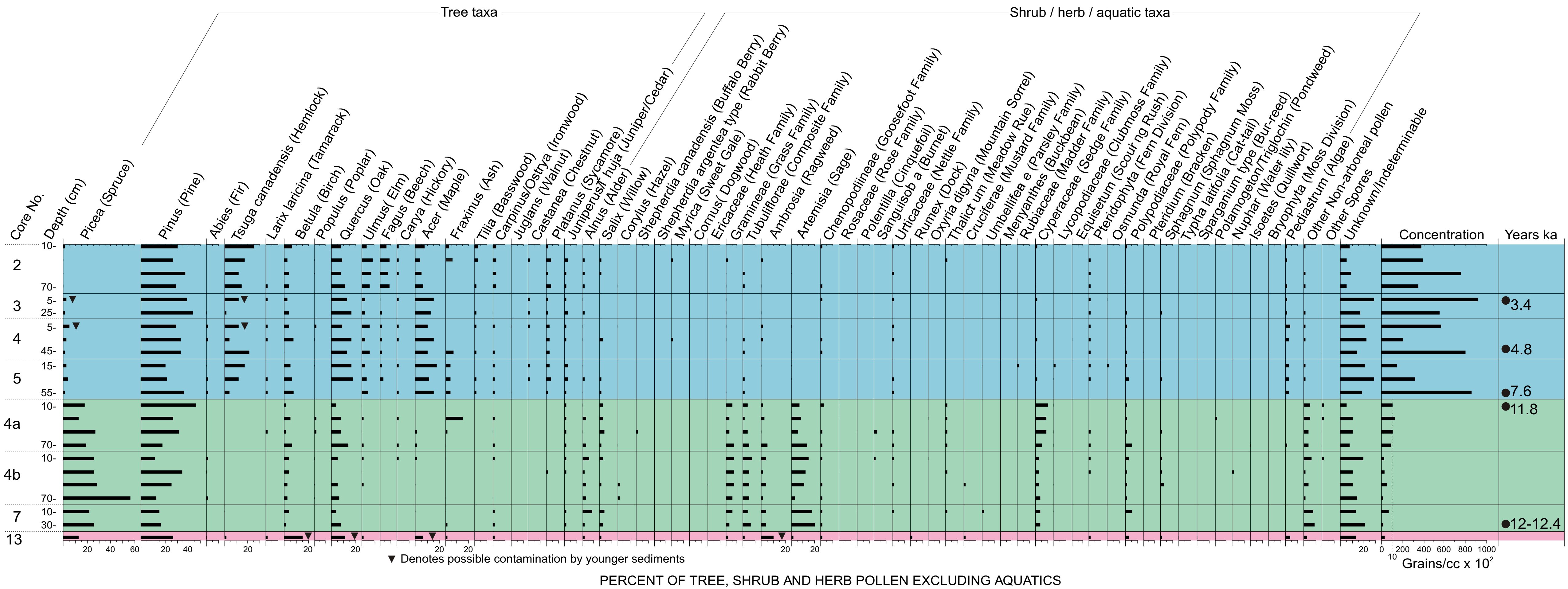


Figure 33. Pollen stratigraphies in gravity cores recovered from seismic reflectors in Lake Simcoe. Note change in scale for the pollen concentration profile for cores 4a, 4b, 7 and 13. Background colours (red, green, blue) correspond to assigned seismostratigraphic sequence colours (Fig. 8). The ^{14}C ages (years ka) are estimated by pollen correlation with other dated pollen records in southern and south-central Ontario.

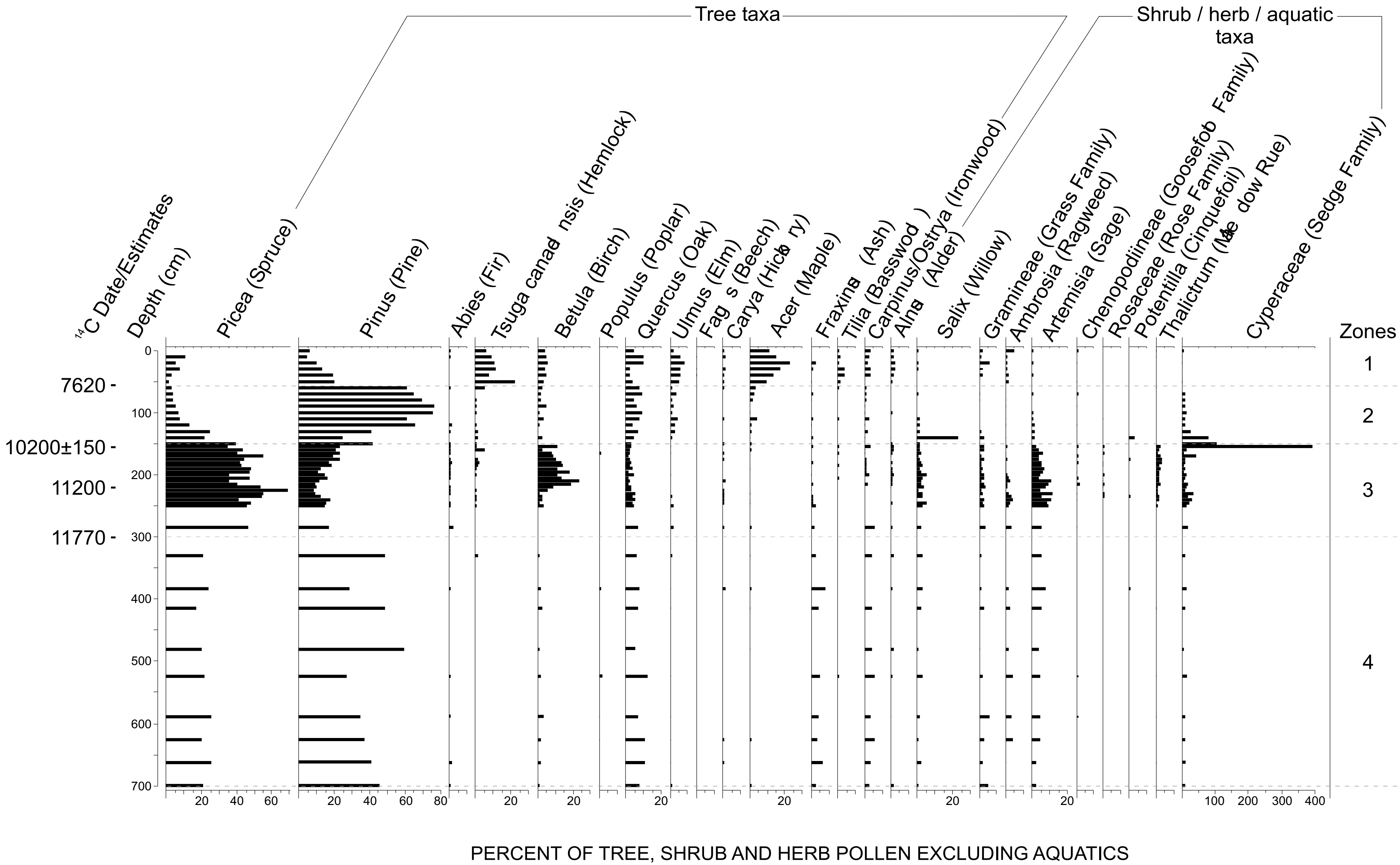


Figure 34. Pollen stratigraphy from Cookstown Bog and underlying Lake Algonquin sediments. The basal 2.5 cm of the peat bog was radiocarbon dated at 10,200 ± 150 BP (GSC-1111). The ^{14}C estimates are based on pollen concentration.

Appendix A: Core photographs

Photographs of Lake Simcoe Benthos gravity cores are provided here in ascending order (2, 3, 4, 4a, 4b, 5 and 7). The cores were split in the Geological Survey of Canada (Atlantic) core processing facility and photographed in approximately 40 cm-long, overlapping images accompanied by a Munsell soil colour chart. The scale on each side of the core-support tray is in centimetres. The three-digit number on the soil-colour reference card is the core depth in centimetres at the level indicated by the prominent, left-pointing arrow.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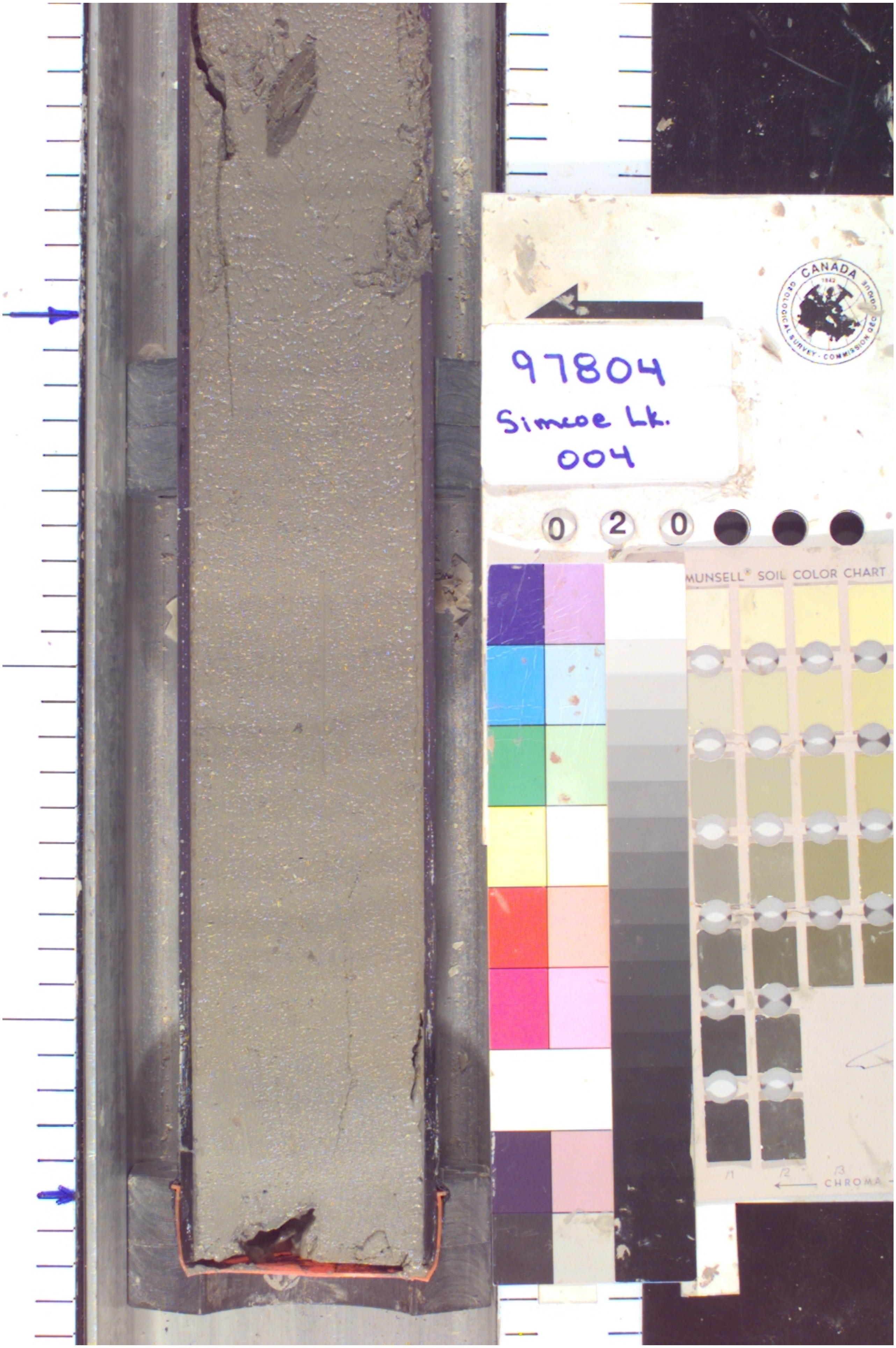
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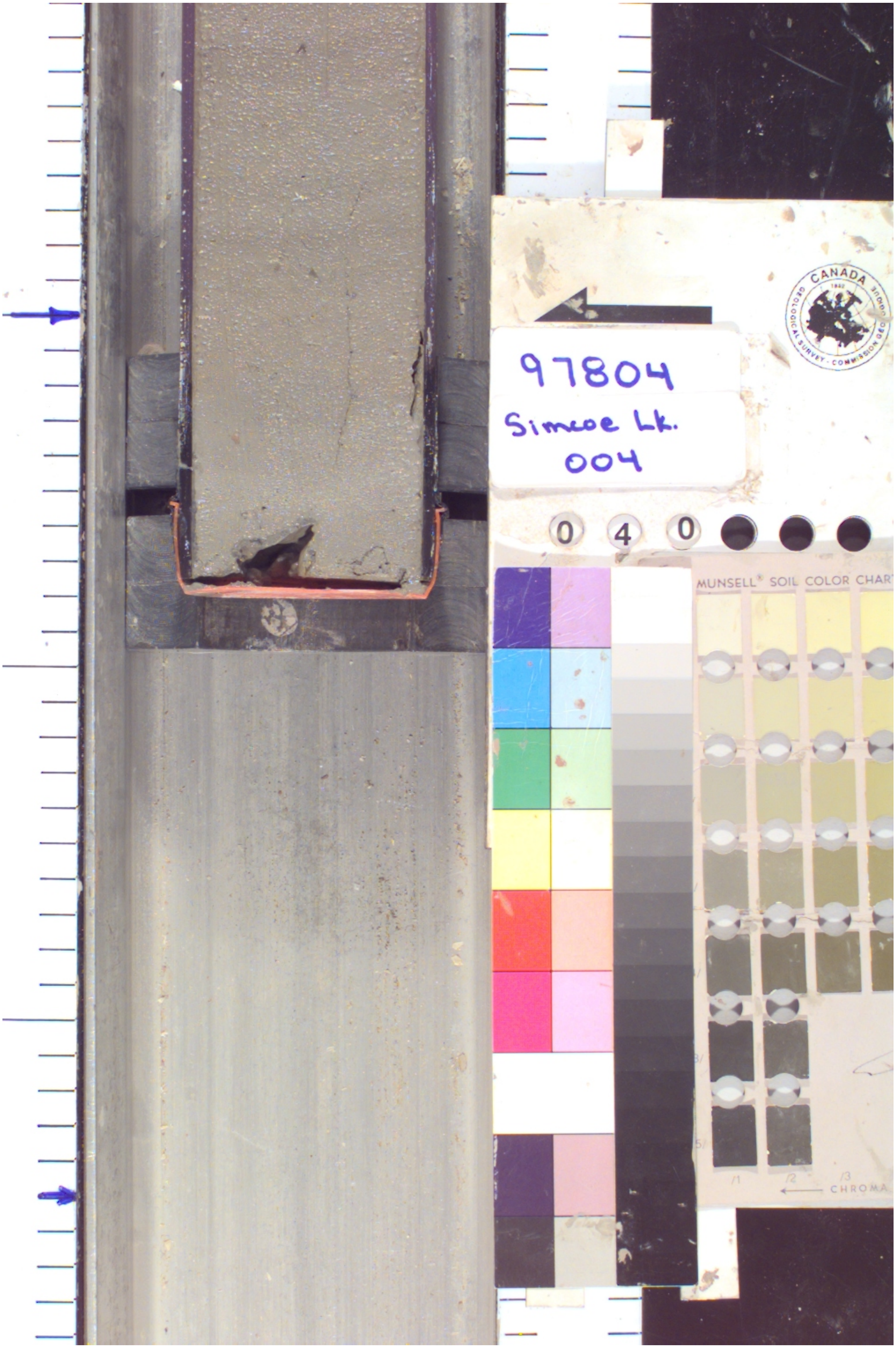
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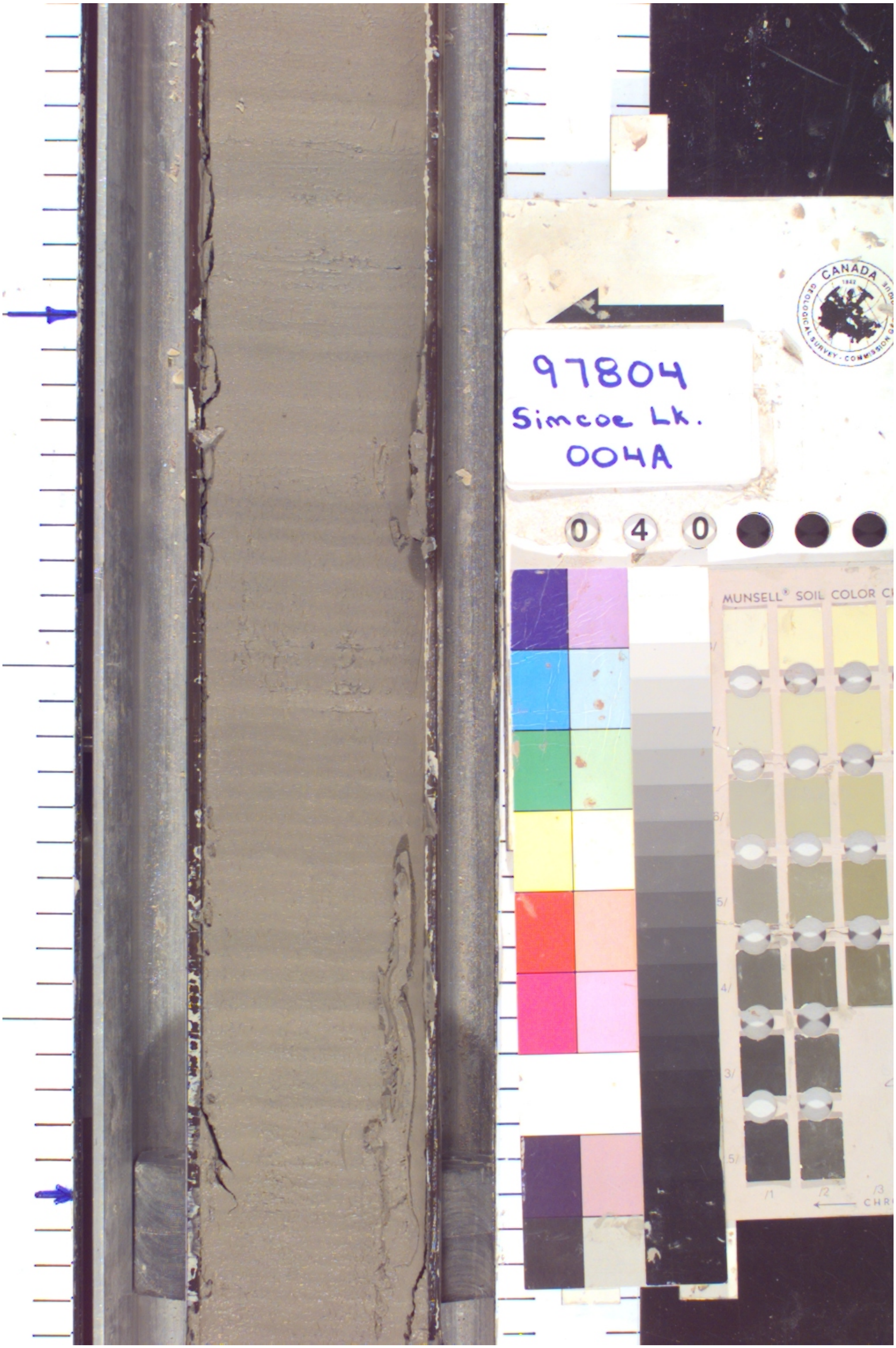
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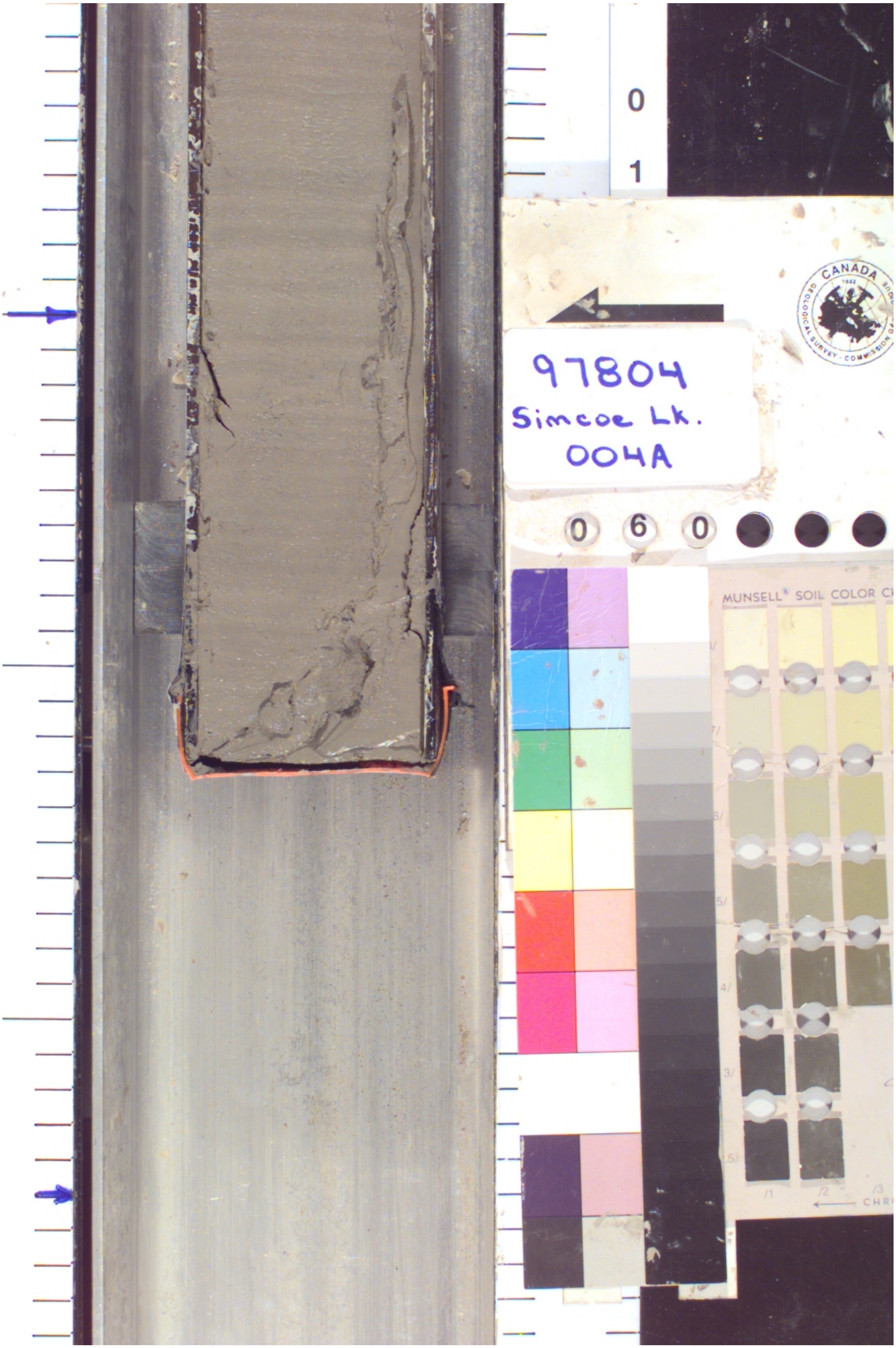
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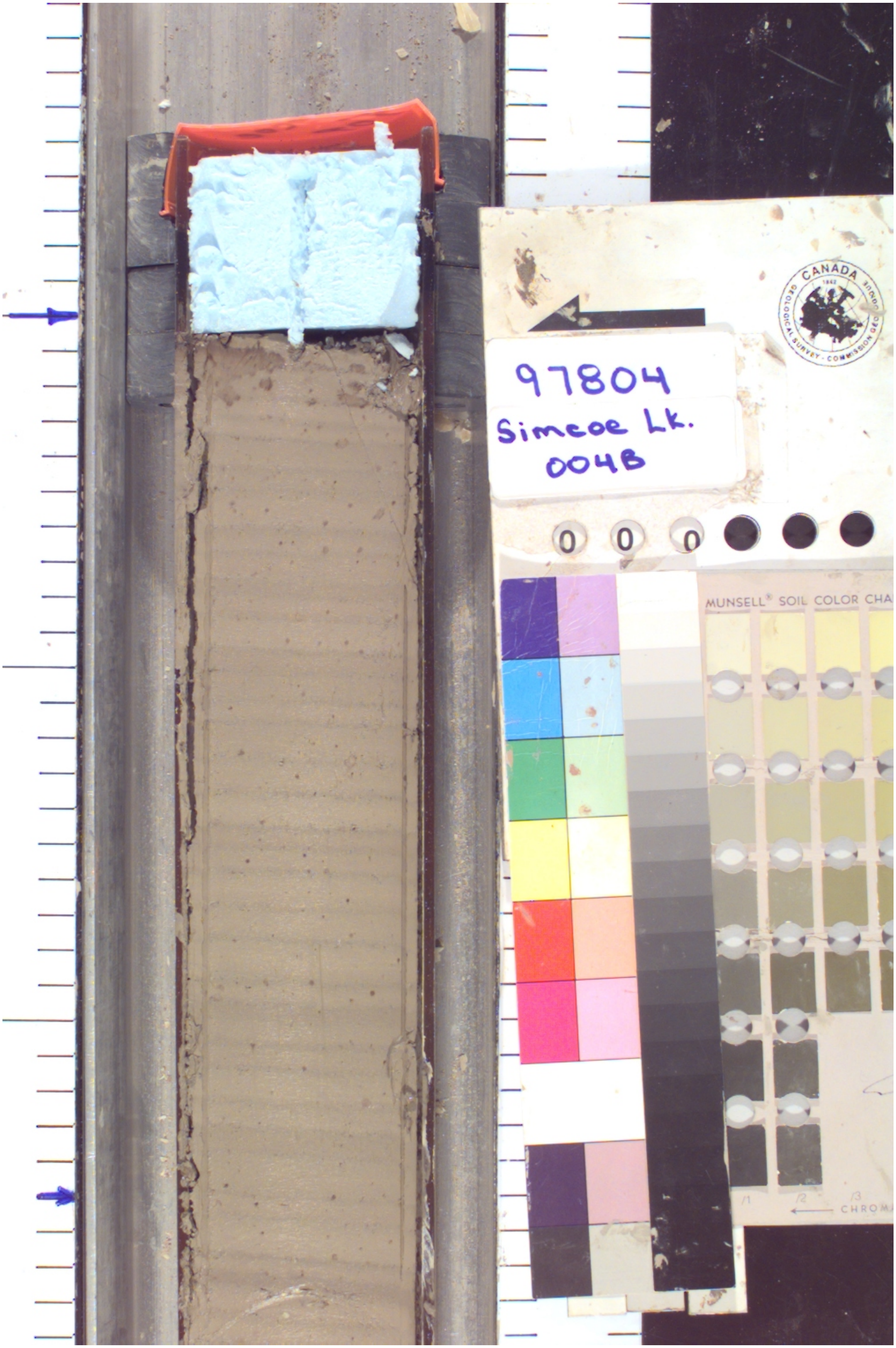
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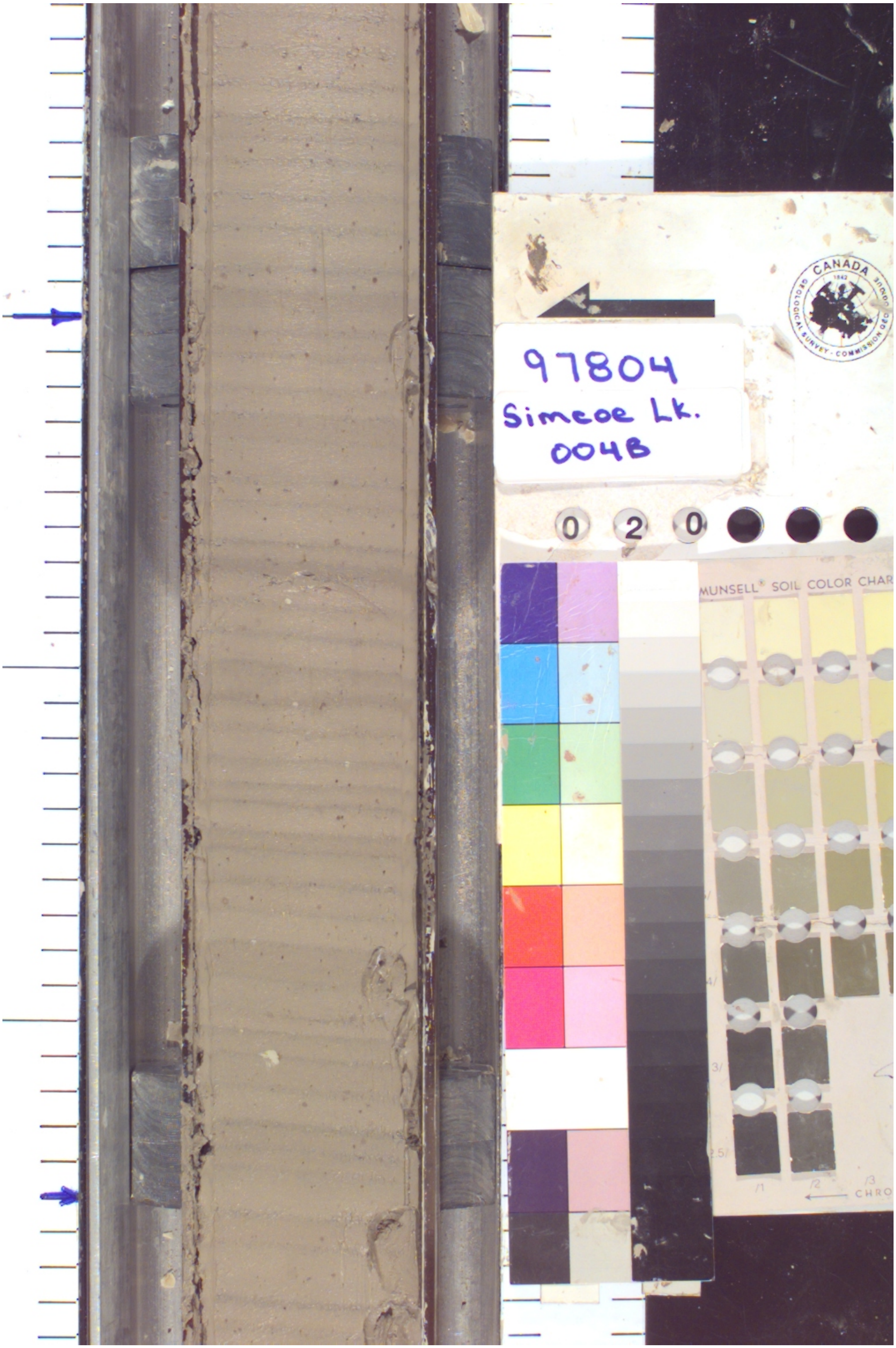
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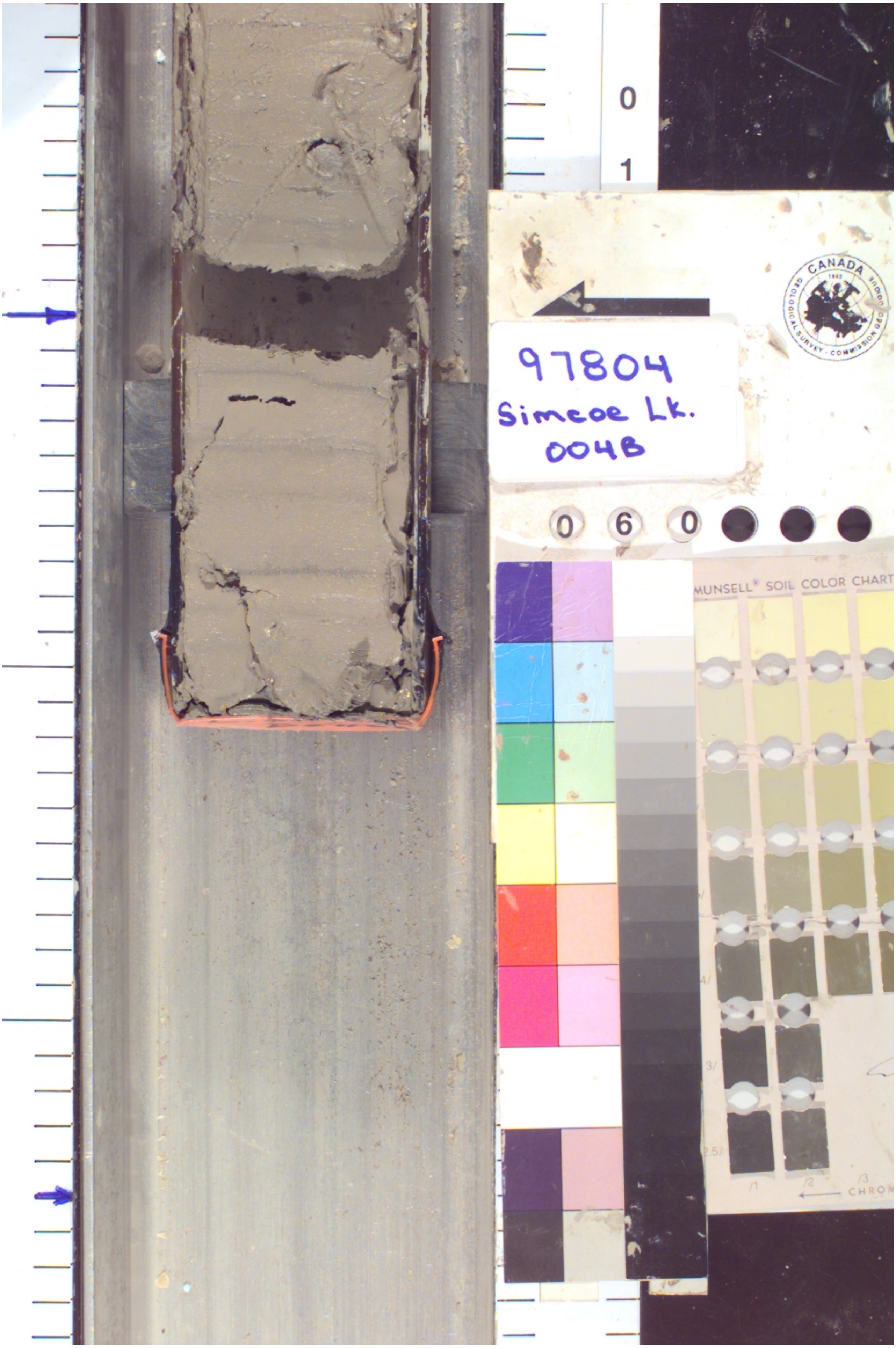
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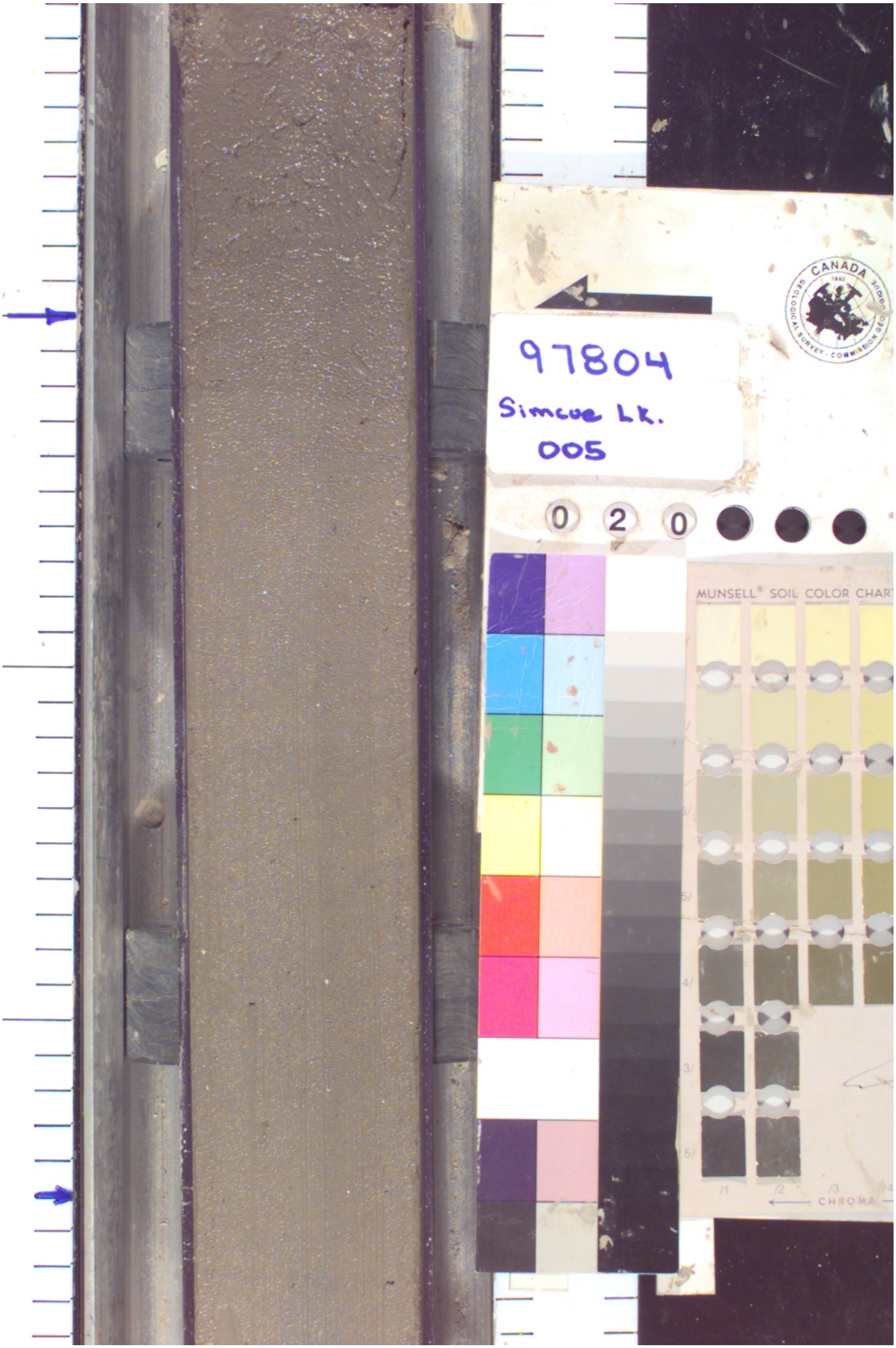
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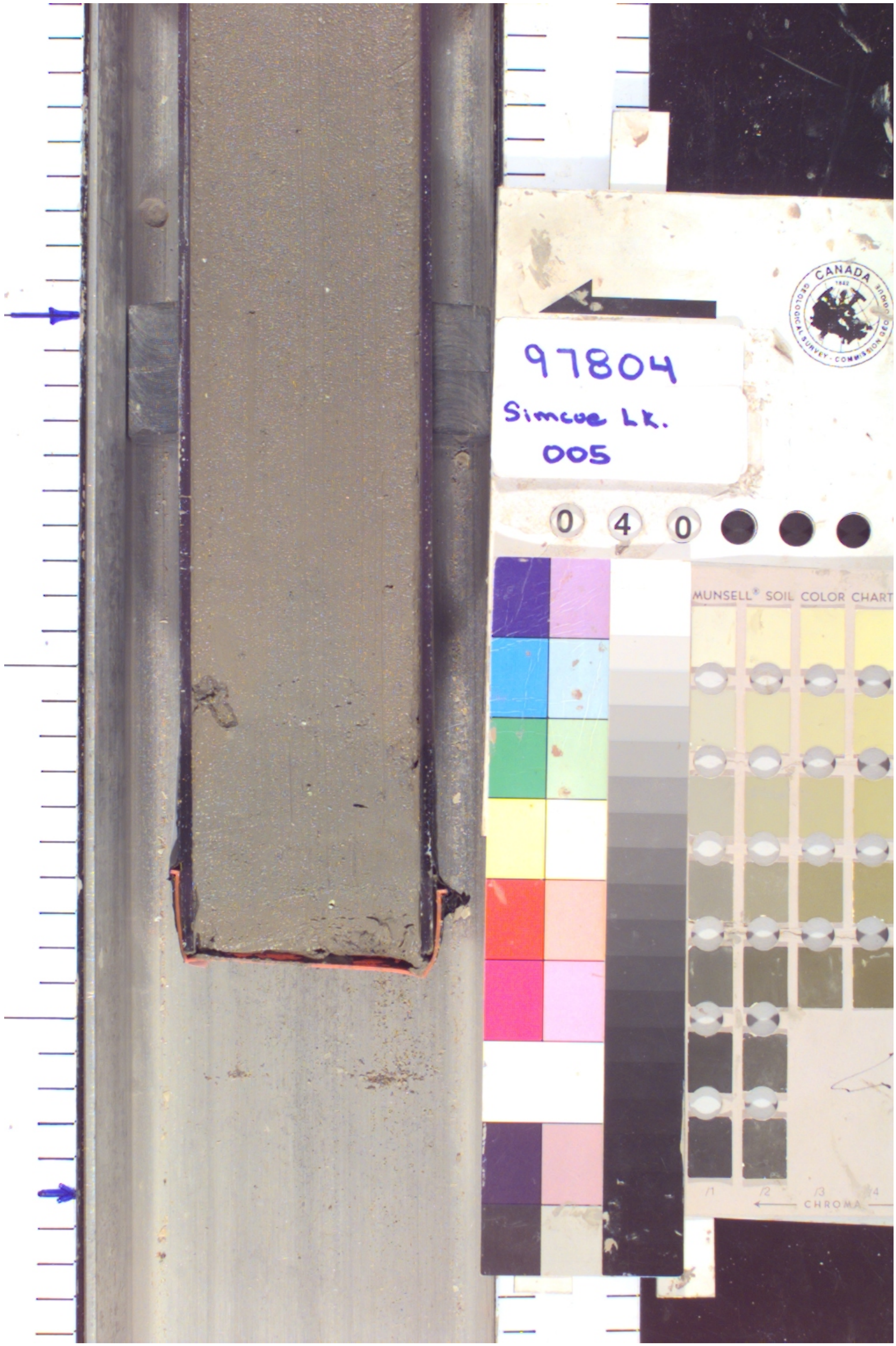
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Appendix B: 1998 navigation data

Navigation data in the form of ASCII files are provided on tis CD-ROM for stations 4, 4a, 4b, 7, 13. The files are located in directory 1998_navigation_data. The files structure is as follows:

Date in day, month, year
UTC time in hours, minutes, seconds
Position in negative longitude (west of Greenwich), positive latitude (north of equator)
Position in UTM, NAD 27 datum in easting (metres), northing (metres)
Elevation above sea level in metres