GLACIAL AND CLIMATIC HISTORY OF LAKE BANOOK, DARTMOUTH, NOVA SCOTIA

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Submitted in Partial Fulfillment of the Requirements
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Department of Earth Sciences
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Abstract

Lake Banook in Dartmouth, Nova Scotia is a part of the historic Shubenacadie Canal system and has received much attention from city planners lately, however, the geological history of the lake and surrounding area has received relatively little attention. Here, reflection seismic, multibeam bathymetry and sediment cores have been used to explore the late glacial and Holocene history and evolution of this lake. Interpretations of high-resolution seismic data (10 kHz profiler) and six short sediment cores (maximum 1.2m) are presented, along with data on thecamoebian assemblages. Six seismic facies have been defined in the 10 m thick sediment column, interpreted from the base up to be glacial till, two glacilacustrine units, mass failures, and two Holocene units. One widespread unconformity and a higher terrace are interpreted as low-stand phenomena. The cores are correlated to seismic profiles and their interpretations. The cores sampled both Holocene units as well as both glacilacustrine units, generally across an unconformity. The light grayish brown glacilacustrine units are finely laminated (varve-like) and are locally unconformably overlain by a reddish-brown, poorly stratified sandy diamict, overlain in turn by a series of soft, dark brown post-glacial muds and gyttja. Thecamoebians, freshwater protozoan microfossils, are abundant in the Holocene muds, but absent elsewhere in the cores. These microorganisms provide information regarding terrigenous and brackish water influence, as well as eutrophication and other anthropogenic influences.

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE OF TABLES

ACKNOWLEDGMENTS

I would like to thank my supervisor, Ned King (GSC-A), for putting countless hours of work into the survey and for his support and discussions throughout the project. I would also like to thank my Dalhousie supervisor, Dave Scott, for this instruction and useful comments. I would also like to thank Gordon Cameron and Kate Jarett (GSC-A), for the core lab facilities and assistance. Thanks also go to Chloe Younger at Dalhousie for her help in the core lab and with processing samples, and Patricia Scallion at Dalhousie for taking the SEM photographs. Thank-you to my fiancé, Tammo Huppertz, for his insight and support. Rob Courtney deserves thanks for rapidly developing the JP2 Viewer program and assisting with any technical difficulties.

I would also like to thank the survey team: Dustin Whalen, Peter Pledge, Steve Solomon, Dave Frobel and Gary Grant from GSCA; Ralph Orton, Don Mosher, Paul Forrest and Fred Horne from The Atlantic Division of Canoe-Kayak Canada; Don Mosher, Jeff Scrutton, Dan Graham and Paul Shouldice from Maritime Environmental Awareness Group Defence R&D Canada Atlantic.

INTRODUCTION

Lakes in the Atlantic region have received much attention in the past few decades, including reviews and summaries of studies carried out over the past 40 years. Much of the work has concentrated on micropaleontology and palynyology of single "representative" cores for each lake, without a detailed seismic survey or stratigraphic framework to tie to the core data.

Lake Banook (Fig 1.1) was chosen for study due to ease of access and interest from the local community and municipality. The lake is of interest to the canoe and kayak clubs as they will be hosting the 2009 World Canoe and Kayak Championships. Also, the lake is a part of the Shubenacadie Canal System, and may provide insight into how the construction of the canal system affected the lake's ecosystem.

This thesis is building on a project which began as a feasibility study for small-craft multibeam surveys at the GSC-A. In addition to the academic interest, data was presented by Ned King (GSC-A) to the canoe association and the Dartmouth Lakes Commission.

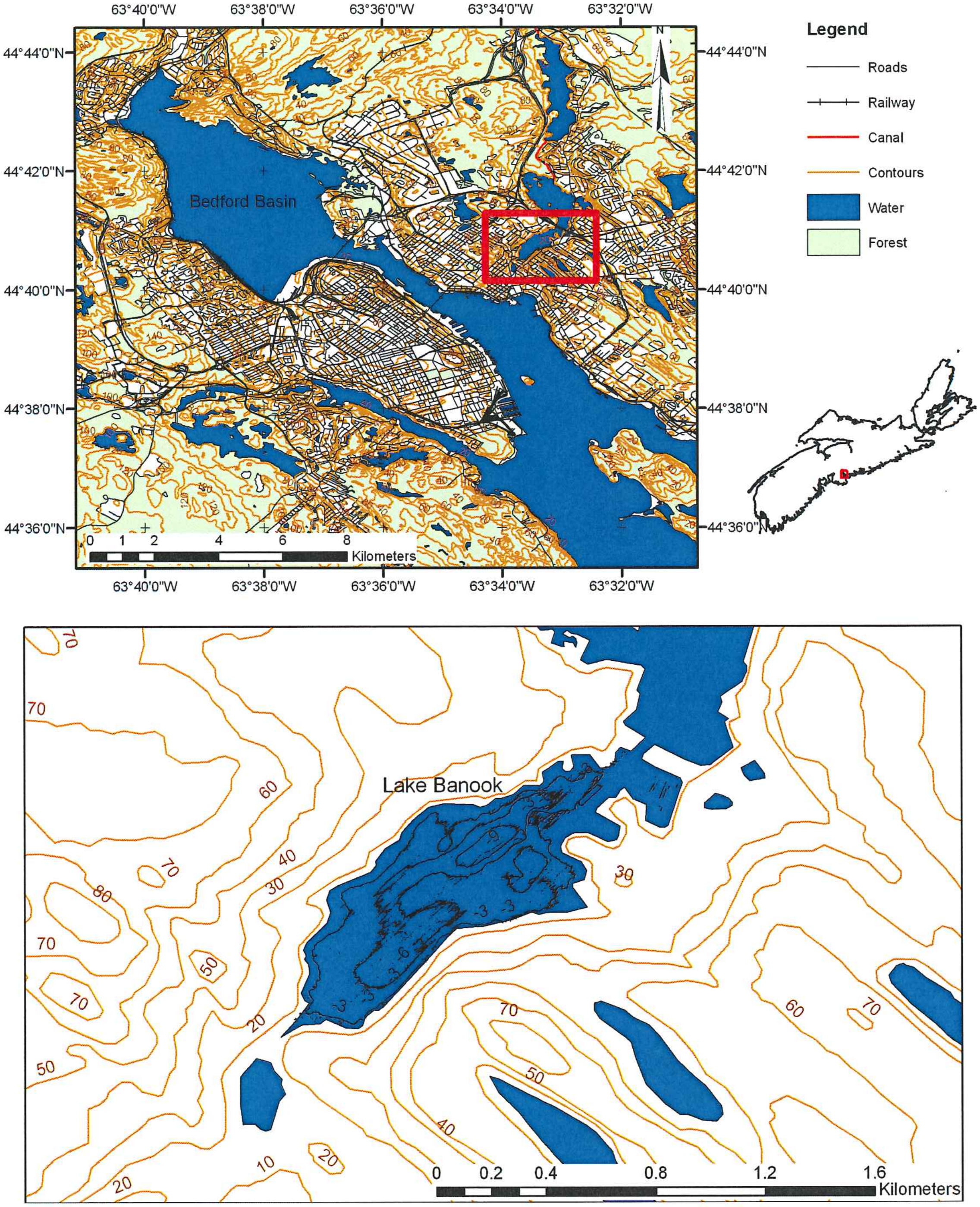


Figure 1.1 – Location of Lake Banook, with some of the other lakes and canals which make up the Shubenacadie Canal system. It lies at 22m above sea level and has a maximum water depth of 12 m. Contours in metres.

1.1 Objectives

This thesis aims to establish a detailed history of Lake Banook, including paleoclimate and paleogeography reconstructions. This project differs from previous studies by combining detailed seismic data with micropaleontology. By studying this lake in detail, we aim to provide new data for models relating to deglaciation of the area, as well as information on the sensitivity of lakes to small changes in climate. We are also attempting to understand the variations between the two sub-basins within the lake. To establish this, we will use a fine grid of high-resolution seismic data to characterize and map the extent of stratal units as well as slump features and debris flows. Also, six short sediment cores have been obtained and analyzed in detail. These analyses include micropaleontology, physical properties and magnetic susceptibility data.

1.2 Setting

Lake Banook is a small lake in central Dartmouth, Nova Scotia, Canada. This lake is approximately 12.5 metres deep, and is currently 500 m wide and 1.5 km long. Underlying the lake sediments are one or more regional tills which are underlain by the Halifax Formation Slate of the Meguma Terrane The lake was carved from the bedrock during a series of glaciations, and was last deglaciated between 15-12 ka (Fader and Miller, 2008). It is surrounded by drumlins oriented SE-NW. Recent studies (Huppertz *et al*, 2008) have identified a low-stand at -4.5 ms.

1.3 Previous Work

Much work has been done on the deglaciation of Nova Scotia and surrounding areas, with most of the work concentrating on the offshore and Scotian Shelf systems, as well as remnant ice caps on areas such as the Cobequid highlands (eg: Dyke and Prest 1987; Shaw et al. 2002). A very detailed regional synthesis of the surficial geology of Halifax Harbour and Bedford Basin, with notes on timing of deglaciation is available as Geological Survey of Canada Bulletin 590 (Fader and Miller, 2008).

Previous work on this lake has been done very recently, with this thesis essentially being a continuation of that work. Multibeam and side-scanning sonar data were collected during the summer of 2007 both as a feasibility study and for the canoe clubs. Video and photographic data was also collected by the DRDC as part of its training operations. These data showed a history which needed further investigation. Seismic data were collected and analysed to define an unconformity at -4.5 m, and the six seismic facieses described in this thesis were defined as well. The majority of this work is presented by Huppertz *et al* (2008).

The study of thecamoebians is relatively new in terms of micropaleontology, but some very useful information can be gained from their study. Thecamoebians are freshwater testate rhizopods, some of which have a tolerance for brackish water influence. Different species of thecamoebians have been shown to be sensitive to changes in salinity, terrigenous influence, water depth, and eutrophication, all of which may have influenced the lake since deglaciation (Scott et al, 2001).

Studies of pollen in the Maritimes essentially began with Livingstone's classic 1968 paper on pollen data collected from lakes all over the Maritimes. Since then, much work has been done, such as an undergraduate thesis by Eric Collins (1985) which looked at thecamoebians in both Penhorn and Albro Lakes. The thecamoebian work in Penhorn Lake was combined with pollen data and summarized into assemblages for Nova Scotia and Newfoundland (McCarthy *et al*, 1995). Porters Lake was also studied, looking at both thecamoebians and foraminifera in a transitional environment (Laidler and Scott, 1996).

METHODS

2.1 Survey Methods

Acoustic surveys were carried out by E.L. King and co-workers from GSC-A from May – September of both 2007 and 2008. As a summer co-op student at GSC-A, the author participated in much of the data acquisition. A variety of vessels (buoy-tending barge, canoe and kayak) and configurations were used, but the basic setup was the same in each of the configurations (Fig. 2.1). Multibeam and sidescan data were also collected, sometimes simultaneous with the seismic data collection. Details on the combined survey configuration and instruments can be found in the 2008 poster publication by Huppertz *et al*. Bathymetric images used in this thesis are derived from that multibeam data.

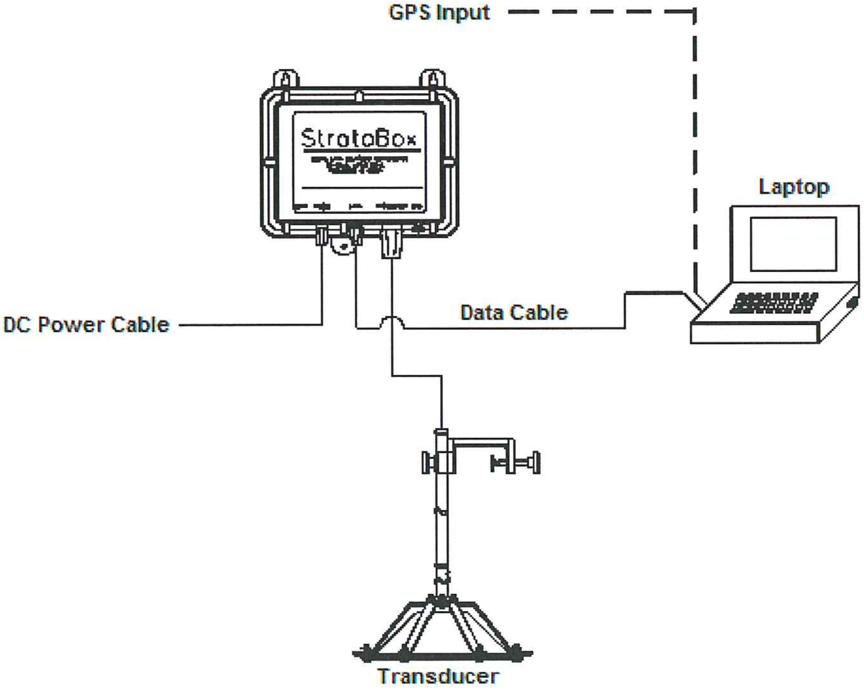


Figure 2.1 Schematic diagram of the basic setup for surveying with the StrataBox system, modified after SyQwest Incorporated 2006.

The seismic instrument used was the SyQwest StrataBox, which includes the StrataBox sensor unit, DC power cable, data I/O cable, transducer and transducer cable. The 10 kHz transducer/receiver was either pole-mounted or otherwise attached to the side or bottom of the survey vessel. The transducer cable was connected to the transducer and then connected to the StrataBox sensor unit, which was placed inside the vessel. The DC power cable was connected to the StrataBox sensor unit and, by alligator clips, to a gel battery. The data cable connected the StrataBox sensor unit to a laptop, where the StrataBox software provided an interface for controlling the transducer and various gains and a real-time data display. Also connected to the laptop was a Garmin GPS unit which provided accurate positioning information. All equipment was powered by batteries (gel cell or car battery), which were sometimes being charged during usage by an on-board generator. In one configuration, the batteries also powered a small electric motor, which was used to power the craft; otherwise, the craft was manually propelled or propelled by a gasoline-powered outboard motor.

2.2 Coring Methods

Six short sediment cores were obtained in February 2008, and range in length from approximately 5-120 cm. Cores were obtained through a variety of methods, all based on the same initial design. A Benthos core liner was fitted with a core catcher at the bottom, and a crude piston at the top. Attached to the top of the liner were lengths of either steel pipe or irrigation pipe, depending on the configuration.

A hole was drilled through the ice manually using an auger (Fig 2.2), and the coring assembly was slowly lowered into the water until we 'felt' the bottom. The assembly then continued to be pushed into the sediment as far as was possible. Sometimes the core would be hammered into the sediment in order to penetrate deeper into the subsurface (Fig 2.2c). To remove the coring mechanism, the entire apparatus was slowly lifted out of the sediment, out of the water and up onto the ice. Cores were immediately capped on the bottom, and some of the water in the top of the core was rmoved by drilling a hole through the liner above the level of the sediment. The cores were then capped on top, and labeled (Fig 2.2d). Cores were transported and stored in an upright position and transferred to cold storage at GSC-A. The samples and seismic parameter data have been incorporated into the GSC-A electronic archive, the online Expedition Database (ED), as part of their regular survey procedure. Lake Banook operations were given the expedition number 2008-900.

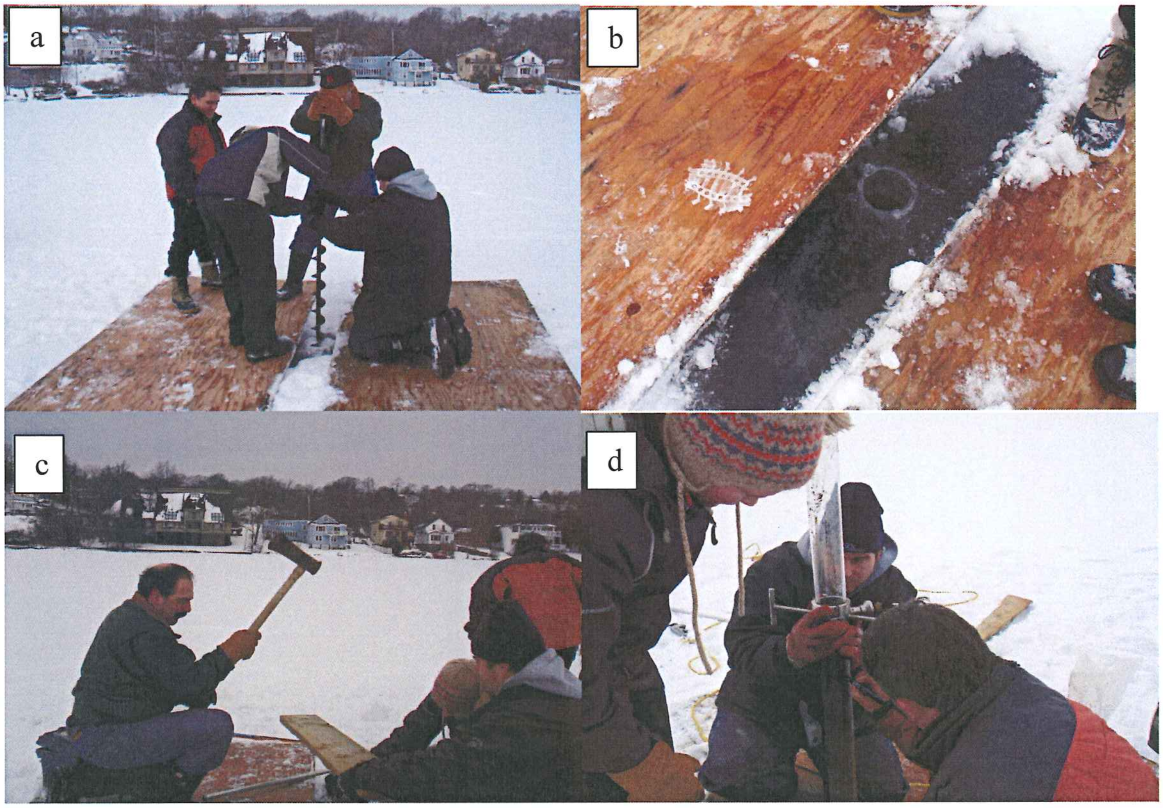


Figure 2.2 – Coring procedure: a) Drilling a hole through the ice b) the hole with plywood on either side for grip c) hammering the core into the sediment d) labeling the core and removing excess core liner before capping the top

2.3 Seismic Analysis Methods

The seismic data were exported from the Syquest Stratabox aquisition program, as the SEGY files generated by the program lacked header information in useable format. To solve this problem, the files were imported into Chesapeake Technologies Sonar WizMap4, as it was able to convert the Syquest files into SEGY format, which is more compatible with other viewing and interpretation programs. The data were then converted into JP2 images and viewed in a GSCA program called JP2 Viewer, which is still under development. In this viewing program, seismic reflectors, debris flows and areas of masking by shallow gas were traced as lines, and hyperbolas indicating possible anthropogenic debris were marked with points as features. These lines and features were exported from the program as ESRI shapefiles. All traced seismic lines were individually exported using the lake surface and then each seismic reflector as a datum, in order to make distribution and isopach maps.

All the techniques for viewing, picking and exporting these files are developments in recent months, spearheaded by R. Courtney (GSC-A) in collaboration with E.L. King. Various methods to view and interpret the data were investigated, including modified AGC Dejitter programs (P. Pledge, GSC-A) and Kingdom Suite. Both of these programs had drawbacks, and even with correct header information we were unable to open the files using Kingdom Suite. The new JP2 Viewer solved these problems, and the easy export into shapefile format made this program easy to work with.

In Arc GIS, the exported shapefiles were combined and transformed into point feature classes, with one shapefile for each datum. Depths were converted from two-way travel time to metres assuming a constant velocity for the sediments of 1400 m/s. For the isopach map, data were gridded using Ordinary Kriging with the program default settings, and then clipped to the extent of the lake.

2.4 Core Analysis Methods

In May 2008, the sediment cores were split and described at GSCA in Dartmouth. Before being split, the cores were analyzed using the Multi-Sensor Track (MST) by Kate Jarrett in the core lab. This collected information from the whole cores on colour, magnetic susceptibility, bulk density, and velocity. Discrete measurements of bulk density and colour were also performed on the split cores by the students working in the lab. Cores were described based on lithology, sedimentary structures, colour according to the Munsell colour chart, stiffness, $CaCO_3$ content, and level of coring disturbance. A detailed summary of the processes and instruments used for the MST and other analyses is presented in GSC Open File Report 5299 (Tripsanas et al., 2007).

2.5 Micropaleontological Analysis Methods

In the core laboratory at GSCA, 10cc samples were taken for analysis of thecamoebians and processed at Dalhousie roughly following the procedure described by (Medioli and Scott 1988). This involved washing the samples through a 0.25 mm screen with a 0.063 mm screen beneath it, and a 0.045 mm sieve beneath that. The coarse mesh retained the coarse organic and mineralogenic debris, while the thecamoebians and fine material were retained in the lower meshes. Clay and other particles < 45 μm were washed down the sink. Samples were washed through the sieves with warm water and dish soap as necessary until all of the mud and as much of the organic material as possible was removed. This resulted in two size fractions for each sample: >63 µm and 45 – 63 µm. The samples were then inspected for initial observations, and each of the smaller fractions was transferred into appropriately labeled 120 ml plastic containers. Alcohol was added to the samples to inhibit bacterial growth, and the samples were stored in a refrigerator.

Each of the samples was counted using a binocular microscope, at magnifications of between 20 and 80x. Numbers of each species present in the sample were counted, using a wet splitter to divide samples containing >1000 specimens into 6 equal parts. These parts were counted until either a minimum of 300 specimens was reached, or the entire sample was counted. The counts were then transformed as necessary to obtain the number of species per 10cc sample, for example, if only 1/6 of the sample was counted, the results would be multiplied by 6 to give the total for the 10cc sample.

Due to time constraints, species were identified and counted simultaneously, without being removed from the sample for later verification. A variety of reference material was used for identification of species, primarily (Medioli and Scott 1983) and (Scott et al. 2001). After identification, the proportion of each species present in each sample, as well as the total number present in each sample was plotted as down-core line graphs next to the core photographs to facilitate interpretation.

RESULTS

3.1 Seismic Stratigraphy

High-resolution shallow seismic data was collected on a regular grid, with a tight spacing over most of the lake (Fig. 3.1). Due to time constraints, not every line was analyzed in detail, but lines were chosen so as to provide a representative picture of the stratigraphy of the lake.

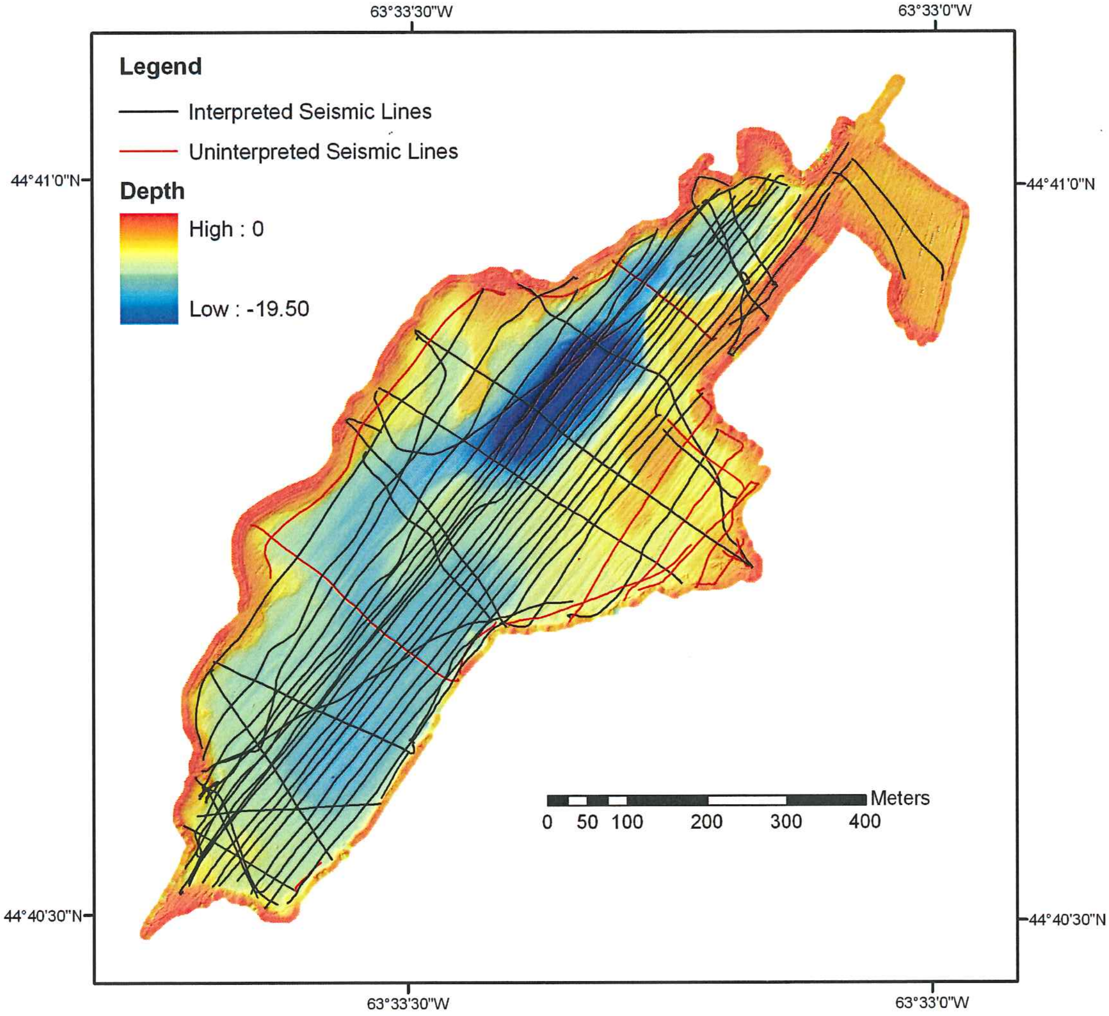


Figure 3.1 - All collected seismic lines shown on a sun-illuminated color shaded lakebed topography image.

Six stratigraphic units have been differentiated in Lake Banook (Fig. 3.2). The lowest unit in the section (Unit 1) appears as a poorly stratified, acoustically chaotic unit. As the bottom of the unit is never imaged, the average thickness is unknown. This unit is paraconformably overlain by a poorly stratified, discontinuous layer (Unit 2), which appears to be draped over the underlying surface. Conformably overlying this is a thick, well-stratified unit with strong continuous, coherent internal reflections (Unit 3). Internal reflections within this unit generally mimic the surface of Unit 1. The top of this unit is defined by an erosional unconformity above 4.5 ms. Occasionally, this unit is overlain by small incoherent lenses of material (Unit 4), which appear to have a scoured base, and in some places are stacked. Above this is a well-stratified unit with weak coherent internal reflections (Unit 5). This unit appears only in the deeper parts of the basisns, and has a ponded occurence. Conformably overlying this unit is an acoustically transparent unit with no internal reflections (Unit 6).

stratigraphic unit	seismic character	interpretation
Unit 6	Unstratified or poorly stratified sequence; almost transparent; draped	post-glacial muddy gyttja
Unit 5	poorly stratified; ponded	Younger Dryas muddy sand with gravel
Unit 4	acoustically incoherent, local occurrence, lobate, erosional base	mass transport deposits? glacial or peri-glacial
Unit 3	strong coherent and rhythmic stratification, mimics till surface; draped	Glacilacustrine muddy rhythmite, possibly varved
Unit 2	poorly stratified, mimics till surface; draped	Late glacial lacustrine sediments
Unit 1	poorly stratified incoherent sequences reflecting acoustic basement	regional tills

Figure 3.2 – The six seismostratigraphic units presented with lithology and brief interpretation.

Core locations were carefully chosen from the seismic data (Fig. 3.3), with each core planned to retrieve a certain feature or interval. Stations one and two were targeting an unconformity between the unstratified Unit 6 and the well-laminated Unit 3 (Fig. 3.4).

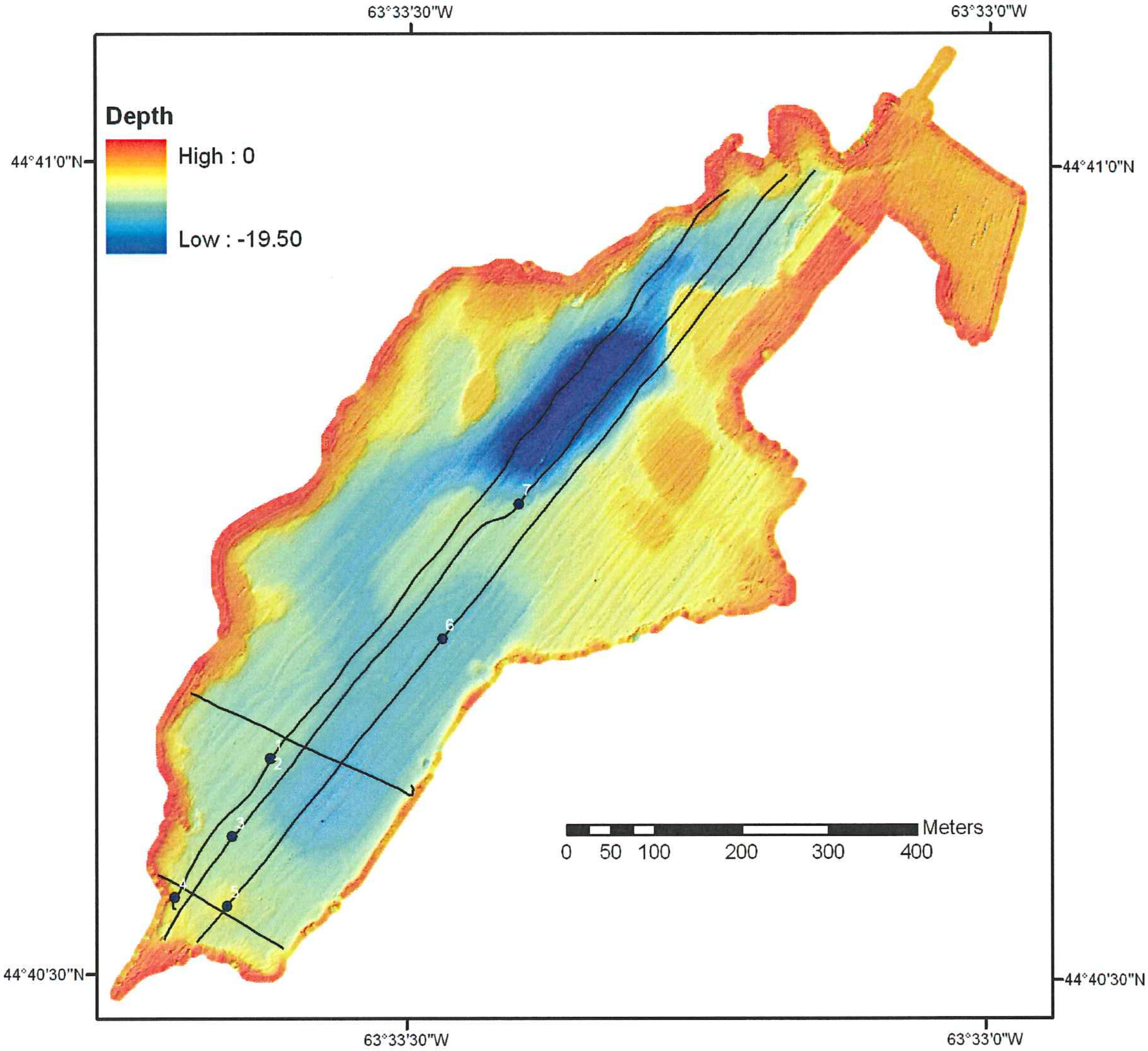


Figure 3.3 - Core locations and corresponding seismic lines on a sun-illuminated color shaded lakebed topography image.

Station 3 was targeting what appears to be Unit 2 subcropping beneath the unstratified Unit 6, and was an attempt to help differentiate lithology between Units 2 and 3. Station 4 was targeting an area with anthropogenic dredging and dredge spoils. The target for Station 5 was an irregular mound in Unit 6 which typically has a draped occurrence. Station 6 was the prime target for a complete section of Unit 6 and was an attempt to sample a relatively large deposit of Unit 4. Station 7 also targeted a deposit of Unit 4.

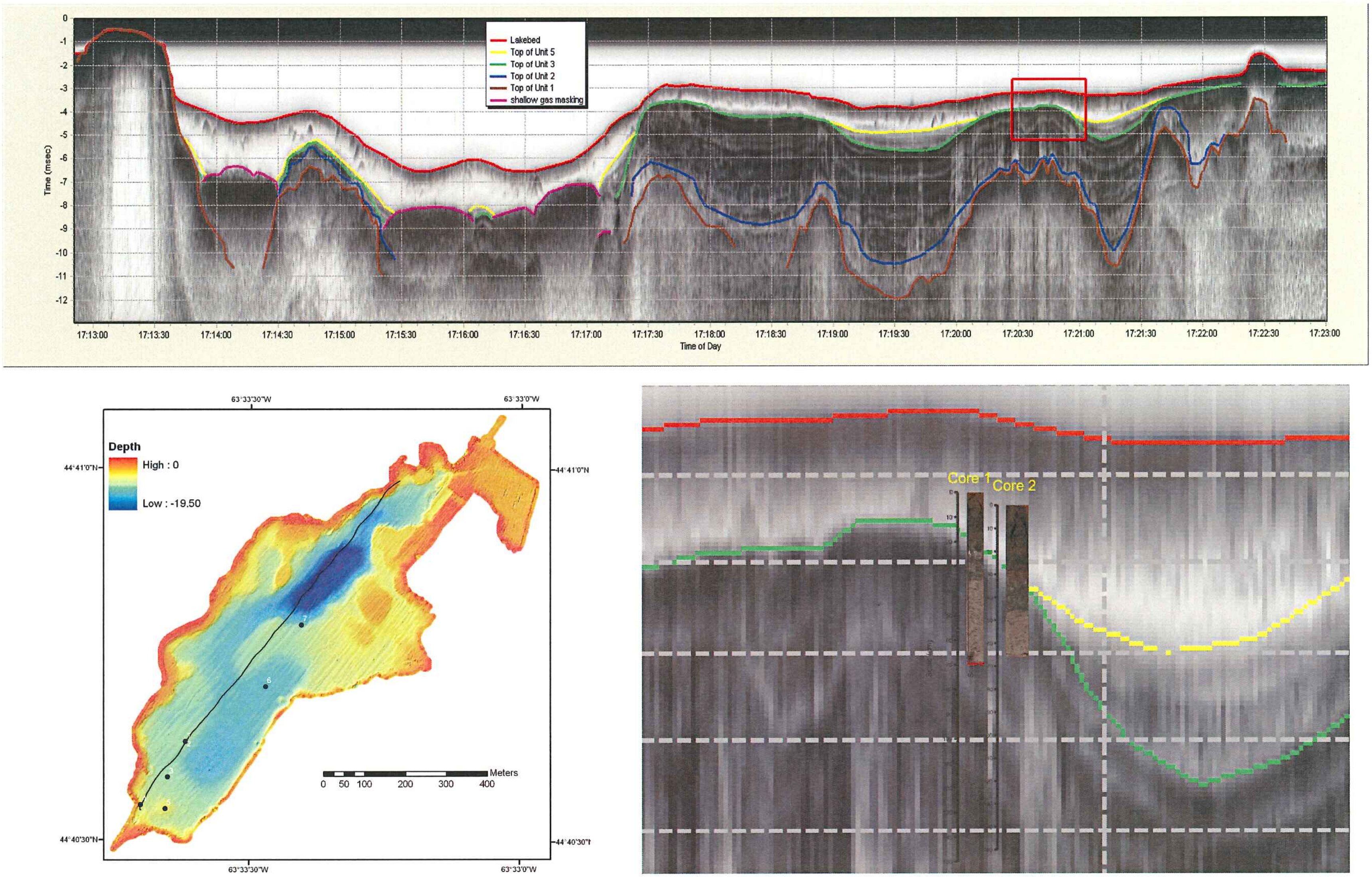


Figure 3.4 – Longitudinal seismic line showing general setting with an enlargement of seismic section surrounding cores 1 and 2. For this and following figures, the vertical scale is 10 ms = 7.5 m.

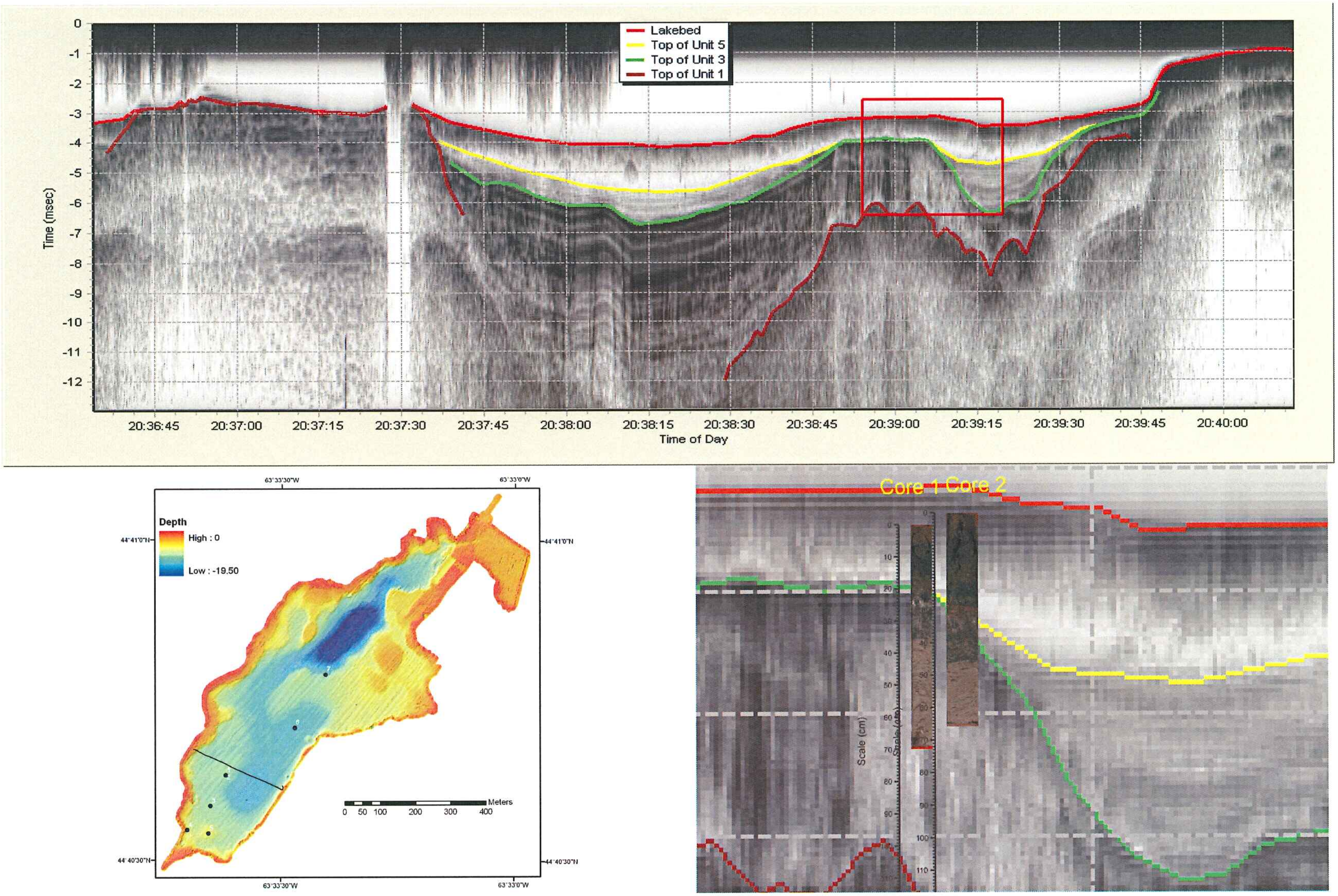
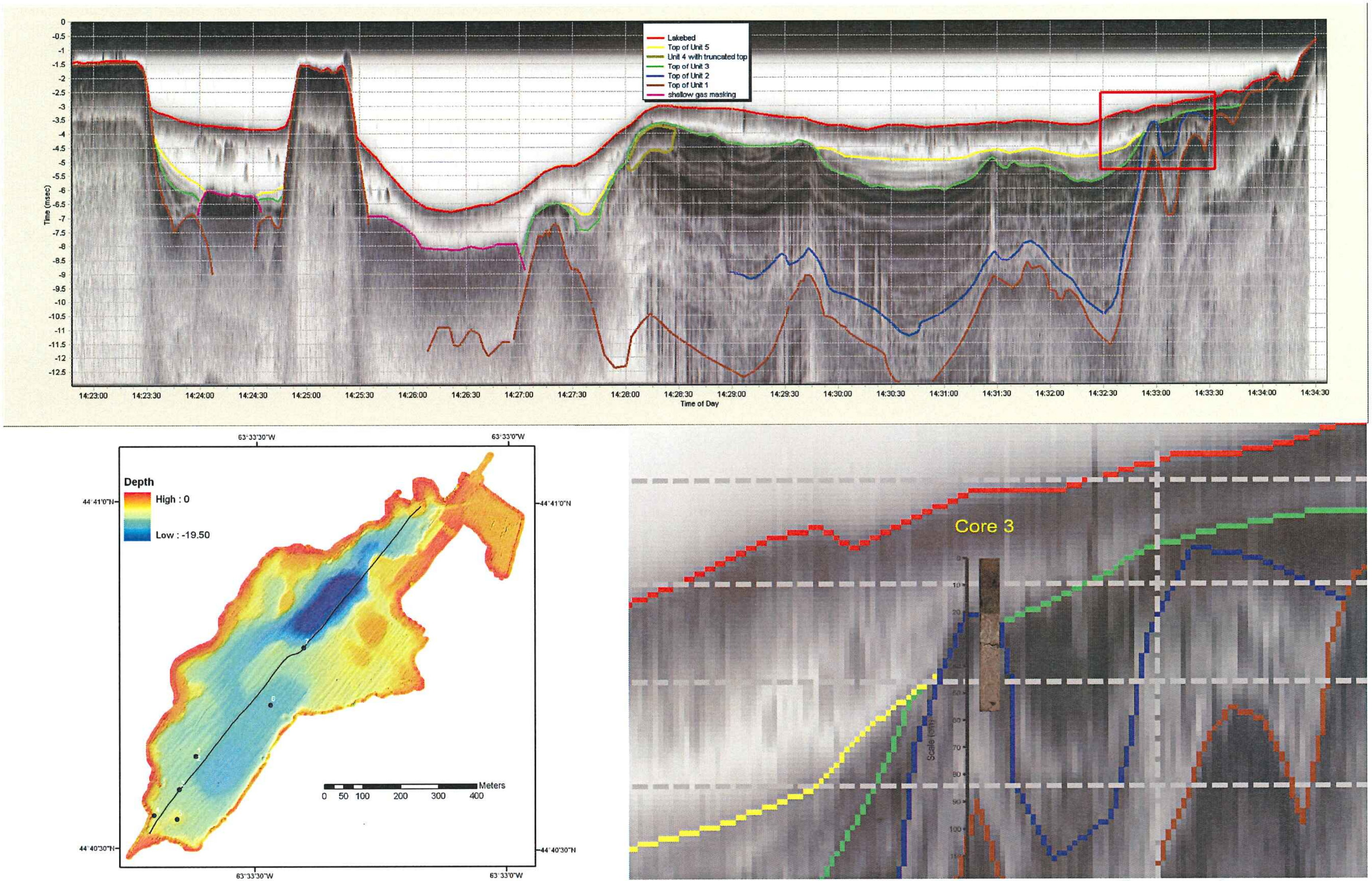


Figure 3.5 – Transverse seismic line showing general setting, with an enlargement of the area surrounding cores 1 and 2.



- **Figure 3.6** - Longitudinal seismic line showing general setting, with an enlargement of the area surrounding core 3.

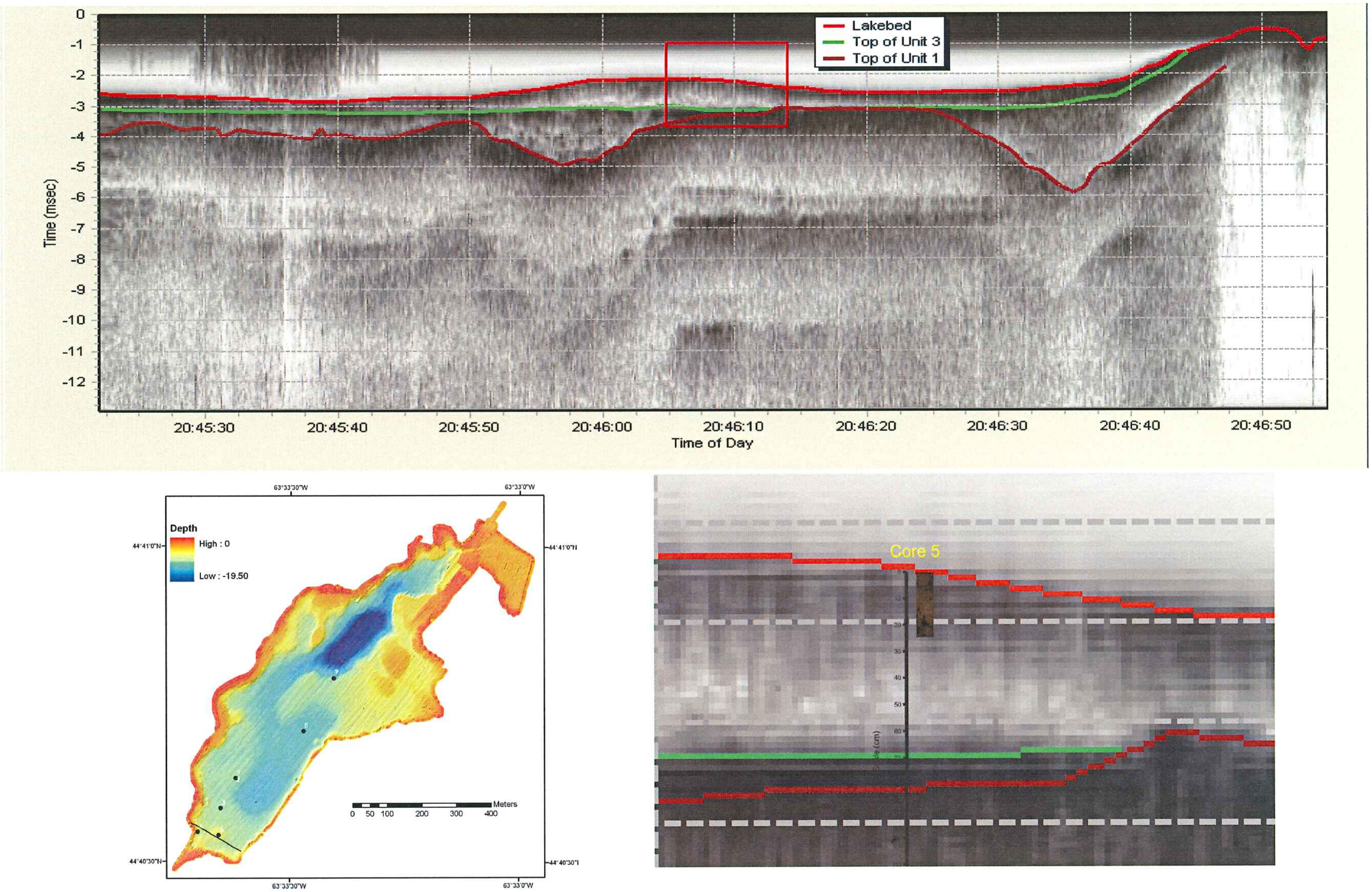


Figure 3.7 – Transverse line showing general setting with an enlargement of the area surrounding core 5.

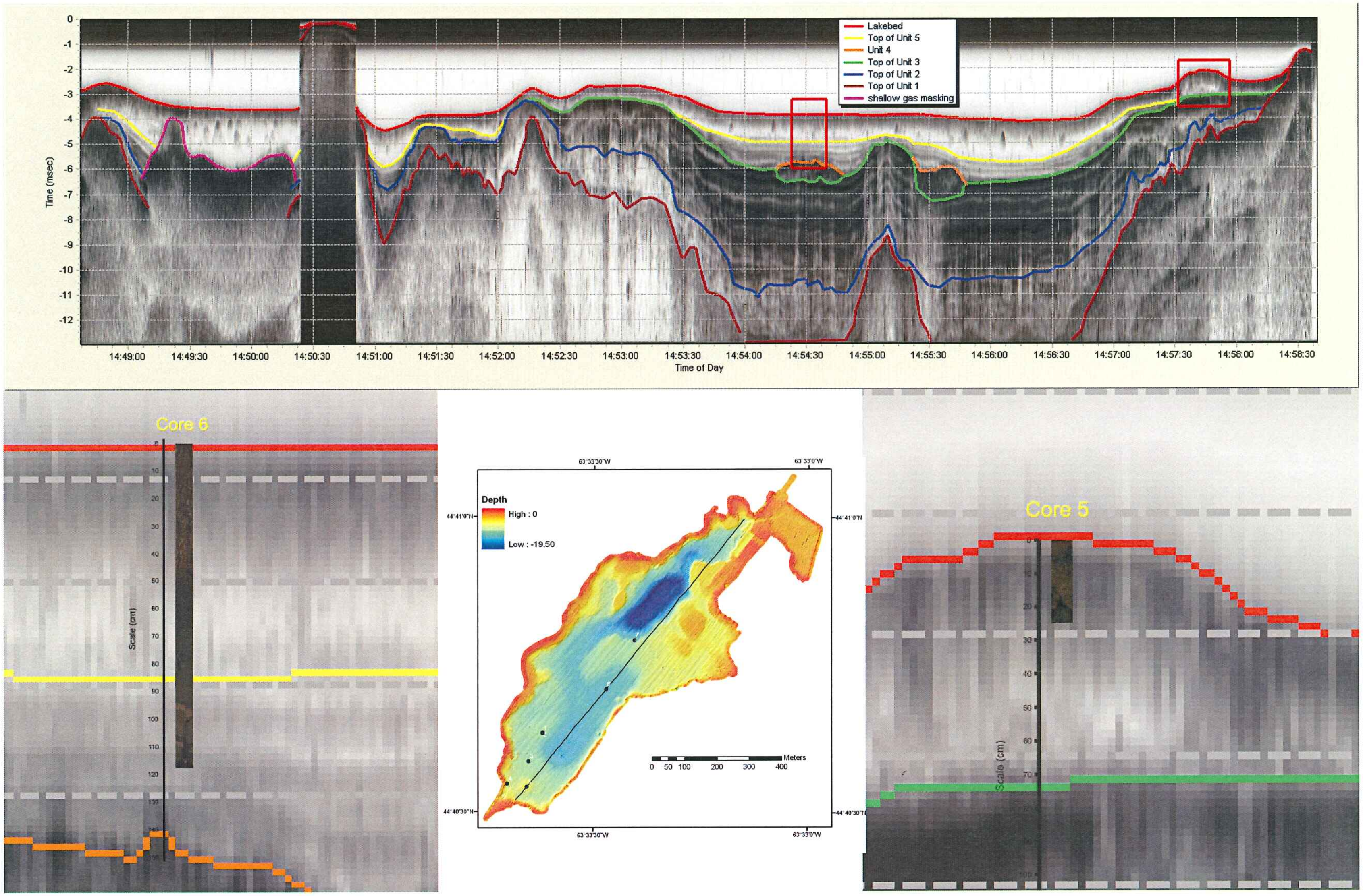


Figure 3.8 – Longitudinal seismic line showing the general setting with an enlargement of the area surrounding cores 5 and 6.

3.2 Lithostratigraphy

Six soft sediment cores were collected, ranging in length from 10-117cm. There was no recovery at station 4, and so the cores have numbers 2008900-001, 2008900-002, 2008900-003, 2008900-005, 2008900-006 and 2008900-007. At station seven, no core was recovered, but material present on the lowermost portion of the outside of the coring assembly was scraped off into a bag. As the cores did not penetrate very far into the sediment, only seismic units 2, 3, 5 and 6 were sampled. Also, the depth of penetration was much greater than the length of recovery in all cases. As seen on the previous series of figures, the projected core locations generally do not reach the sediment surface, and are instead located by using the unconformity between the soft upper sediments and firm underlying sediments as a datum.

Core 1 (Station 1, Fig. 3.3) has a length of 69.5 cm, and was taken in a water depth of 5 m. Three major units are present in this core (Fig 3.9), the lower (22 - 69.5 cm) being comprised of stiff, finely laminated silt and clay, varying in colour from light grey with reddish-brown laminations to dark grey with black laminations. The top portion of this unit has black mottling. Above this, there is a thin (16 – 22 cm), reddish-brown sandy unit. At the top of this unit there is a sharp contact and above this the core consists of a series of very soft gradational subunits, all of which are brownish in colour. All of these subunits are comprised of clay with varying amounts of silt, and an apparently high proportion of fine organic material. There is a noticeable peak in magnetic susceptibility corresponding to the contact between the lower and middle units.

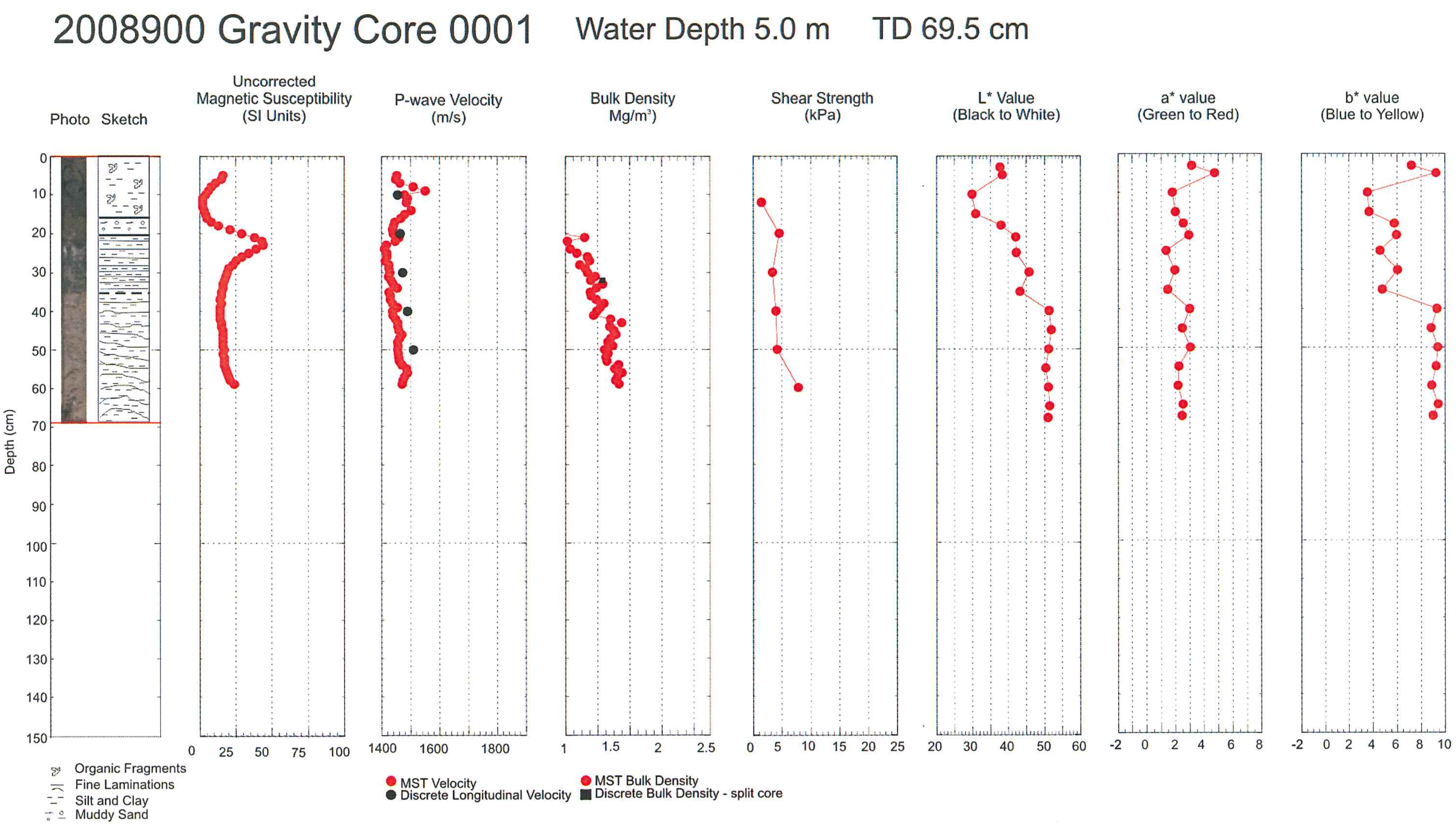


Figure 3.9 – Digital core description for core 1, consisting of photograph, sketch, MST data and physical property data.

Core 2 was recovered near core 1 (Station 2, Fig 3.2) but with a larger diameter core liner used as an attempt to increase the recovery of the upper unit. The core was taken in approximately 5m of water, has a length of 66 cm and is very similar to core 1. Notably, the middle sandy unit (29 - 34 cm) in this core is laminated with more distinct boundaries (Fig 3.10). Here, the magnetic susceptibility also has a spike at the contact between the lower and middle unit, but the values are high until just after the end of the black mottling observed in the upper portion of the lower unit.

Core 3 was taken to the southwest of cores 1 and 2 (Fig 3.2) in approximately 5m of water. The core is 57 cm long, and two major units are noted (Fig. 3.11). The lower portion (21-57 cm) consists of finely laminated silt and clay with a relatively uniform grey and grayish-brown colour, with the black mottling absent here. The laminations are quite disturbed in comparison to the parallel laminations noted in the previous cores, and the bulk density is even higher. Also, the sandy unit noted in cores 1 and 2 is not present here. The contact between this and the upper (0-21 cm) unit is sharp and uneven. The upper unit consists of soupy brown clay with some silt, and appears to contain a high amount of fine organic material. Several sub-units within the upper unit can be determined by variations in colour and texture.

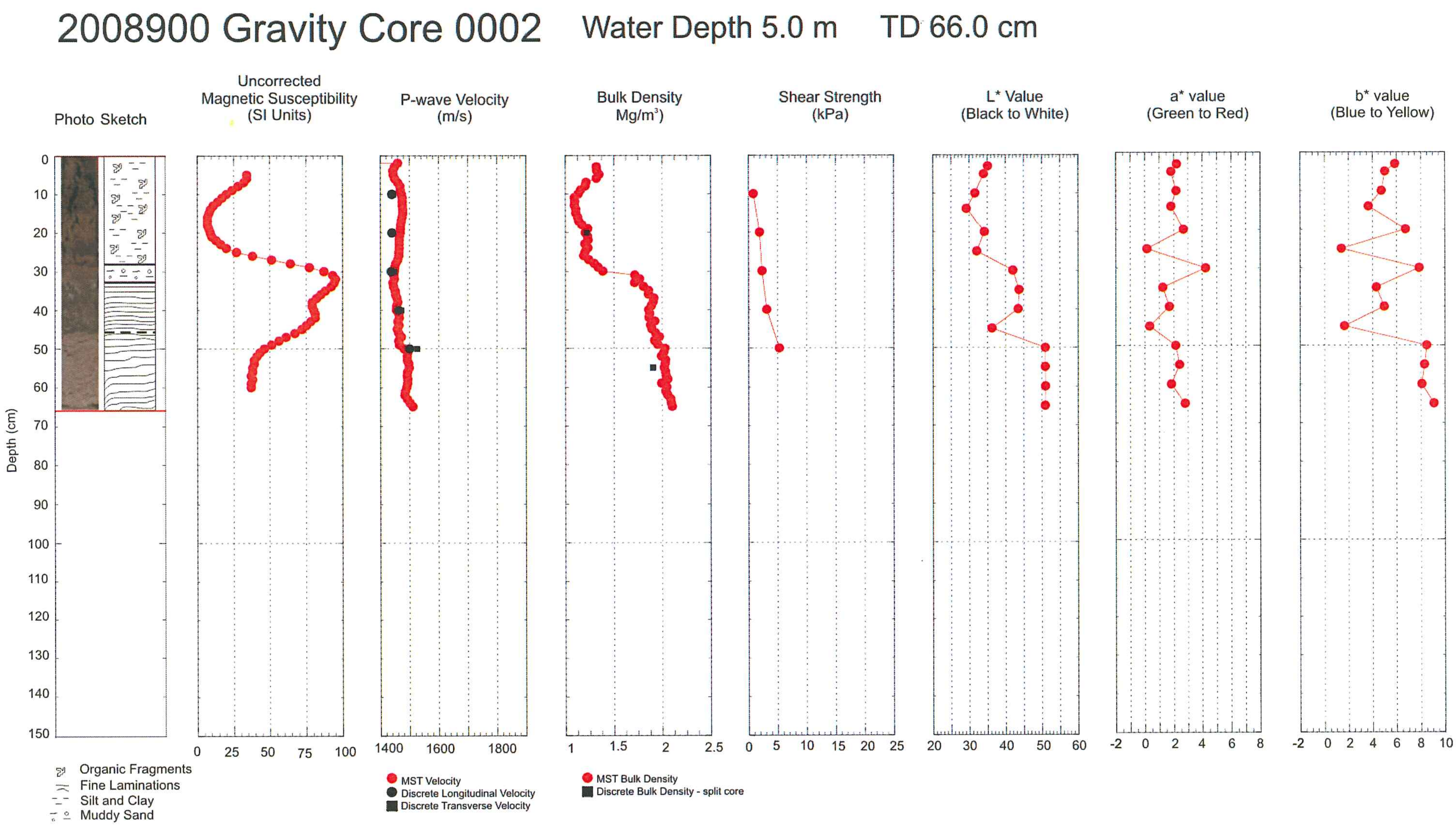


Figure 3.10 - Digital core description for core 2, consisting of photograph, sketch, MST data and physical property data.

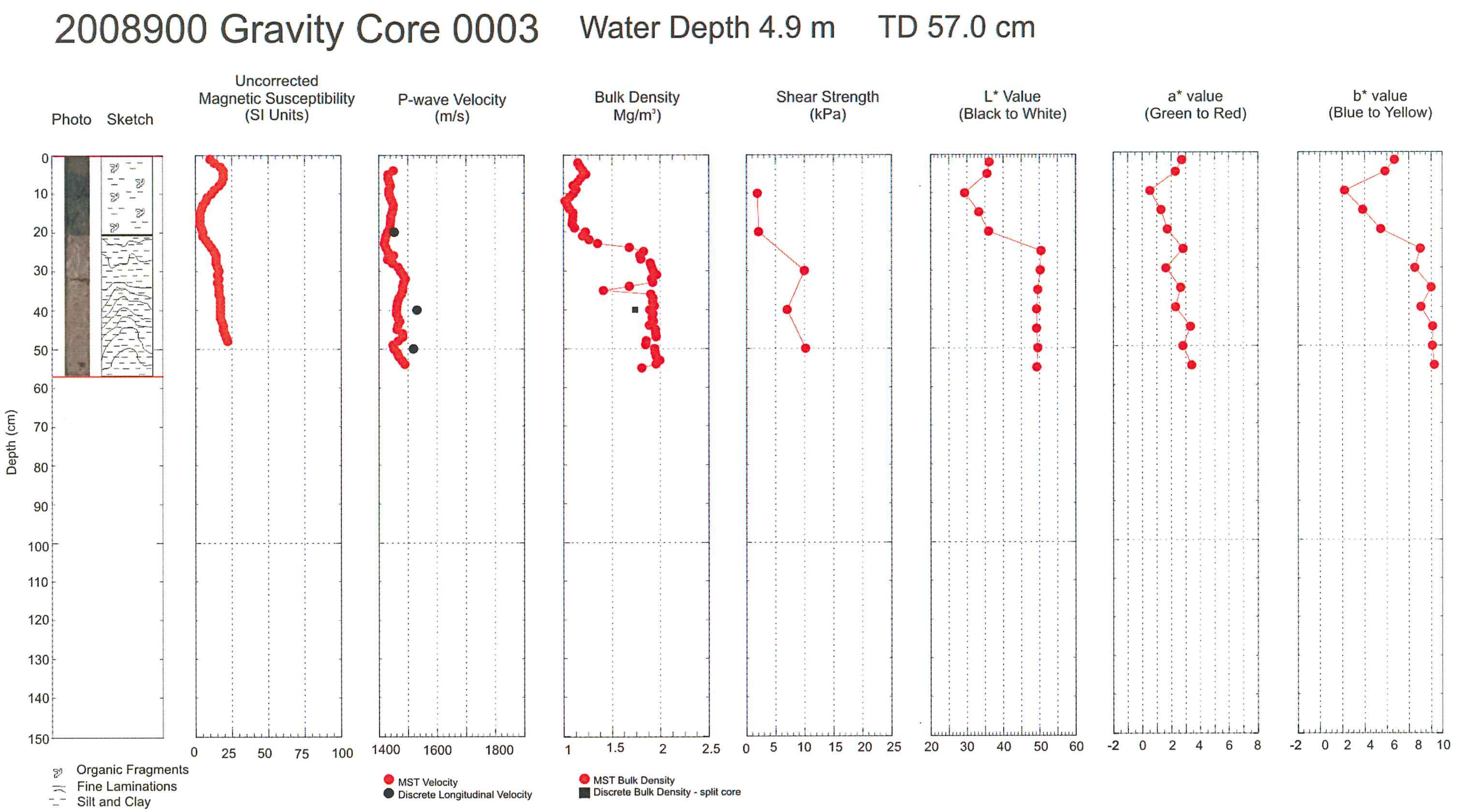


Figure 3.11 - Digital core description for core 3, consisting of photograph, sketch, MST data and physical property data.

Core 5 (Station 5, Fig. 3.2) was taken in 3.5 m of water and has a length of 25 cm. Only one major unit is present, but several gradational subunits can be defined on the basis of variations in color (Fig. 3.12). The core is brownish in colour and has a soupy texture with a high amount of organic material present. Notably, from 12-16 cm there is olive-brown clay with black mottling.

Core 6 (Station 6, Fig. 3.2) was the longest core, taken in 6.1m of water and with a recovery of 116.5 cm. Two main units are noted in this core, a lower sandy silt unit and an upper silty clay unit (Fig. 3.13). The lower unit (93-116.5 cm) has a rhythmic alternation of greyish brown, reddish-brown and black laminations. The upper unit (0-93 cm) consists of brownish soupy and soft silt and clay, with a high proportion of organic material. Several sub-units can be defined on the basis of variations in colour.

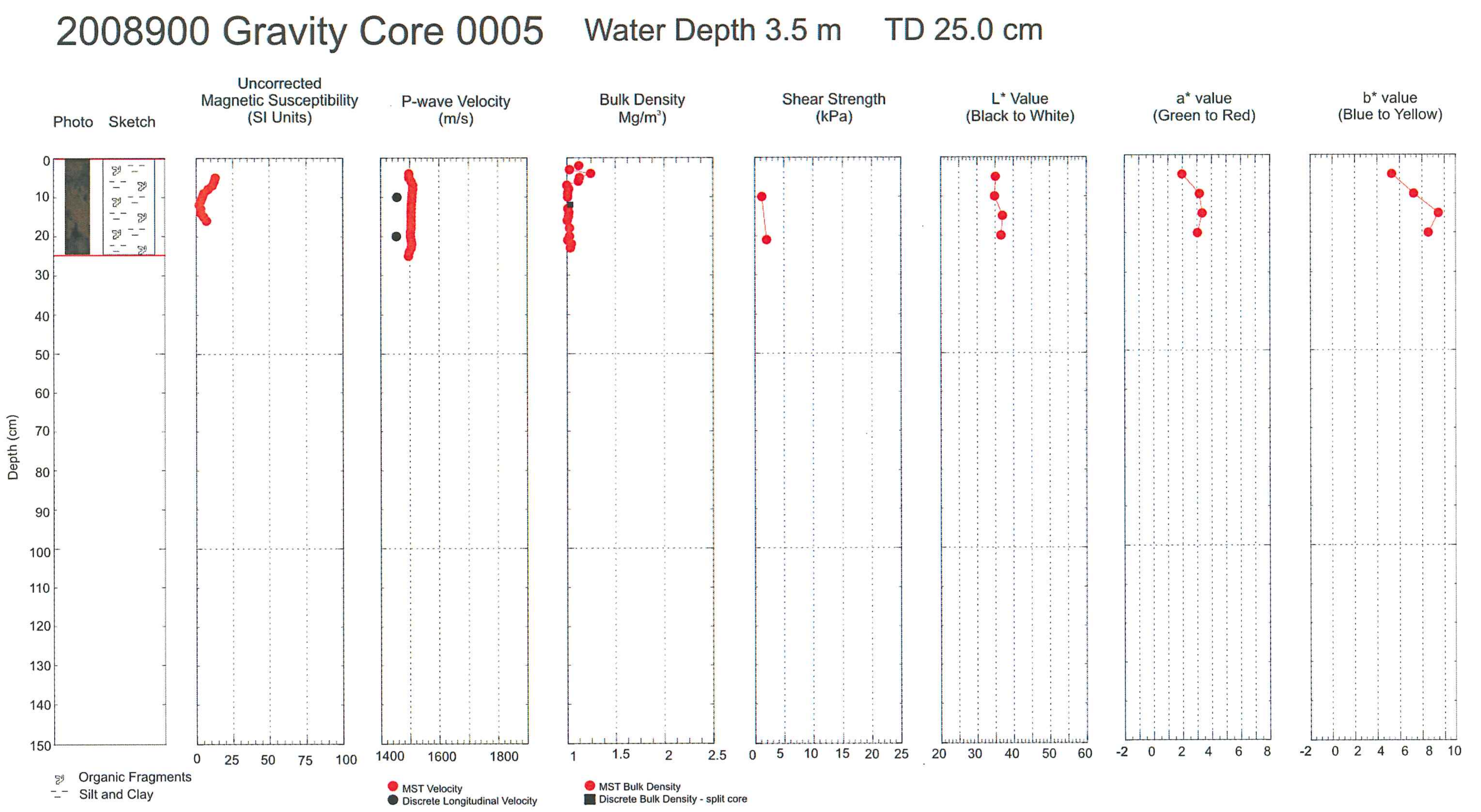


Figure 3.12 - Digital core description for core 5, consisting of photograph, sketch, MST data and physical property data.

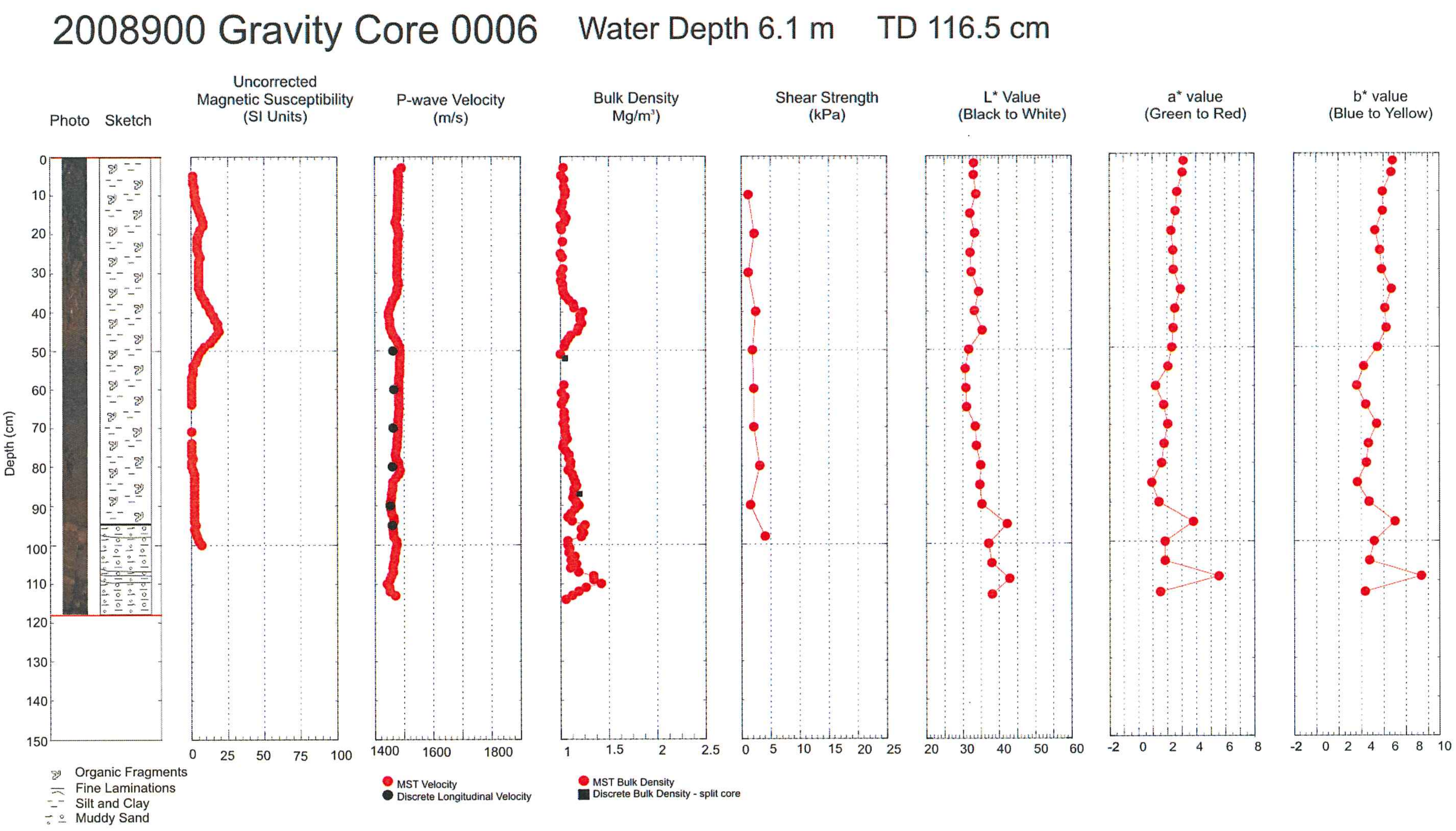


Figure 3.13 - Digital core description of core 6, consisting of photograph, sketch, MST data and physical property data.

The cores have been correlated with one another using the seismic data (Fig 3.14). Unit 4 was not sampled due to the difficulty of reaching a target with limited areal distribution. The lower unit in core 2 samples a small subcrop of the seismic Unit 2. The lowermost unit in cores 1 and 2 correlates with the well-stratified glacilacustrine Unit 3 of the seismic stratigraphy, with the upper unconformity used as a datum with which to correlate the cores. The lower unit in core 6 and the middle units in cores 1 and 2 correspond to the weakly stratified seismic Unit 5, which is absent in core 3 and not reached by core 5. The upper unit in all cores correlates to the nearly transparent Unit 6.

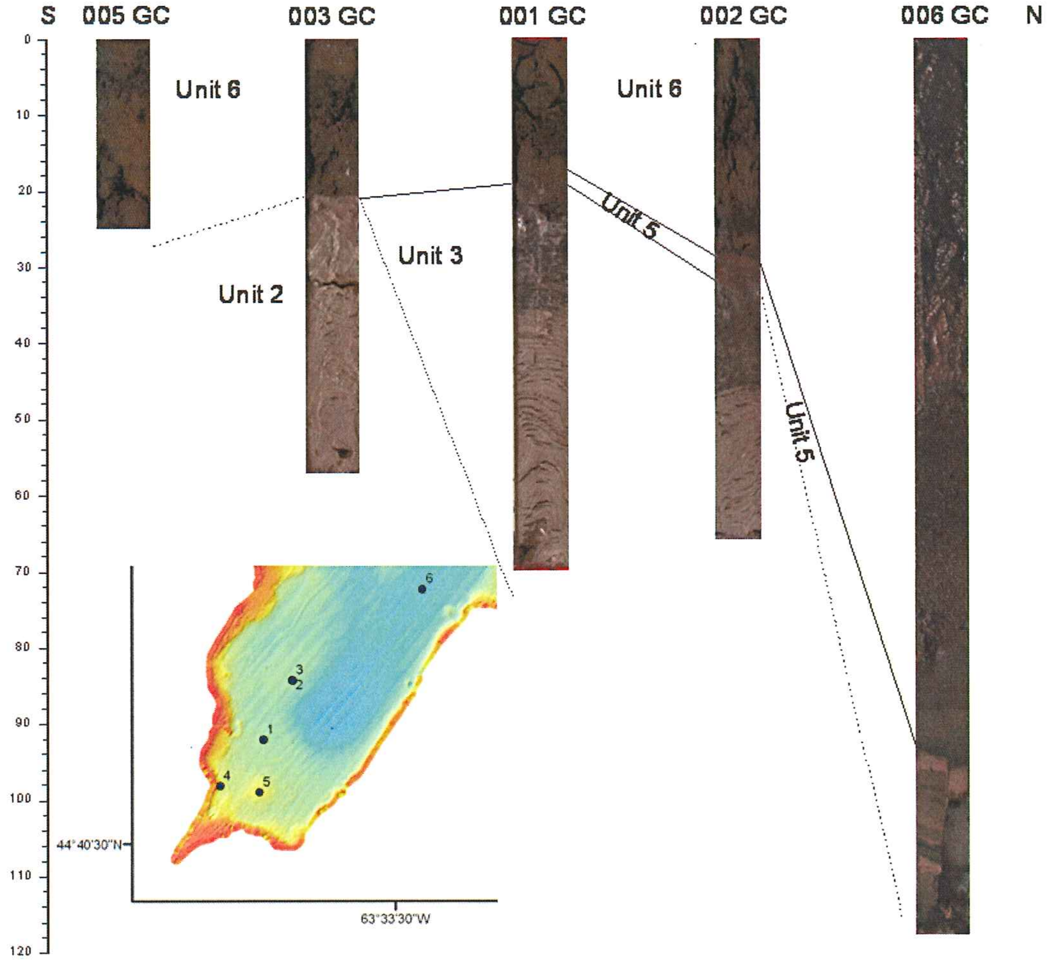


Figure 3.14 – Correlation of the major lithological units with the seismostratigraphic units. Cores arranged from South to North.

3.3 Biostratigraphy

Subsamples from cores 2 and 6 were processed and counted for thecamoebians, with 10 subsamples from core 2 and 15 from core 6. Core 2 was chosen because it is one of two cores which contains units 3, 5 and 6, and has more material available for subsampling than core 1 due to the larger diameter of the core. Core 6 was chosen because it had the longest section of the soft muds, and would therefore have the highest resolution and most likely to record signals from short-term environmental changes.

In core 2 (Fig. 3.15), the uppermost sample contains over 3000 specimens, but total numbers rapidly decrease with the cores barren of thecamoebians below 28 cm in the core (Table 1). In the 23 – 25 cm interval, there is a large jump in the abundance of *D. corona,* so much that the sample is almost monospecific. This trend of decreasing total numbers of thecamoebians downcore (Table 1) in core 2 may indicate that the environment was stressed up until recently, but may also be a result of poor preservation. However, the few specimens present in the lower intervals were well-preserved and rarely fractured, indicating that the degree of preservation did not decrease with depth.

In the 49-51 cm interval of this core, there are a very large number of orange-brown resistant spherules. The spherules occur in both size fraction, and sometimes compound up to 3 spherules together. These as of yet unidentified objects are only present to this extent within this one sample, and very few, if any, are found above or below this interval. In future paleontological studies nearby, providing the length of the core is sufficient, this may serve as a marker bed and facilitate correlation between cores.

Table 1 – Total population and proportion of each species of Thecamoebian present in cores 2 and 6.

Core 2

Depth (cm)	Total	Difflugia oblonga	Difflugia urceolata	Pontigulasia compressa	Centropyxis constricta	Centropyxis aculeata	Nebela sp.	Cucurbitella tricuspis	Difflugia corona
3-5	3042	56.08	12.72	11.41	13.08	6.25	0.46	0	0
9-11	747	23.29	16.60	17.27	11.78	29.45	0.27	1.34	0
16-18	406	33.50	18.23	0.49	15.27	20.69	6.90	4.93	0
23-25	222	0	1.80	0	5.86	3.60	0	0	88.74
26-28	3	0	0	0	33.33	66.67	0	0	0
29-31	0	0	0	0	0	0	0	0	0
34-36	0	0	0	0	0	0	0	0	0
39-41	0	0	0	0	0	0	0	0	0
49-51	0	0	0	0	0	0	0	0	0
59-61	0	0	0	0	0	0	0	0	0

Core 6

Depth (cm)	Total	Difflugia oblonga	Difflugia urceolata	Pontigulasia compressa	Centropyxis constricta	Centropyxis aculeata	Nebela sp.	Cucurbitella tricuspis	Difflugia corona	Difflugia proteiformis
5-7	2149	41.09	11.49	11.63	9.07	5.44	2.28	16.43	0.56	2.00
15-17	2407	51.97	9.68	12.71	7.35	7.73	0.12	7.23	0.37	2.83
25-27	1522	33.97	5.19	15.37	12.22	12.68	1.77	12.42	5.52	0.85
34-36	1995	31.73	15.69	16.14	11.63	15.24	0	8.72	0.75	0.10
40-42	3813	59.09	6.69	12.43	9.83	4.80	0	3.07	0.63	3.46
47-49	3340	45.99	7.60	16.89	11.32	10.15	0.18	3.92	1.71	2.25
55-57	552	43.12	4.89	4.89	15.76	10.14	0	21.20	0	0
65-67	220	43.18	14.09	2.73	6.82	10.91	0.45	19.09	2.73	0
75-77	551	43.01	16.33	1.27	11.98	8.17	0.36	18.15	0.73	0
82-84	226	63.72	7.96	0.00	3.54	4.87	0	15.93	3.98	0
89-91	109	62.39	5.50	3.67	5.50	15.60	0	4.59	2.75	0
94-96	0	0	0	0	0	0	0	0	0	0
100-102	86	31.40	3.49	0	2.33	46.51	0	0	16.28	0
106-108	129	0	0.78	0	4.65	18.60	0	0	75.97	0
110-112	26	15.38	15.38	0	7.69	42.31	0	0	19.23	0

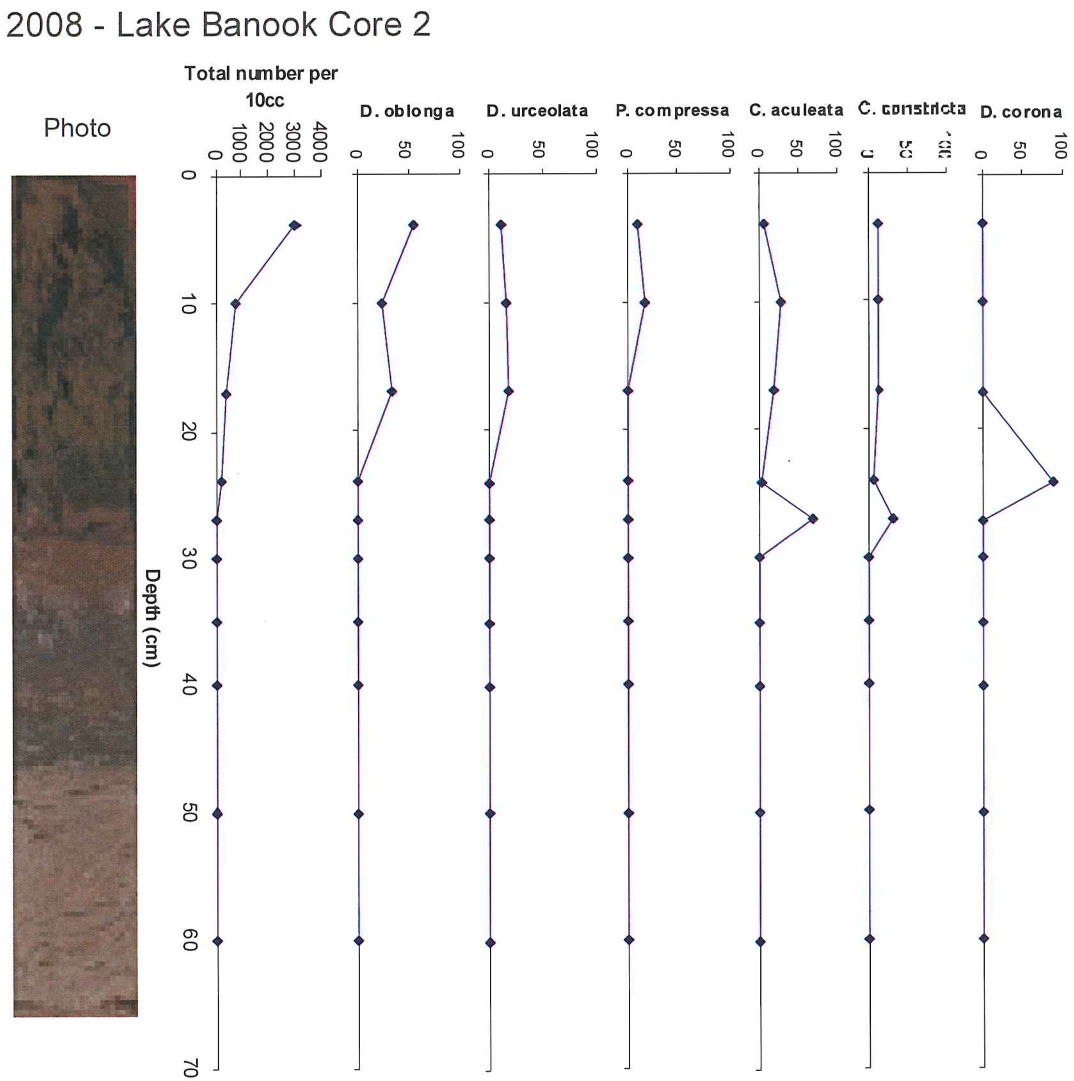


Figure 3.15 – Downcore plot for core 2 of the total number of thecamoebians present per 10cc sample and the proportion of that total represented by each species (%).

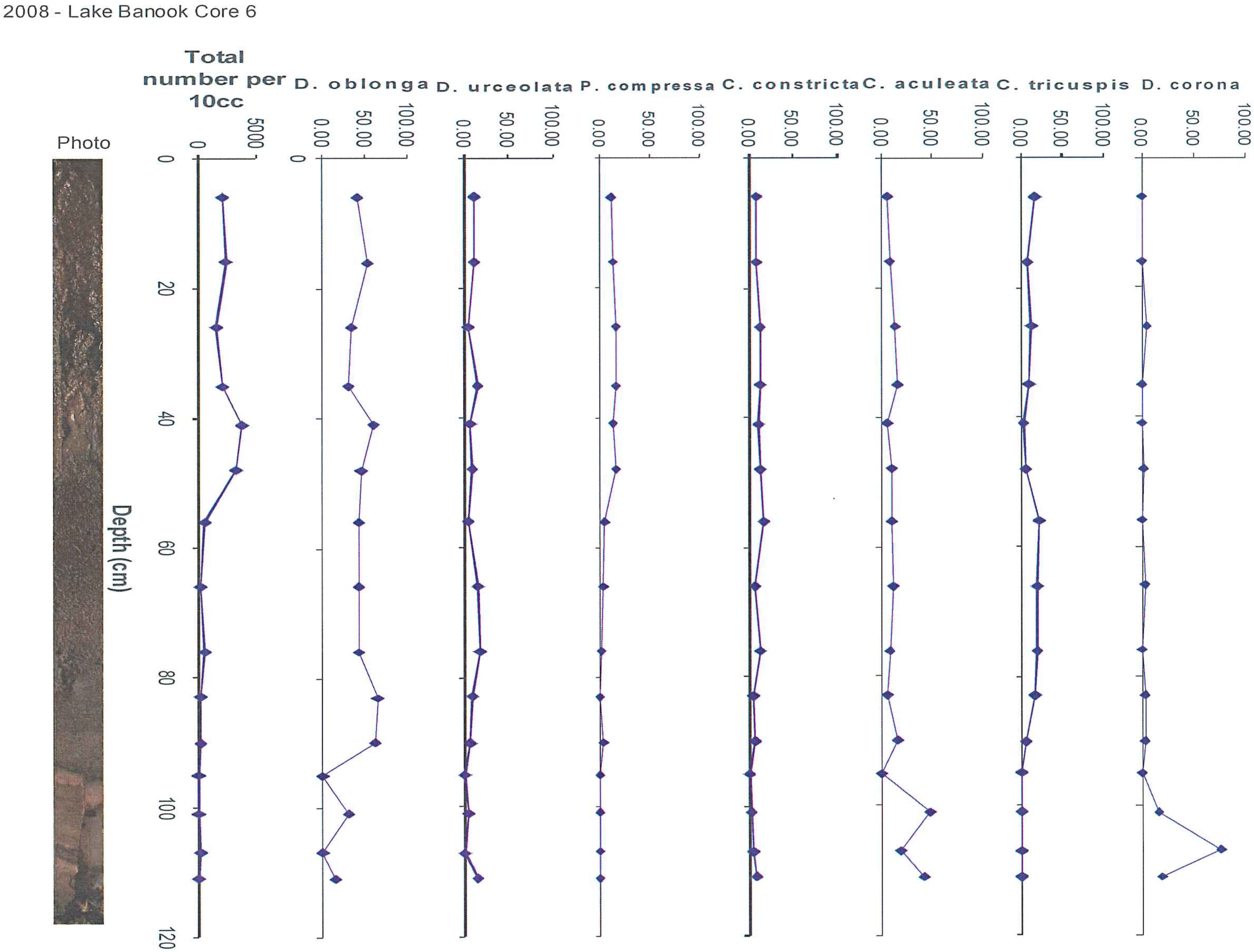


Figure 3.16 - Downcore plot for core 6 of the total number of thecamoebians present per 10cc sample and the proportion of that total represented by each species (%).

In core 6, instead of a steady decrease in total numbers, the total numbers rise and fall in the 1500-4500 range until the 55-57 cm interval where the total number drops sharply to 552 specimens (Table 1). Below here, the numbers never reach above 551 specimens, with the 94 – 96 cm interval barren of thecamoebians. In this upper portion of the core, *C. tricuspis* is present in significant numbers, especially so in the larger populations (Fig. 3.16). Species diversity is very low from the 82 – 84 cm interval nearly to the end of the core, with only a few species dominating – primarily *C. aculeata.* Notably, the 106 – 108 cm interval is dominated by *D. Corona,* with *C. aculeata* being secondary.

In both cores, the presence of *C. tricuspis* in the upper unit shows evidence of eutrophication. This species is not normally present in lakes which have not had anthropogenic influence, suggesting that this lake has anthropogenic influence throughout the time of deposition for this unit. The dominance of *C. aculeata*, as well as the low total numbers in the lower part of core 6 indicates that the environment has been stressed.

Due to inexperience in identifying thecamoebians, a number of individuals may have been misidentified during counting. In the samples containing the most specimens, up to an estimated 10% of specimens identified as *D. oblonga* may have been other difflugids, such as *D. bacifillera* or *Lagenodifflugia vas*. However, this proportion of potentially mistaken identifications is small relative to the dominance of one species against another, and so the overall trends in the dominant species are still valid.

3.4 Paleogeography

From the interpreted seismic data an isopach map of the total thickness of Quaternary sediments, excluding till, was interpolated for most of the lake. Interpolation was done using Ordinary Kriging in Arc GIS. The highest value calculated was a thickness of 9.7 m, but the total thickness would be higher as the seismic data did not reach the top of the till surface in the deeper parts of the basin. The true sediment thickness in the northern basin is unknown, as much of the sediment is masked by shallow gas. Odd linear features of high value present in the northern basin are due to spurious data points.

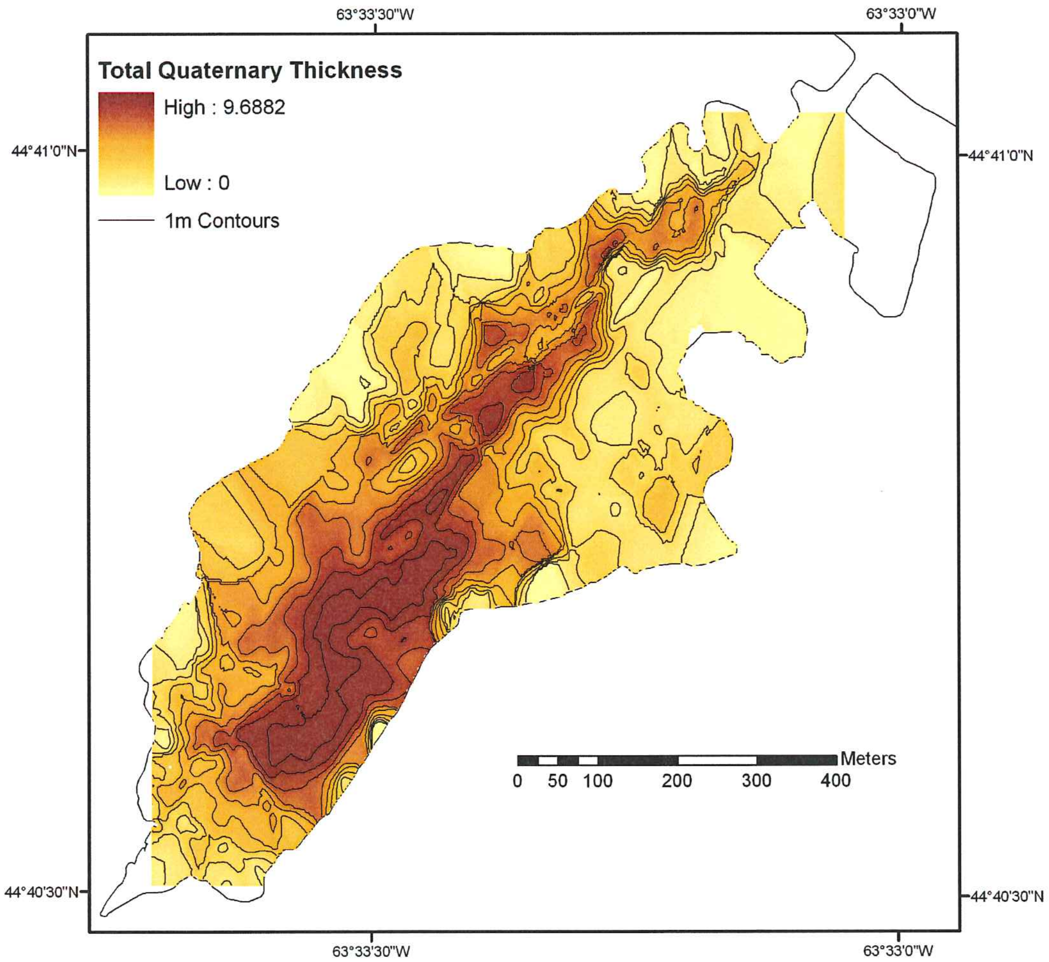


Figure 3.17 – Isopach map of the total Quaternary sediments excluding till. Values in the two basins are minimum estimates.

The large values near the very straight southeastern edge indicate that the lake may have previously extended farther in this direction, but had been infilled at some point. Further evidence of this infilling is the clearly anthropogenic armored shoreline all along this straight edge of the lake.

Shallow gas, potentially biogenic, is visible in the Northern basin of the lake where it can frequently be seen masking the underlying sediments. The extent of this masking (Fig. 3.18) indicates that since the gas is only present in one part of the basin, the conditions must have been different in each basin.

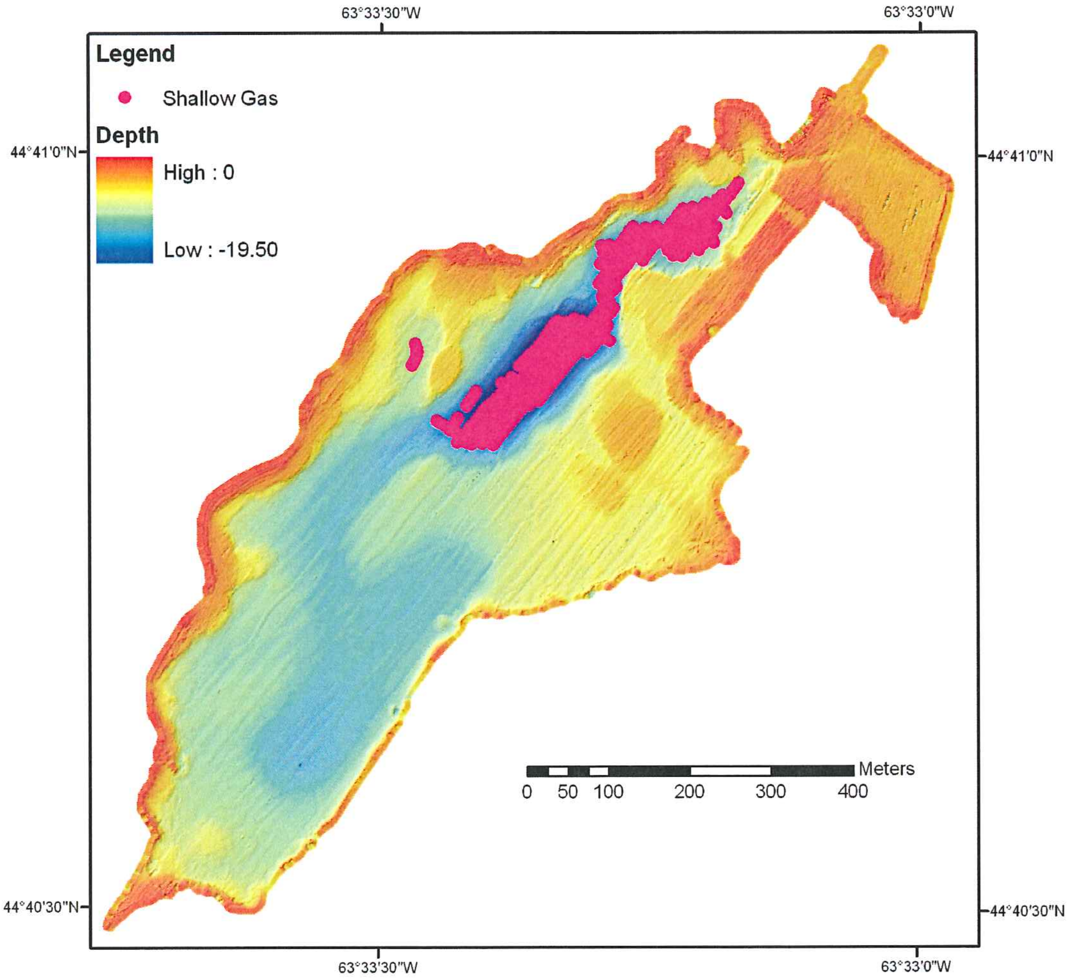


Figure 3.18 – Extent of shallow gas masking seen on the seismic sections, overlain on a sun-illuminated color shaded lakebed topography image.

Unit 5, the poorly stratified muddy sand unit, appears from the seismic sections to have a ponded distribution. The distribution of this unit (Fig. 3.19) shows that it only occurs within the deeper parts of the lake. The apparent absence of this unit in the northern basin is likely due only to the gas masking, and its presence could be inferred. With the depth - controlled nature of this unit, its extent may represent a previous extent of the lake during a lowstand. We see this as a sub-littoral equivalent derived from the lowstand and subsequent coarse-grained sediment influx.

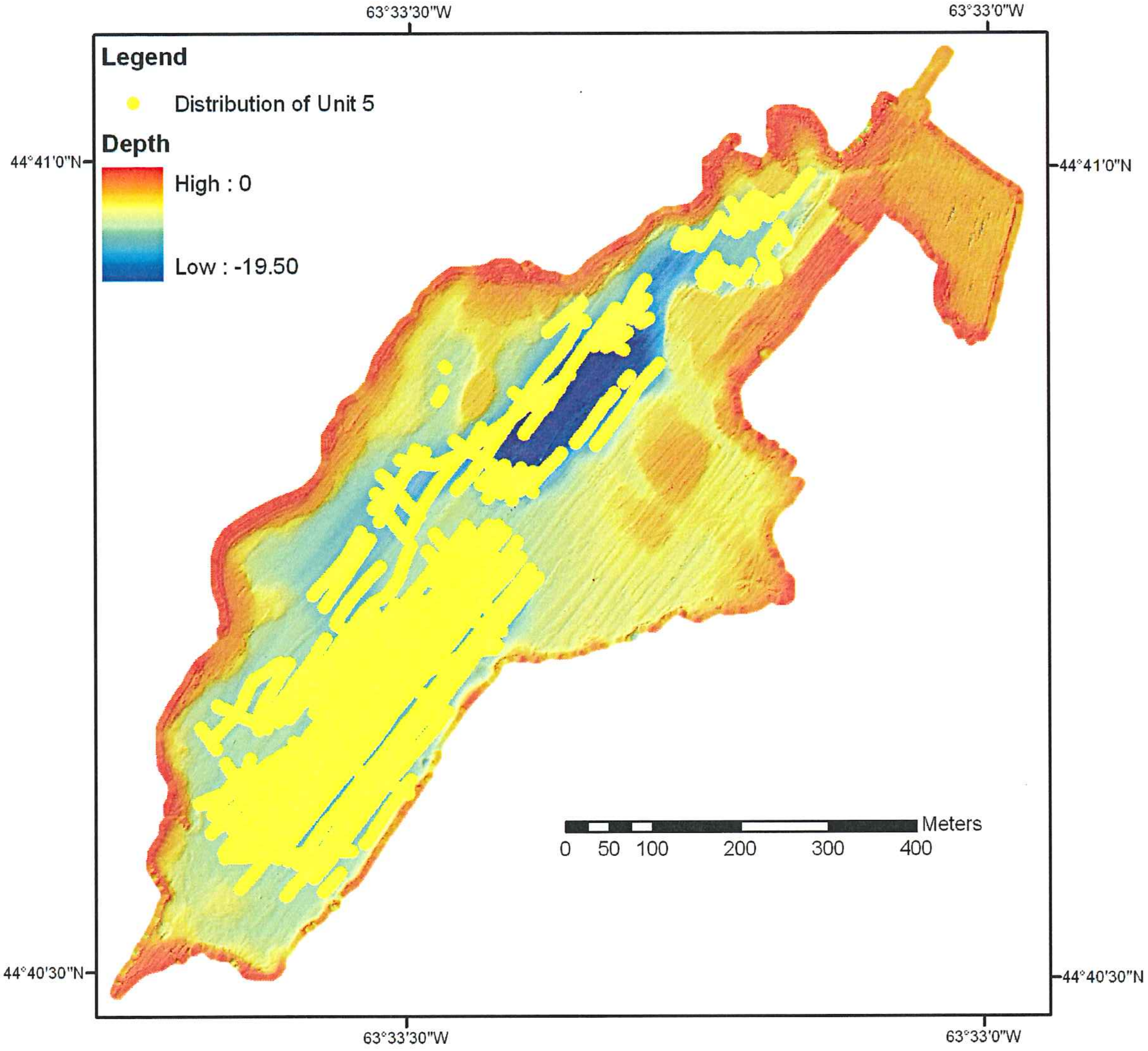


Figure 3.19 – Distribution of the sandy unit 5 overlain on a sun-illuminated color shaded lakebed topography image.

The glacilacustrine unit (Unit 6) is found throughout most of the lake, up to an elevation of 1.3m. The apparent low thickness within the Southern basin is due to spurious data points which were not removed (Fig. 3.20). From the histograms of data distribution, there is a large spike in the number of values at approximately 2.3 m, and another large spike at approximately 4.5 m. Peaks in elevation values generally indicate a partial surface at that level. These two separate terraces in the lake indicate that there may have been two separate erosional events which planed off the sediments at the previously mentioned values.

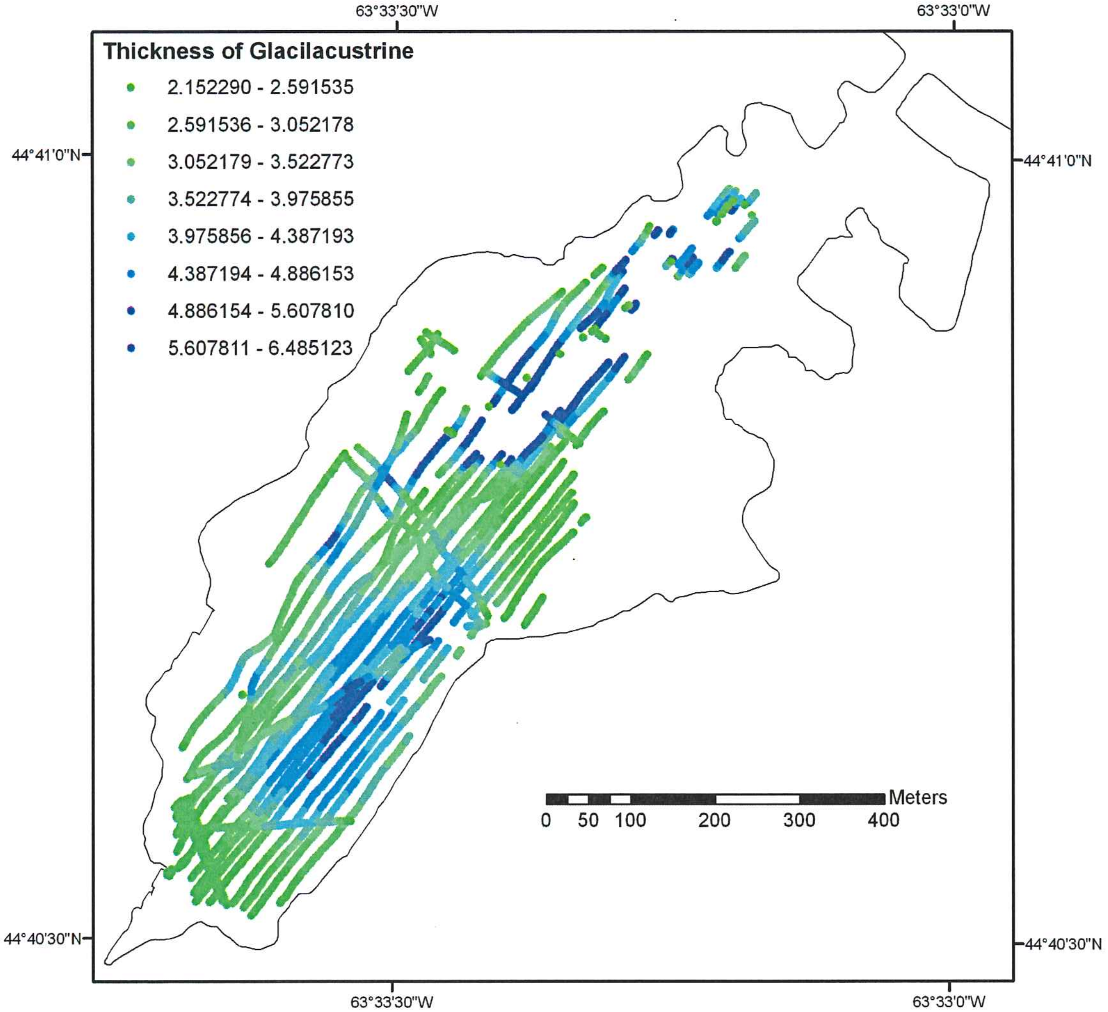


Figure 3.20 – Thickness and distribution of the glacilacustrine unit 3.

The distribution and lobate shape of Unit 4 indicates that it most likely represents multiple debris flows. The majority of Unit 4 occurs in one large mass in the SE side of the lake (Fig. 3.21), and is directly below a very steep hill (Fig. 1.1). This large composite debris flow may be due to natural slumping off the steep hill adjacent to it, or from anthropogenic infill during road construction. The other areas where Unit 4 is present most likely represent localized debris flows, or in the case of the SW patch, anthropogenic fill.

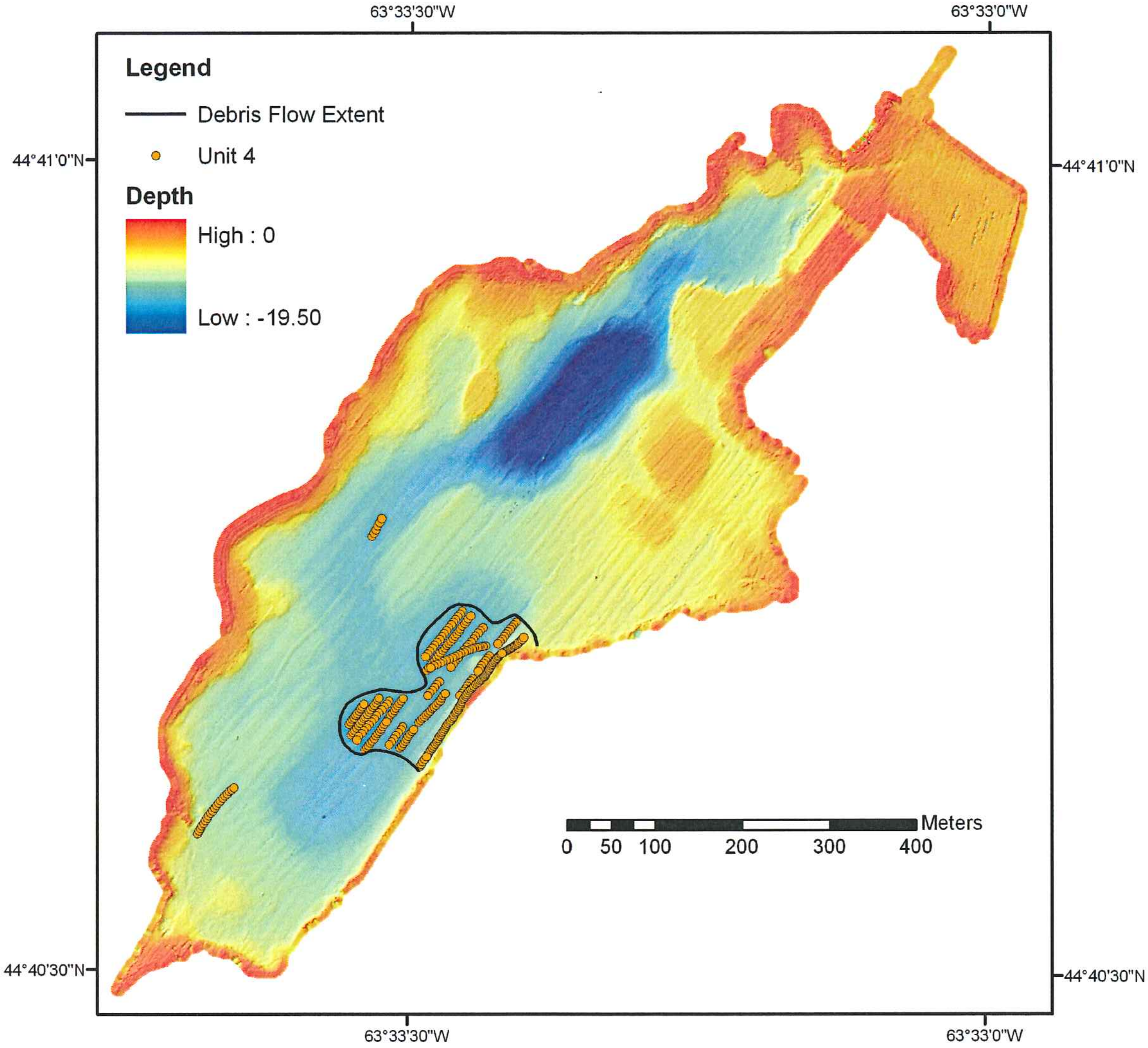


Figure 3.21 – Distribution of Unit 4 overlain on a sun-illuminated color shaded lakebed topography image.

3.5 Summary

The seismo-, litho-, and bio-stratigraphy for Lake Banook correspond well with eachother. Combining all these data with visual observations while the lake level was lowered, we are able to construct a summary diagram (Table 2). The visual observations while the lake level was lowered made it evident that Unit 1, which was not sampled by the cores, was indeed till (Ned King, Pers. Comm.).

Table 2 – Summary diagram of seismic and lithological units with biostratigraphy and envitonmental interpretations.

Unit	Seismic Character	Occurrence	Lithology	Thecamoebians	Interpretation
6	nearly transparent	Draped over most of the lake	muddy brown gyttja	common, diverse	modern lacustrine sediments
5	weakly sratified	ponded in deeper basins	poorly stratified red and brown mud and sand with some gravel	rare	higher energy environment or flood
4	chaotic	local, scoured base	not sampled	not sampled	debris flows
Unconformity	erosional top of Unit 3 with a sharp, wavy contact in cores				
3	strong, rhythmic, coherent	draped throughout most of the lake, top eroded in some areas	stiff, finely laminated grey and brown silt and clay with black mottling at surface	barren	late glacilacustrine rhythmite
2	poorly stratified	draped	very stiff brown and grey silt and clay with convoluted laminations	not assessed	glacial or early post-glacial sediments
1	incoherent	acoustic basement	till	not sampled	regional tills

DISCUSSION

4.1 Comparison with other lakes

Thecamoebians have been shown to be sensitive to both changes in temperature, and chemical changes such as eutrophication or pollution. Given that there have been a number of cold periods since the last glaciation; the lower numbers are most likely due to a much colder environment than present, however, it could also be due to a lack of organic material and thus food. The three foraminifera observed in the 16 – 18 cm interval of core 2 were likely due to transport via birds from the nearby Halifax Harbour, as foraminifera may encyst and be carried for long distances by birds and other animals (Scott *et al*, 2001).

The thecamoebian data are quite different from other nearby lakes, such as Penhorn and Albro Lakes. The upper portion of the core in Lake Banook has significantly higher total numbers in some places than either of the other cores, but has similarly low numbers in the bottom portion of the cores. Compared to the other cores, the section in Lake Banook is quite compressed in terms of lithological changes. The upper approximately 100 cm in these cores has similar lithology to the upper 300 cm of core in Penhorn Lake (see Collins, 1985 and McCarthy *et al*, 1996).

4.2 Implications for paleoclimate

The unconformity at the top of the well-stratified glacilacustrine unit indicates that there must have been a lake lowstand previous to the deposition of unit 5. The large area of glacilacustrine sediments planed off at approximately 4.5 ms gives an approximate depth for this lowstand. From these data, Ned King, Gordon Cameron and I have constructed a very schematic lake level curve, with only a few points well-constrained, and the path between these points rarely known (Fig. 5.1). As we did not obtain any dates, the climatic events we have tied these paleo lake levels to remain uncertain. However, if we assume this timing is correct, it allows further interpretation of the depositional environment of the units, especially the glacilacustrine units.

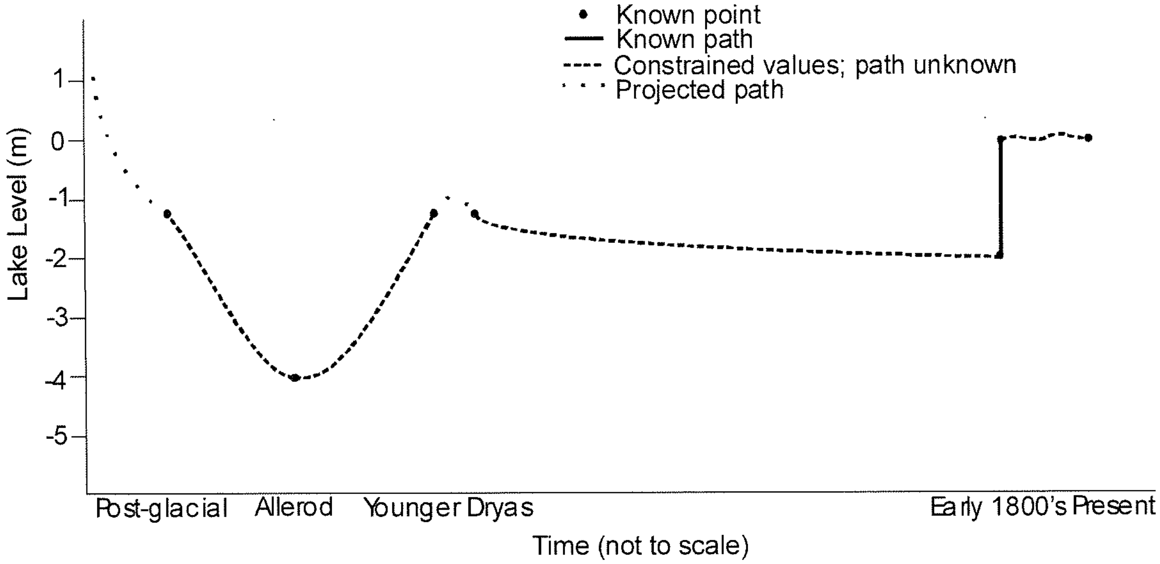


Figure 4.1 – Lake level curve using the present (as of summer 2008) lake level as zero. Known points are interpretations from the seismic data and from correlating lithological units with nearby lakes. The last three points are known from historical records, or measured, with the instantaneous 2m rise in lake level due to the damming of the lake during construction of the Shubenacadie Canal.

The thinly laminated glacilacustrine units necessitate a quiescent environment of depostition, but the timing indicates that the sediments were deposited during or immediately after deglaciation. This leaves two potential environments for deposition: either a subglacial lake with the lakebed beneath the influence of any running water, or a proglacial environment. The lower glacilacustrine unit has disturbed laminations, indicating it may have been ice-proximal, with the upper glacilacustrine unit more distal. This, with the perched glacilacustrine sediments in Lake Micmac, immediately North of

Lake Banook (Ned King, pers. comm.), and the deeper and gas-rich northern basin of Lake Banook, indicate that there may have briefly been an ice margin within Lake Banook. The most likely place for this margin to occur would be at the southern edge of the northern basin.

No evidence of a large flood event is present within the lake, which is unexpected if the lake was thought to be a part of the spillway during deglaciation from 12.5-11 ka (Stea and Mott, 1998). Also, as the lake has not been eroded below the level of the till, there is no known bedrock threshold, with the previous thresholds being till-controlled. Presumably, if there was a large flood, it would have broken through the till threshold, but we found no evidence for this in Lake Banook.

4.3 Limitations and future work

The biggest limitation in this study is the lack of dates. Datable material is only found in the uppermost unit, but even a single date near the bottom of this unit would either validate or invalidate our proposed timing of events. Without dates, the correlation relies almost entirely on seismic and lithological data from other lakes, and only provides one possibility for the timing.

A longer core would have been useful as all seismic units are within reach of most standard coring devices. With a complete section, the interpretations would not be so heavily reliant on correlations from seismic data, and the thecamoebian resolution for the lower section of the core would be higher. Also, deeper penetration of seismic data would have allowed a more accurate estimate of total sediment thickness, and possibly revealed the bedrock surface.

For future studies on this and other lakes, radiocarbon dates are absolutely necessary to constrain the timing of events. Pollen data have also proven useful in previous studies, and new data would contribute to the climatic record of the area as well as being useful for correlation. Future work should include seismic data as it is now fast, easy, and inexpensive to collect.

Similar studies on other lakes within this series of lakes (Lake Charles, Lake Micmac) would be useful in determining whether or not the lakes were part of a spillway during deglaciation, and if an ice margin may have existed anywhere within or between the lakes for a significant period of time. Other lakes in the area should also be studied in order to construct an overview of the paleohistory of the area since deglaciation.

CONCLUSIONS

This study has been a technical and scientific success. The seismic data have revealed a complex history and sedimentologically different sub-basins within a relatively small lake, and proved instrumental in interpreting the cores and other data. Interpretation of these data revealed an unconformity within the sediments, which seems to be uncommon. This unconformity is significant as the processes responsible for forming it are climatic in nature, suggesting that a similar unconformity may also be present in other lakes in the region. Previous studies with radiocarbon dates that did not result in a constant sedimentation rate have inferred a change in sedimentation rate to account for the disparity (Collins, 1985), but there may also be an unconformity that was not recognized.

Thecamoebian assemblages in this lake are different from others observed in the area, which is unsurprising as assemblages can be quite variable from lakes in the same area (Collins, 1985). Very large total numbers of specimens in the upper subsamples of the cores shows that the lake is currently very favourable environments for thecamoebians. The presence of *C. aculeata* in the upper unit of the lake indicates that anthropogenic influence has affected this lake for a significant portion of its history. The absence of thecamoebians in the lower units of the lake indicate an environment in which there is virtually no organic material present in the lake system for the thecamoebians to feed on.

ABBREVIATED TAXONOMY AND PLATE

This study is not taxonomic in nature but, due to the unavoidable confusion of 'species' in a primarily asexual organism and current debate over 'lumping' and 'splitting' of species, an abbreviated taxonomy is presented. For a detailed taxonomy, see Medioli and Scott, 1983 and for a general overview of all genera see Scott et al., 2001.

Centropyxis aculeata (Ehrenberg)

Plate 1, Fig. 5

Arcella aculeata EHRENBERG, 1832, p. 91.

Centropyxisa culeata (Ehrenberg). STEIN, 1859, p. 43.

Centropyxis constricta (Ehrenberg)

Plate 1, Fig. 4

Arcella constricta EHRENBERG, 1843, p. 410, PI. 4, fig. 35, P1. 5, fig. 1.

Centropyxisa culeata (Ehrenberg). DEFLANDRE, 1929, p. 340, text-figs. 60-67.

Cucurbitella tricuspis Carter

Plate 1, Fig. 6

Difflugia tricuspis CARTER, 1856, p. 221, fig. 80.

Cucurbitella tricuspis (Carter). MEDIOLI, SCOTT AND ABBOTT, 1987, p. 28-47, 4 Pls.

Difflugia corona Wallich

Plate 1, Fig. 7

Difflugia proteiformis (sic) (Ehrenberg) subspecies *D. globularis* (Dujardin) var. *D. corona* (Wallich). WALLICH, 1864, p. 244, P1. 15, fig. 4a-c, P1. 16, fig. 19, 20.

Difflugia corona Wallich. ARCHER, 1866, p. 186.

Difflugia oblonga Ehrenberg

Plate 1, Fig. 1

Difflugia oblonga EHRENBERG, 1832, p. 90.

Difflugia proteiformis Lamarck

Plate 1, Fig. 8

Difflugia proteiformis Lamarck, 1816, p.95 (with reference to material in a manuscript by LeClerc)

Difflugia urceolata Carter

Plate 1, Fig. 2

Difflugia urceolata Carter, 1864, p. 27, P1. 1, fig. 7.

Genus *Nebela*

Type species *Difflugia (Nebela) numata* Leidy, 1875.

Pontigulasia compressa (Carter)

Plate 1, Fig. 3

Diffugia compressa CARTER, 1864, p. 22, P1. 1, figs. 5, 6.

Pontigulasia compressa (Carter). RHUMBLER, 1895, p. 105, P1. 4, fig. 13a, b.

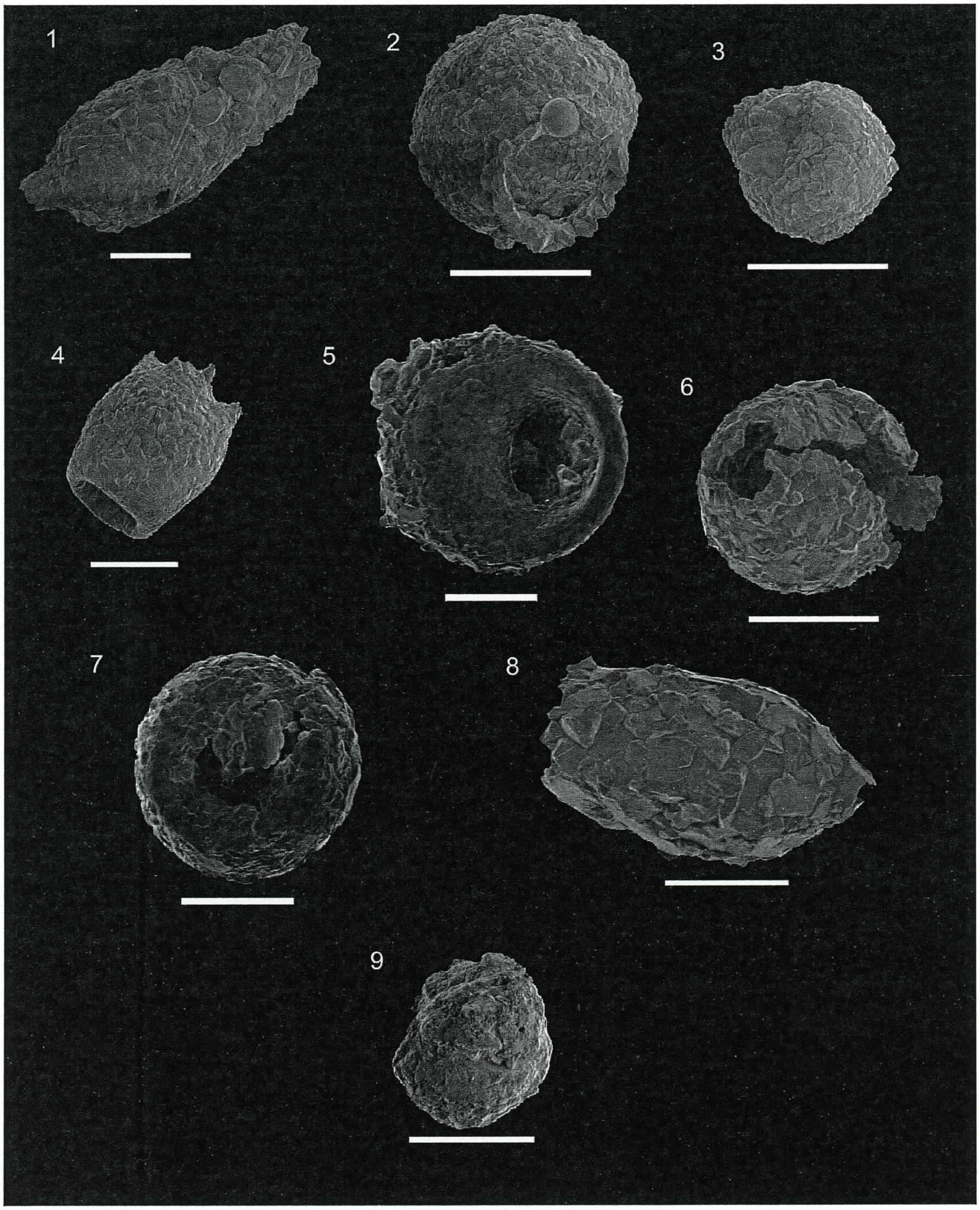


Plate 1

1. *Difflugia oblonga,* side view of specimen with broken spine at fundus. Scale bar 100 um **2.** *Difflugia urceolata*, oblique apertural view. Scale bar 200 um. **3.** *Pontigulasia compressa*, side view. Scale bar 200 um. **4.** *Centropyxis constricta*, ventral view. Scale bar 100 um. **5.** *Centropyxis aculeata*, ventral view. Scale bar 50 um. **6.** *Cucurbitella tricuspis*, oblique apertural view or a fractured specimen. Scale bar 40 um. **7.** *Difflugia corona*, apertural view of damaged specimen. Scale bar 50 um. **8.** *Difflugia proteiformis*, side view. Scale bar 30 um. **9.** Unidentified resistant spherule; fractured surface. Scale bar 100 um.

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